APPENDIX A

MAPS

Figure 4-1. Location Map for the Impoundments Studied in the Prairie Dog Creek Watershed

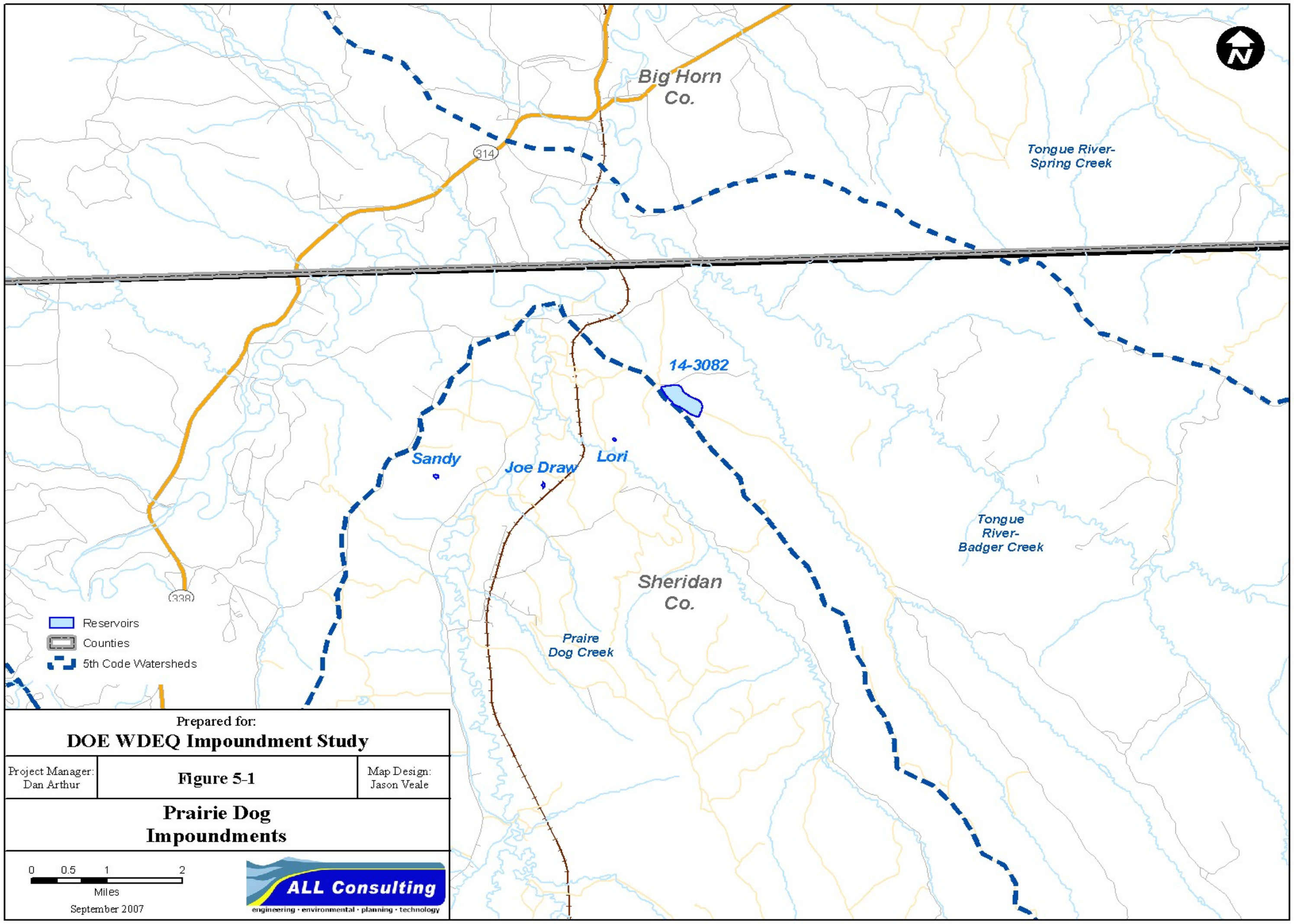


Figure 4-2. Location Map for the Impoundments Studied in the LX Bar Creek Watershed

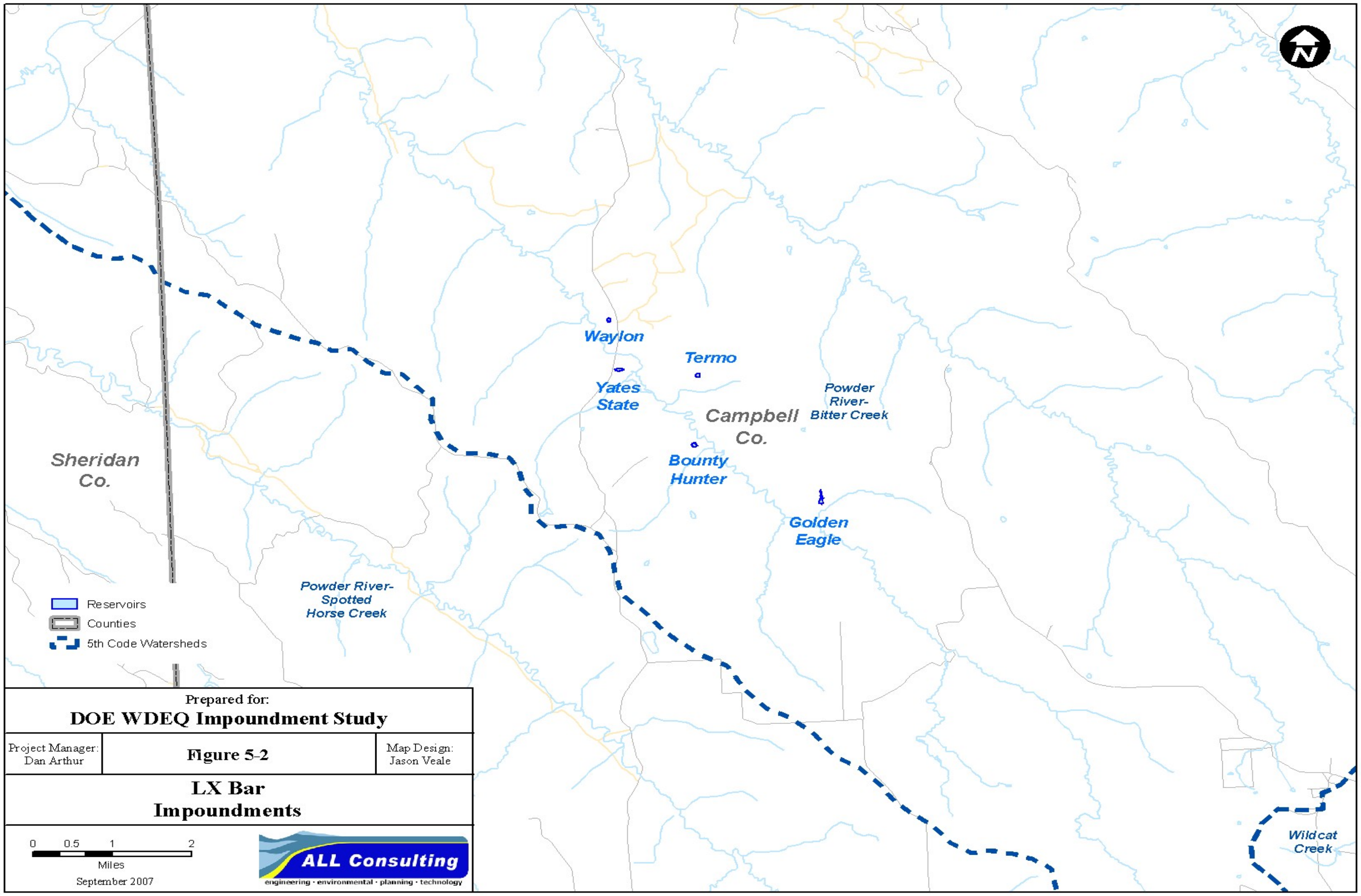


Figure 4-3. Location Map for the Impoundments Studied in the LX Bar Creek Watershed

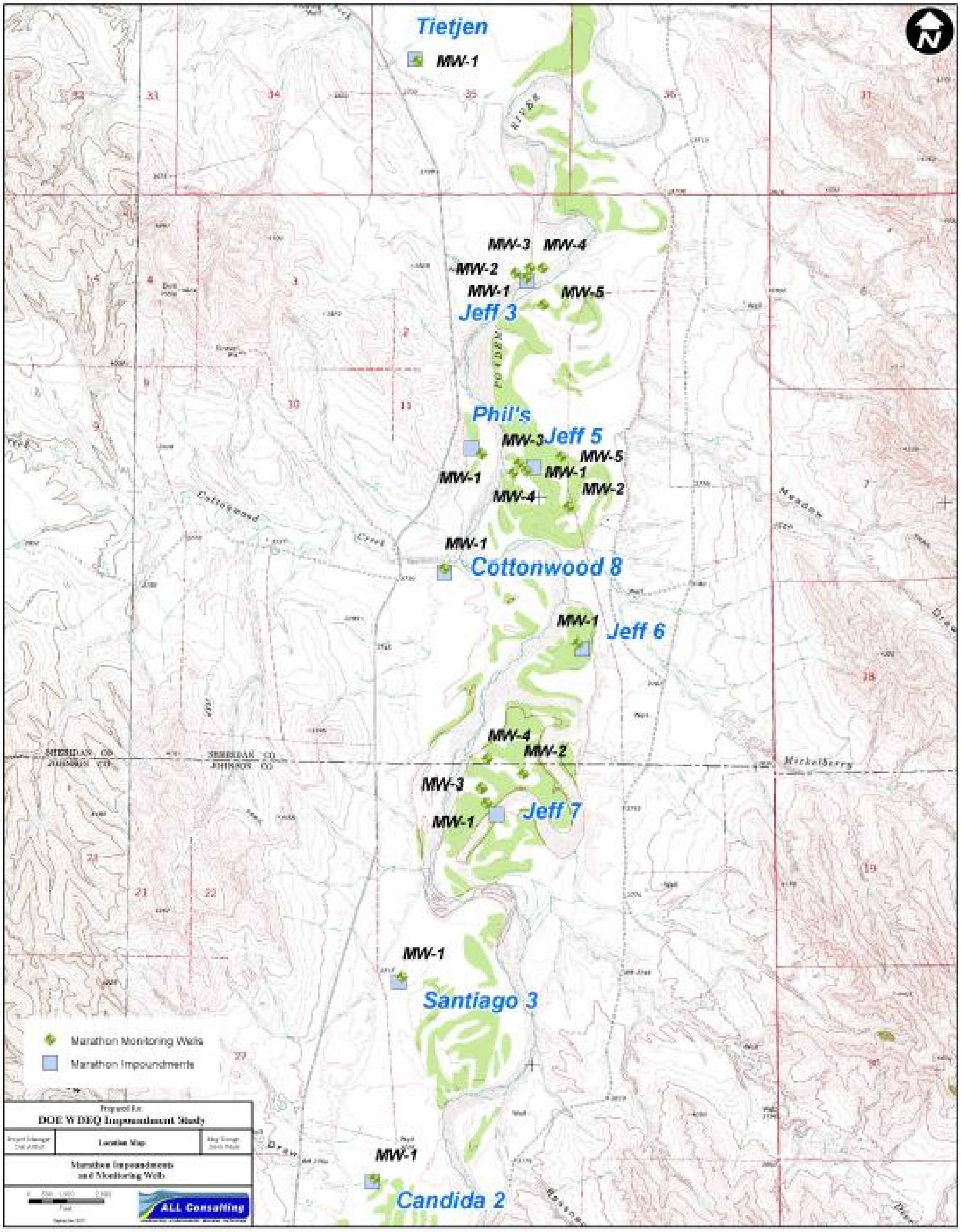


Figure 4-4. Structure map of the Smith Coal seam at the Lori impoundment.

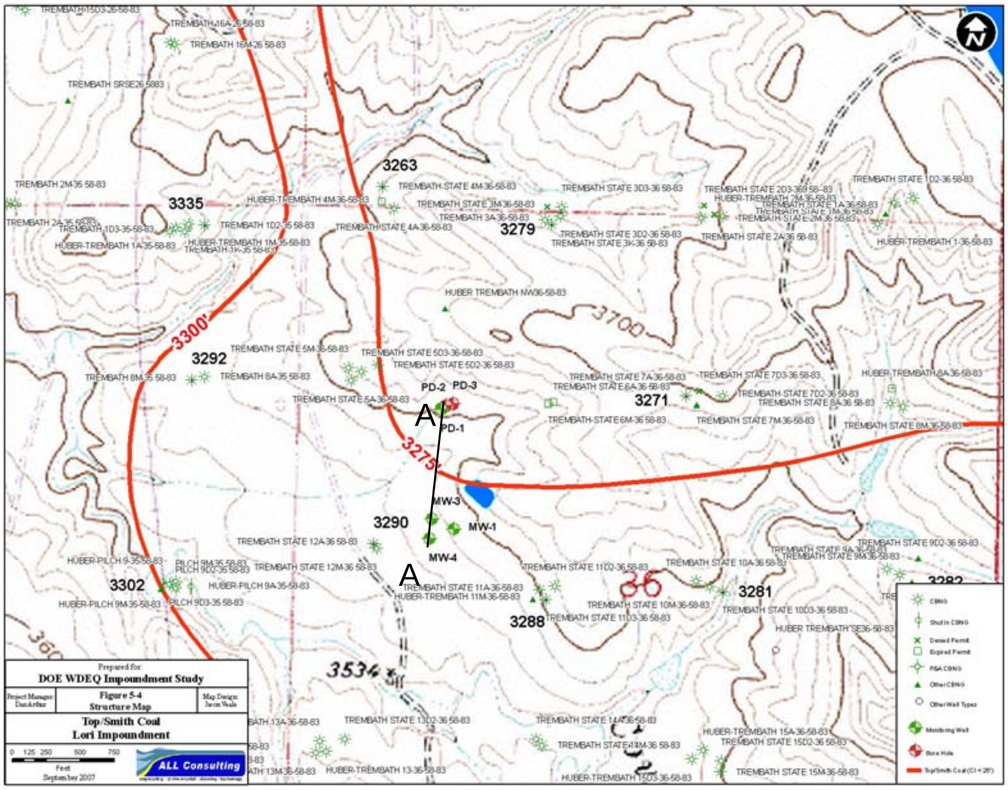


Figure 4-5. Structure map of the Upper Roland Coal seam at the Sandy impoundment.

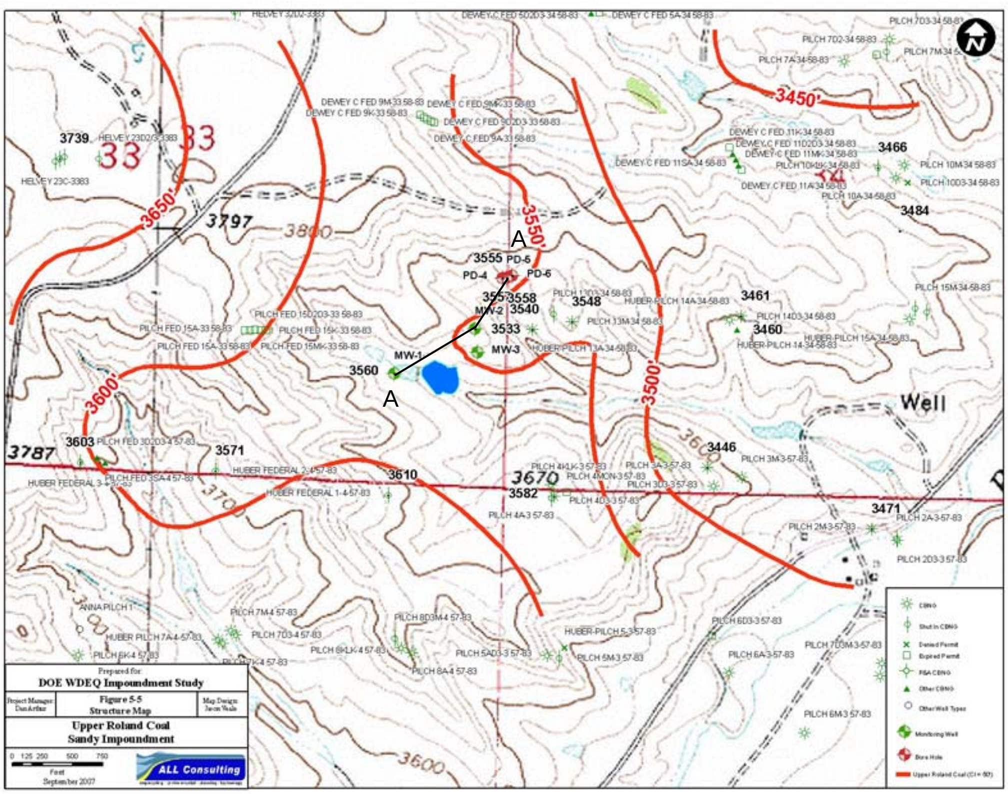


Figure 4-6. Structure map of the Baker T Coal seam at Joe Draw Jr impoundment.

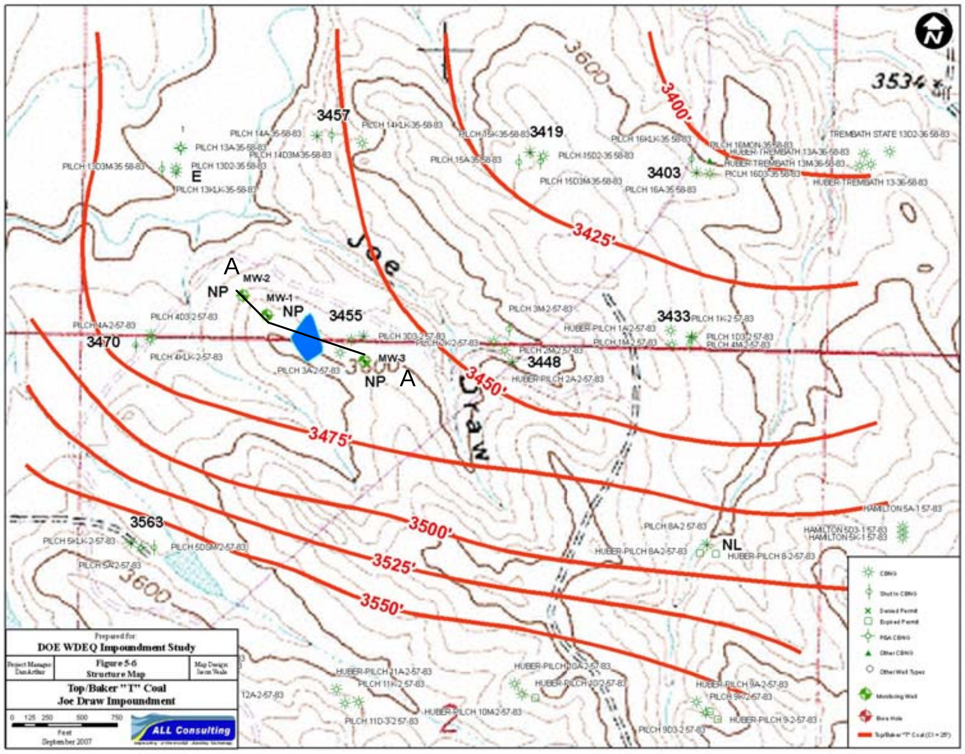


Figure 4-7. Structure map for the Upper Canyon Coal seam at the Yates State impoundment.

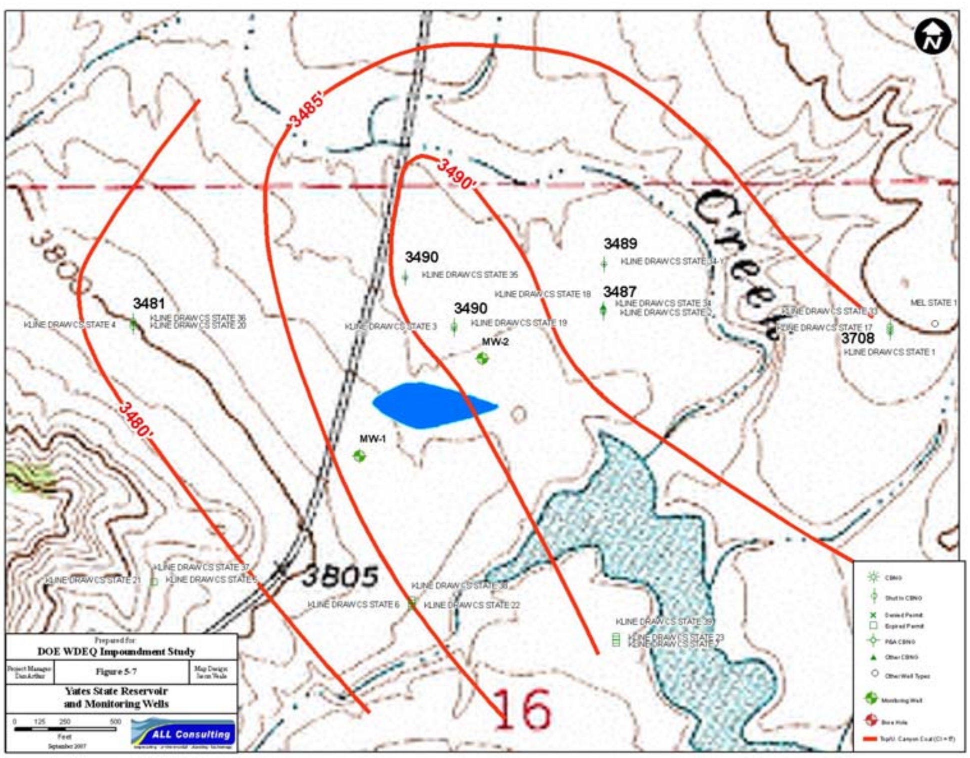


Figure 4-8. Structure map of the Anderson Coal Seam at the Bounty Hunter impoundment.

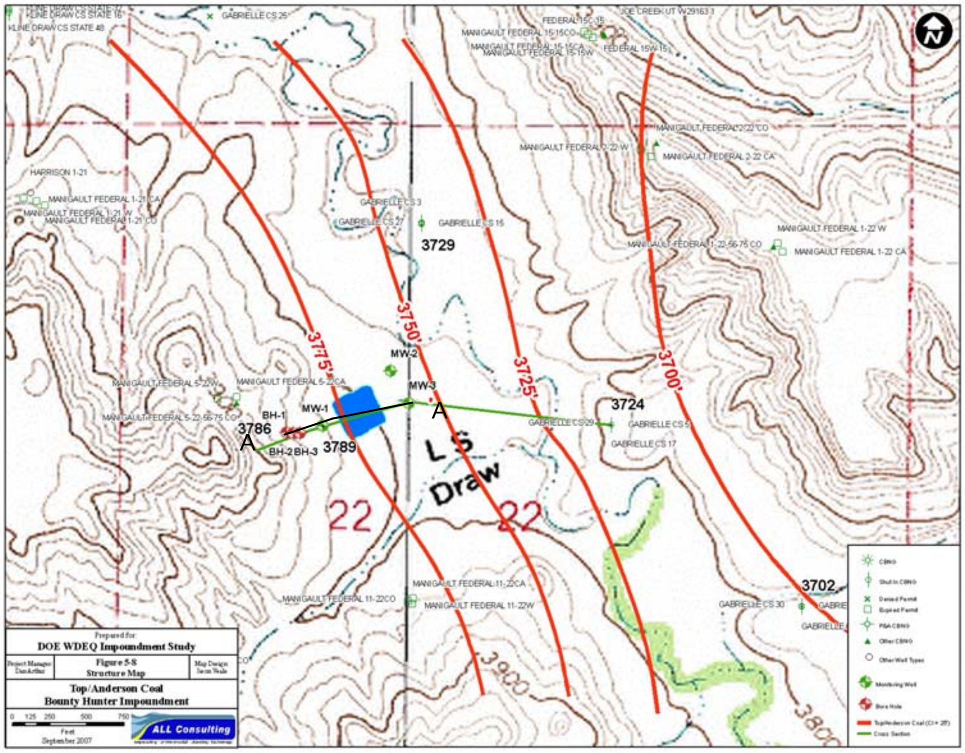


Figure 4-9. Structure map of the Anderson Coal seam at the Termo impoundment.

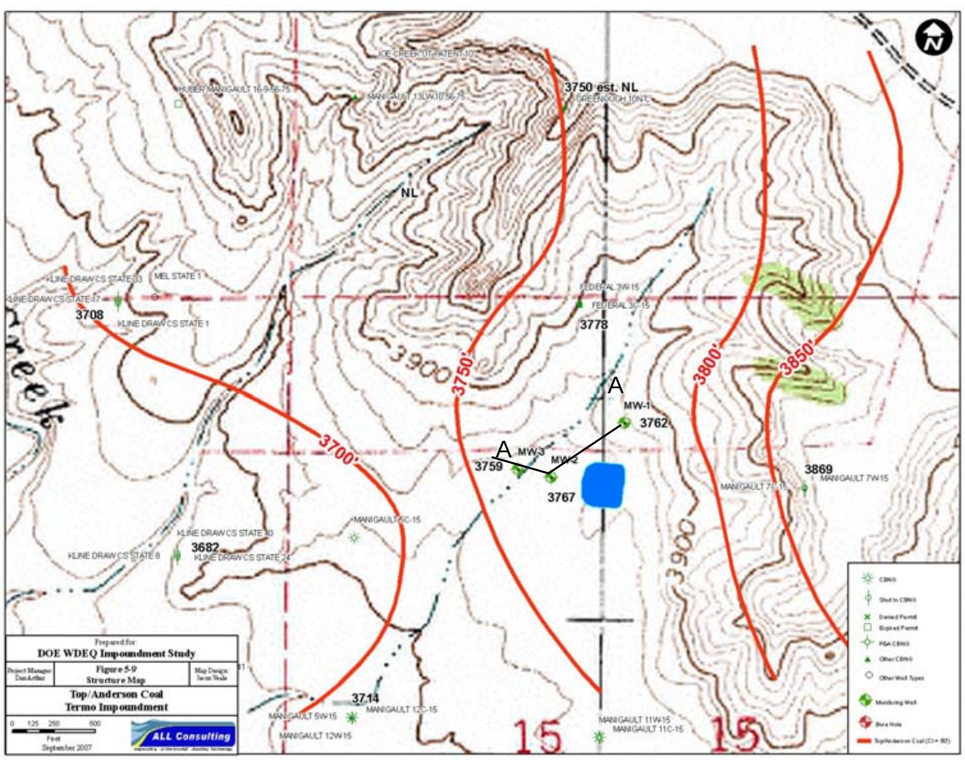


Figure 4-10. Structure map of the Upper Canyon Coal seam at the Waylon impoundment.

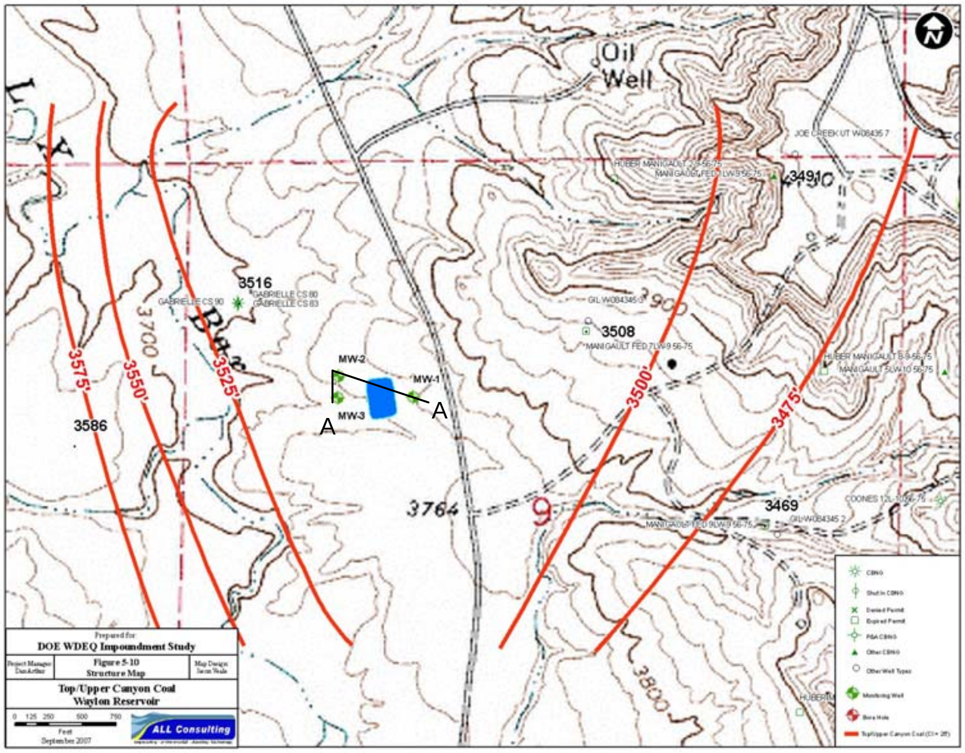
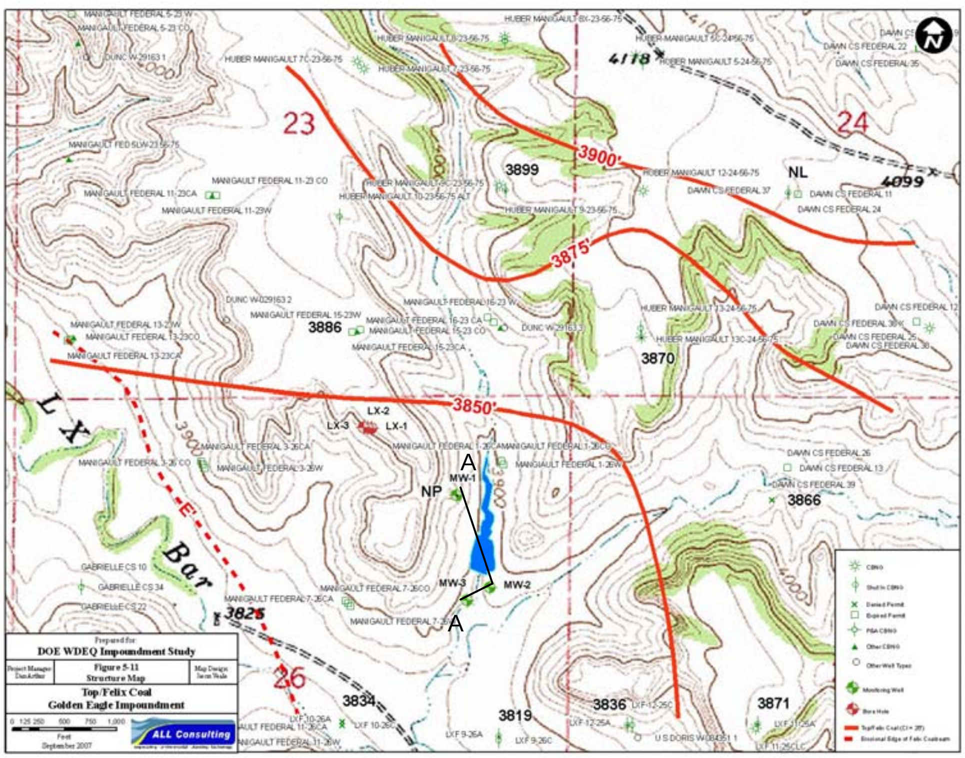


Figure 4-11. Structure map of the Felix Coal seam at the Golden Eagle Reservoir.



APPENDIX B

BOREHOLE LITHOLOGIC LOGS AND WELL CONSTRUCTION DIAGRAMS

Geophysical Logs *Logs Run and Processed by United States Geological Survey*

LX Bar Area Bounty Hunter Impoundment

Well No. BH DOE 2

On-site Geologist: Webster

Latitude: 44°49'06.11284

Longitude: 105°52'42.75805"

Northing: 1905213.52

Easting: 1689826.931

GL Elevation: 3850.31

Total Depth: 74

Qtr Qtr: SWNW

Section: 22

Township: 56N

Range: 75W

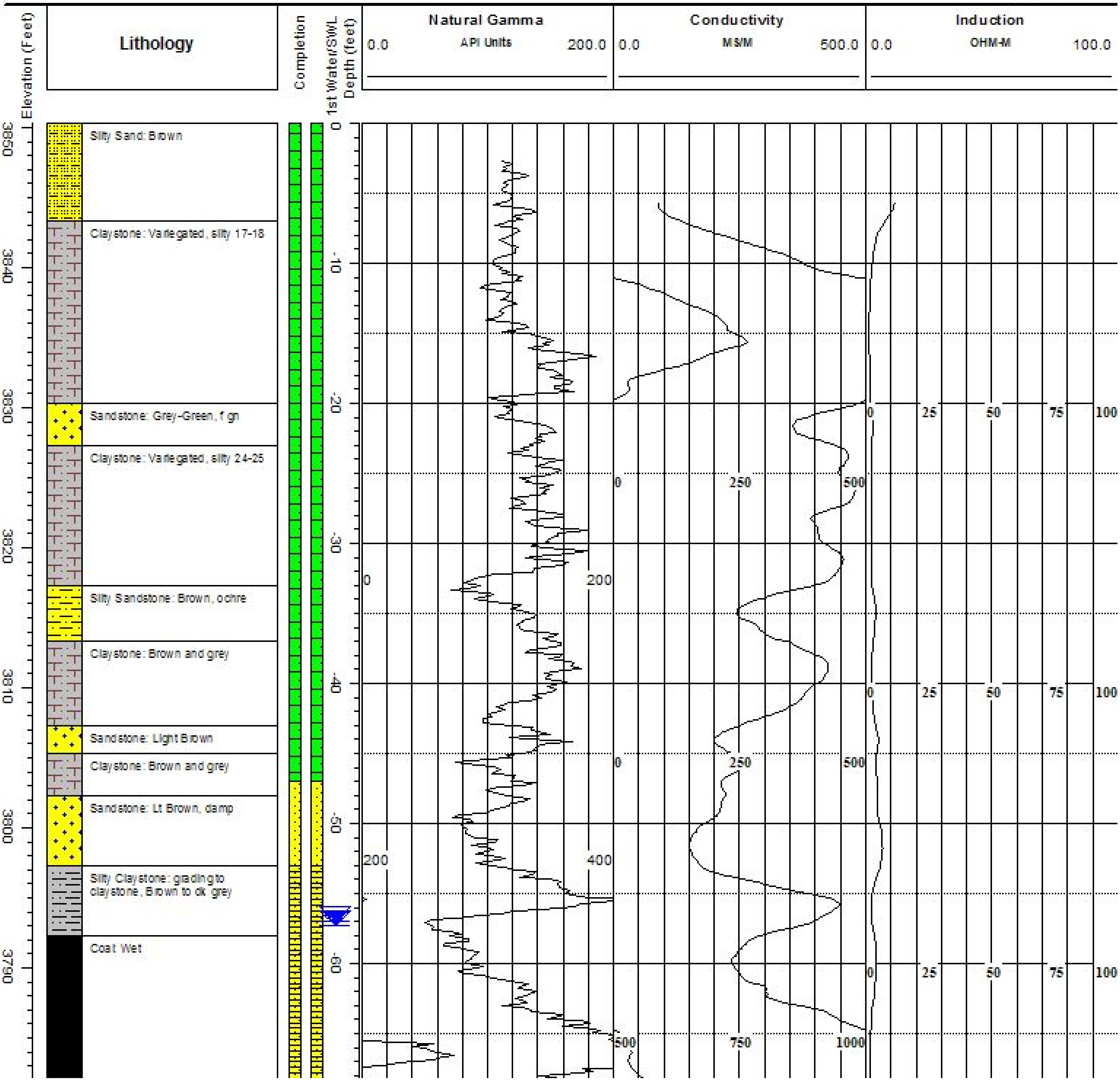
Drilling Contractor: Interstate Drilling

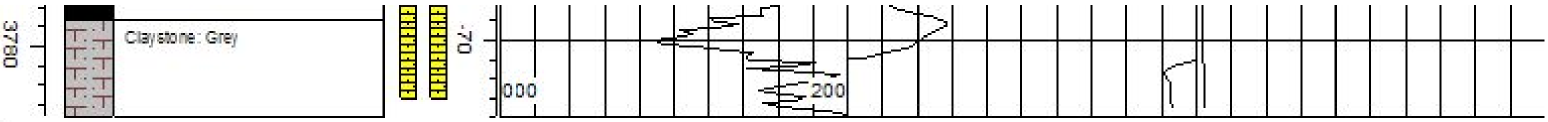
Driller: Dave Proctor

Drilling Dates: 6-27-06

Hole Diameter: 5-7/8"

Comments: Natural Gamma smoothed to aid resolution
SWL from 11-15-06





Major Ion Chemistry (mg/L)

Natural Gamma API Units		Conductivity MS/M		Induction OHM-M	
0.0	200.0	0.0	500.0	0.0	100.0

Ca =	385	CO2/HCO3 =	Carbs		
Mg =	531	SO4 =	6461	pH =	3.5
Na =	889	TDS =	10268	SAR =	7

WDEQ Ground Water Classification = IV

Geophysical Logs *Logs Run and Processed by United States Geological Survey*

LX Bar Area Bounty Hunter Impoundment

Well No. MW-1

On-site Geologist Webster

Latitude: 44°49'08.20777"
Longitude: 105°52'31.97783"

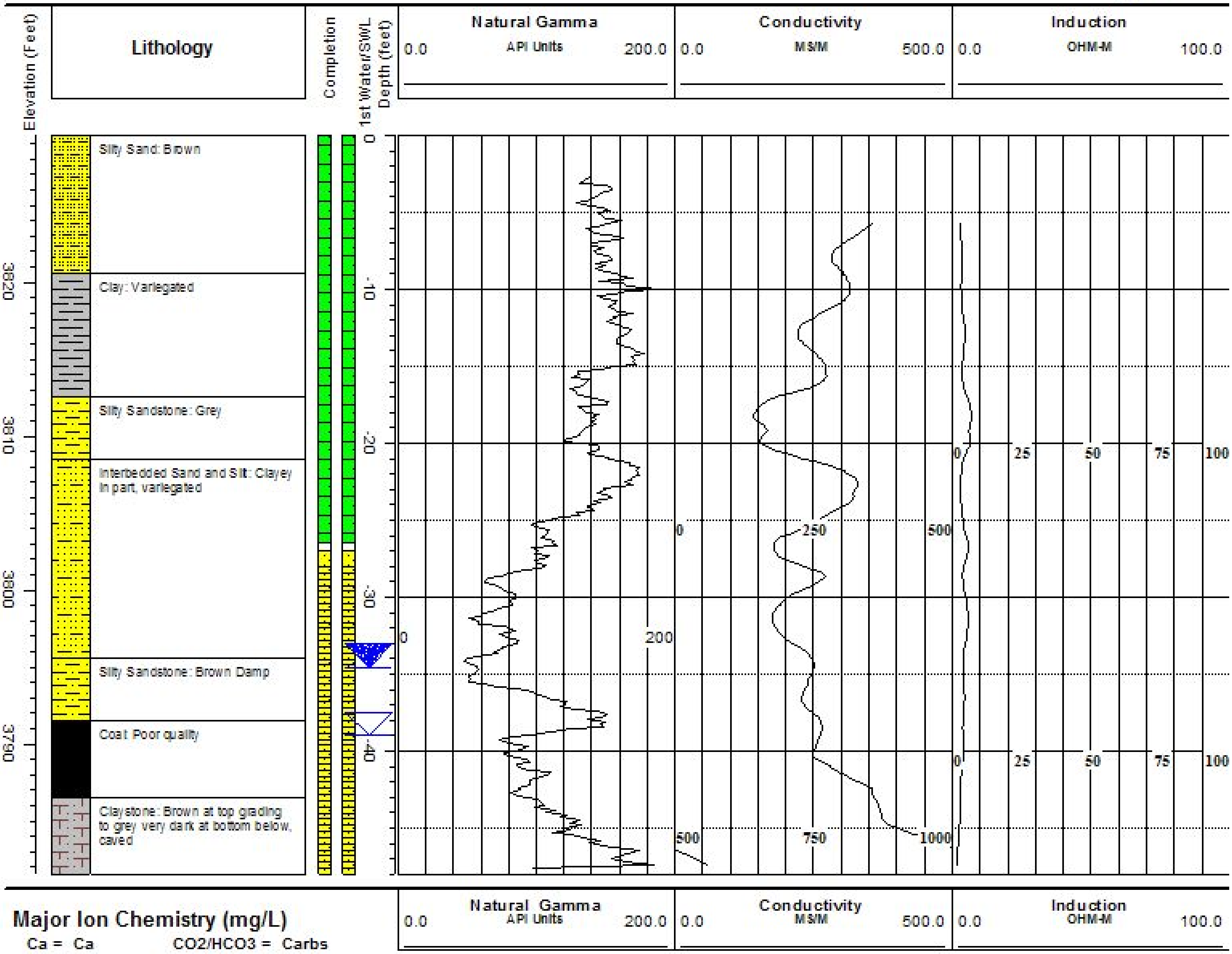
Northing 1905268.75
Easting 1690022.51
GL Elevation 3829.55

Total Depth: 19
Qtr Qtr: SWNW
Section: 22
Township 56N
Range 75W

Drilling Contractor Interstate Drilling
Driller Dave Proctor

Drilling Dates 6-25-06
Hole Diameter 5-7/8"

Comments: Natural Gamma smoothed to aid resolution
No water chemistry data



Major Ion Chemistry (mg/L)

Ca =	Ca	CO2/HCO3 =	Carbs		
Mg =	Mg	SO4 =	Sulfate	pH =	7.0
Na =	Na	TDS =	TDS	SAR =	8

WDEQ Ground Water Classification = IV

Geophysical Logs

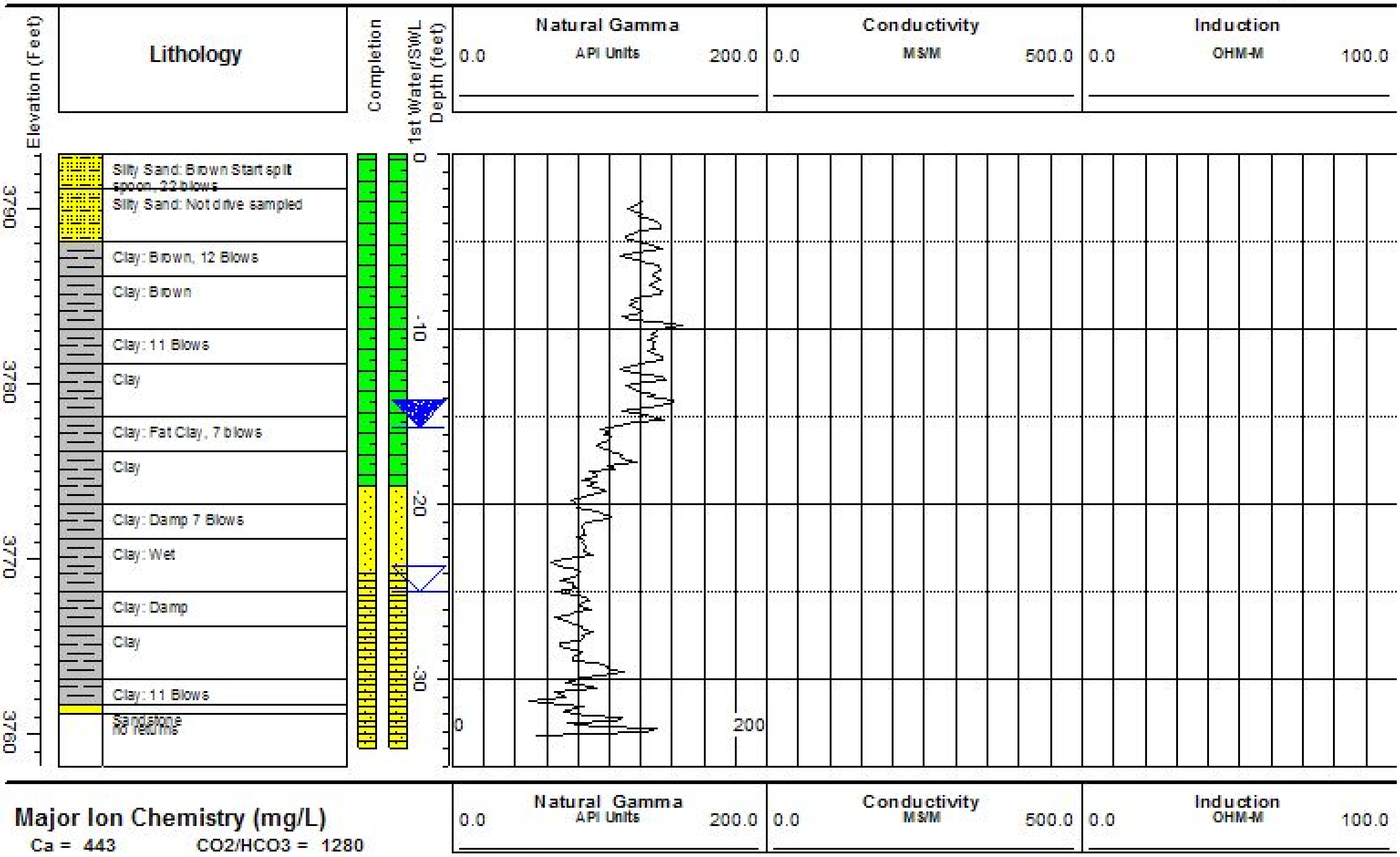
Logs Run and Processed by United States Geological Survey

LX Bar Area Bounty Hunter Impoundment

Well No. MW-2

On-site Geologist: Webster	Latitude:	44°49'10.31308"	Northing	1905650.52	Total Depth: 35
	Longitude:	105°53'33.73889"	Easting	1690469.39	Qtr Qtr: SWNW
			GL Elevation	3793.14	Section: 22
Drilling Contractor: Interstate Drilling	Drilling Dates	6-25-06			Township 57N
Driller: Dave Proctor	Hole Diameter	7-1/2"			Range 75W

Comments: 33 feet of Natural Gamma ONLY Geophysical Log run -- Gamma curve smothed due to excessive electronic noise
SWL from 11-7-06



Major Ion Chemistry (mg/L)

Ca =	443	CO2/HCO3 =	1280		
Mg =	372	SO4 =	4402	pH =	6.5
Na =	844	TDS =	6168	SAR =	7

WDEQ Ground Water Classification = IV

Wyoming Department of Environmental Quality Impoundment Study

Geophysical Logs

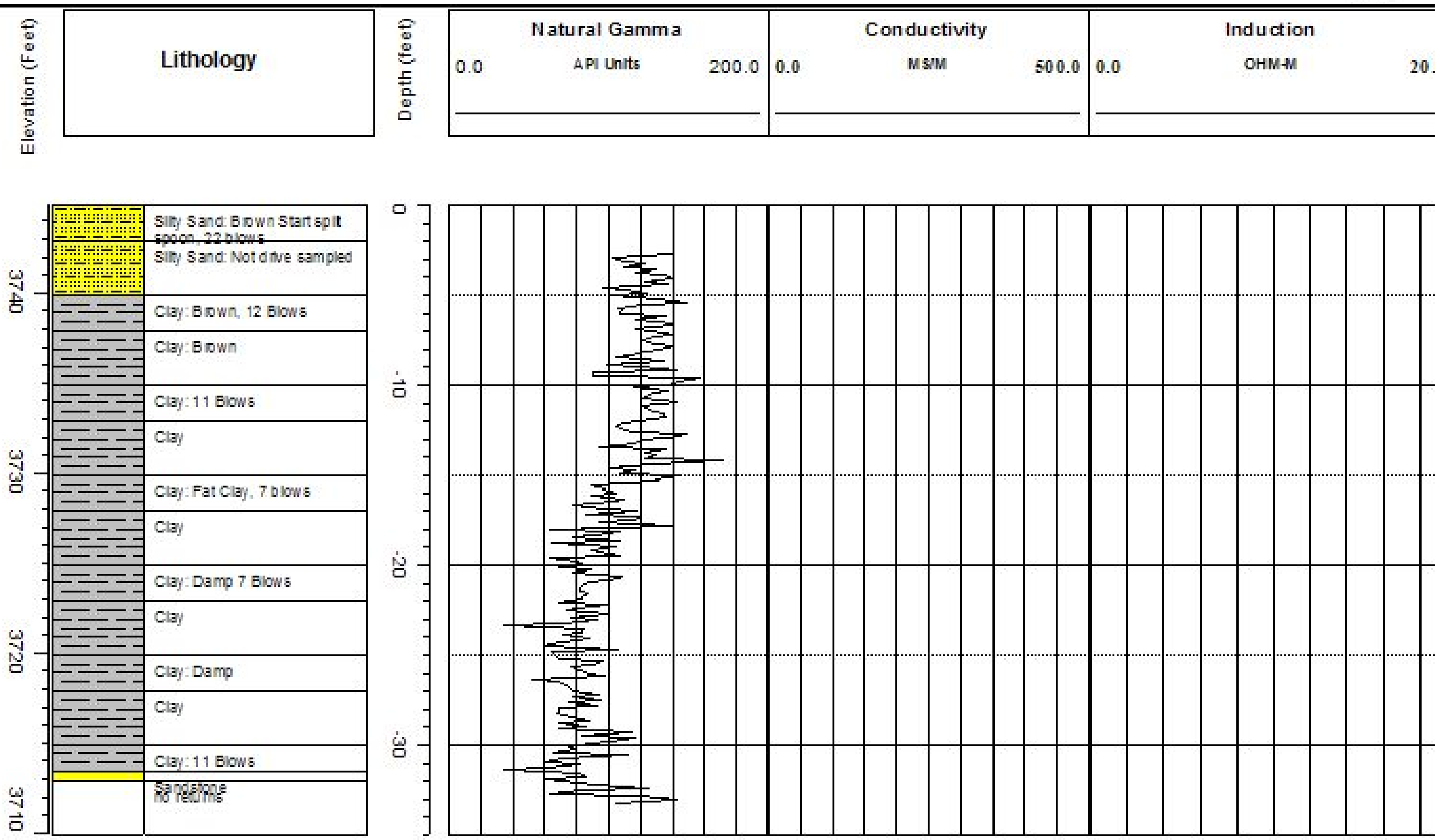
LX Bar Area Bounty Hunter Impoundment

Well Boring No. MW-3

Logs Run and Processed by US Department of Energy
Depth Matching by Pete Vogel-WDEQ

Logging Engineer	Smith	Drilling Dates	2-30-02	Latitude:	44.xxxxxxxx	Total Depth:	35
On-site Geologist	Webster	Hole Diameter	5-7/8"	Longitude:	-106.xxxxxxxx	Qtr Qtr	SWSW
Drilling Contractor	Flying by Knight Drilling Co.			GL Elevation	3744.87	Section	16
Driller	Doug Oakley			Northing	1905650.52	Township	57N
				Easting	1690469.39	Range	83W

Comments: 33 feet of Natural Gamma ONLY Geophysical Log run



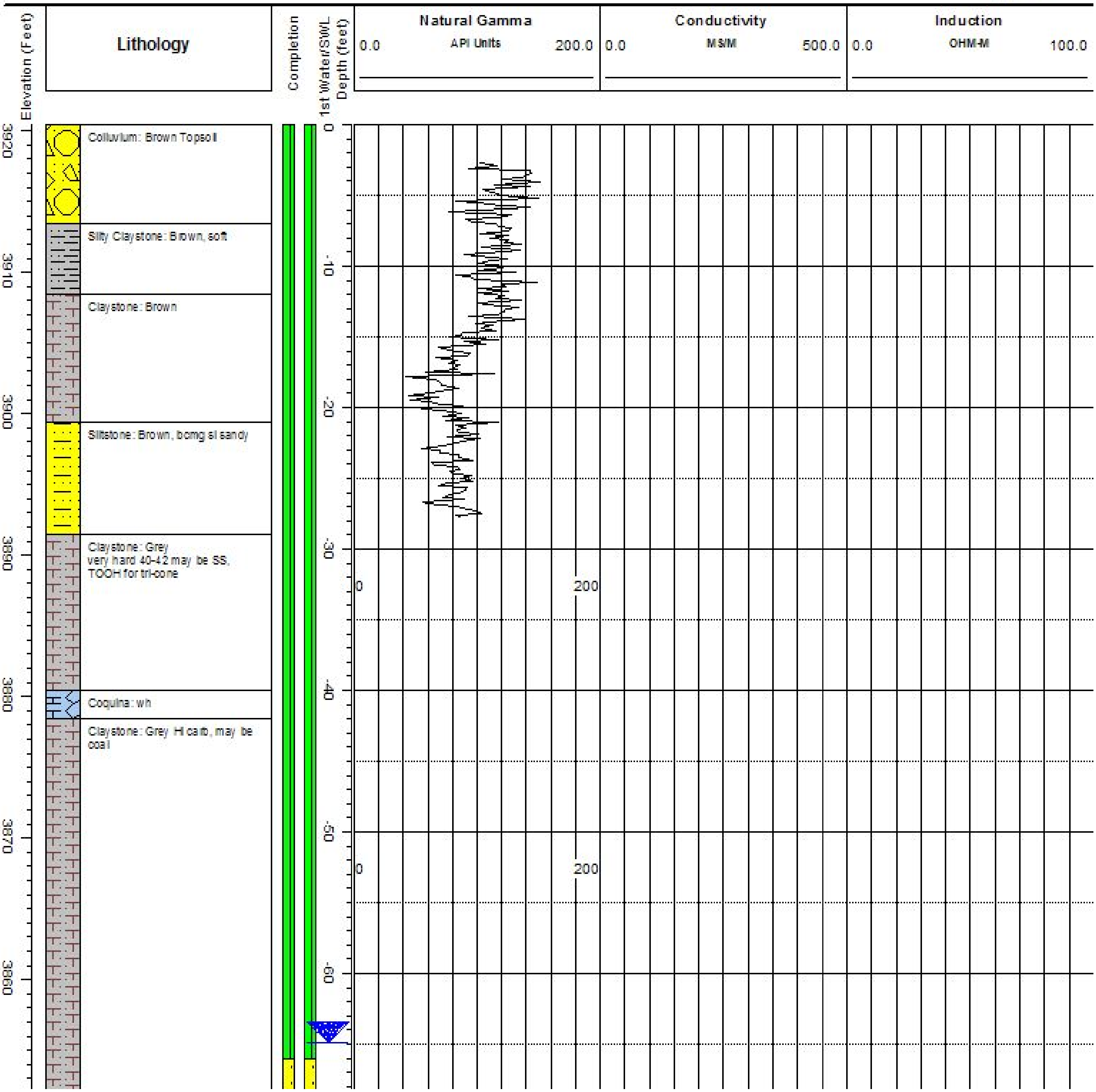
Geophysical Logs *Logs Run and Processed by United States Geological Survey*

LX Bar Area Golden Eagle Impoundment

Well No. MW-1

On-site Geologist	Webster	Latitude:	44°48'26.01904"	Northing	1901305.48	Total Depth:	87
		Longitude:	105°50'46.06339"	Easting	1698312.44	Qtr Qtr:	NENE
				GL Elevation	3920.43	Section:	26
Drilling Contractor	Interstate Drilling	Drilling Dates	6-23-06			Township	56N
Driller	Dave Proctor	Hole Diameter	5-7/8"			Range	75W

Comments: 27 feet of Natural Gamma ONLY Geophysical Log run
SWL from 12-8-06



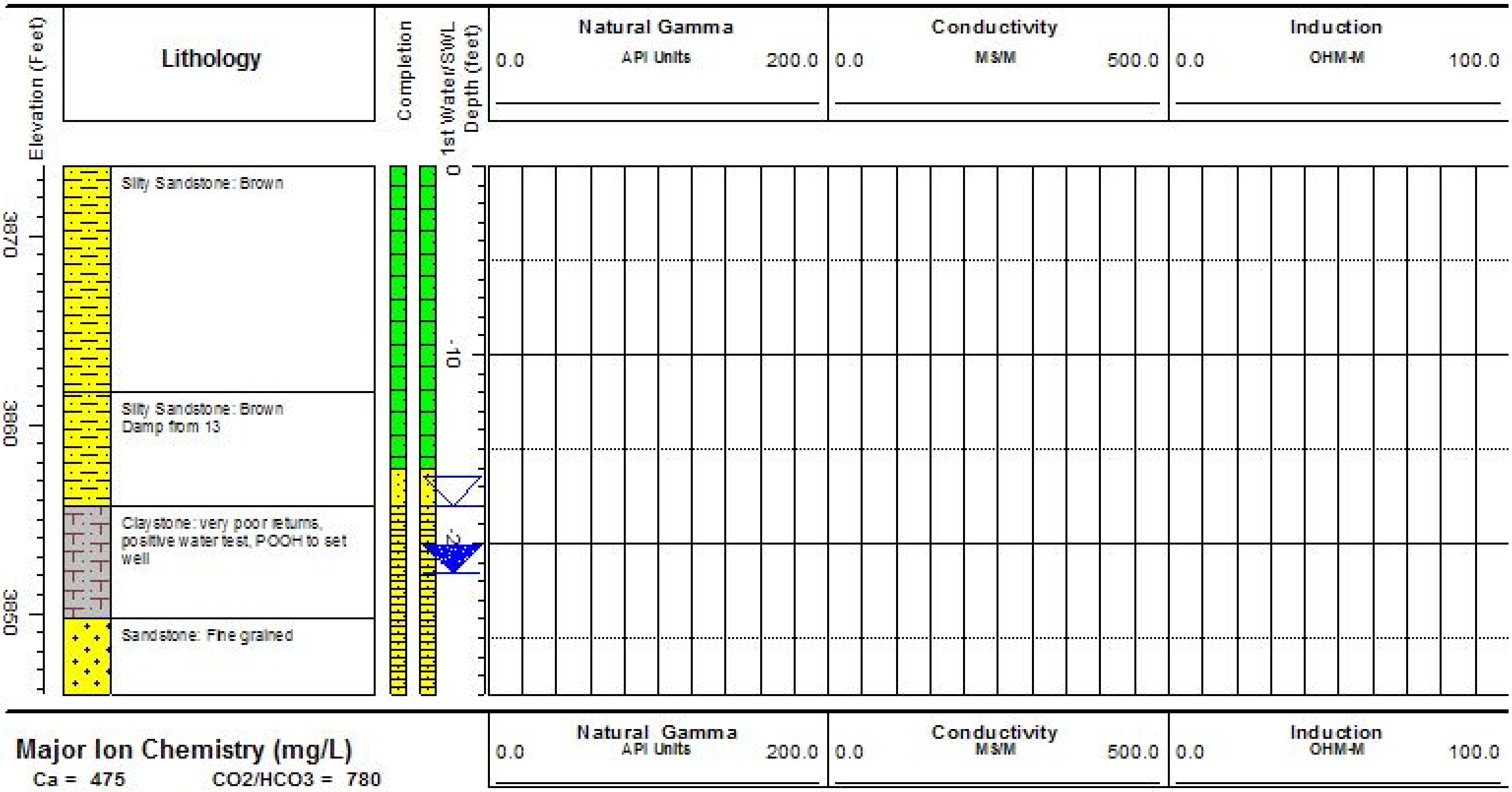
Geophysical Logs *Logs Run and Processed by United States Geological Survey*

LX Bar Area Golden Eagle Impoundment

Well No. MW-2

On-site Geologist	Latitude: 44°48'17.31163"	Northing	1900429.63	Total Depth:	26
Webster	Longitude: 105°50'41.55974"	Easting	1698653.27	Qtr Qtr:	SENE
		GL Elevation	3873.70	Section:	26
Drilling Contractor: Interstate Drilling	Drilling Dates: 6-24-06			Township	56N
Driller: Dave Proctor	Hole Diameter: 5-7/8"			Range	75W

Comments: NO Geophysical Logs Run
SWL from 12-6-06



Major Ion Chemistry (mg/L)

Ca = 475	CO2/HCO3 = 780		
Mg = 429	SO4 = 3740	pH = 7.1	
Na = 652	TDS = 6450	SAR = 5	

WDEQ Ground Water Classification = IV

Geophysical Logs

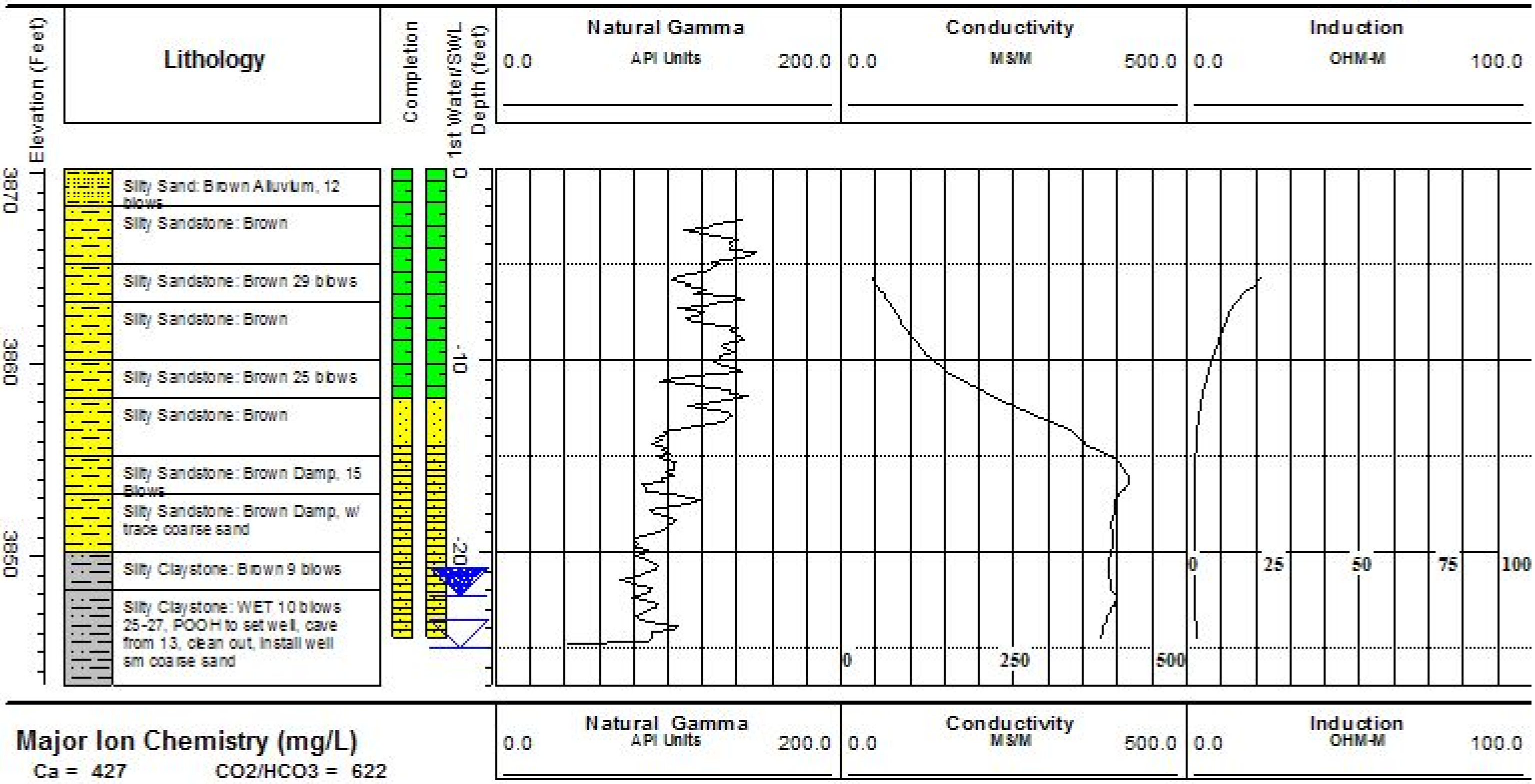
Logs Run and Processed by United States Geological Survey

LX Bar Area Golden Eagle Impoundment

Well No. MW-3

On-site Geologist	Terry Webster	Latitude:	44°48'16.06870"	Northing	1900299.814	Total Depth:	27
		Longitude:	105°50'44.54532"	Easting	1698440.325	Qtr Qtr:	SENE
				GL Elevation	3870.23	Section:	26
Drilling Contractor	Interstate Drilling	Drilling Dates	6-25-06			Township	56N
Driller	Dave Proctor	Hole Diameter	7-1/2"			Range	75W

Comments: Natural Gamma Curve smoothed due to excessive electronic noise
SWL on 12-8-06



Major Ion Chemistry (mg/L)

Ca =	427	CO2/HCO3 =	622		
Mg =	691	SO4 =	4659	pH =	7.22
Na =	550	TDS =	7920	SAR =	4

WDEQ Ground Water Classification = IV

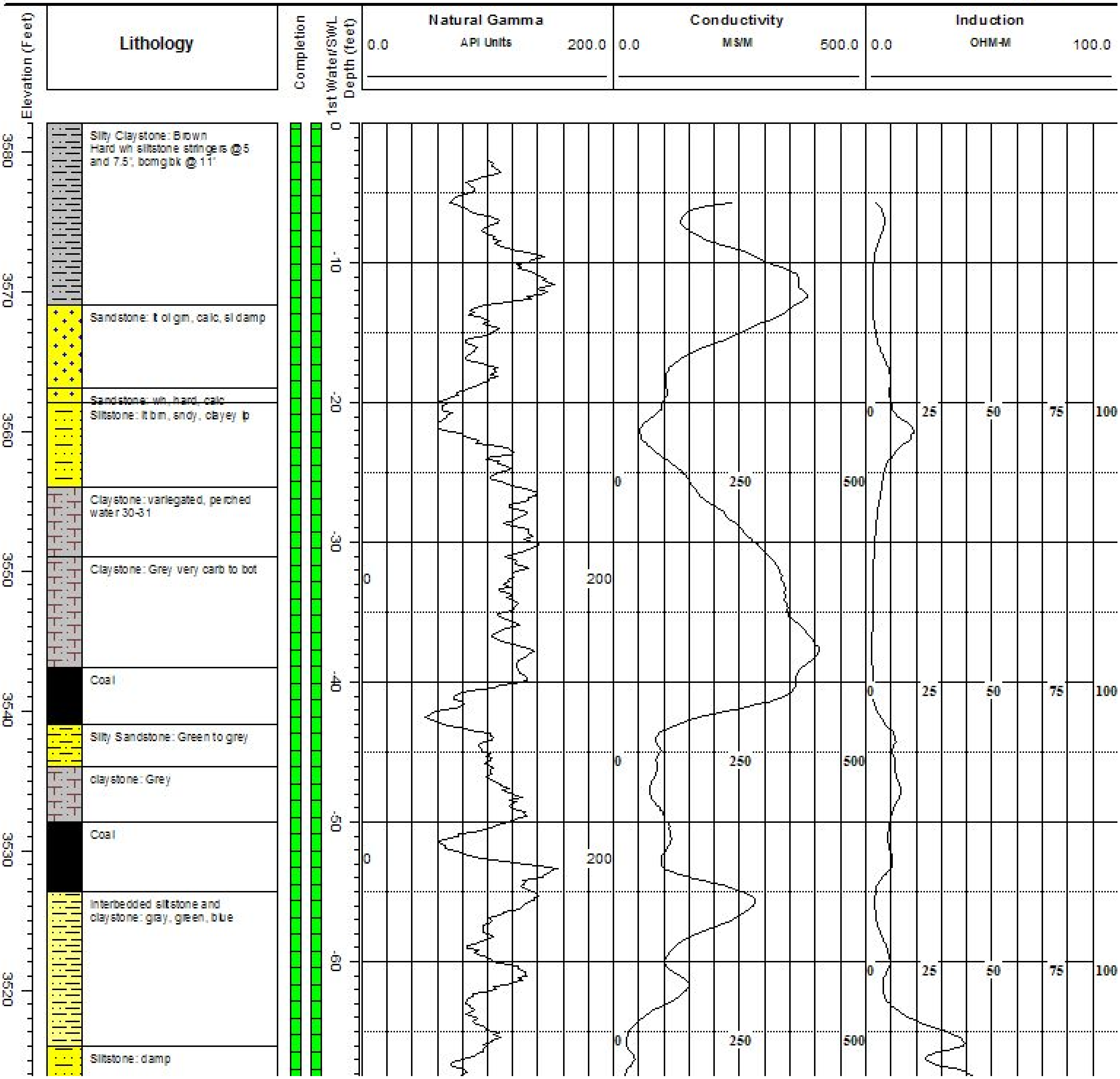
Geophysical Logs
Logs Run and Processed by United States Geological Survey

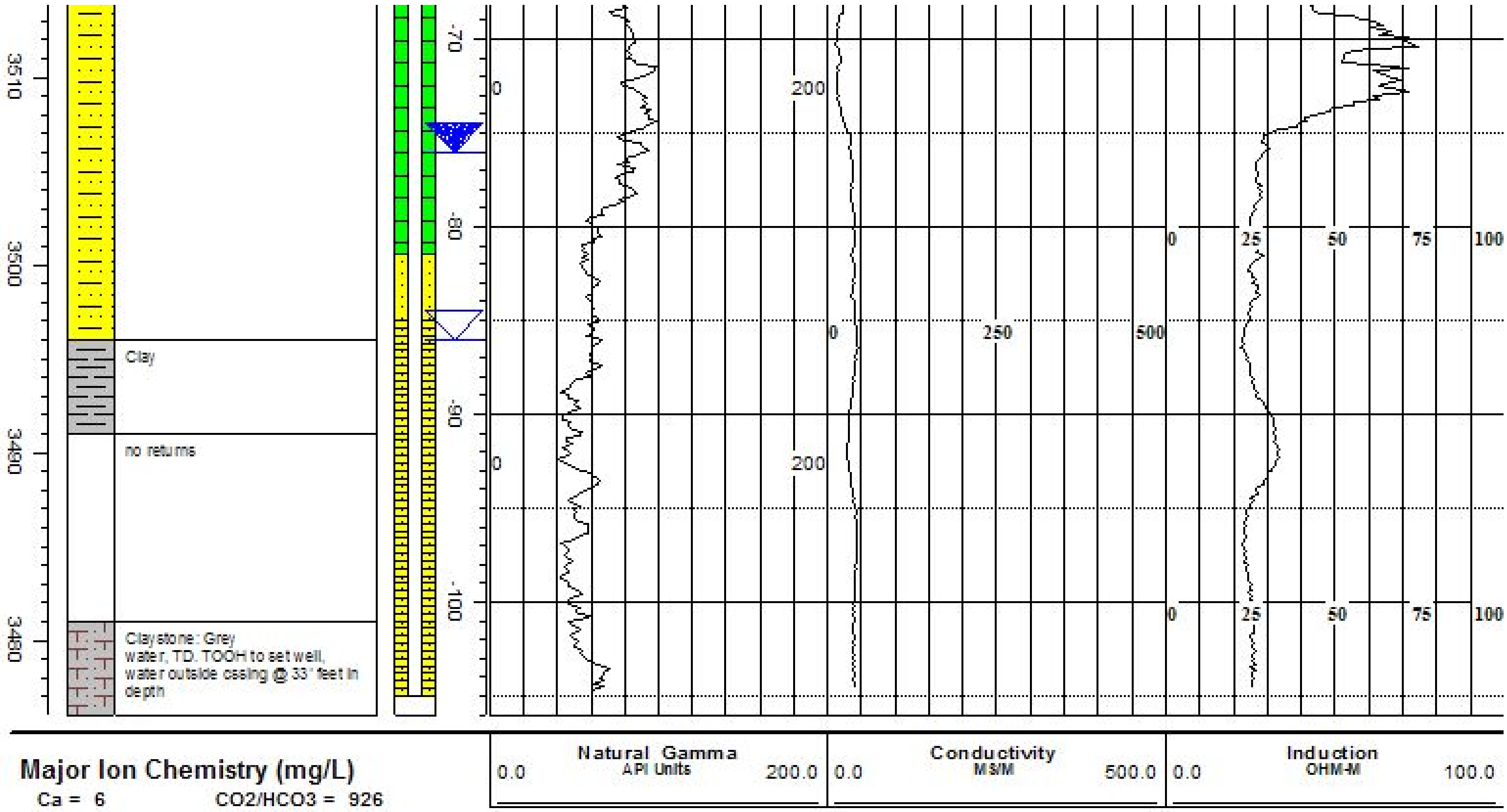
Prairie Dog Area Joe Draw Jr Impoundment

Well No. MW-1

On-site Geologist	Webster	Latitude:	44°57'03.91205"	Northing	1950613.68	Total Depth:	106
		Longitude:	-106°50'17.19139"	Easting	1440540.63	Qtr Qtr:	SESW
				GL Elevation	3582.04	Section:	35
Drilling Contractor	Interstate Drilling	Drilling Dates	6/11/2006			Township	58N
Driller	Dan Krueger	Hole Diameter	5-7/8"			Range	83W

Comments: Natural Gamma Curve smoothed due to excessive electronic noise
SWL from 10-16-06 -- First water questionable due to drilling conditions





Major Ion Chemistry (mg/L)

Ca = 6	CO2/HCO3 = 926		
Mg = 2	SO4 = 0	pH = 7.83	
Na = 316	TDS = 1116	SAR = 28	

WDEQ Ground Water Classification = III

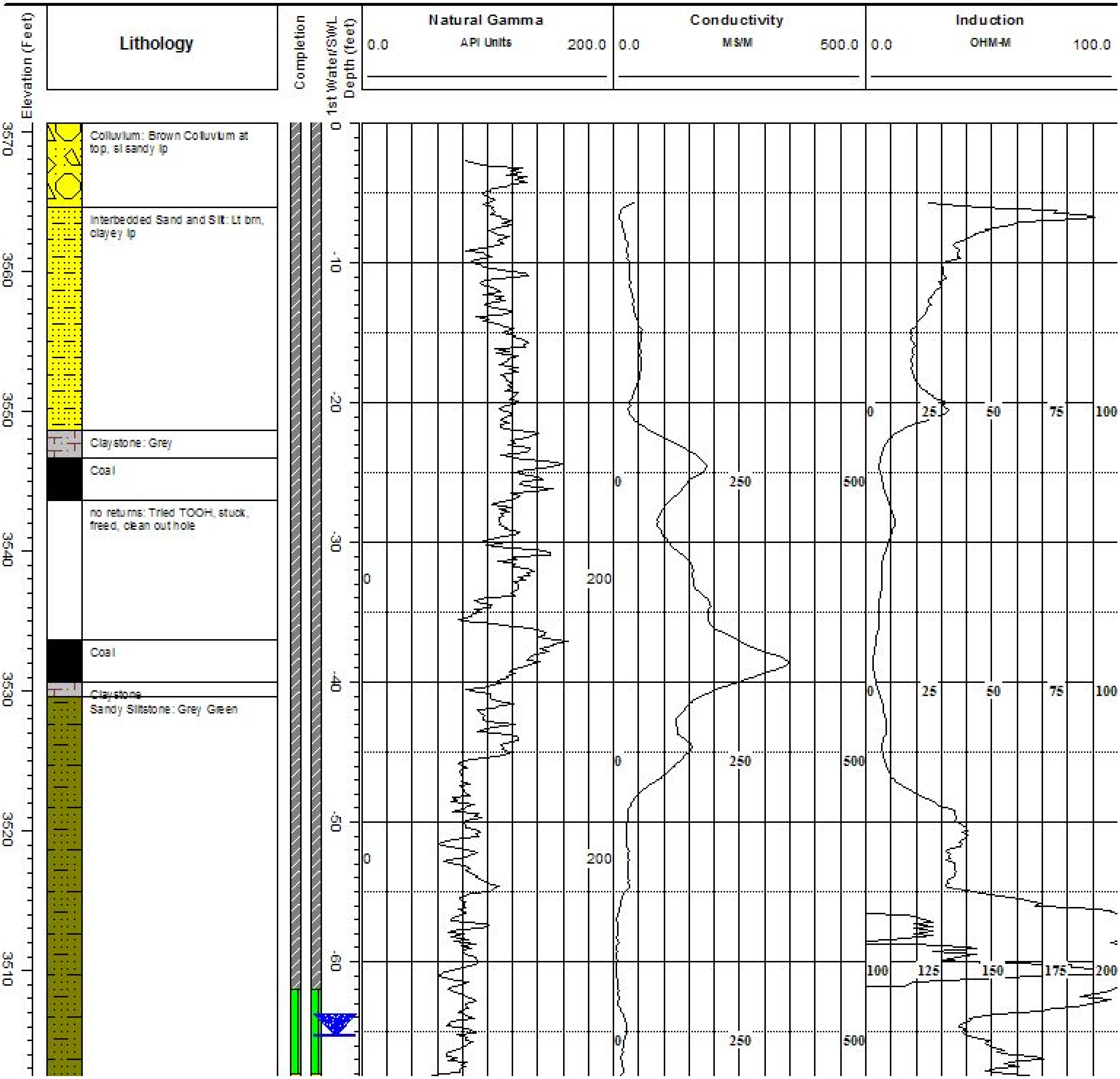
Geophysical Logs *Logs Run and Processed by United States Geological Survey*

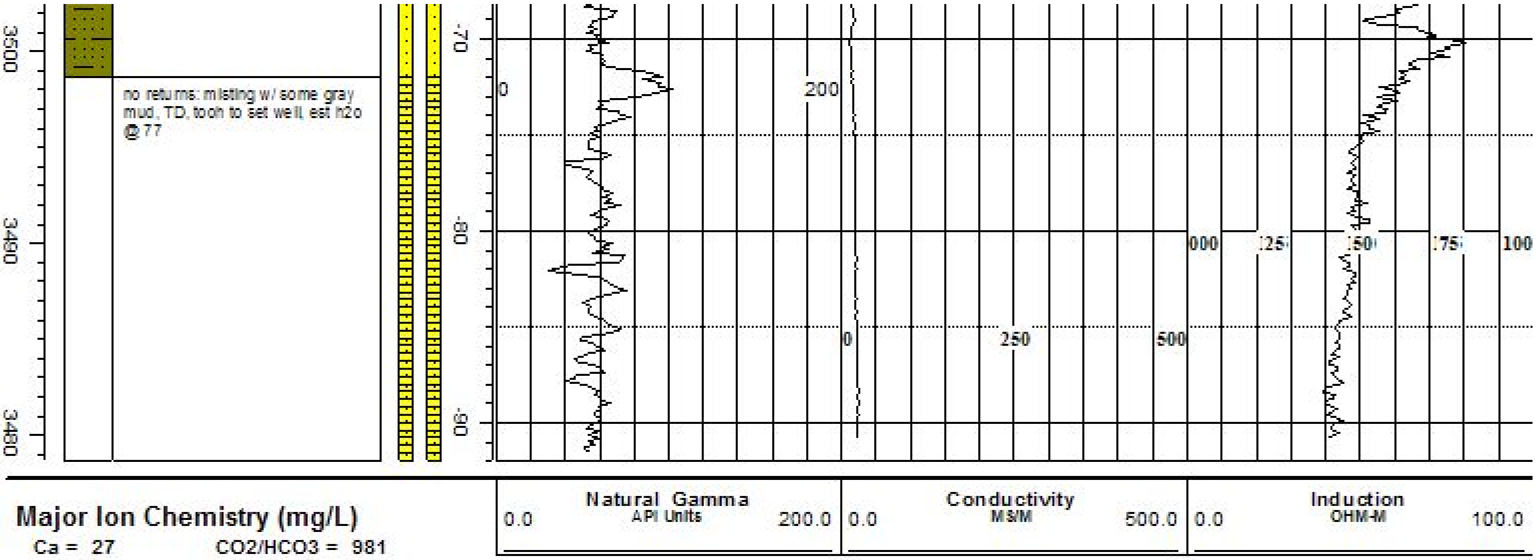
Prairie Dog Area Joe Draw Jr Impoundment

Well No. MW-2

On-site Geologist	Webster	Latitude:	44°57'05.25621"	Northing	1950748.76	Total Depth:	92
		Longitude:	-106°50'19.55964"	Easting	1440369.49	Qtr Qtr:	SESW
				GL Elevation	3570.65	Section:	35
Drilling Contractor	Interstate Drilling	Drilling Dates	6/12/2006			Township	58N
Driller	Dan Krueger	Hole Diameter	5-7/8"			Range	83W

Comments: Natural Gamma Curve smoothed due to excessive electronic noise
Swl from 10-25-06





Major Ion Chemistry (mg/L)

Ca = 27	CO2/HCO3 =	981			
Mg = 3	SO4 =	0	pH =	8.04	
Na = 351	TDS =	1160	SAR =	17	

WDEQ Ground Water Classification = III

Geophysical Logs *Logs Run and Processed by United States Geological Survey*

Prairie Dog Area Joe Draw Jr Impoundment

Well No. MW-3

On-site Geologist: Webster

Latitude: 44°57'00.83811"
Longitude: -106°50.07.38950"

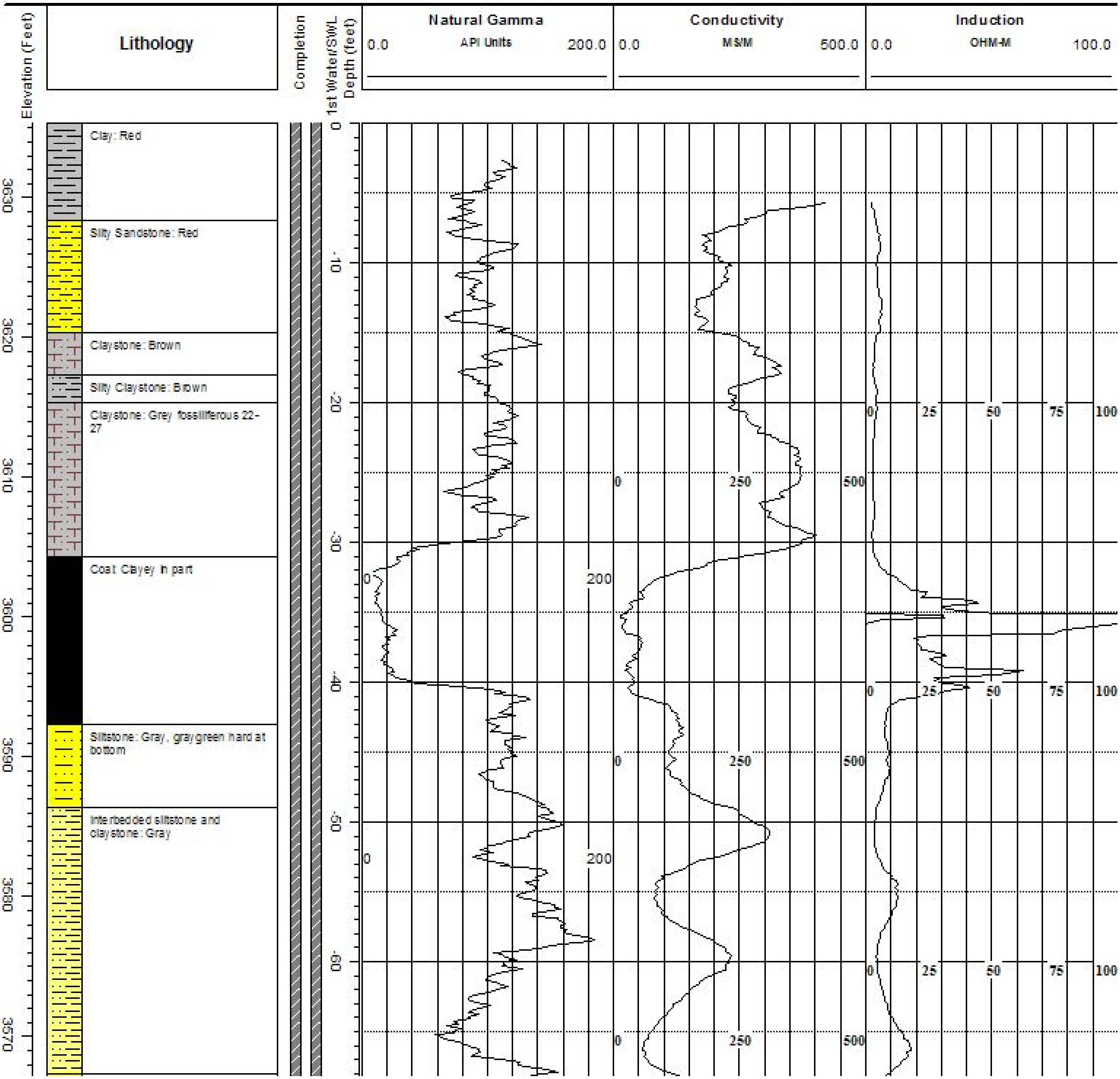
Northing: 1950306.69
Easting: 1441247.42
GL Elevation: 3635.36

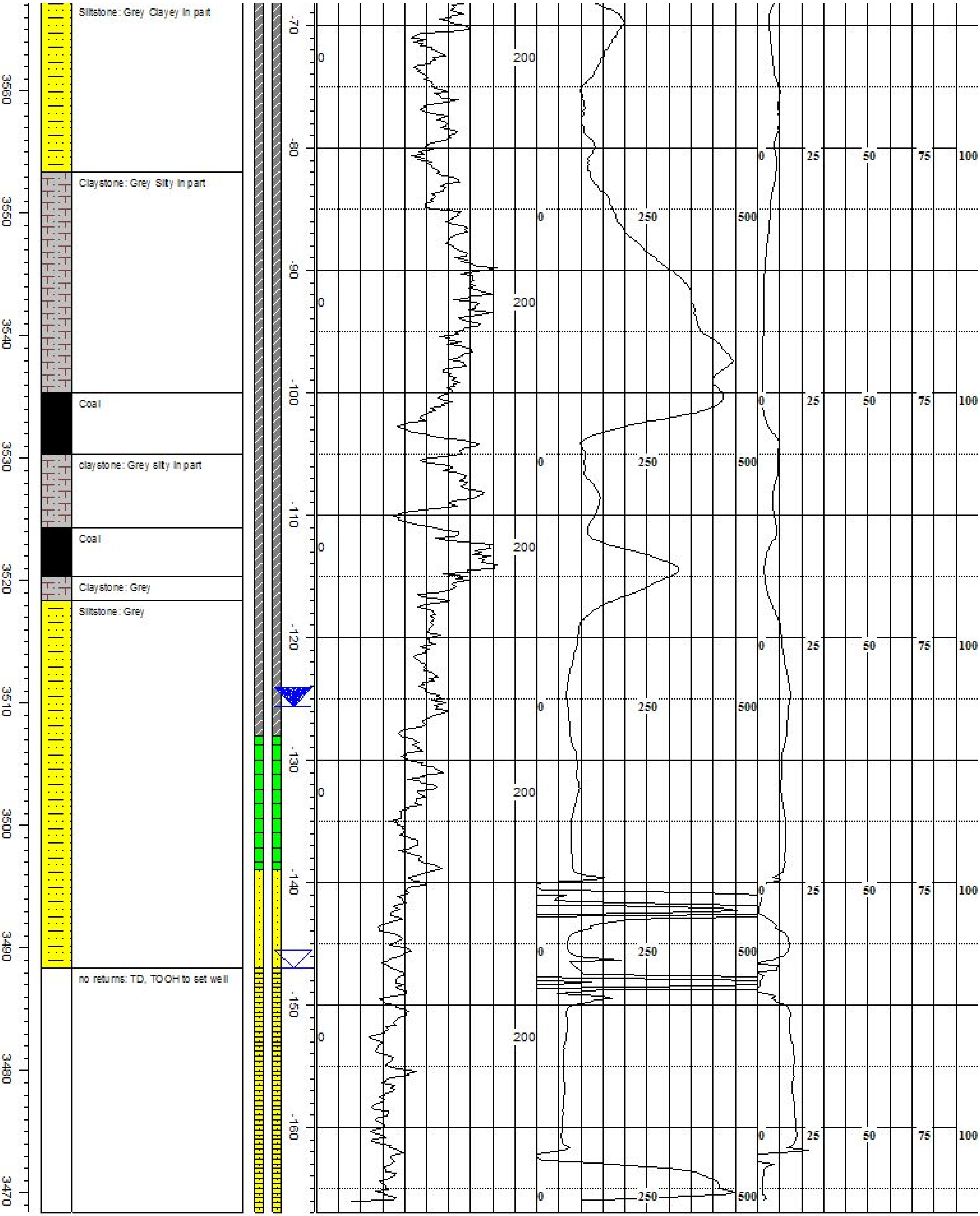
Total Depth: 167
Qtr Qtr: NENW
Section: 2
Township: 57N
Range: 83W

Drilling Contractor: Interstate Drilling
Driller: Dan Krueger

Drilling Dates: 6/12-13/2006
Hole Diameter: 5-7/8"

Comments: All Curves Smoothed due to excessive electronic noise
SWL from 10-5-06





Siltstone: Grey Clayey in part
Claystone: Grey Silty in part
Coal
claystone: Grey silty in part
Coal
Claystone: Grey
Siltstone: Grey
no returns: TD, TOOH to set well
3560
3550
3540
3530
3520
3510
3500
3490
3480
3470
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
0
200
250
500
25
50
75
100

Major Ion Chemistry (mg/L)		Natural Gamma API Units (0.0 – 200.0)	Conductivity MS/M (0.0 – 500.0)	Induction OHM-M (0.0 – 100.0)
Ca = 21	CO2/HCO3 = 1128			
Mg = 3	SO4 = 0	pH = 8.15		
Na = 382	TDS = 1464	SAR = 21		

WDEQ Ground Water Classification = III

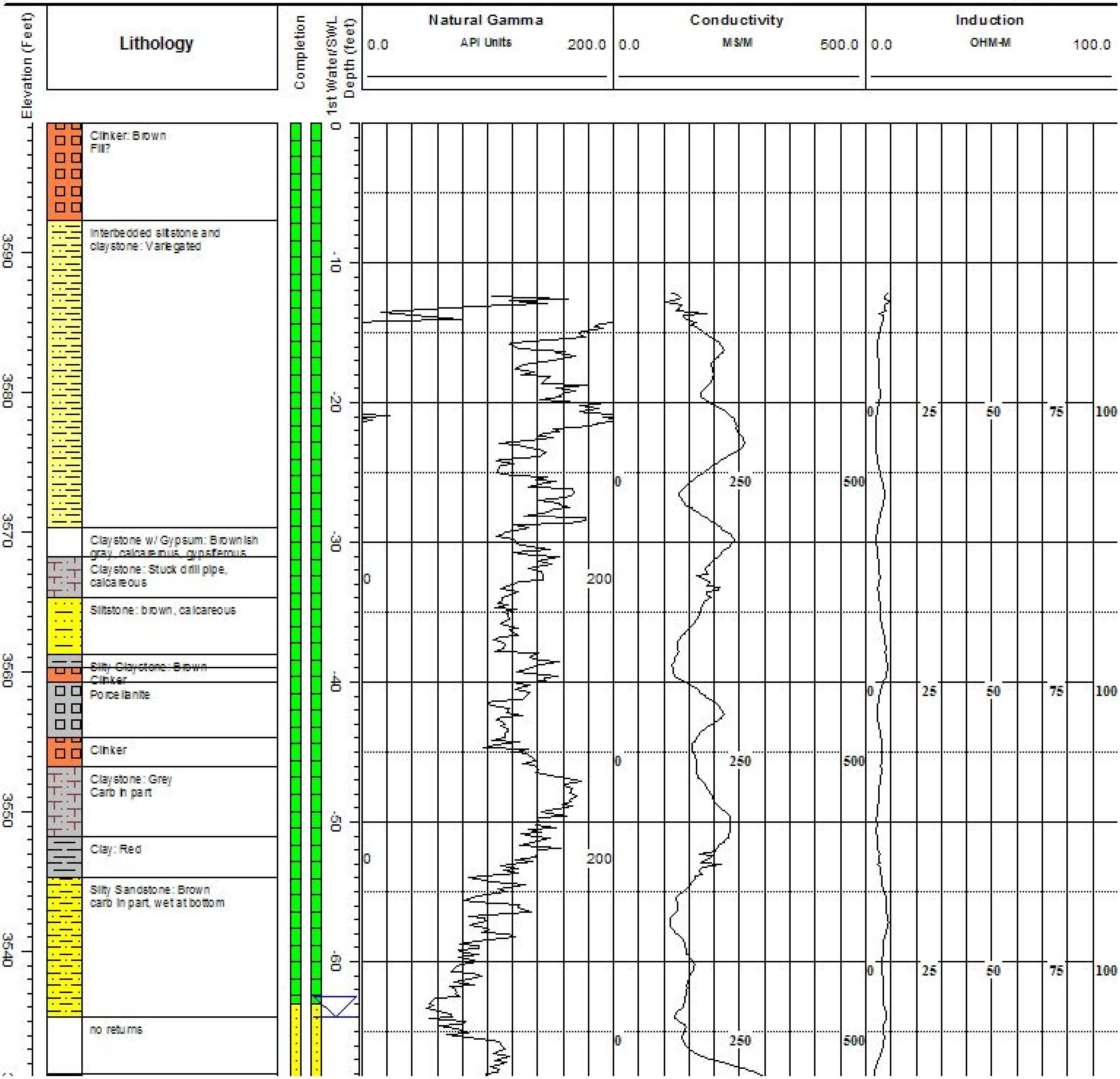
Geophysical Logs *Logs Run and Processed by United States Geological Survey*

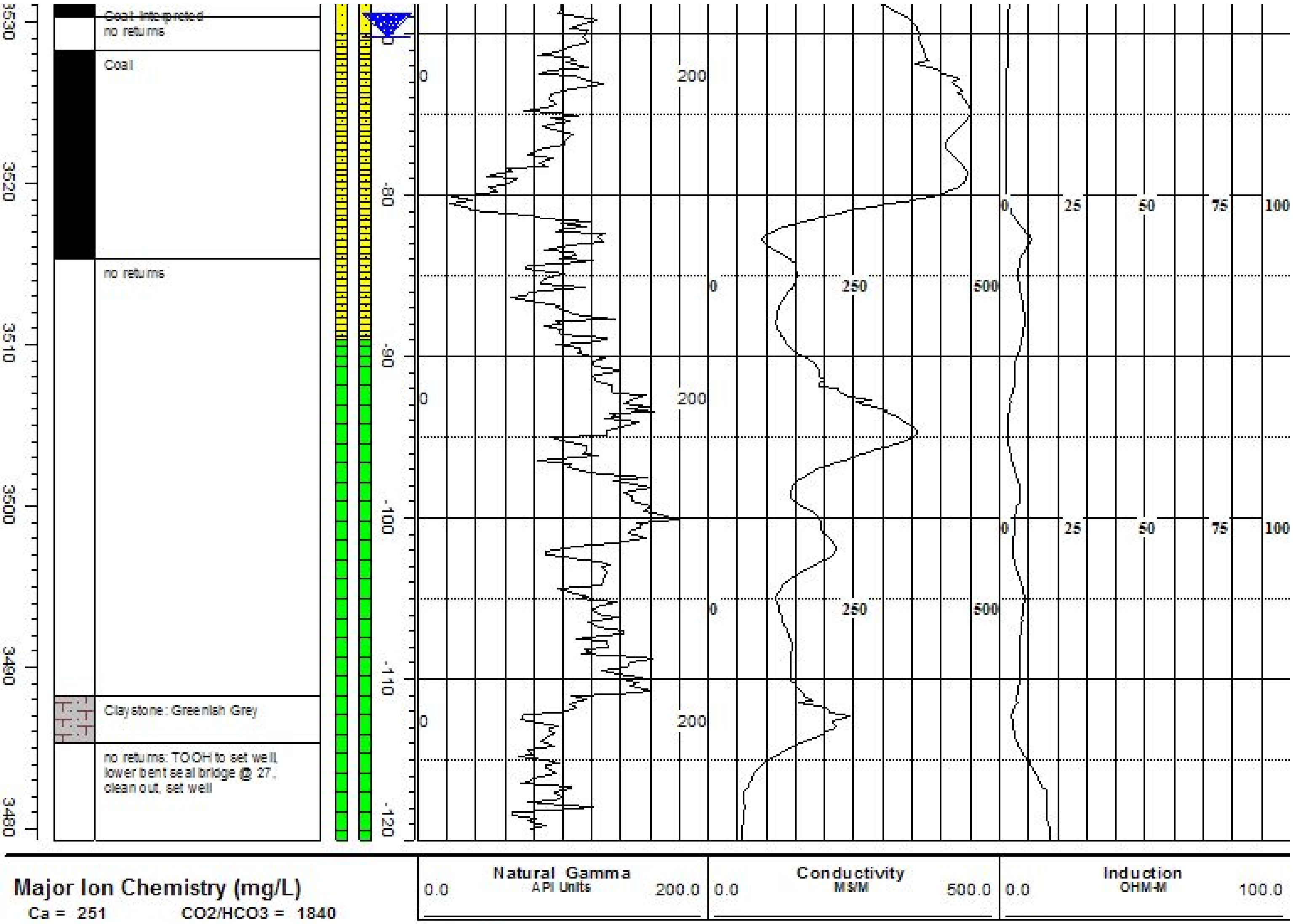
Prairie Dog Area — Lori Impoundment

Well No. PD-1

On-site Geologist	Terry Webster	Latitude:	44°57'40.54044"	Northing	1954354.77	Total Depth:	120
		Longitude:	-106°49'06.50550"	Easting	1445600.31	Qtr Qtr:	SENW
				GL Elevation	3599.27	Section:	36
Drilling Contractor	Interstate Drilling	Drilling Dates	5-24-2006			Township	58N
Driller	Dan Krueger	Hole Diameter	5-7/8"			Range	83W

Comments: SWL from 10-24-06





Major Ion Chemistry (mg/L)

Ca = 251 CO2/HCO3 = 1840

Mg = 214 SO4 = 3128 pH = 6.82

Na = 1130 TDS = 5732 SAR = 13

WDEQ Ground Water Classification = IV

Geophysical Logs

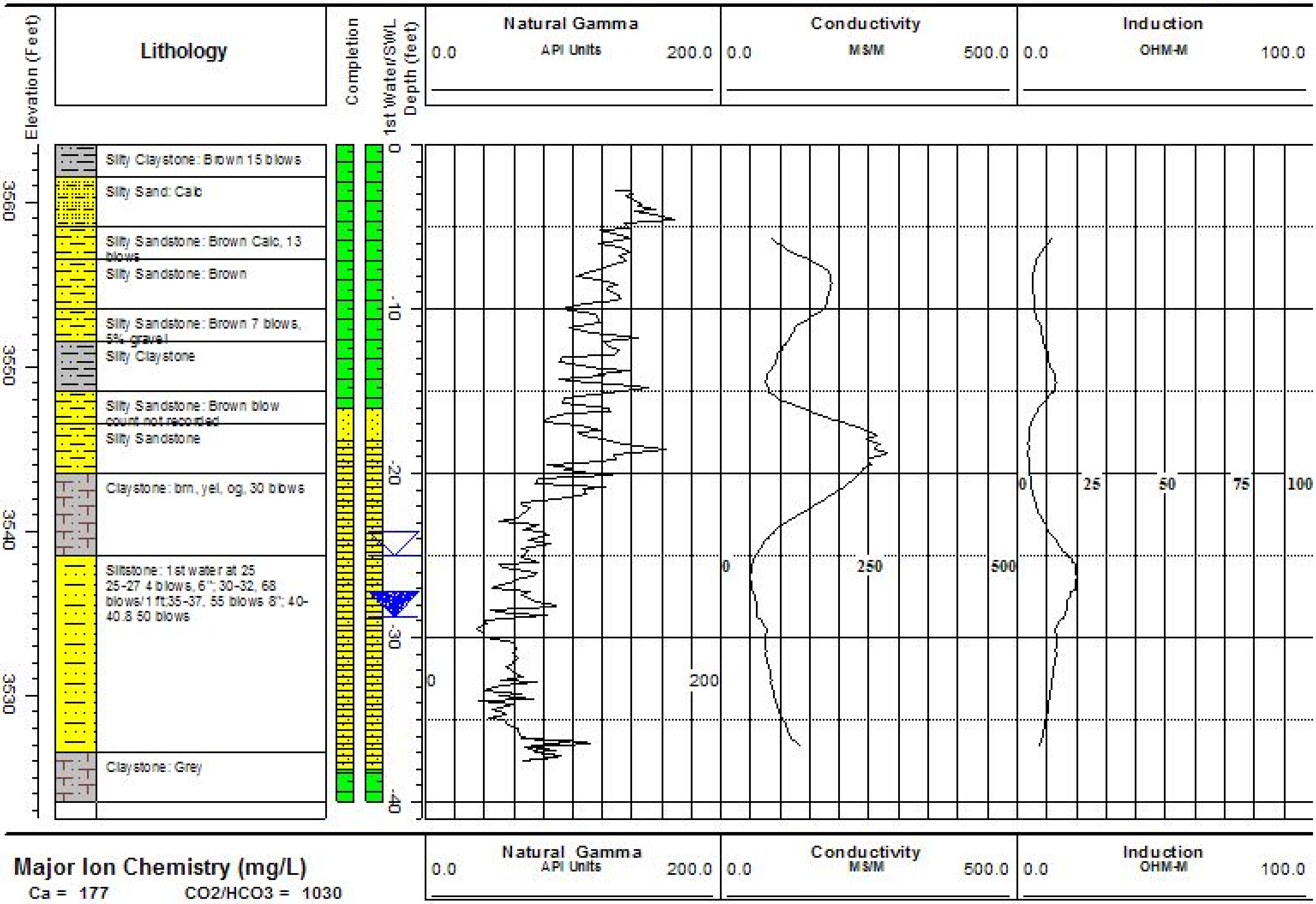
Logs Run and Processed by United States Geological Survey

Prairie Dog Area — Lori Impoundment

Well No. MW-1

On-site Geologist	Webster	Latitude:	44°57'31.86098"	Northing	1953476.51	Total Depth:	41
		Longitude:	-106°49'04.90558"	Easting	1445720.94	Qtr Qtr:	NESW
				GL Elevation	3563.53	Section:	36
Drilling Contractor	Interstate Drilling	Drilling Dates	5/20/2006			Township	58N
Driller	Dan Krueger	Hole Diameter	7-1/2"			Range	83W

Comments: All geophysical log traces appear reversed
SWL from 10-18-06



Major Ion Chemistry (mg/L)

Ca =	177	CO2/HCO3 =	1030		
Mg =	184	SO4 =	2653	pH =	7.39
Na =	938	TDS =	5148	SAR =	12

WDEQ Ground Water Classification = IV

Geophysical Logs

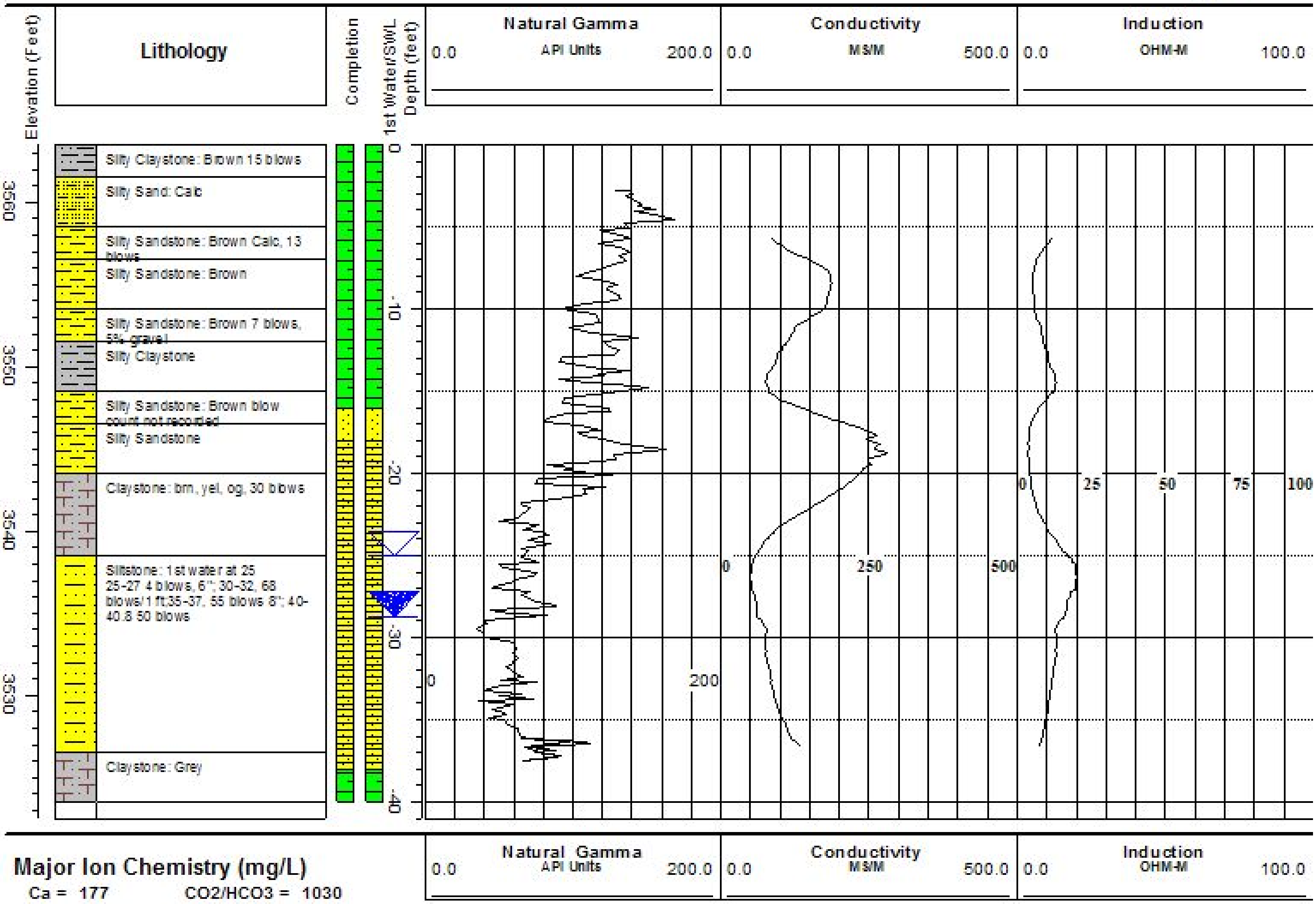
Logs Run and Processed by United States Geological Survey

Prairie Dog Area — Lori Impoundment

Well No. MW-1

On-site Geologist	Webster	Latitude:	44°57'31.86098"	Northing	1953476.51	Total Depth:	41
		Longitude:	-106°49'04.90558"	Easting	1445720.94	Qtr Qtr:	NESW
				GL Elevation	3563.53	Section:	36
Drilling Contractor	Interstate Drilling	Drilling Dates	5/20/2006			Township	58N
Driller	Dan Krueger	Hole Diameter	7-1/2"			Range	83W

Comments: All geophysical log traces appear reversed
SWL from 10-18-06



Major Ion Chemistry (mg/L)

Ca =	177	CO2/HCO3 =	1030		
Mg =	184	SO4 =	2653	pH =	7.39
Na =	938	TDS =	5148	SAR =	12

WDEQ Ground Water Classification = IV

Geophysical Logs

Logs Run and Processed by United States Geological Survey

Prairie Dog Area — Lori Impoundment

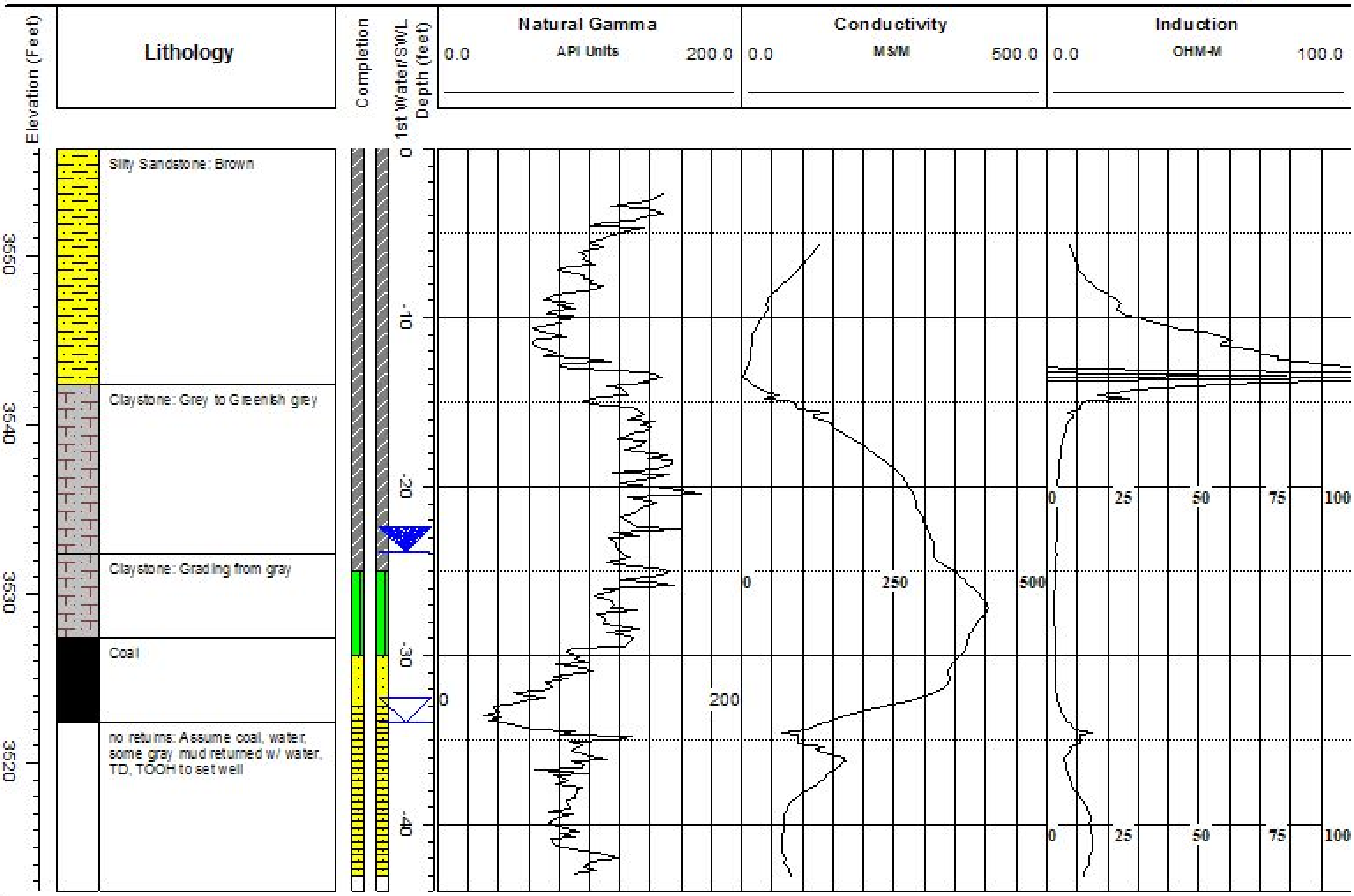
Well No. MW-4

On-site Geologist	Terry Webster	Latitude:	44°57'31.12699"	Northing	1953401.04
		Longitude:	-106°49'07.12693"	Easting	1445542.9
				GL Elevation	3556.35
Drilling Contractor	Interstate Drilling	Drilling Dates	5-22-2006		
Driller	Dan Krueger	Hole Diameter	5-7/8"		

Total Depth:	44
Qtr Qtr:	NESW
Section:	16
Township	58N
Range	83W

Comments: SWL from 5/22/06, Not recorded on sampling date 10-24-06

Page 1 of 1



Natural Gamma	Conductivity	Induction
API Units: 0.0 – 200.0	MS/M: 0.0 – 500.0	OHM-M: 0.0 – 100.0

Major Ion Chemistry (mg/L)

Ca =	156	CO2/HCO3 =	1146		
Mg =	94	SO4 =	1168	pH =	6.84
Na =	603	TDS =	2840	SAR =	9

WDEQ Ground Water Classification = III

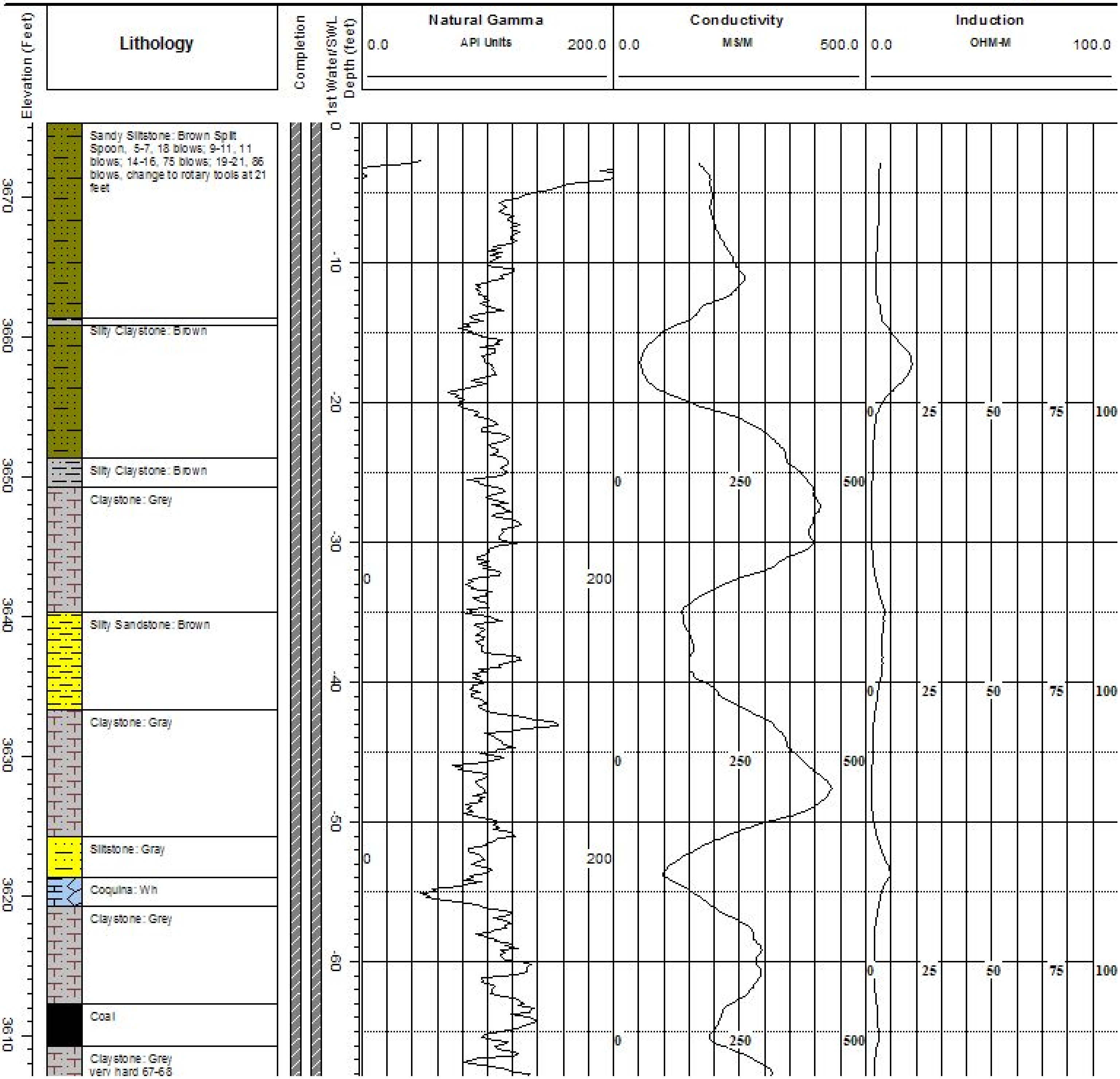
Geophysical Logs *Logs Run and Processed by United States Geological Survey*

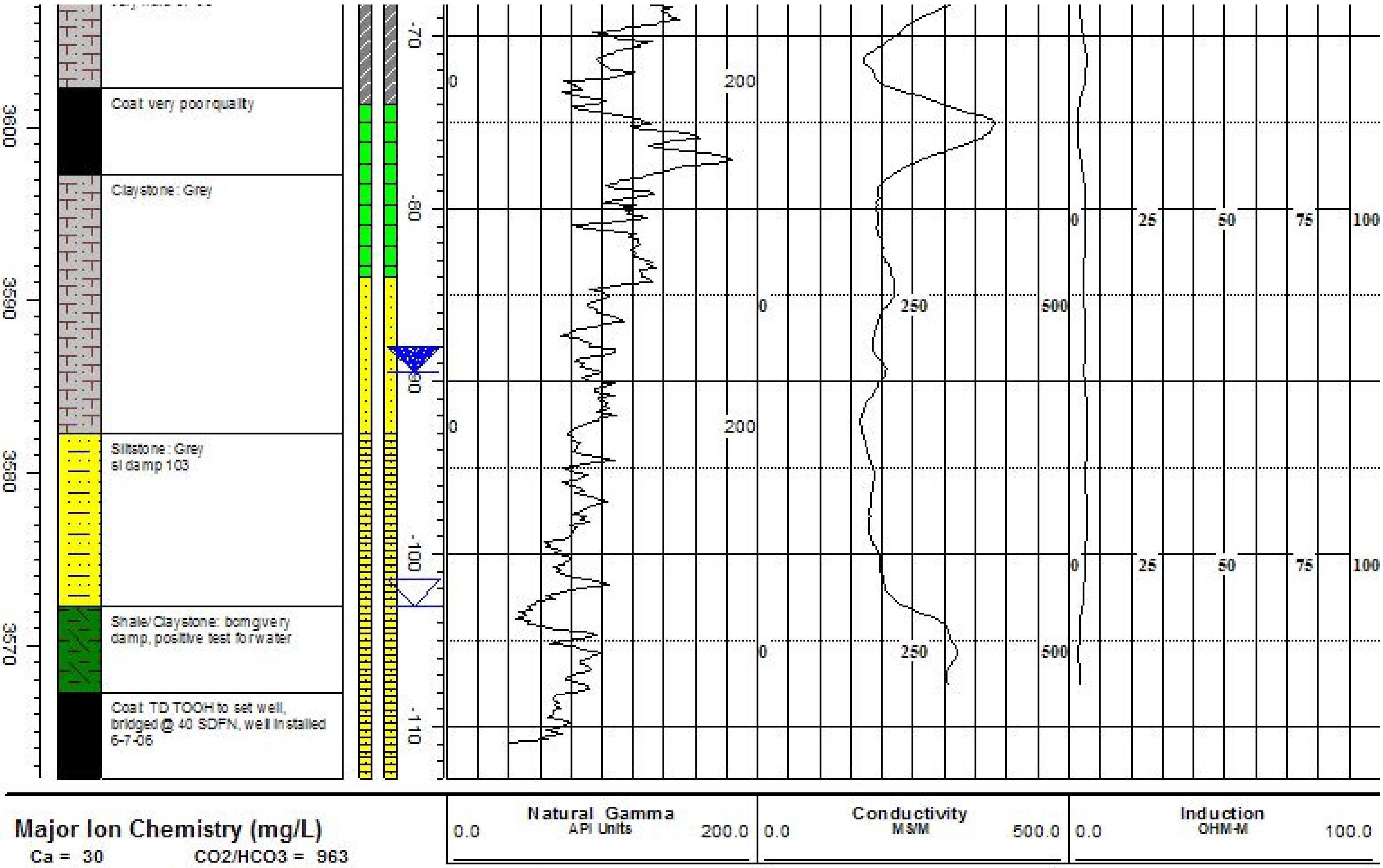
Prairie Dog Area — Sandy Impoundment

Well No. MW-1

On-site Geologist	Webster	Latitude:	44°57'11.50839"	Northing	1951338.11	Total Depth:	113
		Longitude:	-106°52'02.46863"	Easting	1432965.39	Qtr Qtr:	SESE
				GL Elevation	3675.29	Section:	33
Drilling Contractor	Interstate Drilling	Drilling Dates	6/06-07/2006			Township	57N
Driller	Dan Krueger	Hole Diameter	5-7/8"			Range	83W

Comments: Natural Gamma curve smoothed to aid in interpretation
SWL from 10-2-06





Major Ion Chemistry (mg/L)

Ca = 30 CO2/HCO3 = 963

Mg = 226 SO4 = 3464 pH = 7.12

Na = 964 TDS = 5816 SAR = 13

WDEQ Ground Water Classification = IV

Geophysical Logs *Logs Run and Processed by United States Geological Survey*

Prairie Dog Area Sandy Impoundment

Well No. MW-2

On-site Geologist Webster

Latitude: 44°57'15.32785"
Longitude: 106°51'53.27517"

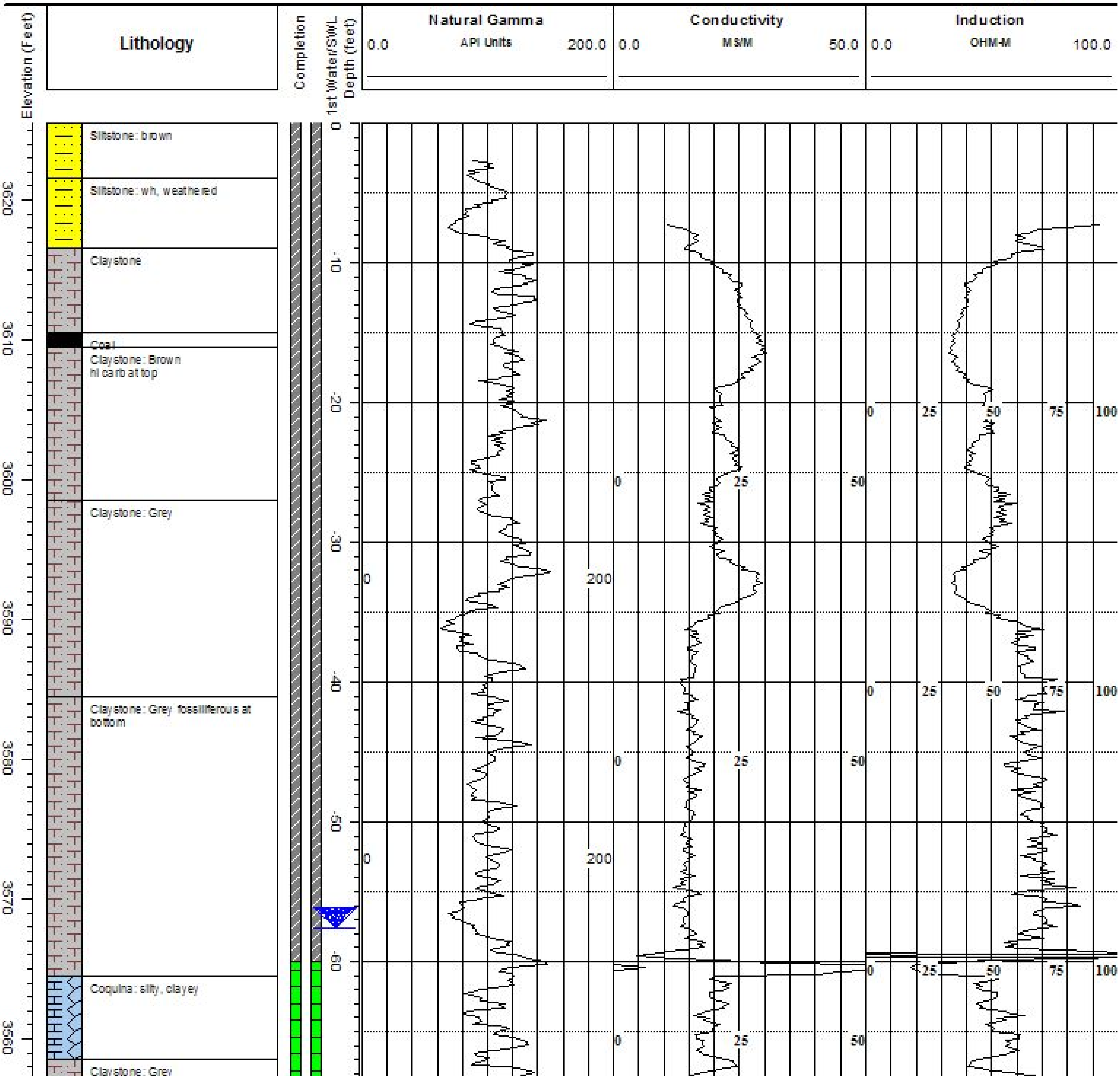
Northing 1951728.72
Easting 1433624.26
GL Elevation 3625.52

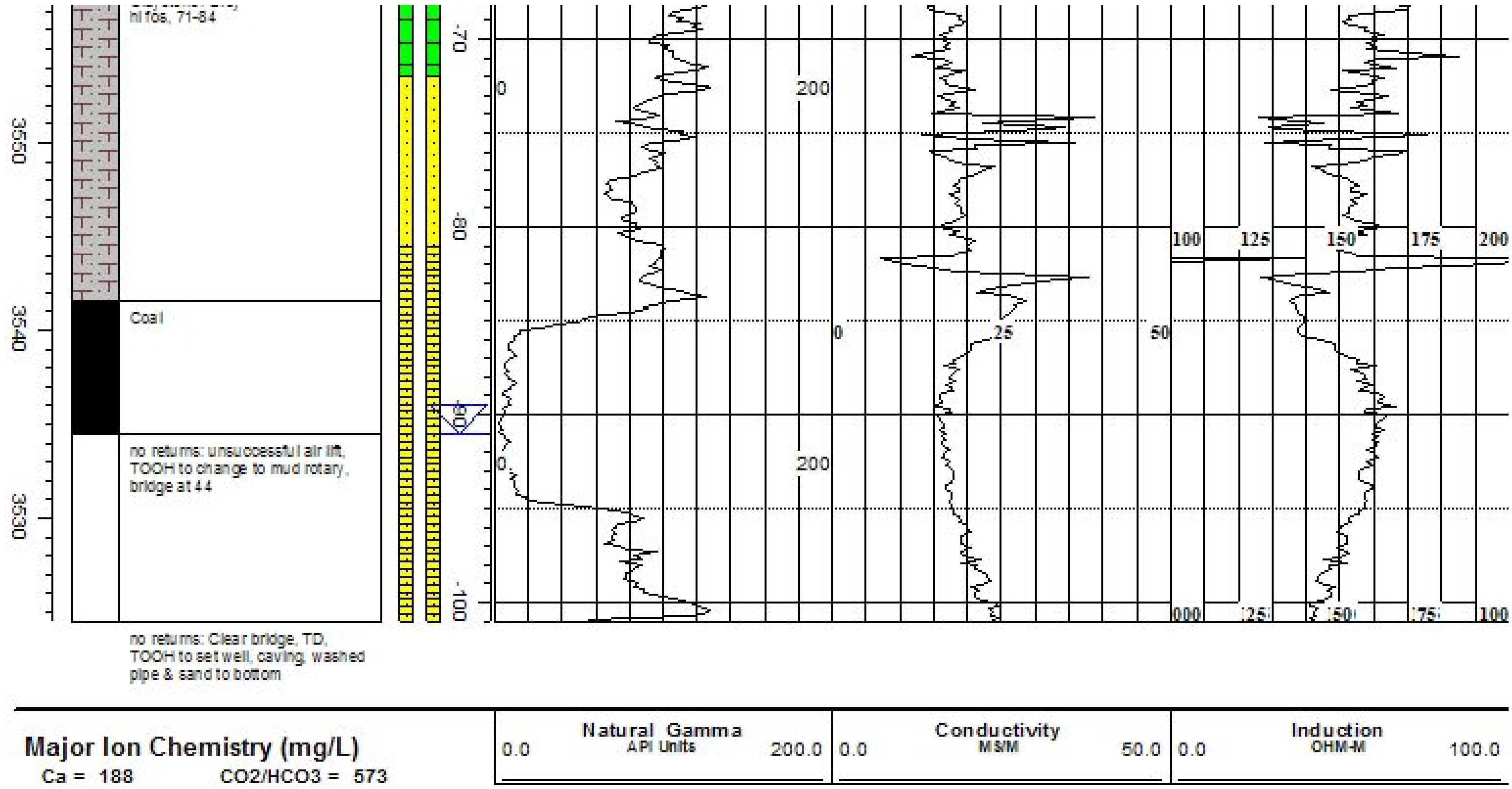
Total Depth: 101
Qtr Qtr: SESE
Section: 33
Township 57N
Range 83W

Drilling Contractor Interstate Drilliing
Driller Dan Krueger

Drilling Dates 6-7-2006
Hole Diameter 5-7/8"

Comments: Natural Gamma Curve Smoothed to aid interpretation
SWL from 10-3-06





Major Ion Chemistry (mg/L)

Ca = 188	CO2/HCO3 = 573		
Mg = 63	SO4 = 3060	pH = 7.64	
Na = 1320	TDS = 5288	SAR = 21	

WDEQ Ground Water Classification = IV

Geophysical Logs *Logs Run and Processed by United States Geological Survey*

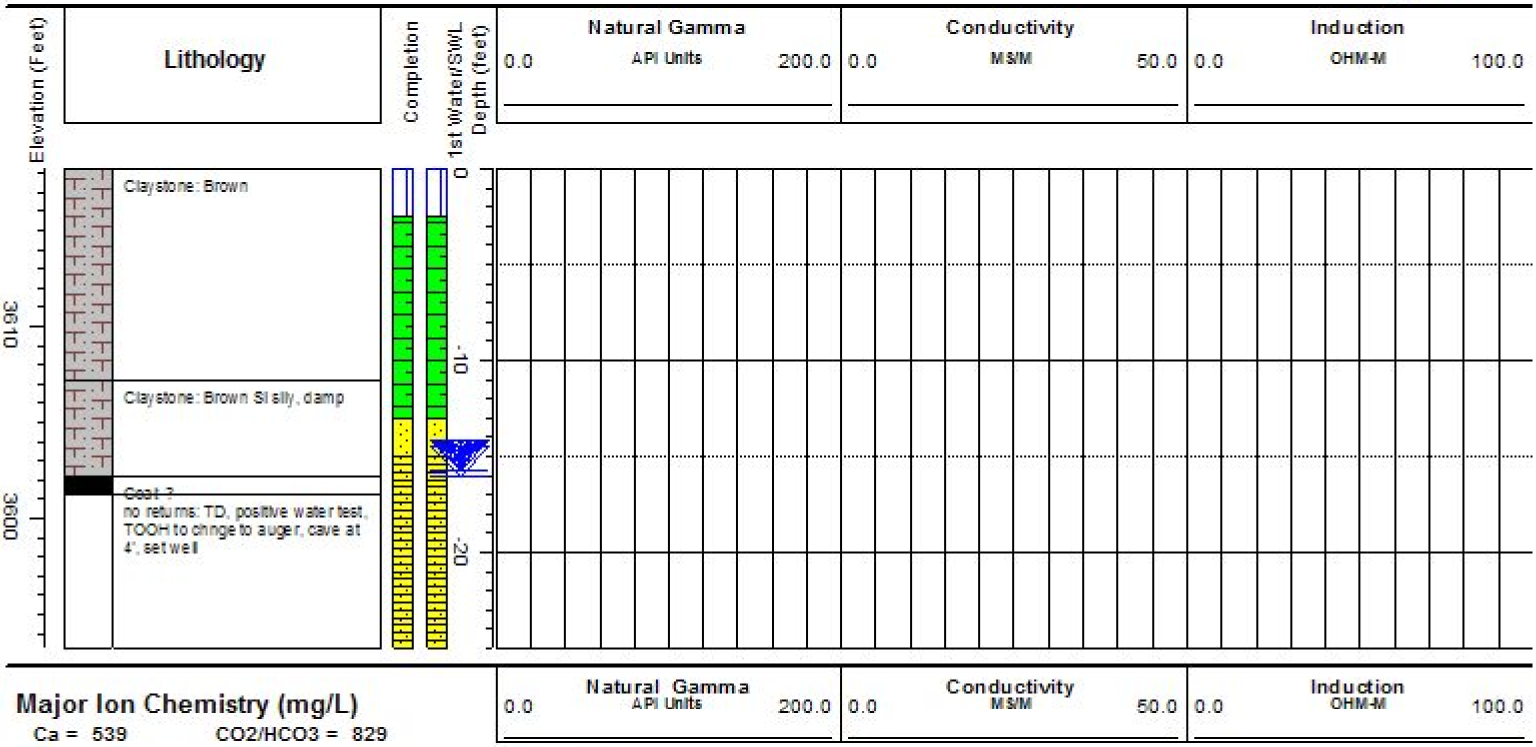
Prairie Dog Area — Sandy Impoundment

Well No. MW-3

On-site Geologist	Terry Webster	Latitude:	44°57'13.39706"	Northing	1951533.32
		Longitude:	-106°51'52.94648"	Easting	1433649.03
				GL Elevation	3618.22
Drilling Contractor	Interstate Drilling	Drilling Dates	6-11-2006		
Driller	Dan Krueger	Hole Diameter	7-1/2"		

Total Depth:	25
Qtr Qtr:	SESE
Section:	33
Township	57N
Range	83W

Comments: Geophysical logs not run
SWL: from 10-4-06



Major Ion Chemistry (mg/L)

Ca = 539	CO2/HCO3 = 829		
Mg = 408	SO4 = 3290	pH = 6.86	
Na = 609	TDS = 5080	SAR = 5	

WDEQ Ground Water Classification = IV

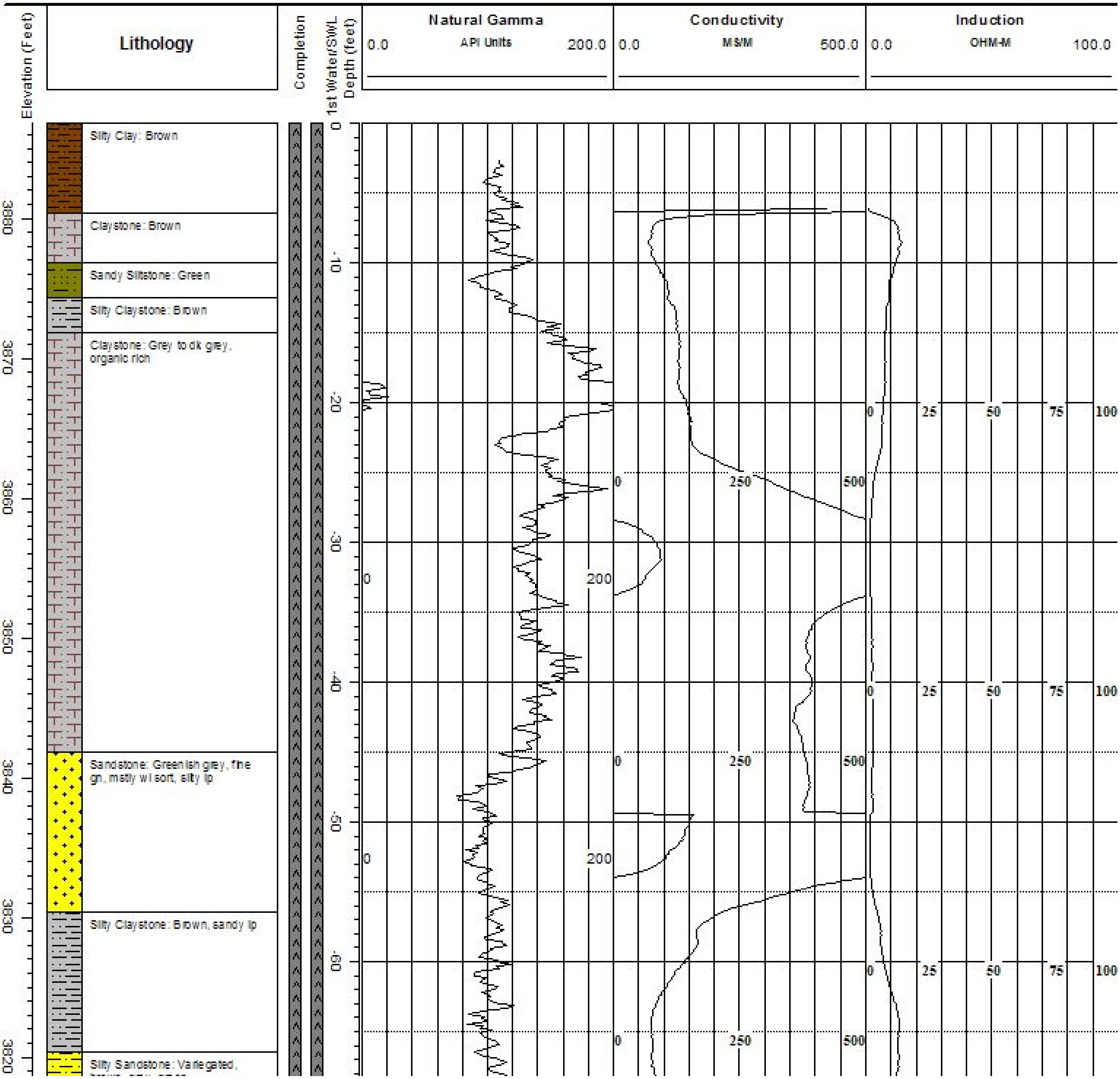
Geophysical Logs *Logs Run and Processed by United States Geological Survey*

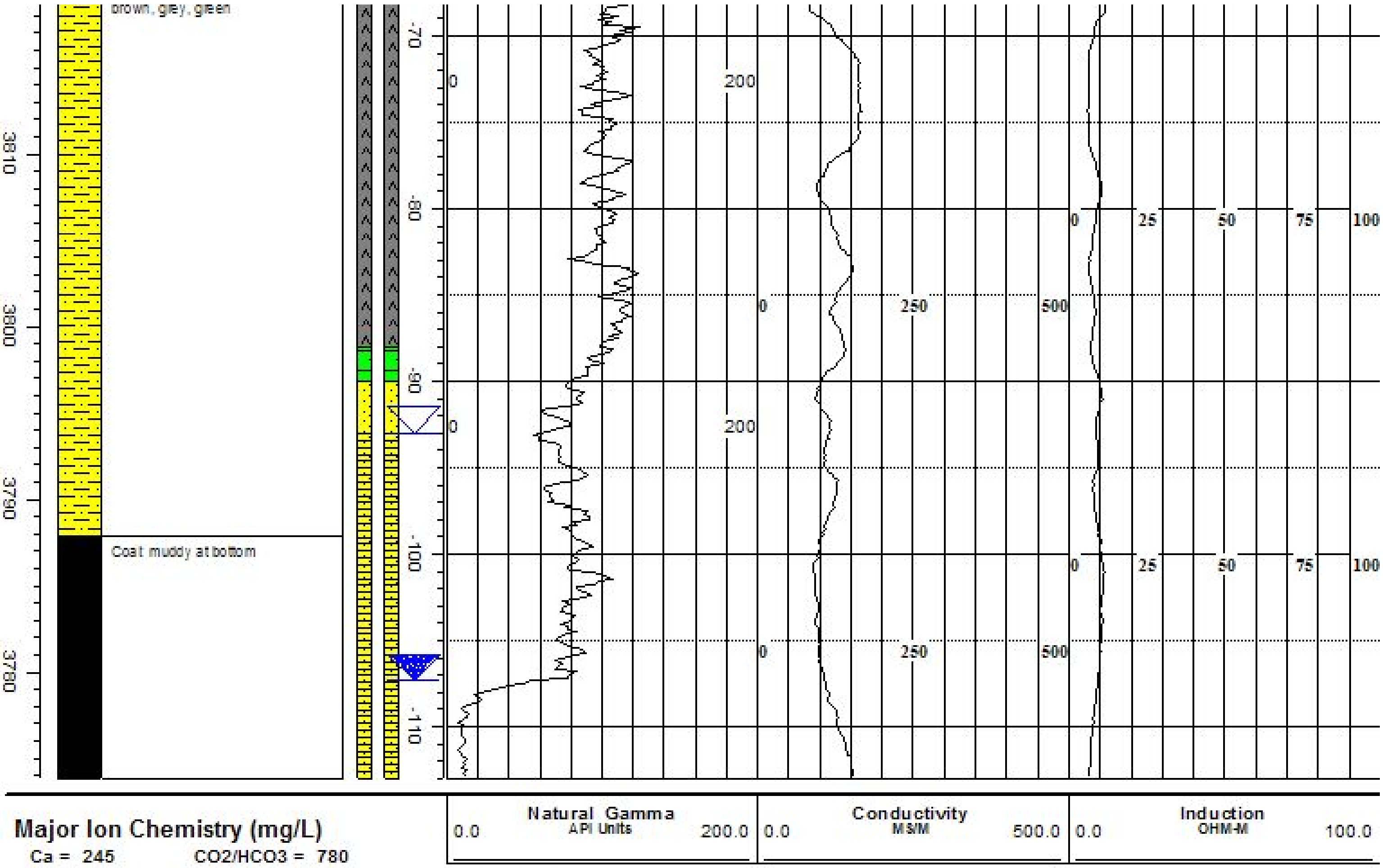
LX Bar Area Termo Impoundment

Well No. MW-1

On-site Geologist	Webster	Latitude:	44°50'04.77249"	Northing	1911172.772	Total Depth:	113
		Longitude:	105°52'28.21364"	Easting	1690768.625	Qtr Qtr:	SENW
				GL Elevation	3886.84	Section:	15
Drilling Contractor	Interstate Drilling	Drilling Dates	6-20-06			Township	56N
Driller	Dave Proctor	Hole Diameter	5-7/8"			Range	75W

Comments: Conductivity and Induction Interval from 6 feet to 49.3 feet rerun -- data questionable
Natural Gamma curve smoothed due to ezxcessive electronic noise SWL from 11-21-08





Major Ion Chemistry (mg/L)

Ca =	245	CO2/HCO3 =	780		
Mg =	171	SO4 =	2074	pH =	6.41
Na =	444	TDS =	3760	SAR =	5

WDEQ Ground Water Classification = III

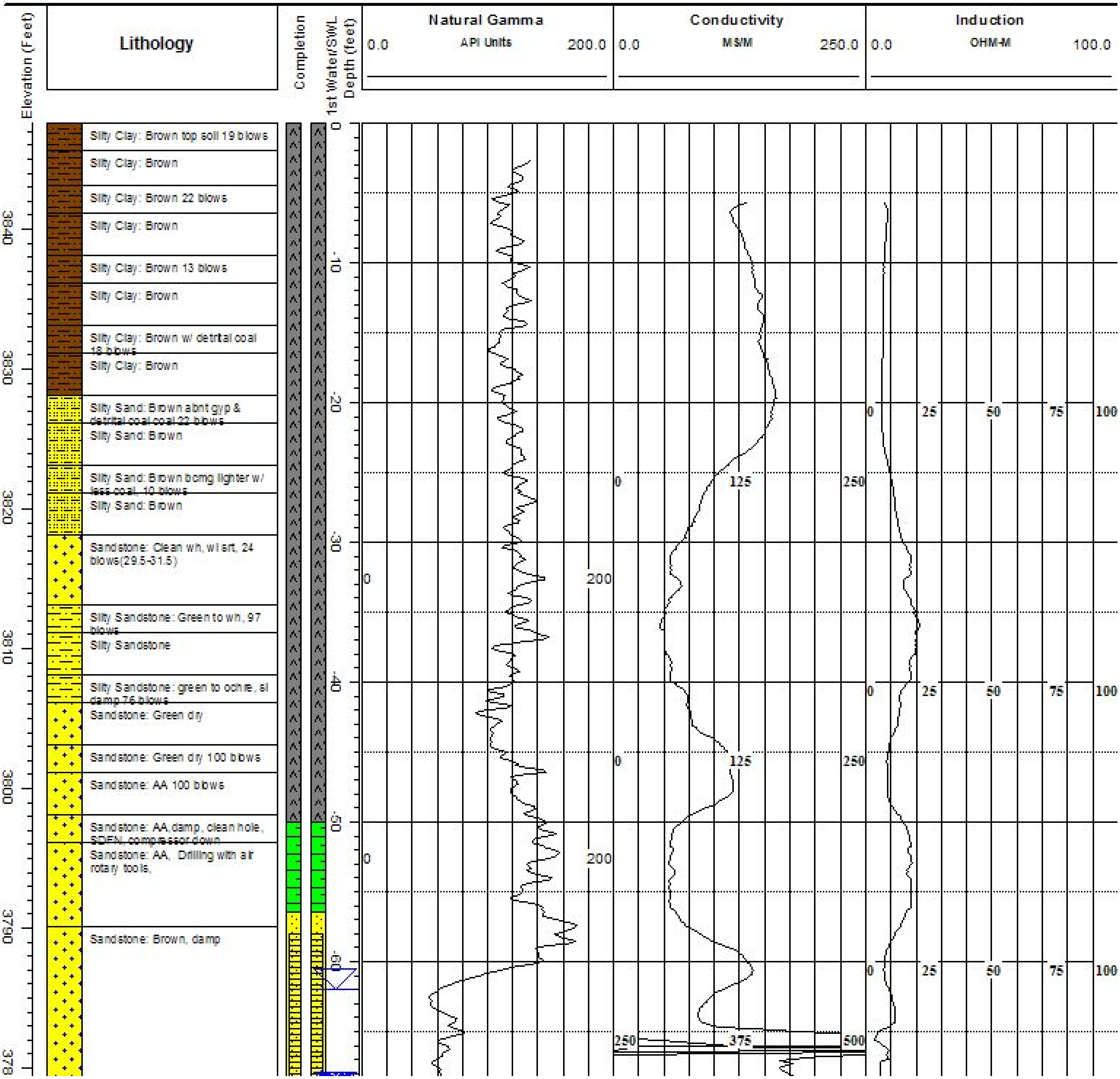
Geophysical Logs *Logs Run and Processed by United States Geological Survey*

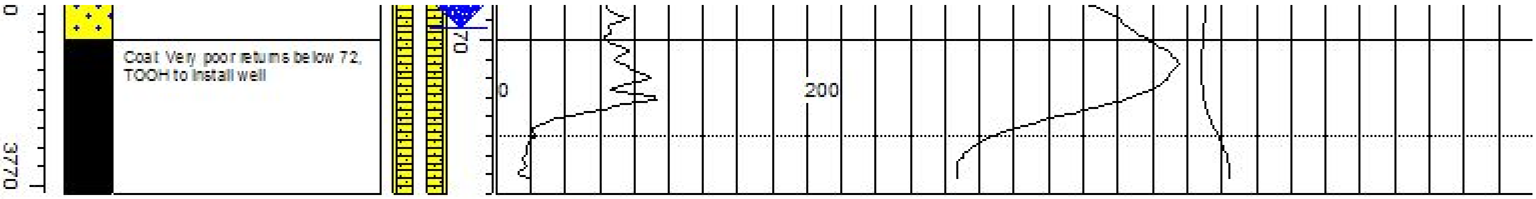
LX Bar Area Termo Impoundment

Well No. MW-2

On-site Geologist: Webster	Latitude: 44°50'01.45675"	Northing	1910829.1	Total Depth:	78
	Longitude: 105°52'34.31635"	Easting	1690334.9	Qtr Qtr:	SENW
		GL Elevation	3847.60	Section:	15
Drilling Contractor: Interstate Drilling	Drilling Dates: 6-22-06			Township	56N
Driller: Dave Proctor	Hole Diameter: 7-1/2 / 5-7/8"			Range	75W

Comments: SWL from 11-27-06





Natural Gamma API Units		Conductivity MS/M		Induction OHM-M	
0.0	200.0	0.0	250.0	0.0	100.0

Major Ion Chemistry (mg/L)

Ca = 510	CO2/HCO3 = 768		
Mg = 302	SO4 = 4172	pH = 6.41	
Na = 758	TDS = 7000	SAR = 7	

WDEQ Ground Water Classification = IV

Geophysical Logs *Logs Run and Processed by United States Geological Survey*

LX Bar Area Termo Impoundment

Well No. MW-3

On-site Geologist Webster

Latitude: 44°50'01.91123"

Longitude: 105°52'37.08461"

Northing 1911172.772

Easting 1910871.544

GL Elevation 3839.96

Total Depth: 78

Qtr Qtr: SENW

Section: 15

Township 56N

Range 75W

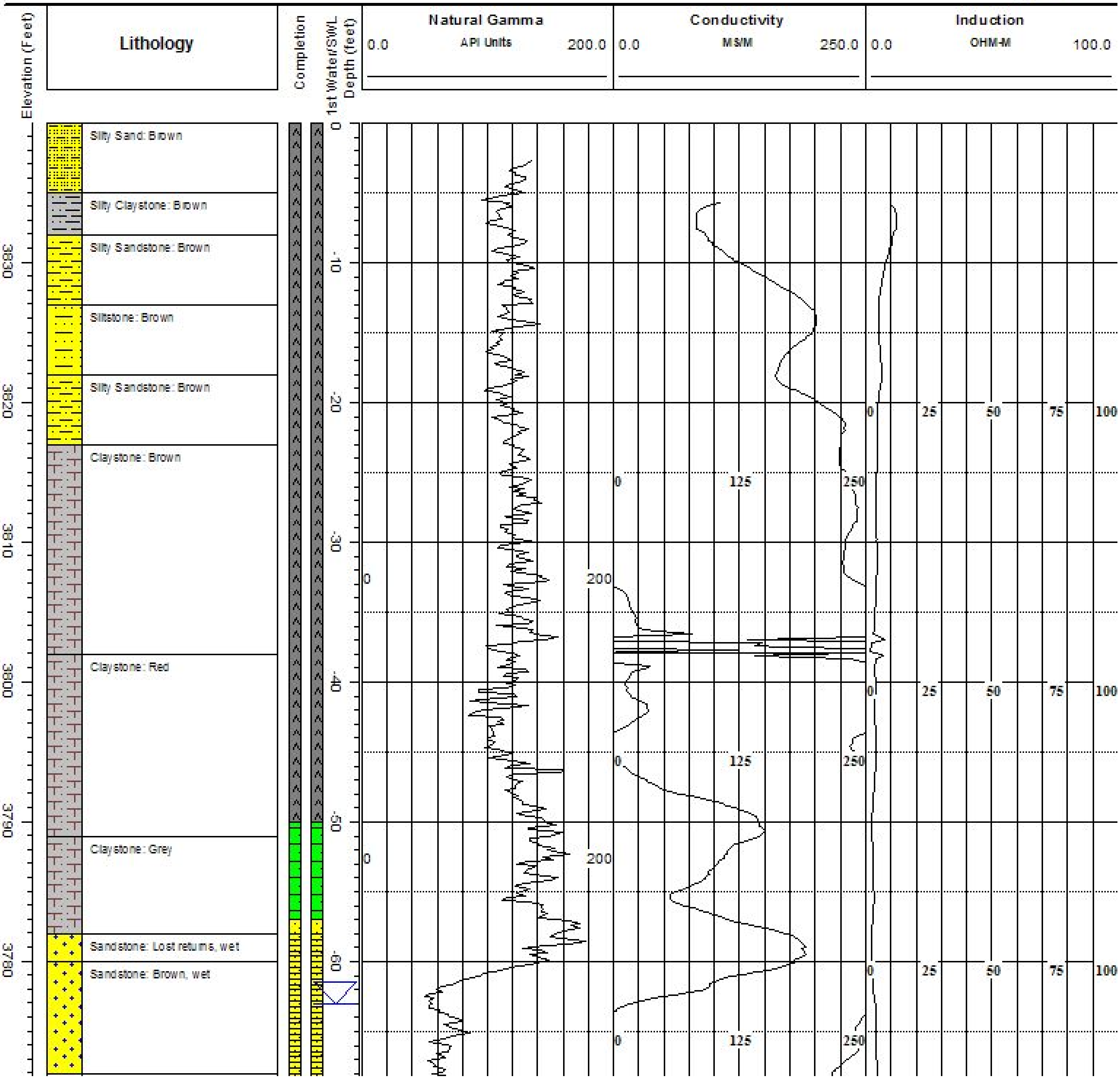
Drilling Contractor Interstate Drilling

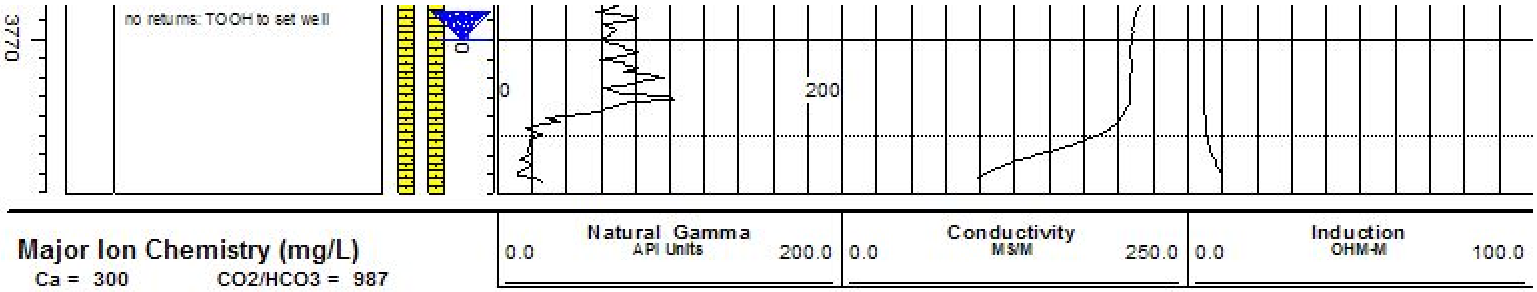
Driller Dave Proctor

Drilling Dates 6-22-06

Hole Diameter 5-7/8"

Comments: SWL from 12-4-06





Major Ion Chemistry (mg/L)

Ca = 300 CO2/HCO3 = 987

Mg = 169 SO4 = 2530 pH = 6.8

Na = 809 TDS = 4776 SAR = 9

WDEQ Ground Water Classification = IV

Geophysical Logs

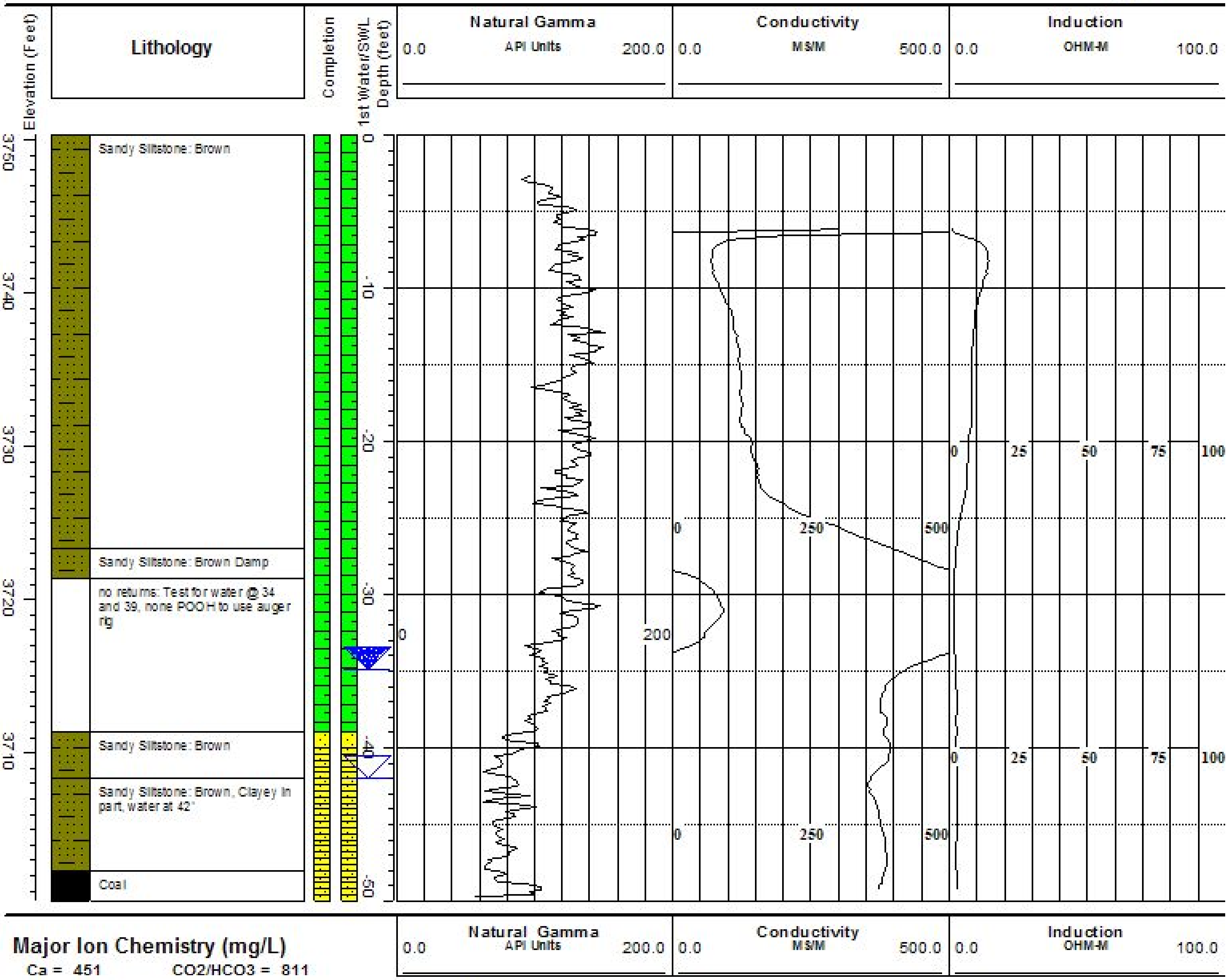
Logs Run and Processed by United States Geological Survey

LX Bar Area — Waylon Impoundment

Well No. MW-1

On-site Geologist	Webster	Latitude:	44°50'46.17192"	Northing	1915255.753	Total Depth:	50
		Longitude:	105°53'53.57445"	Easting	1684543.589	Qtr Qtr:	SENW
				GL Elevation	3750.33	Section:	9
Drilling Contractor	Interstate Drilling	Drilling Dates	7-12-06			Township	56N
Driller	Dave Proctor	Hole Diameter	5-7/8"			Range	75W

Comments: SWL from 11-21-06



Major Ion Chemistry (mg/L)

Ca = 451	CO2/HCO3 =	811			
Mg = 553	SO4 =	4362	pH =	7.19	
Na = 760	TDS =	7840	SAR =	6	

WDEQ Ground Water Classification = IV

Geophysical Logs *Logs Run and Processed by United States Geological Survey*

LX Bar Area Waylon Impoundment

Well No. MW-2

On-site Geologist: Webster

Latitude: 44°50'47.69186"
Longitude: 105°53'53.51575"

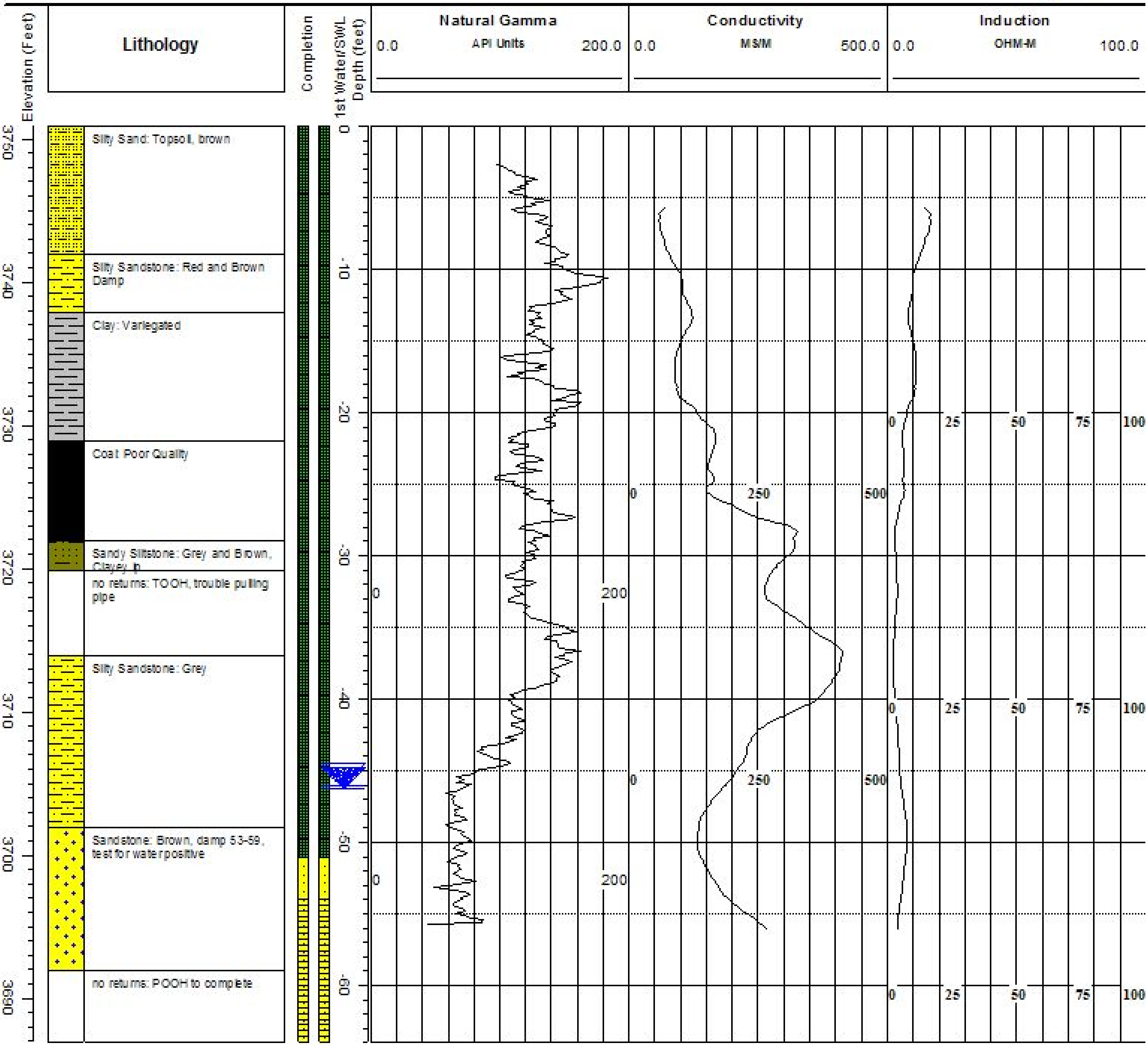
Northing: 1915409.752
Easting: 1684545.099
GL Elevation: 3750.89

Total Depth: 64
Qtr Qtr: SENW
Section: 16
Township: 56N
Range: 83W

Drilling Contractor: Interstate Drilling
Driller: Dave Proctor

Drilling Dates: 7-11-06
Hole Diameter: 5-7/8"

Comments: Natural Gamma Curve Smoothed due to excessive noise
SWL from 11-18-06



Major Ion Chemistry (mg/L)			Natural Gamma API Units (0.0 – 200.0)	Conductivity MS/M (0.0 – 500.0)	Induction OHM-M (0.0 – 100.0)
Ca = 343	CO2/HCO3 = 744				
Mg = 300	SO4 = 3311	pH = 7.36			
Na = 761	TDS = 6406	SAR = 7			

WDEQ Ground Water Classification = IV

Geophysical Logs

Logs Run and Processed by United States Geological Survey

LX Bar Area Waylon Impoundment

Well No. MW-3

On-site Geologist: Terry Webster

Latitude: 44°50'46.26189"
Longitude: 105°53'45.86640"

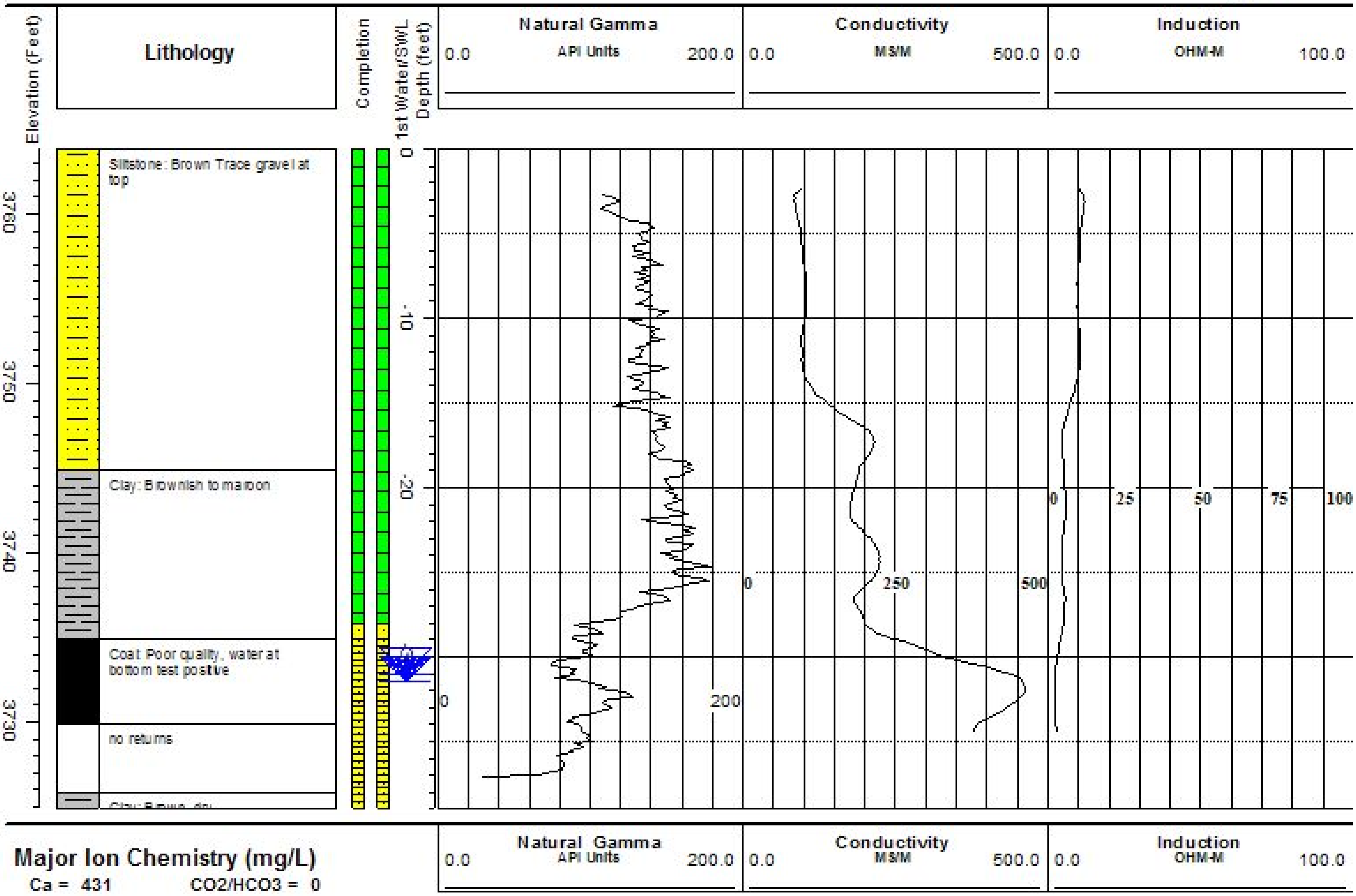
Northing: 1915274.682
Easting: 1685098.748
GL Elevation: 3763.85

Total Depth: 39
Qtr Qtr: SENW
Section: 9
Township: 57N
Range: 75W

Drilling Contractor: Interstate Drilling
Driller: David Proctor

Drilling Dates: 7-12-06
Hole Diameter: 5-7/8"

Comments: Natural Gamma curve smoothed due to excessive electronic noise
SWL from 11-18-06



Major Ion Chemistry (mg/L)

Ca = 431	CO2/HCO3 = 0		
Mg = 1047	SO4 = 7328	pH = 3.1	
Na = 849	TDS = 12624	SAR = 5	

WDEQ Ground Water Classification = IV

Geophysical Logs *Logs Run and Processed by United States Geological Survey*

LX Bar Area Yates State Impoundment

Well No. MW-1

On-site Geologist: Webster

Latitude: 44 50'05.19835"

Longitude: -105 53'46.99453"

Northing: 1911114.73

Easting: 1685091.03

GL Elevation: 3770.94

Total Depth: 57.5

Qtr Qtr: SENW

Section: 16

Township: 57N

Range: 75W

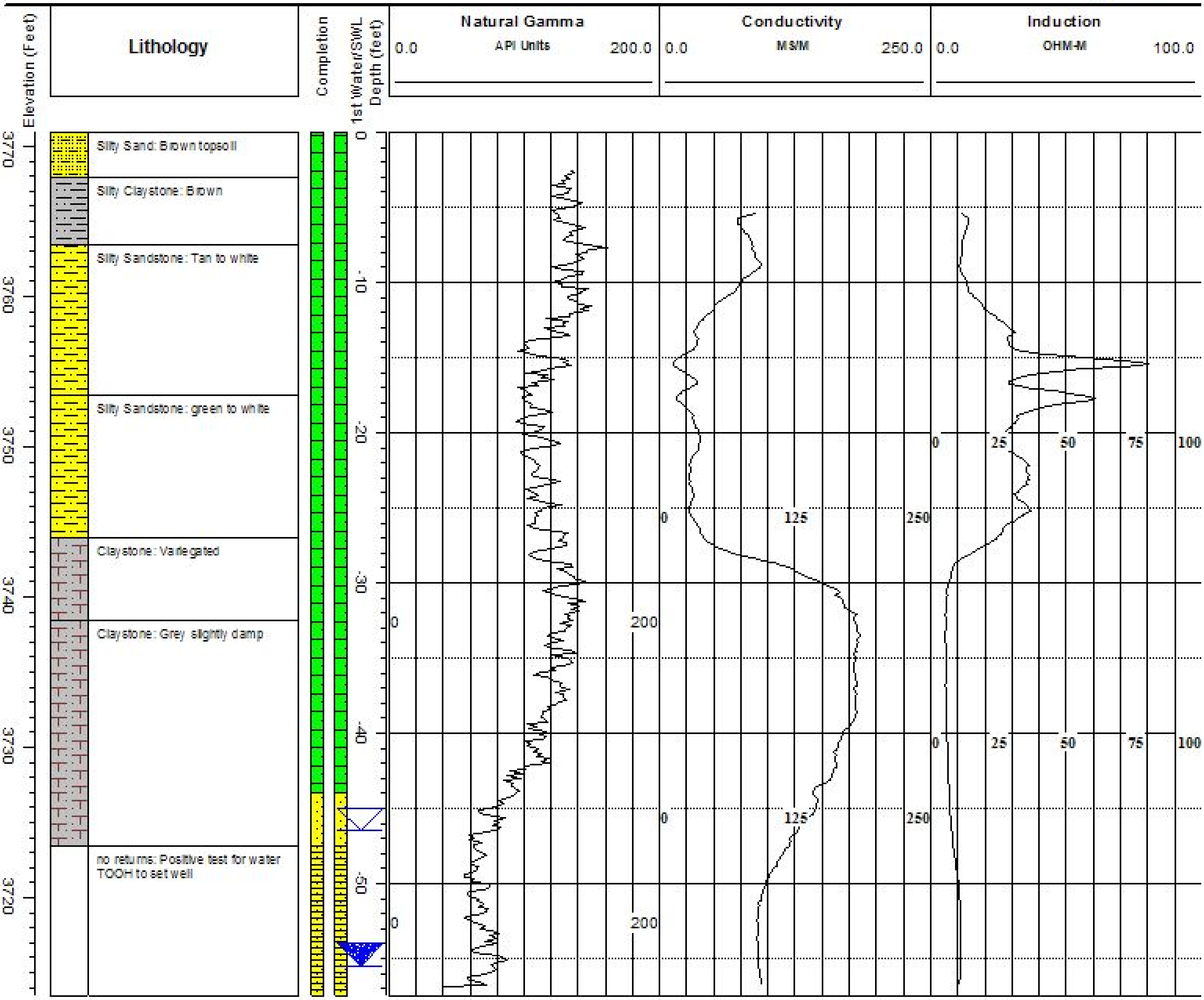
Drilling Contractor: Interstate Drilling

Driller: Dave Proctor

Drilling Dates: 6-12-06

Hole Diameter: 5-7/8"

Comments: Natural Gamma Curve smoothed due to excessive electronic noise
SWL from 11-2-06



Major Ion Chemistry (mg/L)		Natural Gamma API Units 0.0 – 200.0	Conductivity MS/M 0.0 – 250.0	Induction OHM-M 0.0 – 100.0
Ca = 176	CO2/HCO3 = 610			
Mg = 119	SO4 = 693	pH = 7.03		
Na = 82	TDS = 1568	SAR = 1		

WDEQ Ground Water Classification = III

Geophysical Logs

Logs Run and Processed by United States Geological Survey

LX Bar Area — Yates State Impoundment

Well No. MW-2

On-site Geologist: Webster

Latitude: 44 50'09.99240"
Longitude: -105 53'38.68128"

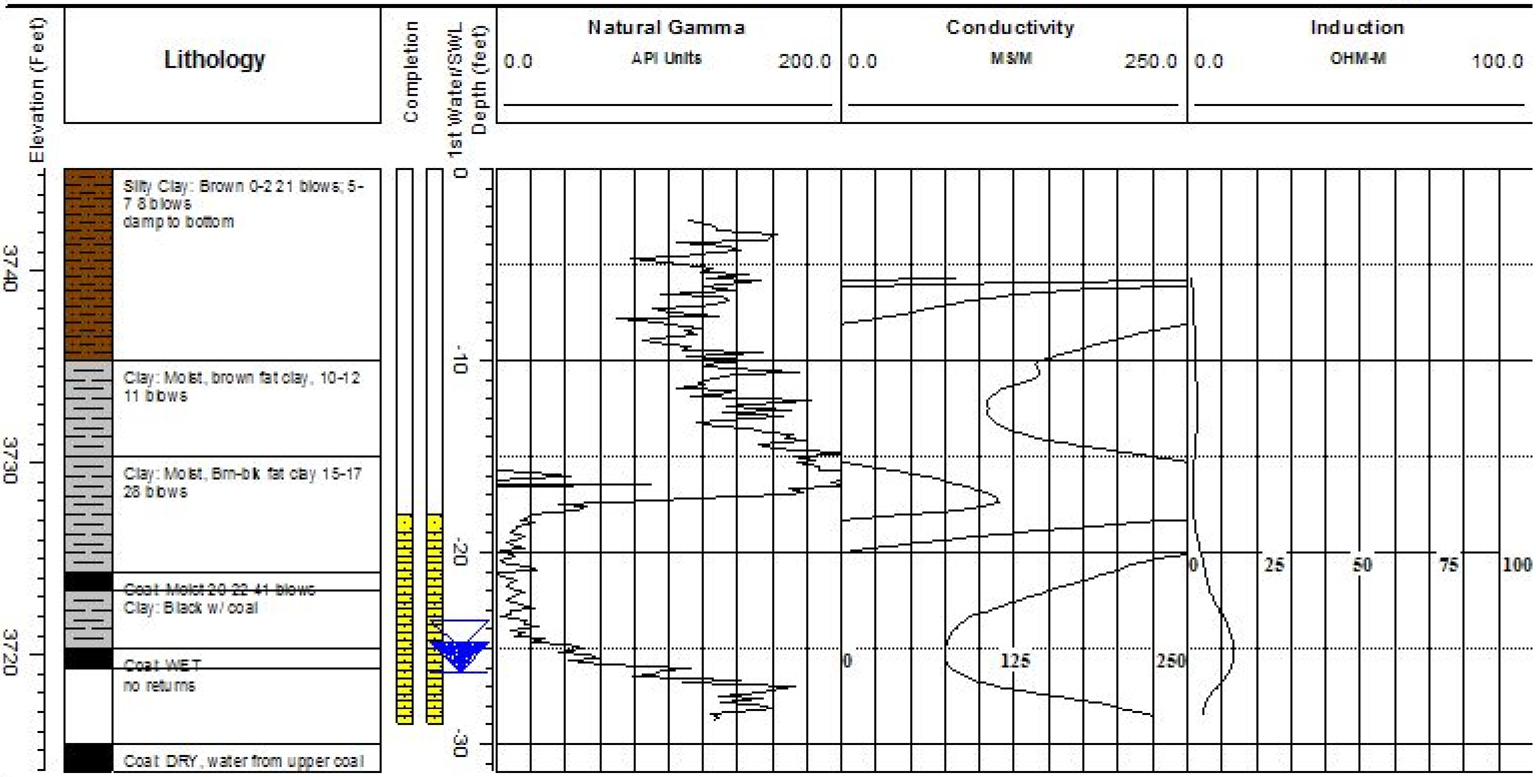
Northing: 1911610.83
Easting: 1685681.47
GL Elevation: 3745.33

Total Depth: 31.5
Qtr Qtr: SENW
Section: 16
Township: 56N
Range: 75W

Drilling Contractor: Interstate Drilling
Driller: Dave Proctor

Drilling Dates: 06-20-06
Hole Diameter: 5-7/8"

Comments: SWL from 11-7-06



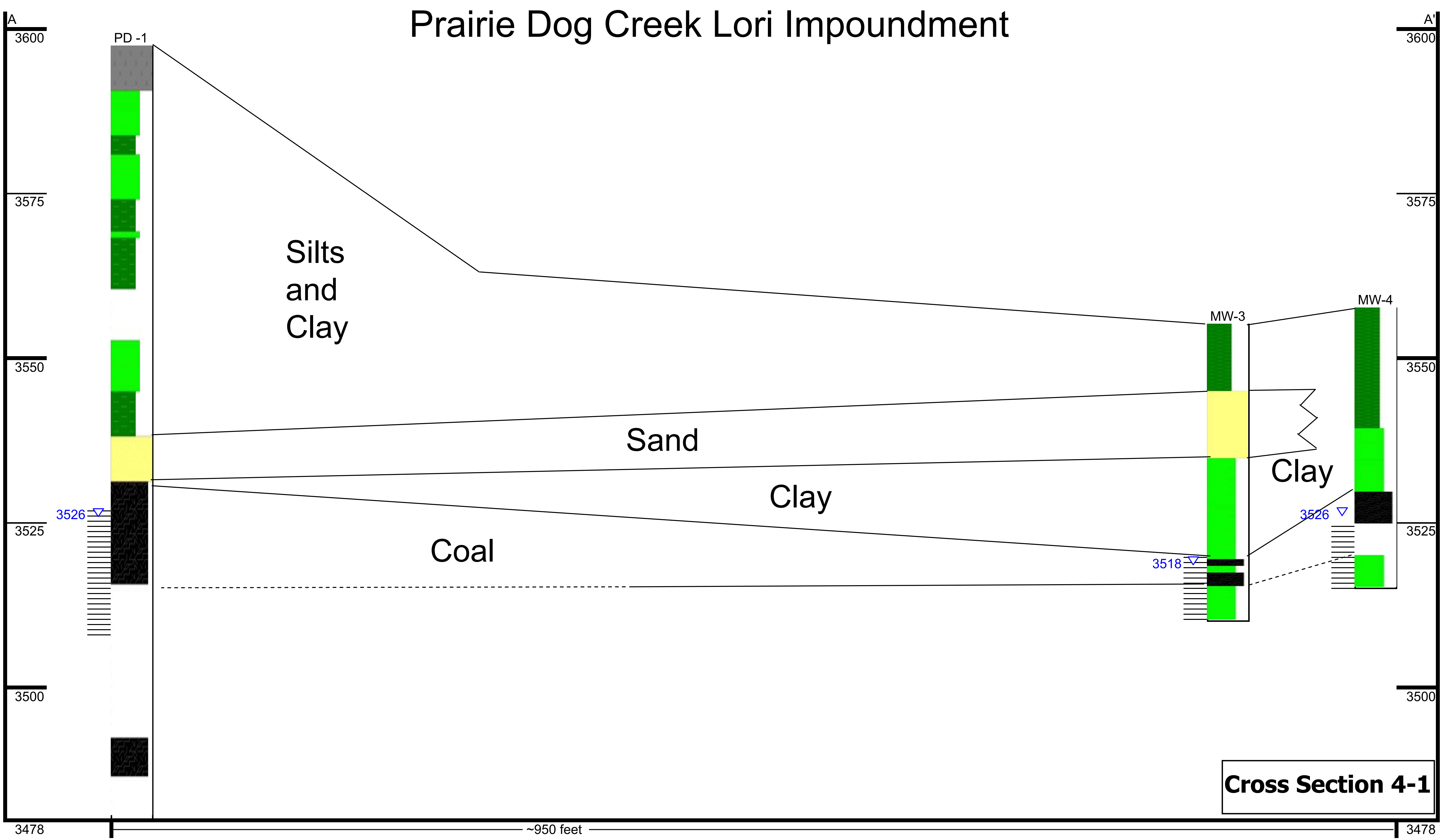
Major Ion Chemistry (mg/L)

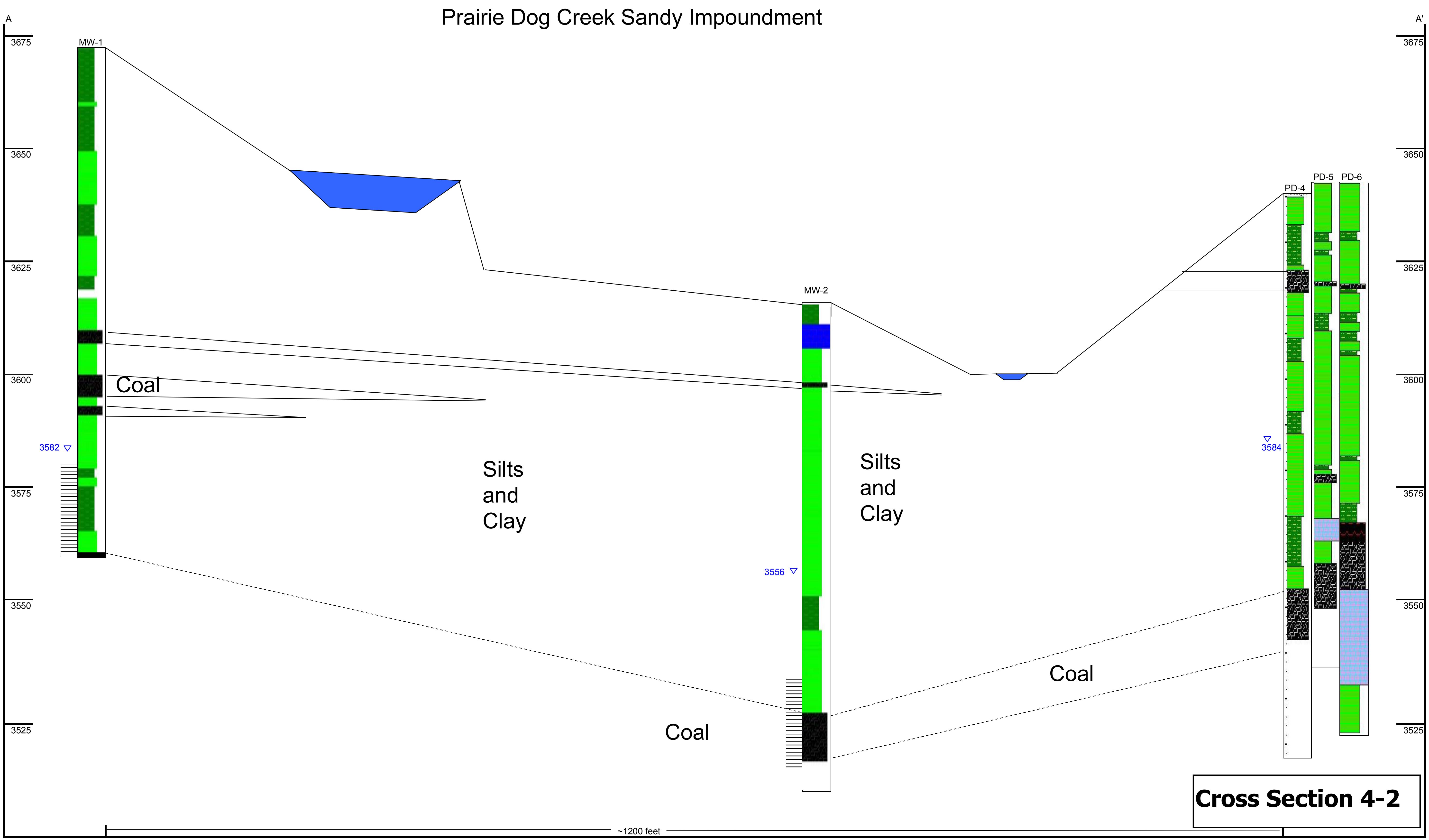
Ca =	112	CO2/HCO3 =	841		
Mg =	88	SO4 =	326	pH =	6.2
Na =	157	TDS =	1200	SAR =	3

WDEQ Ground Water Classification = III

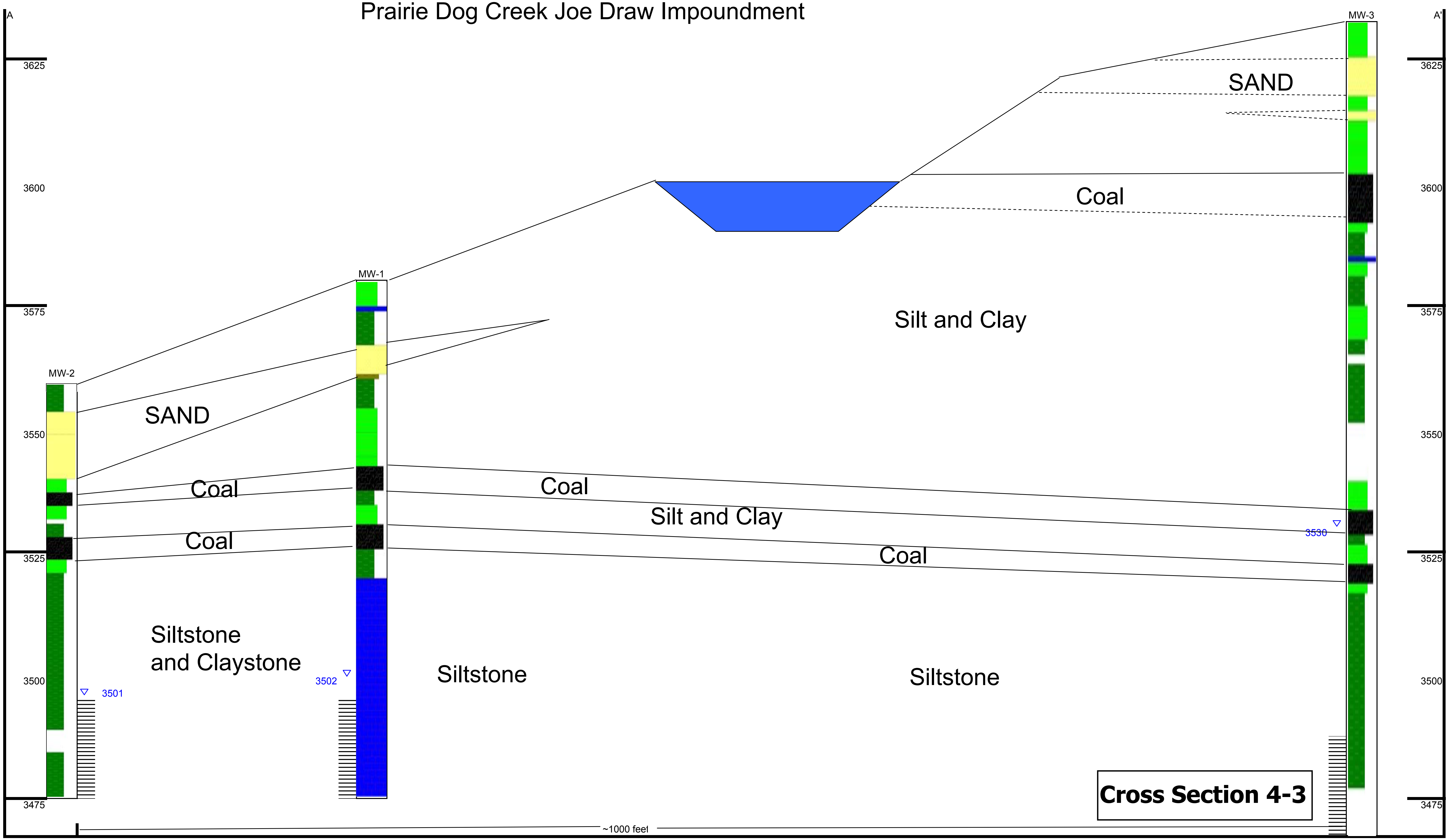
APPENDIX C

CROSS SECTIONS


Prairie Dog Creek Lori Impoundment
A
A'
3600
3575
3550
3525
3500
3478
PD -1
MW-3
MW-4
Silts and Clay
Sand
Clay
Coal
Clay
3526
3518
3526
~950 feet
Cross Section 4-1

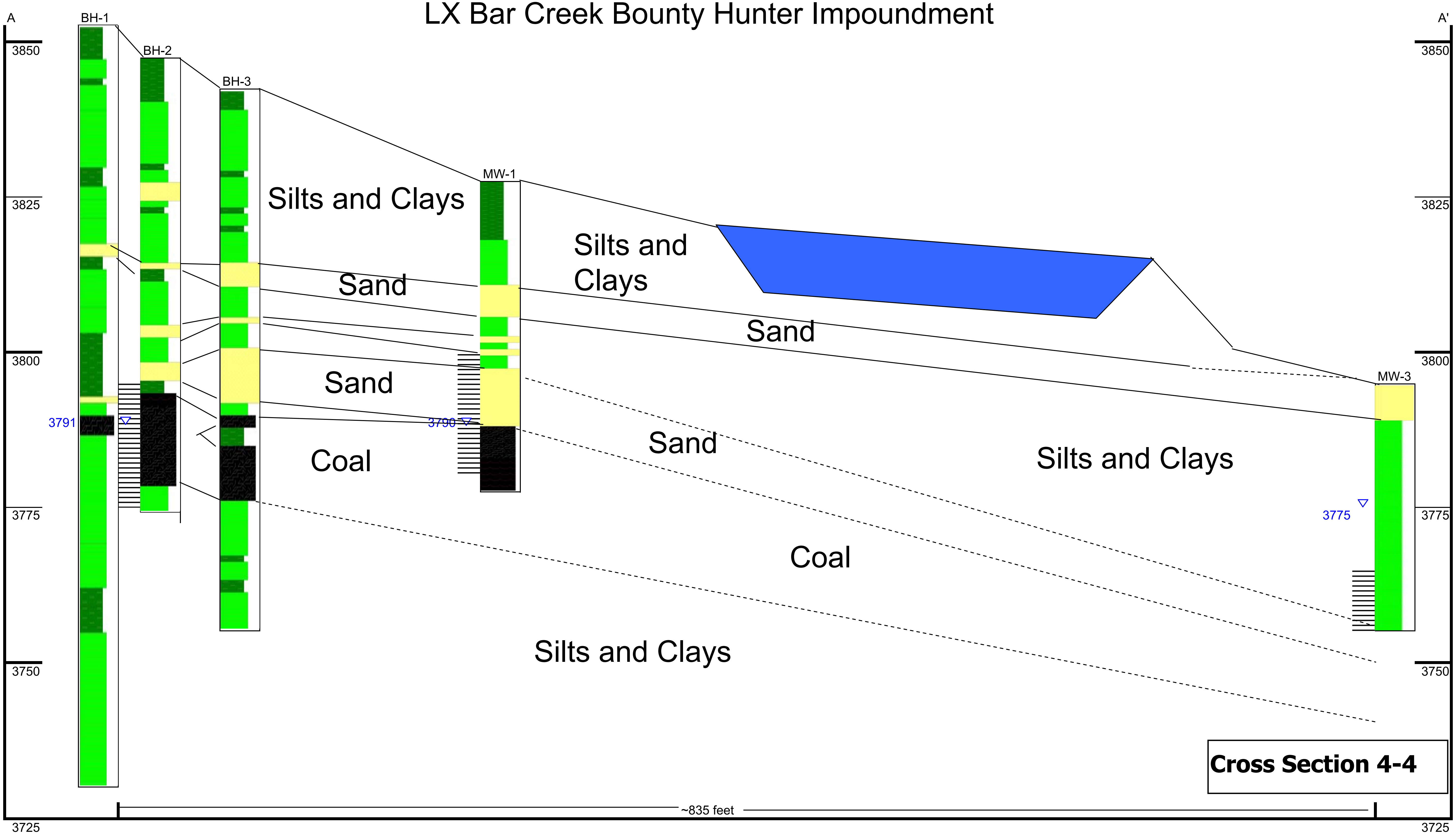

Prairie Dog Creek Sandy Impoundment
A
A'
3675
3650
3625
3600
3575
3550
3525
MW-1
MW-2
PD-4
PD-5
PD-6
3582
3556
3584
Coal
Silts
and
Clay
Silts
and
Clay
Coal
Coal
~1200 feet
Cross Section 4-2

Prairie Dog Creek Joe Draw Impoundment



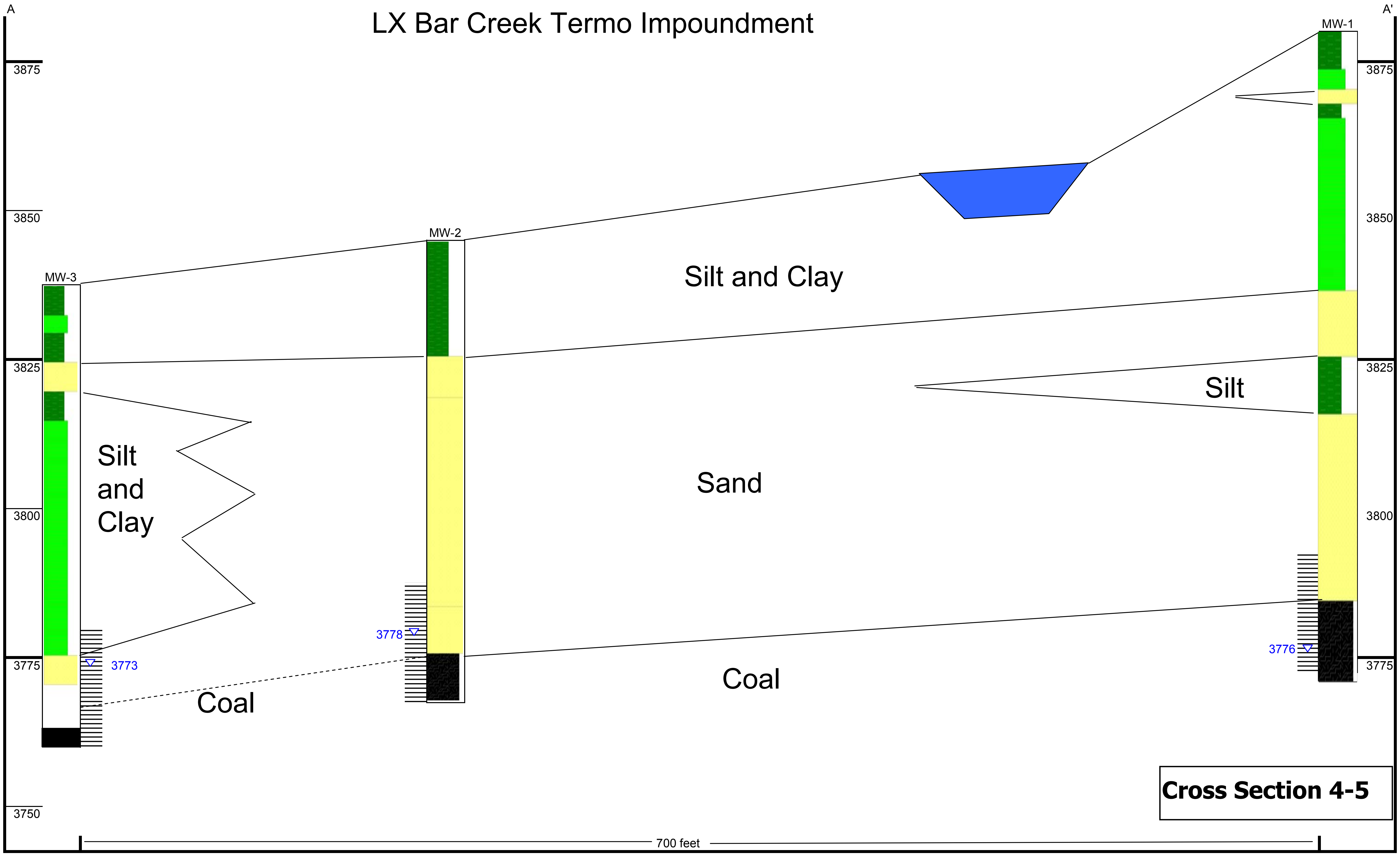
Cross Section 4-3

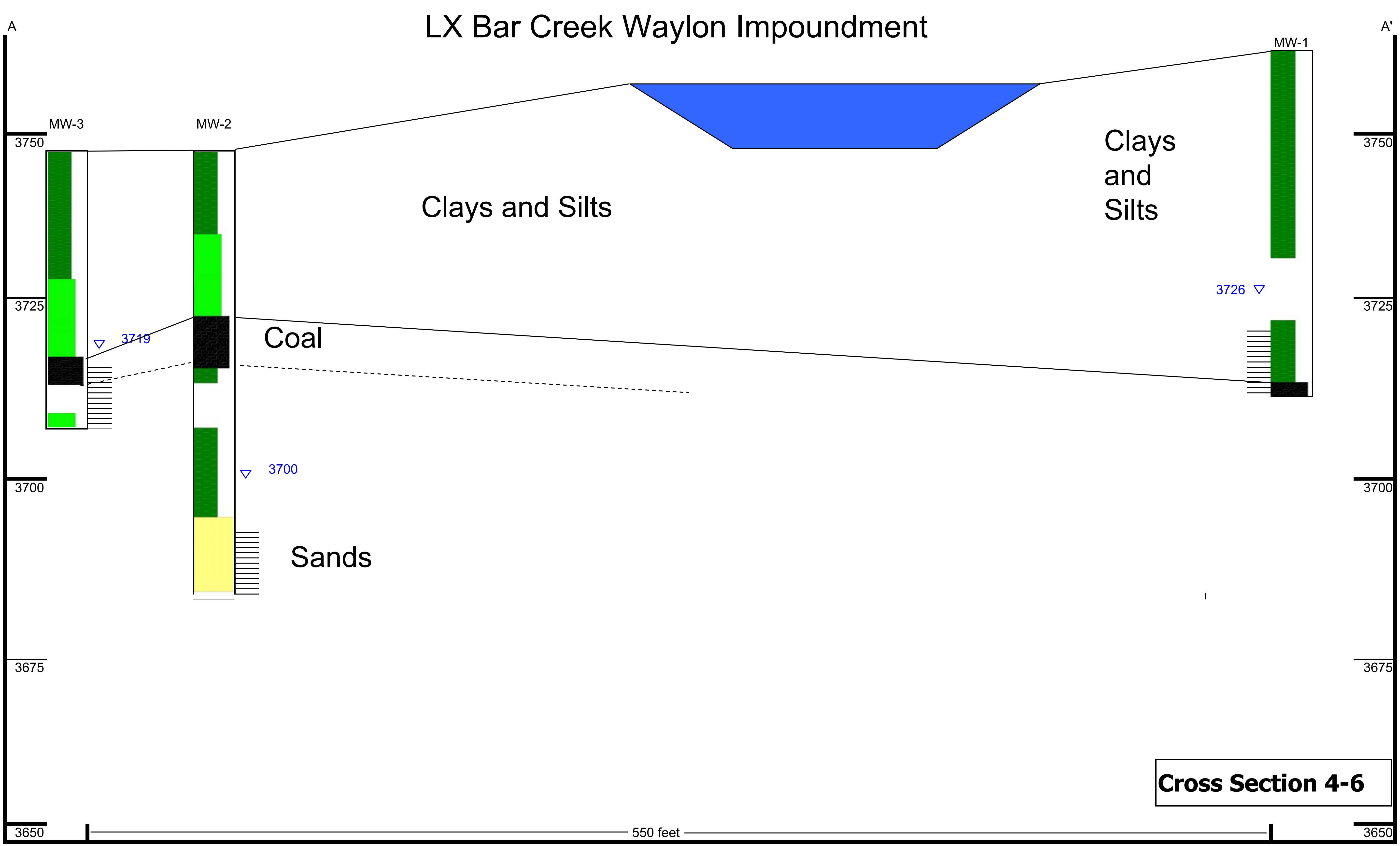
LX Bar Creek Bounty Hunter Impoundment



Cross Section 4-4

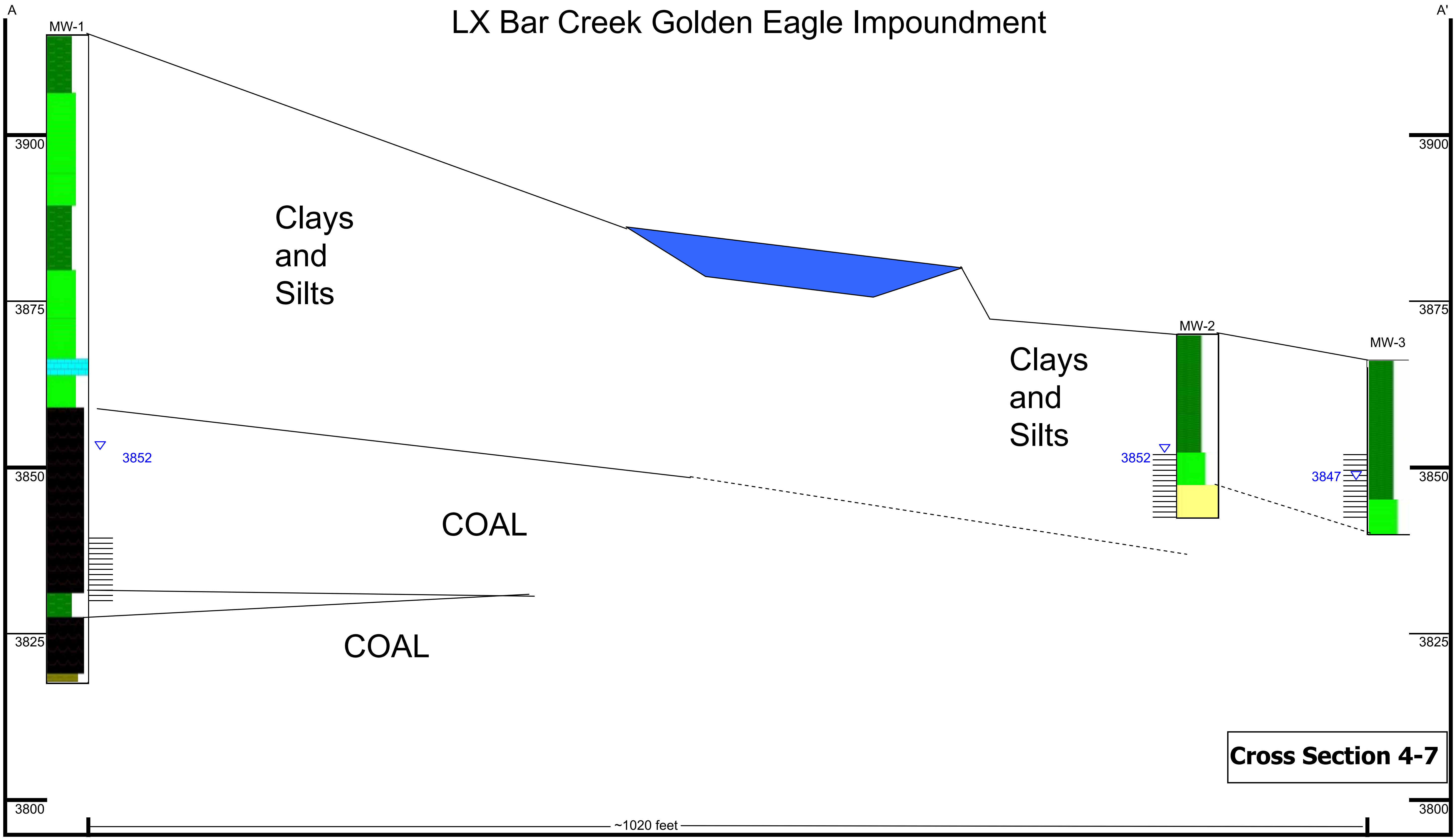
LX Bar Creek Termo Impoundment





LX Bar Creek Waylon Impoundment
A
A'
MW-3
MW-2
MW-1
3750
3725
3700
3675
3650
Clays and Silts
Clays
and
Silts
Coal
Sands
3719
3700
3726
550 feet
Cross Section 4-6

LX Bar Creek Golden Eagle Impoundment



Cross Section 4-7

APPENDIX D

CALCULATIONS

OBJECTID	LATITUDE	LONGITUDE	ELEV	TYPE_	NAME	X_COORD	Y_COORD	GW_ELEV	LABEL	TYPE	ElevMeters	ElevFeet
1	44.88299683	-106.0521089	3609	MW-1	Wyoma MW-1	416909.1083	4970491.337	3500	MW-1	Monitoring Well	1100.169067	3609.478568
2	44.69024998	-105.69749	4120	MW-2	Joan MW-2	444731.7176	4948778.627	0	MW-2	Monitoring Well	1255.710205	4119.784137
3	44.68916003	-105.69779	4102	MW-1	Joan MW-1	444706.9122	4948657.756	0	MW-1	Monitoring Well	1250.344727	4102.180861
4	44.68888004	-105.69602	4118	MW-3	Joan MW-3	444846.8988	4948625.455	0	MW-3	Monitoring Well	1255.190063	4118.077636
5	44.68485998	-105.6856	4106	MW-2	Jim MW-2	445668.8286	4948171.9	0	MW-2	Monitoring Well	1251.656738	4106.485362
6	44.68459997	-105.68663	4098	MW-1	Jim MW-1	445586.9633	4948143.706	0	MW-1	Monitoring Well	1249.044189	4097.914007
7	44.68546	-105.6871901	4117	MW-3	Jim MW-3	445543.3863	4948239.612	0	MW-3	Monitoring Well	1254.880981	4117.063587
8	44.70205002	-105.6625199	4059	MW-1	JW MW-1	447513.3659	4950066.263	0	MW-1	Monitoring Well	1237.146118	4058.87834
9	44.70197001	-105.664	4075	MW-2	JW MW-2	447396.0431	4950058.329	0	MW-2	Monitoring Well	1242.113159	4075.174407
10	44.72140001	-105.6695999	4032	MW-1	Prairie Dog MW-1	446970.1428	4952220.281	0	MW-1	Monitoring Well	1229.029053	4032.247548
11	44.72032001	-105.67056	4042	MW-2	Prairie Dog MW-2	446893.1195	4952100.937	0	MW-2	Monitoring Well	1232.095825	4042.309138
12	44.72198002	-105.67306	4047	MW-3	Prairie Dog MW-3	446696.6504	4952286.968	0	MW-3	Monitoring Well	1233.409424	4046.618845
13	44.76949002	-105.66853	4123	MW	Brug 2/3 MW-1	447098.7602	4957561.539	0	MW	Monitoring Well	1256.74585	4123.181921
14	44.77848001	-105.66617	4074	MW	Brug MW-1	447293.6837	4958558.643	0	MW	Monitoring Well	1241.823242	4074.223236
15	44.75843003	-105.65338	4061	MW	Brug 1 MW-1	448287.7241	4956323.225	0	MW	Monitoring Well	1237.895264	4061.336167
16	44.88207884	-106.0500393	3644	MW-2	Wyoma MW-2	417071.2372	4970387.245	3517	MW-2	Monitoring Well	1110.776367	3644.27942
17	44.88185538	-106.0523142	3640	MW-3	Wyoma MW-3	416891.2492	4970364.749	3503	MW-3	Monitoring Well	1109.578979	3640.350983
18	44.759922	-105.6556327	4080	MW-2	Brug 1 MW-2	448110.7622	4956490.392	0	MW-2	Monitoring Well	1243.610474	4080.086856
19	44.8347773	-105.8963874	3772	MW-1	Yates State MW-1	429148.1911	4964987.307	0	MW-1	Monitoring Well	1149.692383	3771.956637
20	44.83610898	-105.8940781	3745	MW-2	Yates State MW-2	429332.3506	4965133.225	0	MW-2	Monitoring Well	1141.582153	3745.348272
21	44.83465905	-105.8745038	3861	MW-1	Termo MW-1	430877.7614	4964955.322	3768	MW-1	Monitoring Well	1176.728882	3860.659061
22	44.83373801	-105.8761989	3837	MW-2	Termo MW-2	430742.6727	4964854.453	3764	MW-2	Monitoring Well	1169.620239	3837.336743
23	44.83386421	-105.876968	3832	MW-3	Termo MW-3	430682.0373	4964869.127	3769	MW-3	Monitoring Well	1168.00415	3832.034614
24	44.81850652	-105.8777866	3827	MW-1	Bounty Hunter MW-1	430598.9057	4963163.832	3799	MW-1	Monitoring Well	1166.547119	3827.254328
25	44.81953142	-105.8760386	3791	MW-2	Bounty Hunter MW-2	430738.3336	4963276.191	3767	MW-2	Monitoring Well	1155.647949	3791.495896
26	44.81894657	-105.8755494	3794	MW-3	Bounty Hunter MW-3	430776.3145	4963210.807	3775	MW-3	Monitoring Well	1156.403564	3793.974949
27	44.81837973	-105.8787194	3847	BH-1	Bounty Hunter BH-1	430525.0017	4963150.544	0	BH-1	Bore Hole	1172.642944	3847.253754
28	44.81836465	-105.8785439	3843	BH-2	Bounty Hunter BH-2	430538.8569	4963148.719	0	BH-2	Bore Hole	1171.338501	3842.974085
29	44.81836544	-105.8783754	3840	BH-3	Bounty Hunter BH-3	430552.1815	4963148.663	0	BH-3	Bore Hole	1170.279663	3839.500207
30	44.80722749	-105.8461287	3952	MW-1	Golden Eagle MW-1	433088.8579	4961884.371	3875.5	MW-1	Monitoring Well	1204.465576	3951.658714
31	44.80446354	-105.845707	3881	MW-3	Golden Eagle MW-3	433119.008	4961576.995	3862	MW-3	Monitoring Well	1182.952759	3881.078605
32	44.8089814	-105.8493128	4020	LX-1	Golden Eagle LX-1	432839.1001	4962081.827	0	LX-1	Bore Hole	1225.319092	4020.07576
33	44.80898123	-105.849447	4013	LX-2	Golden Eagle LX-2	432828.4852	4962081.92	0	LX-2	Bore Hole	1223.036011	4012.585337
34	44.80899134	-105.8496103	4004	LX-3	Golden Eagle LX-3	432815.5797	4962083.177	0	LX-3	Bore Hole	1220.363403	4003.81694
35	44.95108668	-106.8381087	3577	MW-1	Joe Draw MW-1	355005.6327	4979160.232	3492	MW-1	Monitoring Well	1090.351929	3577.270107
36	44.95146007	-106.8387666	3561	MW-2	Joe Draw MW-2	354954.6718	4979202.887	3489	MW-2	Monitoring Well	1085.520142	3561.417787
37	44.95023285	-106.835386	3627	MW-3	Joe Draw MW-3	355218.2569	4979060.517	3480	MW-3	Monitoring Well	1105.566406	3627.186372
38	44.84618385	-105.896074	3759	MW-1	Waylon MW-1	429186.9356	4966254.123	3717	MW-1	Monitoring Well	1145.740234	3758.99027
39	44.84658107	-105.8981988	3748	MW-2	Waylon MW-2	429019.5085	4966300.102	3689	MW-2	Monitoring Well	1142.444214	3748.176555
40	44.8461589	-105.8982151	3745	MW-3	Waylon MW-3	429017.7021	4966253.219	3716	MW-3	Monitoring Well	1141.420166	3744.816818
41	44.80480882	-105.8448778	3886	MW-2	Golden Eagle MW-2	433184.9881	4961614.668	3868	MW-2	Monitoring Well	1184.439331	3885.955811
42	44.95885028	-106.8180293	3545	MW-1	Lori MW-1	356608.8855	4979986.948	3520	MW-1	Monitoring Well	1080.455566	3544.801727
43	44.95904212	-106.8186464	3537	MW-3	Lori MW-3	356560.6901	4980009.351	3503	MW-3	Monitoring Well	1077.971436	3536.651691
44	44.95864643	-106.8187189	3542	MW-4	Lori MW-4	356553.9859	4979965.522	3509	MW-4	Monitoring Well	1079.685791	3542.276217
45	44.96136389	-106.8181339	3598	PD-3	Lori PD-3	356606.8929	4980266.362	0	PD-3	Bore Hole	1096.805908	3598.444581
46	44.96132201	-106.8183168	3590	PD-2	Lori PD-2	356592.3672	4980262.032	0	PD-2	Bore Hole	1094.365845	3590.439123
47	44.96126125	-106.8184738	3583	PD-1	Lori PD-1	356579.8342	4980255.561	0	PD-1	Monitoring Well	1091.98877	3582.64032
48	44.95319679	-106.8673524	3673	MW-1	Sandy MW-1	352704.2163	4979447.356	0	MW-1	Monitoring Well	1119.407104	3672.595487
49	44.95425771	-106.8647986	3617	MW-2	Sandy MW-2	352908.3673	4979560.572	0	MW-2	Monitoring Well	1102.442383	3616.936951
50	44.95372141	-106.8647073	3632	MW-3	Sandy MW-3	352914.1961	4979500.831	0	MW-3	Monitoring Well	1107.030518	3631.989887
51	44.95541847	-106.8639557	3644	PD-4	Sandy BH-4	352977.8205	4979687.989	0	PD-4	Bore Hole	1110.681519	3643.968237
52	44.9554413	-106.8638203	3639	PD-5	Sandy BH-5	352988.5564	4979690.279	0	PD-5	Bore Hole	1109.281494	3639.374981
53	44.95547651	-106.8636558	3632	PD-6	Sandy BH-6	353001.6202	4979693.892	0	PD-6	Bore Hole	1107.138672	3632.344724
54	44.97165012	-106.8004065	3808	MW-1	14-3082 MW-1	358030.4091	4981377.818	0	MW-1	Bore Hole	1160.673462	3807.983799
55	44.96759766	-106.7934409	3796	MW-2	14-3082 MW-2	358569.7121	4980915.464	0	MW-2	Monitoring Well	1156.88501	3795.554494

Distance	Direction	FromMW	ToMW	DirectionTxt
765.8870958	67.44049442	Sandy MW-1	Sandy MW-2	N 67.4404553558127 E
710.8974746	78.7815873	Sandy MW-1	Sandy MW-3	N 78.7816105350609 E
218.0331338	299.5742085	Joe Draw MW-1	Joe Draw MW-2	N 60.4256112506166 W
770.487108	107.4114418	Joe Draw MW-1	Joe Draw MW-3	S 72.5885980390282 E
174.3694327	287.2690937	Lori MW-1	Lori MW-3	N 72.7312547746885 W
193.3468992	253.5321869	Lori MW-1	MW-4	S 73.5321286089855 W
46.27666834	68.84215963	Lori PD-1	Lori PD-2	N 68.8435353882282 E
95.58666677	73.1935497	Lori PD-1	Lori PD-3	N 73.1938675068874 E
2330.590467	120.1901455	14-3082 MW-1	14-3082 MW-2	S 59.80981170912 E
632.1101339	113.9202047	Wyoma MW-1	Wyoma MW-2	S 66.0798161663399 E
419.425421	190.1970918	Wyoma MW-1	Wyoma MW-3	S 10.1973561222572 W
569.6372832	280.5889269	Waylon MW-1	Waylon MW-2	N 79.4110997875734 W
555.2347281	269.332257	Waylon MW-1	Waylon MW-3	S 89.3323250726614 W
770.8685238	60.02981828	Yates State MW-1	Yates State MW-2	N 60.0298008137892 E
553.1260065	241.4827259	Termo MW-1	Termo MW-2	S 61.482701844776 W
701.6498237	252.1223461	Termo MW-1	Termo MW-3	S 72.1223623313403 W
587.4879846	59.61502263	Bounty Hunter MW-1	Bounty Hunter MW-2	N 59.6150278200439 E
602.1076261	78.87197962	Bounty Hunter MW-1	Bounty Hunter MW-3	N 78.8719738423227 E
45.84931569	94.91106847	Bounty Hunter BH-1	Bounty Hunter BH-2	S 85.088374159193 E
89.38557267	92.37865837	Bounty Hunter BH-1	Bounty Hunter BH-3	S 87.6218447155779 E
34.82704979	269.9302455	Golden Eagle LX-1	Golden Eagle LX-2	S 89.9315938189409 W
77.29350013	271.9131609	Golden Eagle LX-1	Golden Eagle LX-3	N 88.0868102433483 W
939.3761388	152.6521024	Golden Eagle MW-1	Golden Eagle MW-2	S 27.3479034612692 E
1013.290135	171.3261941	Golden Eagle MW-1	Golden Eagle MW-3	S 8.67385027858717 E
3333.25431	194.7087752	Brug MW-1	Brug 2/3 MW-1	S 14.7088087056019 W
7295.913346	150.412033	Brug MW-1	Brug 1 MW-2	S 29.5879744228432 E
8026.455718	147.4658794	Brug MW-1	Brug 1 MW-1	S 32.5341114338966 E
466.0103892	221.6359725	Prairie Dog MW-1	Prairie Dog MW-2	S 41.6359198496447 W
923.5725837	279.5159666	Prairie Dog MW-1	Prairie Dog MW-3	N 80.4840505300118 W
385.79544	266.9054008	Prairie Dog MW-1	JW MW-2	S 86.9054508852342 W
284.068942	75.83213998	Jim MW-1	Jim MW-2	N 75.8322227010332 E
345.6112756	326.9271422	Jim MW-1	Jim MW-3	N 33.072744335085 W
404.8201006	15.3872064	Joan MW-1	Joan MW-2	N 15.3869989559068 E
471.3403195	98.98910275	Joan MW-1	Joan MW-3	S 81.0109803217234 E
1195.42734	56.81241507	Sandy MW-1	Sandy BH-4	N 56.812424997895 E
1226.965715	57.56537467	Sandy MW-1	Sandy BH-5	N 57.5653767613443 E
1267.391827	58.33716642	Sandy MW-1	Sandy BH-6	N 58.3372118800007 E
810.2127833	184.4475368	Lori PD-1	Lori MW-3	S 4.44756121574 W
955.3396392	185.3551498	Lori PD-1	Lori MW-4	S 5.35500191626994 W
886.4145695	349.5535769	Lori MW-1	Lori PD-1	N 10.446461085837 W
904.1325013	353.3647908	Lori MW-1	Lori PD-2	N 6.63517541031558 W
835.4950612	188.2260017	Lori PD-2	Lori MW-3	S 8.22610226806808 W
980.9157963	188.5466504	Lori PD-2	Lori MW-4	S 8.5465909860965 W
916.7355829	357.6153494	Lori MW-1	Lori PD-3	N 2.38456525368019 W
36.01556337	80.42749842	Sandy BH-4	Sandy BH-5	N 80.4274320329605 E
80.44914691	79.04559963	Sandy BH-4	Sandy BH-6	N 79.0457187142449 E

Three-Point Problem Solver

Usage

This spreadsheet calculates the strike and true dip of a structural plane given three points on the plane that hav
known elevation and relative bearings and distances. Normally this is the case when a planar geologic contact ca
be traced over irregular topography. The three elevations are determined from topographic contours whereas th
bearings are measured with a protractor relative to geographic north. Distances between points are measured usin
the maps scale. Alternatively, contours of subsurface structures may be used to measure the required parameters, howeve
remember that this method assumes that the structure is planar! This spreadsheet may be used to determine the hydrauli
flow direction below the water table, which is the true dip direction.
Detailed steps for using the below worksheet can be found in the "Documentation" sheet (next sheet
NOTE: Magenta and green cells contain formulae, therefore, they are by default "protected" so they are not accidentally corrupted from inadvertent typir
Also note that by default the cells below "App. dip 1" & "App. dip 2" receive the calculated vector attitudes. If you already have the apparent d
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that you need to revert back to using elevation and distance measurements. The combined strike and dip attitude is displayed in green at lower rigl
in case the solution needs to be copied to another application such as NETPROG

Calculation Method

The method works via the cross-product of two vectors. The two vectors defined by "A>B" and "A>C" must lie within the structural plan
for which we want to know the strike and dip. The upper portion of the spreadsheet converts the raw data into the attitude of these tw
vectors. In the upper portion of the spreadsheet the two vectors are converted into directional cosines, and then the cross-product is take
The cross-product yields the attitude of the vector perpendicular to the plane that contains the original two vectors. This is analogous to th
problem of calculating a strike and dip of a plane from two given apparent dips, which are in fact simply two lines that lay within the plane
The rest of the spreadsheet converts the pole into a more familiar strike and true dip in quadrant forma

Angular Precision:	2	Angular Field Width:	5	H/V Conversion:	1000.000	m/km	
Three Points with known elevations, relative bearings, and distances							
	Bearing	Distance	Elevation	Inclination	Vector attitude		
Point A	#N/A	#N/A	3500.500	#N/A	#N/A		
Point B	N 60.43 W	218.030	3496.000	1.182	N 60.43 W 1.18		
Point C	S 72.59 E	770.490	3507.000	-0.483	S 72.59 E -0.48		
	Quadrant	Quadrant					
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	
Joe Draw JR	N 60.43 W 1.18	S 72.59 E -0.48	299.570	1.180	107.410	-0.480	
App. dip 1			App. dip 2			Theta	
Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(radians)	
-0.870	0.493	0.021	0.954	-0.299	-0.008	2.929	
Lower Hemisphere	Cross-product			Pole	Pole	Strike of	True
Flag	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Plane	Dip
-0.998	-0.010	-0.059	0.998	189.315	86.595	N 80.68 W	3.40 NE
Hydraulic Flow	Gradient					Plane	
Azimuth	m/km					Strike & Dip	
9.32	59.498					N 80.68 W 3.40 NE	
Graphical Data							
X	Y	Point	Elev.				
0.000	0.000	A	3500.500				
-189.632	107.595	B	3496.000				
735.192	-230.536	C	3507.000				
0.000	0.000	A					
-189.632	107.595	B					
25.522	72.302	Strike	N 80.68 W 3.40 NE				
-404.787	142.887	Strike	N 80.68 W 3.40 NE				

Symbolic block names

Symbolic names are used extensively throughout the three point solver spreadsheet
to clarify calculation equations. The blue cells are where raw data is entered. Below are the definitions:

Name	Definition or Value
AppDip1	Apparent dip bearing and plunge of A>B vector
AppDip2	Apparent dip bearing and plunge of A>C vector
Az_1	Azimuth (0-360) of apparent dip 1 (A>B).
Az_2	Azimuth of apparent dip 2 (A>C).
Bearing_B	Entered bearing (quadrant format) of vector A>B.
Bearing_C	Entered bearing of vector A>C.
CalcAppDip1	Calculated apparent dip vector 1 (A>B).
CalcAppdip2	Calculated apparent dip vector 2 (A>C).
DistB	Entered horizontal map distance from A to B.
DistC	Entered horizontal map distance from A to C.
Elev1	Entered elevation at point A.
Elev2	Entered elevation at point B.
Elev3	Entered elevation at point C.
fl	Field size (characters) for reported angular values.
H_V_Conversion	Conversion factor for gradient units.
Incline_B	Calculated inclination (degrees) from point A to B.
Incline_C	Calculated inclination (degrees) from point A to C.
LowerFlag	Positive if cross product has a positive plunge angle, negative if not.
Ndec	Number of decimal places for reported angular values.
Pl_1	Plunge angle of the A>B vector.
Pl_2	Plunge angle of the A>C vector.
PoleAz	Calculated azimuth angle (degrees) of the pole (cross product) vector.
PolePl	Calculated plunge angle (degrees) of the pole (cross product) vector.
Theta_S	Calculated angle (radians) between the apparent dip vectors.
X_1,Y_1,Z_1	Directional components of apparent dip 1 (A>B).
X_2,Y_2,Z_2	Directional components of apparent dip 2 (A>C).
X_S,Y_S,Z_S	Directional components of the cross product solution (pole to plane).

Note that the geometry of the problem is depicted in graphical form in the following worksheet chart. The user
should be aware that the chart will almost always use different X and Y scales by default. It will be the responsibility
of the user to override the default scaling so that the X and Y scales are equivalent. If the grid on the chart appears
as "squares", the X and Y scales are equivalent (or nearly so).

STEP 1: From the base map pick the higher elevation point and label it as "A". Label the intermediate and lowest elevation points "B" and "C".
Make sure that point A is the highest elevation, "B" is the intermediate, and that point "C" is the lowest elevation value.
STEP 2: Measure the relative bearings in quadrant format between "A>B" and "A>C". Also measure distances according to scale.
Note that bearings must be entered according to the precision (I.e. decimal places) setting named "Angular Precision".
For example, a bearing measured as south 9.3 degrees west would be entered as "S 09.3 W" if angular precision = 1.
STEP 3: Calculate the elevations of points A,B, and C with topographic contours or other means. Remember to convert drill depts to elevations!
The worksheet assumes that units are equivalent among distance and elevation measurements. If not, convert to a consistent unit system at this step.
STEP 4: Enter the measurements from steps 1-3 into the cells in blue color below. The attitudes of the two vectors "A>B" and "A>C"
will appear below the heading "Vector Attitude".
STEP 5: Read the strike and dip of the plane containing apparent dips 1 & 2 at the lower right
of the spreadsheet. Answers appear in dark green color. Also calculated are the pole azimuth and plunge, the hydraulic flow
direction azimuth, and the gradient. The gradient horizontal vs. vertical scale conversion is controlled by the cell
right of the label "H/V conversion". Use 1000 for meters per kilometer, or 5280 for feet per mile gradient units.
NOTE: Magenta and green cells contain formulae, therefore, they are by default "protected" so they are not accidentally currupted from inadvertent typing.
Also note that by default the cells below App. dip 1 & App. dip 2 receive the calculated vector attitudes. If you already have the apparent dip
attitudes you should over-type the formulae, however, make sure that you keep a copy of the original worksheet in the event
that you nee to revert back to using elevation and distance measurements.

Accumulation Macro

The accumulation macro is designed to copy the calculated results of the current 3-point problem to the sheet named
Accumulation". You can run the macro with the menu sequence "Tools > Macro > Macros", and then indicate the
name "AccumulateMacro" as the macro to run.

Graphical Plot

The graphical diagram in the sheet "Map" displays a map view of the elements of the 3-point problem. The points
labelled "A", "B", and "C" correspond to the 3 control points in the problem. The line lablled "strike" indicates the
attitude of the strike line calculated by the algorithm. By default the X and Y axis are set to an "autoscale" that
unfortunately will not generally set equivalent X and Y increments. After the elements of the problem are entered you
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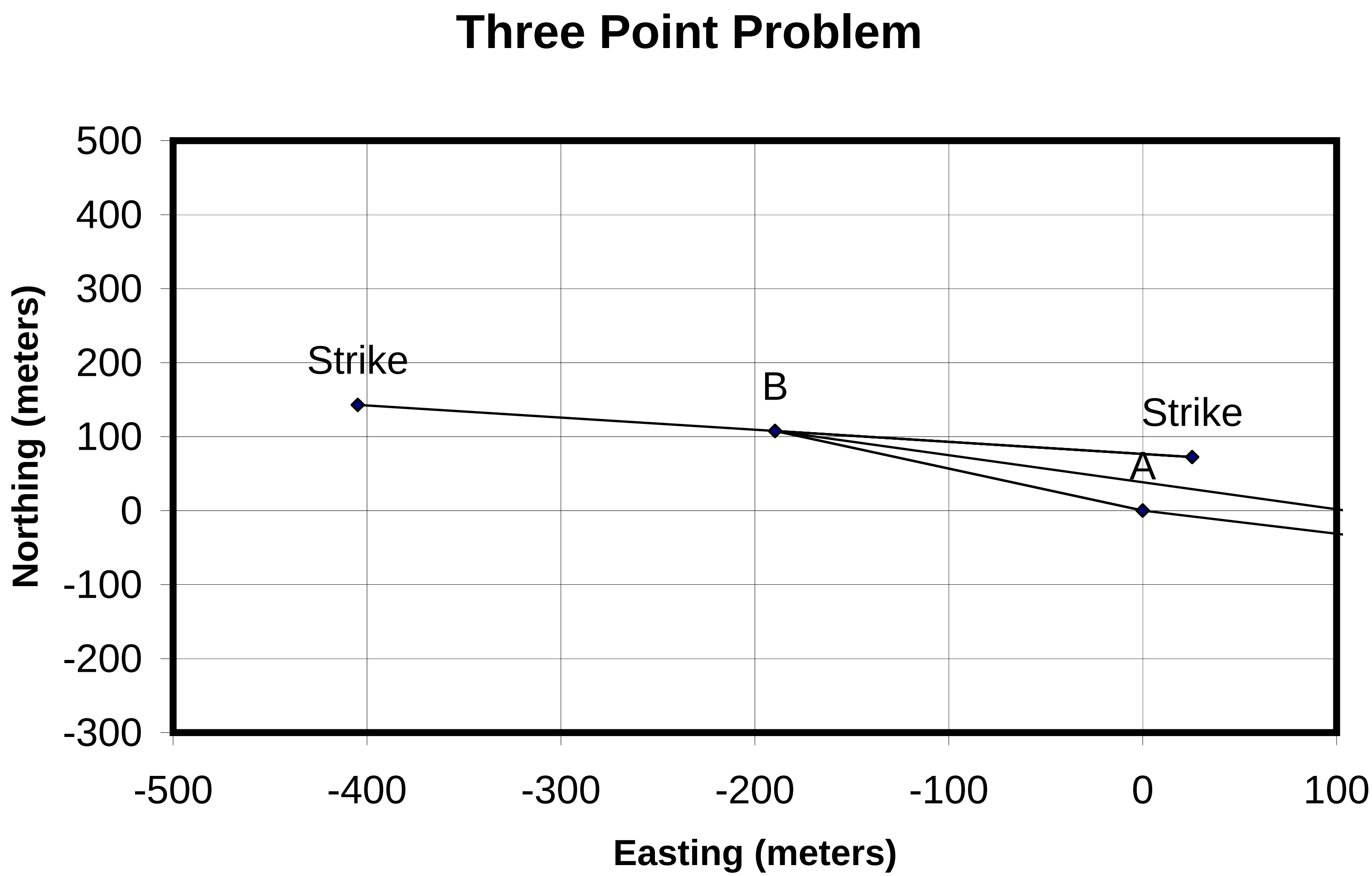
Three Point Problem
Northing (meters)
500
400
300
200
100
0
-100
-200
-300
Easting (meters)
-500
-400
-300
-200
-100
0
100
Strike
B
Strike
A

Accumulated 3-point problem solutions

	Quadrant	Quadrant					App. dip 1			App. dip 2			Theta	Cross-product			Pole	Pole	Plane
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(rad.)	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Strike & Dip

Three-Point Problem Solver

Usage

This spreadsheet calculates the strike and true dip of a structural plane given three points on the plane that hav
known elevation and relative bearings and distances. Normally this is the case when a planar geologic contact ca
be traced over irregular topography. The three elevations are determined from topographic contours whereas th
bearings are measured with a protractor relative to geographic north. Distances between points are measured usin
the maps scale. Alternatively, contours of subsurface structures may be used to measure the required parameters, howeve
remember that this method assumes that the structure is planar! This spreadsheet may be used to determine the hydrauli
flow direction below the water table, which is the true dip direction.
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The rest of the spreadsheet converts the pole into a more familiar strike and true dip in quadrant forma

Angular Precision:	2	Angular Field Width:	5	H/V Conversion:	1000.000	m/km	
Three Points with known elevations, relative bearings, and distances							
	Bearing	Distance	Elevation	Inclination	Vector attitude		
Point A	#N/A	#N/A	3516.000	#N/A	#N/A		
Point B	S 08.23 W	83.500	3504.400	7.909	S 08.23 W 7.91		
Point C	S 08.55 W	980.920	3515.600	0.023	S 08.55 W 0.02		
	Quadrant	Quadrant					
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	
Coal stringer Aqui	S 08.23 W 7.91	S 08.55 W 0.02	188.230	7.910	188.550	0.020	
App. dip 1			App. dip 2			Theta	
Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(radians)	
-0.142	-0.980	0.138	-0.149	-0.989	0.000	0.138	
Lower Hemisphere	Cross-product			Pole	Pole	Strike of	True
Flag	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Plane	Dip
-0.040	-0.988	0.149	0.040	278.551	2.308	N 8.55 E	87.69 SE
Hydraulic Flow	Gradient					Plane	
Azimuth	m/km					Strike & Dip	
98.55	24814.627					N 8.55 E 87.69 SE	
Graphical Data							
X	Y	Point	Elev.				
0.000	0.000	A	3516.000				
-11.953	-82.640	B	3504.400				
-145.836	-970.019	C	3515.600				
0.000	0.000	A					
-11.953	-82.640	B					
-24.368	-165.212	Strike	N 8.55 E 87.69 SE				
0.463	-0.068	Strike	N 8.55 E 87.69 SE				

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For example, a bearing measured as south 9.3 degrees west would be entered as "S 09.3 W" if angular precision = 1
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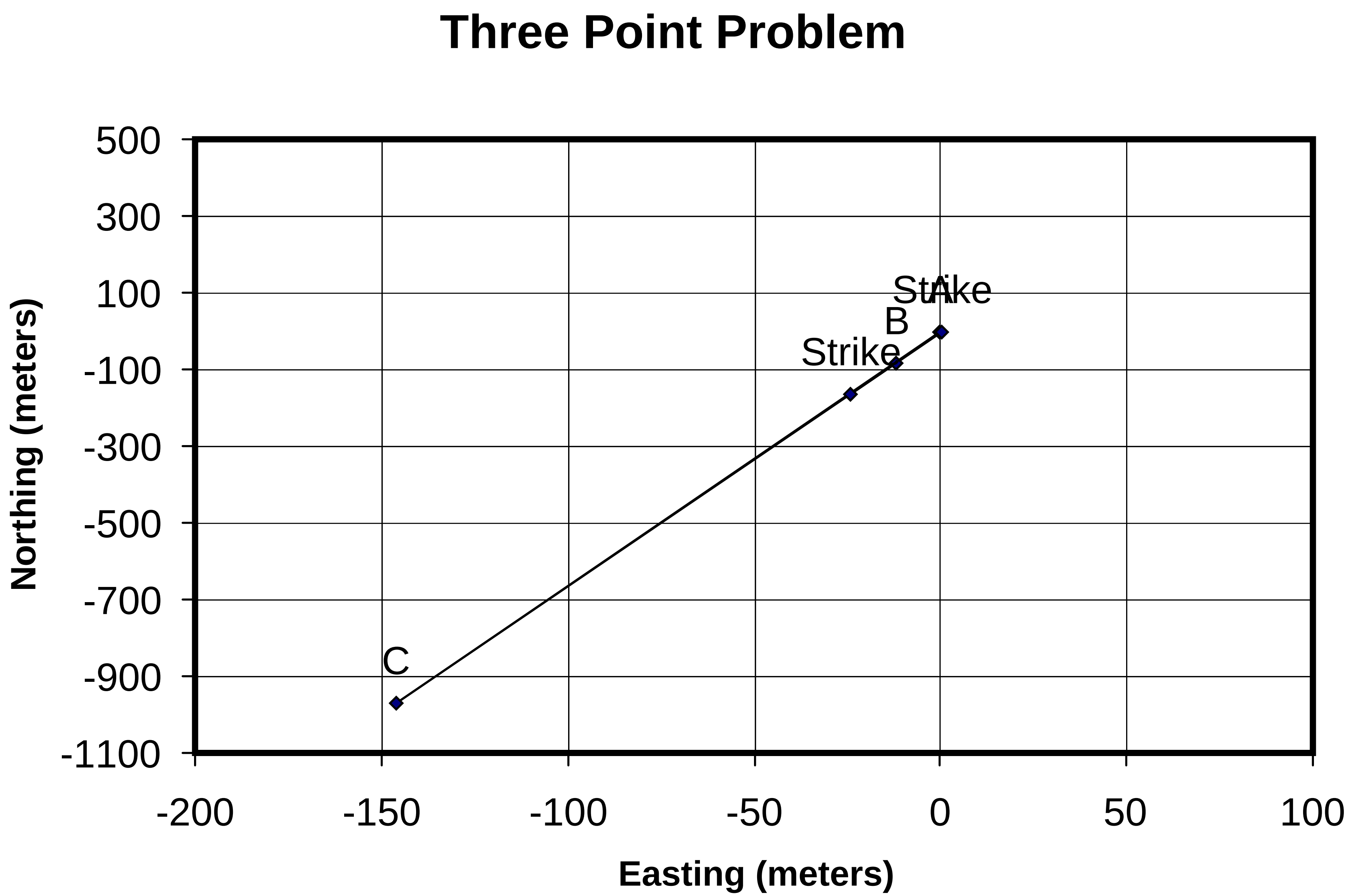

Three Point Problem
Northing (meters)
500
300
100
-100
-300
-500
-700
-900
-1100
Easting (meters)
-200
-150
-100
-50
0
50
100
A
Strike
B
Strike
C

Accumulated 3-point problem solutions

	Quadrant	Quadrant					App. dip 1			App. dip 2			Theta	Cross-product			Pole	Pole	Plane
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(rad.)	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Strike & Dip

Three-Point Problem Solver

Usage

This spreadsheet calculates the strike and true dip of a structural plane given three points on the plane that have known elevation and relative bearings and distances. Normally this is the case when a planar geologic contact can be traced over irregular topography. The three elevations are determined from topographic contours whereas the bearings are measured with a protractor relative to geographic north. Distances between points are measured using the maps scale. Alternatively, contours of subsurface structures may be used to measure the required parameters, however, remember that this method assumes that the structure is planar! This spreadsheet may be used to determine the hydraulic flow direction below the water table, which is the true dip direction.

Detailed steps for using the below worksheet can be found in the "Documentation" sheet (next sheet).

NOTE: Magenta and green cells contain formulae, therefore, they are by default "protected" so they are not accidentally corrupted from inadvertent typing.

Also note that by default the cells below "App. dip 1" & "App. dip 2" receive the calculated vector attitudes. If you already have the apparent dip attitudes you should over-type the formulae, however, make sure that you keep a copy of the original worksheet in the event that you need to revert back to using elevation and distance measurements. The combined strike and dip attitude is displayed in green at lower right in case the solution needs to be copied to another application such as NETPROG.

Calculation Method

The method works via the cross-product of two vectors. The two vectors defined by "A>B" and "A>C" must lie within the structural plane for which we want to know the strike and dip. The upper portion of the spreadsheet converts the raw data into the attitude of these two vectors. In the upper portion of the spreadsheet the two vectors are converted into directional cosines, and then the cross-product is taken. The cross-product yields the attitude of the vector perpendicular to the plane that contains the original two vectors. This is analogous to the problem of calculating a strike and dip of a plane from two given apparent dips, which are in fact simply two lines that lay within the plane

The rest of the spreadsheet converts the pole into a more familiar strike and true dip in quadrant format.

Angular Precision:	2	Angular Field Width:	5	H/V Conversion:	1000.000	m/km	
Three Points with known elevations, relative bearings, and distances.							
	Bearing	Distance	Elevation	Inclination	Vector attitude		
Point A	#N/A	#N/A	3520.000	#N/A	#N/A		
Point B	N 10.45 W	886.410	3514.000	0.388	N 10.45 W 0.39		
Point C	N 06.64 W	904.130	3519.000	0.063	N 06.64 W 0.06		
	Quadrant	Quadrant					
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	
Siltstone Aquifer	N 10.45 W 0.39	N 06.64 W 0.06	349.550	0.390	353.360	0.060	
App. dip 1			App. dip 2			Theta	
Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(radians)	
-0.181	0.983	0.007	-0.116	0.993	0.001	0.067	
Lower Hemisphere	Cross-product			Pole	Pole	Strike of	True
Flag	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Plane	Dip
-0.996	0.086	0.009	0.996	84.052	85.044	N 5.95 W	4.96 SW
Hydraulic Flow	Gradient					Plane	
Azimuth	m/km					Strike & Dip	
264.05	86.721					N 5.95 W 4.96 SW	
Graphical Data							
X	Y	Point	Elev.				
0.000	0.000	A	3520.000				
-160.775	871.708	B	3514.000				
-104.545	898.065	C	3519.000				
0.000	0.000	A					
-160.775	871.708	B					
-252.631	1753.345	Strike	N 5.95 W 4.96 SW				
-68.918	-9.930	Strike	N 5.95 W 4.96 SW				

Symbolic block names

Symbolic names are used extensively throughout the three point solver spreadshee
to clarify calculation equations. The blue cells are where raw data is entered. Below are the definition:

Name	Definition or Value
AppDip1	Apparent dip bearing and plunge of A>B vecto
AppDip2	Apparent dip bearing and plunge of A>C vecto
Az_1	Azimuth (0-360) of apparent dip 1 (A>B).
Az_2	Azimuth of apparent dip 2 (A>C).
Bearing_B	Entered bearing (quadrant format) of vector A>B
Bearing_C	Entered bearing of vector A>C
CalcAppDip1	Calculated apparent dip vector 1 (A>B).
CalcAppdip2	Calculated apparent dip vector 2 (A>C).
DistB	Entered horizontal map distance from A to B
DistC	Entered horizontal map distance from A to C
Elev1	Entered elevation at point A
Elev2	Entered elevation at point B
Elev3	Entered elevation at point C
fl	Field size (characters) for reported angular values
H_V_Conversion	Conversion factor for gradient units
Incline_B	Calculated inclination (degrees) from point A to B
Incline_C	Calculated inclination (degrees) from point A to C
LowerFlag	Positive if cross product has a positive plunge angle, negative if not
Ndec	Number of decimal places for reported angular values
Pl_1	Plunge angle of the A>B vector
Pl_2	Plunge angle of the A>C vector
PoleAz	Calculated azimuth angle (degrees) of the pole (cross product) vector
PolePl	Calculated plunge angle (degrees) of the pole (cross product) vector
Theta_S	Calculated angle (radians) between the apparent dip vectors
X_1,Y_1,Z_1	Directional components of apparent dip 1 (A>B)
X_2,Y_2,Z_2	Directional components of apparent dip 2 (A>C)
X_S,Y_S,Z_S	Directional components of the cross product solution (pole to plane)

Note that the geometry of the problem is depicted in graphical form in the following worksheet chart. The use
should be aware that the chart will almost always use different X and Y scales by default. It will be the responsibili
of the user to override the default scaling so that the X and Y scales are equivalent. If the grid on the chart appea
as "squares", the X and Y scales are equivalent (or nearly so)

STEP 1: From the base map pick the higher elevation point and label it as "A". Label the intermediate and lowest elevation points "B" and "C"
Make sure that point A is the highest elevation, "B" is the intermediate, and that point "C" is the lowest elevation valu
STEP 2: Measure the relative bearings in quadrant format between "A>B" and "A>C". Also measure distances according to scal
Note that bearings must be entered according to the precision (I.e. decimal places) setting named "Angular Precision"
For example, a bearing measured as south 9.3 degrees west would be entered as "S 09.3 W" if angular precision = 1
STEP 3: Calculate the elevations of points A,B, and C with topographic contours or other means. Remember to convert drill depts to elevation
The worksheet assumes that units are equivalent among distance and elevation measurements. If not, convert to a consistent unit system at this ste
STEP 4: Enter the measurements from steps 1-3 into the cells in blue color below. The attitudes of the two vectors "A>B" and "A>C
will appear below the heading "Vector Attitude"
STEP 5: Read the strike and dip of the plane containing apparent dips 1 & 2 at the lower righ
of the spreadsheet. Answers appear in dark green color. Also calculated are the pole azimuth and plunge, the hydraulic flo
direction azimuth, and the gradient. The gradient horizontal vs. vertical scale conversion is controlled by the ce
right of the label "H/V conversion". Use 1000 for meters per kilometer, or 5280 for feet per mile gradient units
NOTE: Magenta and green cells contain formulae, therefore, they are by default "protected" so they are not accidentally currupted from inadvertent typin
Also note that by default the cells below App. dip 1 & App. dip 2 receive the calculated vector attitudes. If you already have the apparent d
attitudes you should over-type the formulae, however, make sure that you keep a copy of the original worksheet in the eve
that you nee to revert back to using elevation and distance measurements

Accumulation Macro

The accumulation macro is designed to copy the calculated results of the current 3-point problem to the sheet name
Accumulation". You can run the macro with the menu sequence "Tools > Macro > Macros", and then indicate th
name "AccumulateMacro" as the macro to run

Graphical Plot

The graphical diagram in the sheet "Map" displays a map view of the elements of the 3-point problem. The point
labelled "A", "B", and "C" correspond to the 3 control points in the problem. The line lablled "strike" indicates the
attitude of the strike line calculated by the algorithm. By default the X and Y axis are set to an "autoscale" th
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should edit the X and Y scale settings in "manual" mode so that the grid on the graph appears as a collection
squares" rather than rectangles. This means that the scaling is equivalent (or very close) on both axes, therefor
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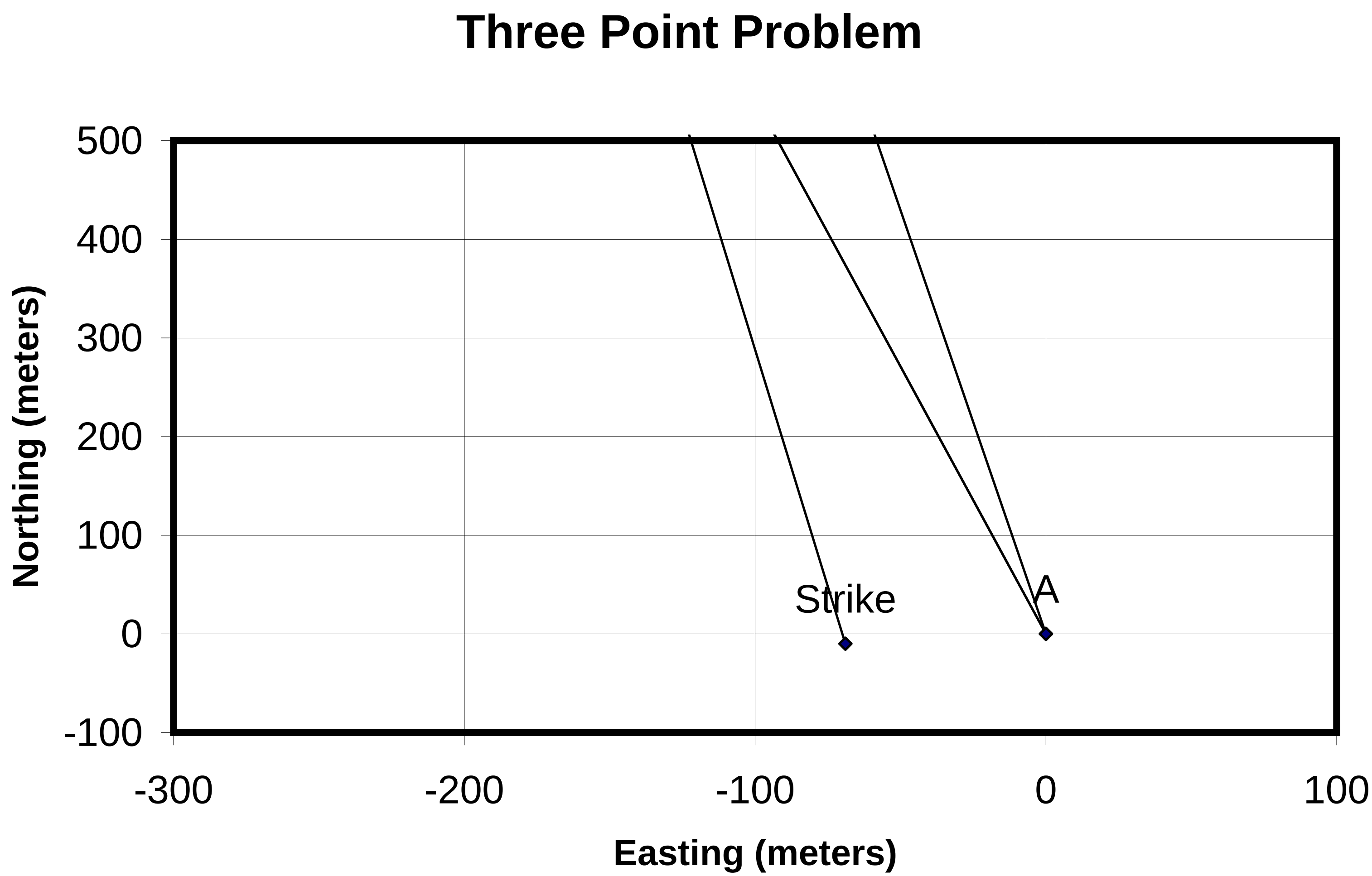

Three Point Problem
Northing (meters)
500
400
300
200
100
0
-100
Strike
A
-300
-200
-100
0
100
Easting (meters)

Accumulated 3-point problem solutions

	Quadrant	Quadrant					App. dip 1			App. dip 2			Theta	Cross-product			Pole	Pole	Plane
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(rad.)	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Strike & Dip

Three-Point Problem Solver

Usage

This spreadsheet calculates the strike and true dip of a structural plane given three points on the plane that hav
known elevation and relative bearings and distances. Normally this is the case when a planar geologic contact ca
be traced over irregular topography. The three elevations are determined from topographic contours whereas the
bearings are measured with a protractor relative to geographic north. Distances between points are measured usin
the maps scale. Alternatively, contours of subsurface structures may be used to measure the required parameters, however
remember that this method assumes that the structure is planar! This spreadsheet may be used to determine the hydrauli
flow direction below the water table, which is the true dip direction.
Detailed steps for using the below worksheet can be found in the "Documentation" sheet (next sheet
NOTE: Magenta and green cells contain formulae, therefore, they are by default "protected" so they are not accidentally corrupted from inadvertent typing
Also note that by default the cells below "App. dip 1" & "App. dip 2" receive the calculated vector attitudes. If you already have the apparent dip
attitudes you should over-type the formulae, however, make sure that you keep a copy of the original worksheet in the ever
that you need to revert back to using elevation and distance measurements. The combined strike and dip attitude is displayed in green at lower rig
in case the solution needs to be copied to another application such as NETPROG

Calculation Method

The method works via the cross-product of two vectors. The two vectors defined by "A>B" and "A>C" must lie within the structural plane
for which we want to know the strike and dip. The upper portion of the spreadsheet converts the raw data into the attitude of these two
vectors. In the upper portion of the spreadsheet the two vectors are converted into directional cosines, and then the cross-product is taken
The cross-product yields the attitude of the vector perpendicular to the plane that contains the original two vectors. This is analogous to th
problem of calculating a strike and dip of a plane from two given apparent dips, which are in fact simply two lines that lay within the plane
The rest of the spreadsheet converts the pole into a more familiar strike and true dip in quadrant format

Angular Precision	2	Angular Field Width:	5	H/V Conversion	1000.000	m/km	
Three Points with known elevations, relative bearings, and distances							
	Bearing	Distance	Elevation	Inclination	Vector attitude		
Point A	#N/A	#N/A	3576.000	#N/A	#N/A		
Point B	N 68.84 E	46.280	3509.000	55.365	N 68.84 E 55.37		
Point C	S 73.19 E	95.590	3574.000	1.199	S 73.19 E 1.20		
	Quadrant	Quadrant					
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	
Squirrel Coal Sear	N 68.84 E 55.37	S 73.19 E 1.20	68.840	55.370	106.810	1.200	
App. dip 1			App. dip 2			Theta	
Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(radians)	
0.530	0.205	0.823	0.957	-0.289	0.021	1.087	
Lower Hemisphere	Cross-product			Pole	Pole	Strike of	True
Flag	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Plane	Dip
-0.395	-0.274	-0.877	0.395	197.326	23.258	N 72.67 W	66.74 NE
Hydraulic Flow	Gradient					Plane	
Azimuth	m/km					Strike & Dip	
17.33	2326.709					N 72.67 W 66.74 NE	
Graphical Data							
X	Y	Point	Elev.				
0.000	0.000	A	3576.000				
43.160	16.706	B	3509.000				
91.505	-27.645	C	3574.000				
0.000	0.000	A					
43.160	16.706	B					
87.340	2.923	Strike	N 72.67 W 66.74 NE				
-1.021	30.488	Strike	N 72.67 W 66.74 NE				

Symbolic block names

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Elev3	Entered elevation at point C
fl	Field size (characters) for reported angular values
H_V_Conversion	Conversion factor for gradient units
Incline_B	Calculated inclination (degrees) from point A to B
Incline_C	Calculated inclination (degrees) from point A to C
LowerFlag	Positive if cross product has a positive plunge angle, negative if not
Ndec	Number of decimal places for reported angular values
Pl_1	Plunge angle of the A>B vector
Pl_2	Plunge angle of the A>C vector.
PoleAz	Calculated azimuth angle (degrees) of the pole (cross product) vector
PolePl	Calculated plunge angle (degrees) of the pole (cross product) vector
Theta_S	Calculated angle (radians) between the apparent dip vectors
X_1,Y_1,Z_1	Directional components of apparent dip 1 (A>B)
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Note that bearings must be entered according to the precision (I.e. decimal places) setting named "Angular Precision"
For example, a bearing measured as south 9.3 degrees west would be entered as "S 09.3 W" if angular precision = 1
STEP 3: Calculate the elevations of points A,B, and C with topographic contours or other means. Remember to convert drill depts to elevation
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right of the label "H/V conversion". Use 1000 for meters per kilometer, or 5280 for feet per mile gradient units
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Graphical Plot

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labelled "A", "B", and "C" correspond to the 3 control points in the problem. The line lablled "strike" indicates the
attitude of the strike line calculated by the algorithm. By default the X and Y axis are set to an "autoscale" tha
unfortunately will not generally set equivalent X and Y increments. After the elements of the problem are entered yo
should edit the X and Y scale settings in "manual" mode so that the grid on the graph appears as a collection o
squares" rather than rectangles. This means that the scaling is equivalent (or very close) on both axes, therefor
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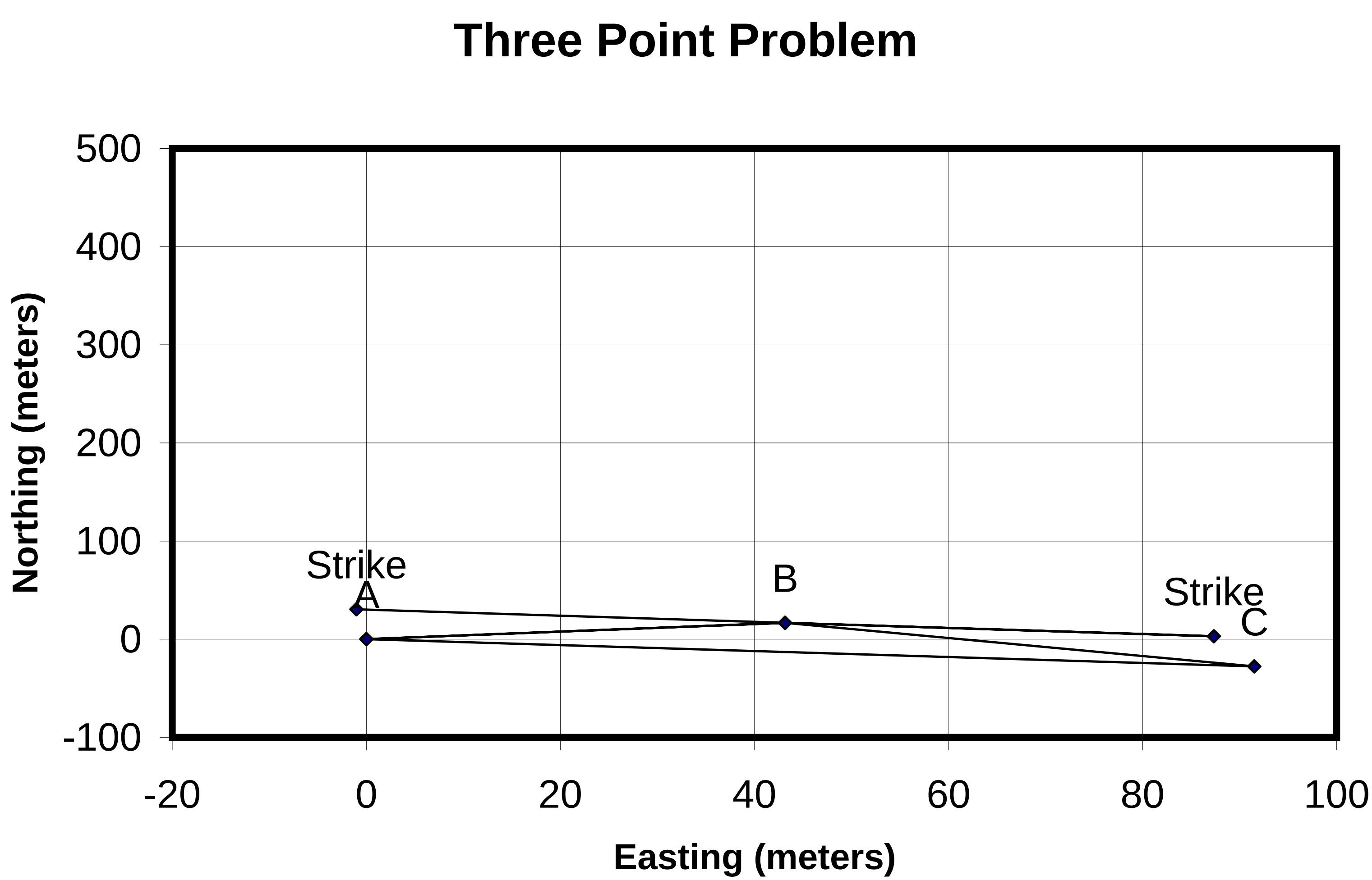
Three Point Problem
Northing (meters)
500
400
300
200
100
0
-100
-20
0
20
40
60
80
100
Easting (meters)
Strike
A
B
Strike
C

Accumulated 3-point problem solutions

	Quadrant	Quadrant					App. dip 1			App. dip 2			Theta	Cross-product			Pole	Pole	Plane
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(rad.)	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Strike & Dip

Note: This calculation was performed for the Sqirrel Coal Seam proximal to the Lori reservoir using data obtained at PD #1, PD #2, and PD #3.

Three-Point Problem Solver

Usage

This spreadsheet calculates the strike and true dip of a structural plane given three points on the plane that h
known elevation and relative bearings and distances. Normally this is the case when a planar geologic contact c
be traced over irregular topography. The three elevations are determined from topographic contours whereas t
bearings are measured with a protractor relative to geographic north. Distances between points are measured usi
the maps scale. Alternatively, contours of subsurface structures may be used to measure the required parameters, howev
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flow direction below the water table, which is the true dip directior
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attitudes you should over-type the formulae, however, make sure that you keep a copy of the original worksheet in the ev
that you need to revert back to using elevation and distance measurements. The combined strike and dip attitude is displayed in green at lower r
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Calculation Method

The method works via the cross-product of two vectors. The two vectors defined by "A>B" and "A>C" must lie within the structural pla
for which we want to know the strike and dip. The upper portion of the spreadsheet converts the raw data into the attitude of these t
vectors. In the upper portion of the spreadsheet the two vectors are converted into directional cosines, and then the cross-product is tak
The cross-product yields the attitude of the vector perpendicular to the plane that contains the original two vectors. This is analogous to
problem of calculating a strike and dip of a plane from two given apparent dips, which are in fact simply two lines that lay within the pla
The rest of the spreadsheet converts the pole into a more familiar strike and true dip in quadrant forma

Angular Precision	2	Angular Field Width:	5	H/V Conversion:	1000.000	m/km	
Three Points with known elevations, relative bearings, and distance							
	Bearing	Distance	Elevation	Inclinatior	Vector attitude		
Point A	#N/A	#N/A	3598.100	#N/A	#N/A		
Point B	N 67.44 E	765.890	3558.000	2.997	N 67.44 E 3.00		
Point C	N 58.34 E	1267.390	3560.000	1.722	N 58.34 E 1.72		
	Quadrant	Quadrant					
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	
Upper Roland Coal	N 67.44 E 3.00	N 58.34 E 1.72	67.440	3.000	58.340	1.720	
App. dip 1			App. dip 2			Theta	
Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(radians)	
0.922	0.383	0.052	0.851	0.525	0.030	0.160	
Lower Hemisphere	Cross-product			Pole	Pole	Strike of	True
Flag	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Plane	Dip
0.989	-0.100	0.106	0.989	316.552	81.638	N 46.55 E	8.36 SE
Hydraulic Flow	Gradient					Plane	
Azimuth	m/km					Strike & Dip	
136.55	146.988					N 46.55 E 8.36 SE	
Graphical Data							
X	Y	Point	Elev.				
0.000	0.000	A	3598.100				
707.283	293.834	B	3558.000				
1078.774	665.225	C	3560.000				
0.000	0.000	A					
707.283	293.834	B					
151.249	-232.867	Strike	N 46.55 E 8.36 SE				
1263.317	820.535	Strike	N 46.55 E 8.36 SE				

Symbolic block names

Symbolic names are used extensively throughout the three point solver spreadshee
to clarify calculation equations. The blue cells are where raw data is entered. Below are the definitions

Name	Definition or Value
AppDip1	Apparent dip bearing and plunge of A>B vectoı
AppDip2	Apparent dip bearing and plunge of A>C vectoı
Az_1	Azimuth (0-360) of apparent dip 1 (A>B).
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Bearing_B	Entered bearing (quadrant format) of vector A>B
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Incline_C	Calculated inclination (degrees) from point A to C
LowerFlag	Positive if cross product has a positive plunge angle, negative if not
Ndec	Number of decimal places for reported angular values
Pl_1	Plunge angle of the A>B vector
Pl_2	Plunge angle of the A>C vector.
PoleAz	Calculated azimuth angle (degrees) of the pole (cross product) vector
PolePl	Calculated plunge angle (degrees) of the pole (cross product) vector
Theta_S	Calculated angle (radians) between the apparent dip vectors
X_1,Y_1,Z_1	Directional components of apparent dip 1 (A>B)
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X_S,Y_S,Z_S	Directional components of the cross product solution (pole to plane)

Note that the geometry of the problem is depicted in graphical form in the following worksheet chart. The use
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of the user to override the default scaling so that the X and Y scales are equivalent. If the grid on the chart appea
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Note that bearings must be entered according to the precision (I.e. decimal places) setting named "Angular Precision"
For example, a bearing measured as south 9.3 degrees west would be entered as "S 09.3 W" if angular precision = 1
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right of the label "H/V conversion". Use 1000 for meters per kilometer, or 5280 for feet per mile gradient units
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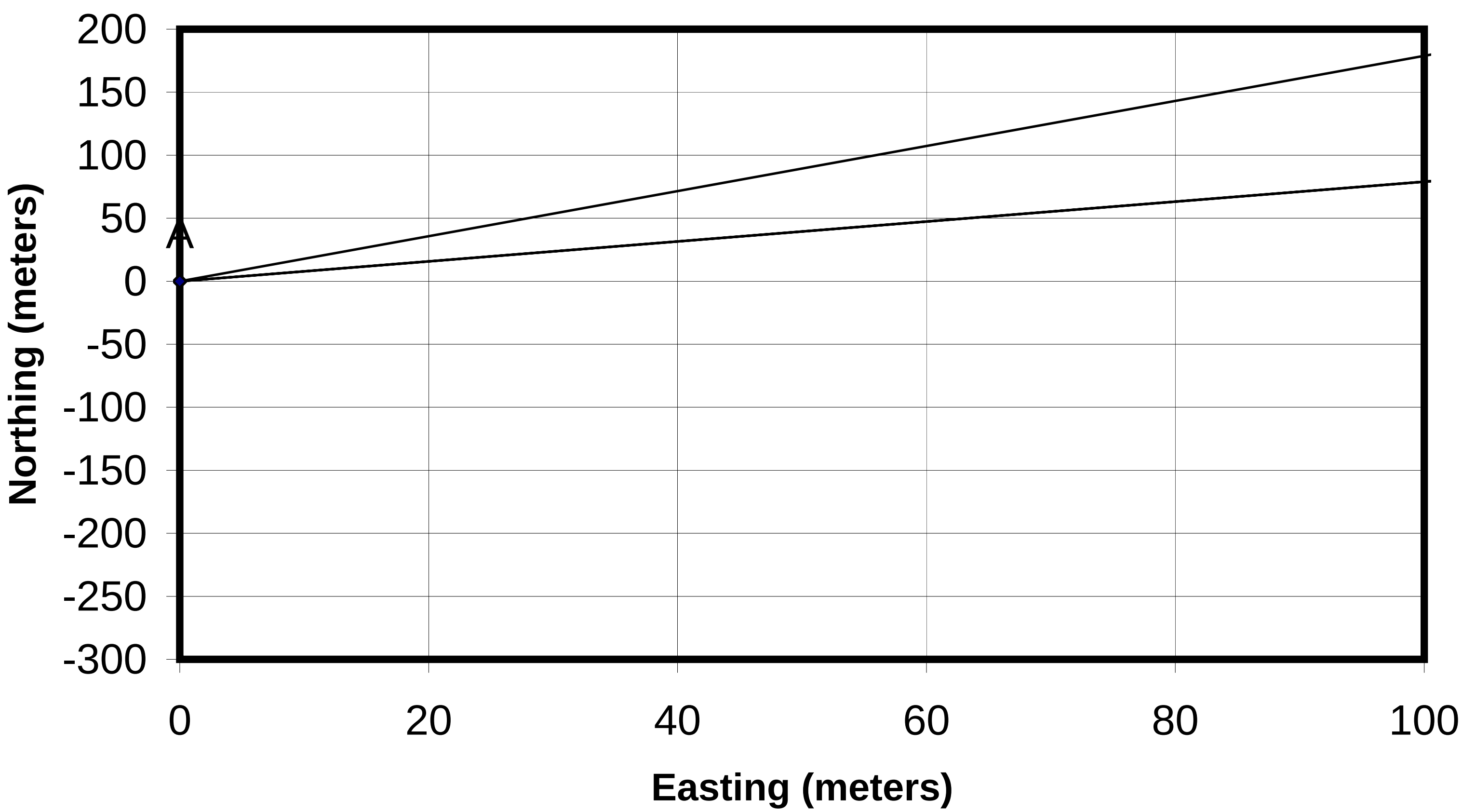
Three Point Problem



Accumulated 3-point problem solutions

	Quadrant	Quadrant					App. dip 1			App. dip 2			Theta	Cross-product			Pole	Pole	Plane
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(rad.)	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Strike & Dip

Three-Point Problem Solver

Usage

This spreadsheet calculates the strike and true dip of a structural plane given three points on the plane that h
known elevation and relative bearings and distances. Normally this is the case when a planar geologic contact c
be traced over irregular topography. The three elevations are determined from topographic contours whereas tl
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that you need to revert back to using elevation and distance measurements. The combined strike and dip attitude is displayed in green at lower r
in case the solution needs to be copied to another application such as NETPROC

Calculation Method

The method works via the cross-product of two vectors. The two vectors defined by "A>B" and "A>C" must lie within the structural pla
for which we want to know the strike and dip. The upper portion of the spreadsheet converts the raw data into the attitude of these t
vectors. In the upper portion of the spreadsheet the two vectors are converted into directional cosines, and then the cross-product is tak
The cross-product yields the attitude of the vector perpendicular to the plane that contains the original two vectors. This is analogous to
problem of calculating a strike and dip of a plane from two given apparent dips, which are in fact simply two lines that lay within the pla
The rest of the spreadsheet converts the pole into a more familiar strike and true dip in quadrant forma

Angular Precision	2	Angular Field Width:	5	H/V Conversion:	1000.000	m/km	
Three Points with known elevations, relative bearings, and distance							
	Bearing	Distance	Elevation	Inclinatior	Vector attitude		
Point A	#N/A	#N/A	3768.000	#N/A	#N/A		
Point B	S 61.48 W	587.490	3764.000	0.390	S 61.48 W 0.39		
Point C	S 72.12 W	602.110	3769.000	-0.095	S 72.12 W -0.10		
	Quadrant	Quadrant					
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	
Termo	S 61.48 W 0.39	S 72.12 W -0.10	241.480	0.390	252.120	-0.100	
App. dip 1			App. dip 2			Theta	
Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(radians)	
-0.879	-0.477	0.007	-0.952	-0.307	-0.002	0.186	
Lower Hemisphere	Cross-product			Pole	Pole	Strike of	True
Flag	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Plane	Dip
-0.999	-0.016	0.043	0.999	339.954	87.355	N 69.95 E	2.64 SE
Hydraulic Flow	Gradient					Plane	
Azimuth	m/km					Strike & Dip	
159.95	46.189					N 69.95 E 2.64 SE	
Graphical Data							
X	Y	Point	Elev.				
0.000	0.000	A	3768.000				
-516.198	-280.506	B	3764.000				
-573.029	-184.862	C	3769.000				
0.000	0.000	A					
-516.198	-280.506	B					
-1068.099	-481.878	Strike	N 69.95 E 2.64 SE				
35.702	-79.134	Strike	N 69.95 E 2.64 SE				

Symbolic block names

Symbolic names are used extensively throughout the three point solver spreadshee
to clarify calculation equations. The blue cells are where raw data is entered. Below are the definition:

Name	Definition or Value
AppDip1	Apparent dip bearing and plunge of A>B vecto
AppDip2	Apparent dip bearing and plunge of A>C vecto
Az_1	Azimuth (0-360) of apparent dip 1 (A>B).
Az_2	Azimuth of apparent dip 2 (A>C).
Bearing_B	Entered bearing (quadrant format) of vector A>B
Bearing_C	Entered bearing of vector A>C
CalcAppDip1	Calculated apparent dip vector 1 (A>B).
CalcAppdip2	Calculated apparent dip vector 2 (A>C).
DistB	Entered horizontal map distance from A to B
DistC	Entered horizontal map distance from A to C
Elev1	Entered elevation at point A
Elev2	Entered elevation at point B
Elev3	Entered elevation at point C
fl	Field size (characters) for reported angular values
H_V_Conversion	Conversion factor for gradient units
Incline_B	Calculated inclination (degrees) from point A to B
Incline_C	Calculated inclination (degrees) from point A to C
LowerFlag	Positive if cross product has a positive plunge angle, negative if not
Ndec	Number of decimal places for reported angular values
Pl_1	Plunge angle of the A>B vector
Pl_2	Plunge angle of the A>C vector
PoleAz	Calculated azimuth angle (degrees) of the pole (cross product) vector
PolePl	Calculated plunge angle (degrees) of the pole (cross product) vector
Theta_S	Calculated angle (radians) between the apparent dip vectors
X_1,Y_1,Z_1	Directional components of apparent dip 1 (A>B)
X_2,Y_2,Z_2	Directional components of apparent dip 2 (A>C)
X_S,Y_S,Z_S	Directional components of the cross product solution (pole to plane)

Note that the geometry of the problem is depicted in graphical form in the following worksheet chart. The use
should be aware that the chart will almost always use different X and Y scales by default. It will be the responsibili
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STEP 1: From the base map pick the higher elevation point and label it as "A". Label the intermediate and lowest elevation points "B" and "C"
Make sure that point A is the highest elevation, "B" is the intermediate, and that point "C" is the lowest elevation valu
STEP 2: Measure the relative bearings in quadrant format between "A>B" and "A>C". Also measure distances according to scal
Note that bearings must be entered according to the precision (I.e. decimal places) setting named "Angular Precision"
For example, a bearing measured as south 9.3 degrees west would be entered as "S 09.3 W" if angular precision = 1
STEP 3: Calculate the elevations of points A,B, and C with topographic contours or other means. Remember to convert drill depts to elevation
The worksheet assumes that units are equivalent among distance and elevation measurements. If not, convert to a consistent unit system at this ste
STEP 4: Enter the measurements from steps 1-3 into the cells in blue color below. The attitudes of the two vectors "A>B" and "A>C
will appear below the heading "Vector Attitude"
STEP 5: Read the strike and dip of the plane containing apparent dips 1 & 2 at the lower righ
of the spreadsheet. Answers appear in dark green color. Also calculated are the pole azimuth and plunge, the hydraulic flo
direction azimuth, and the gradient. The gradient horizontal vs. vertical scale conversion is controlled by the ce
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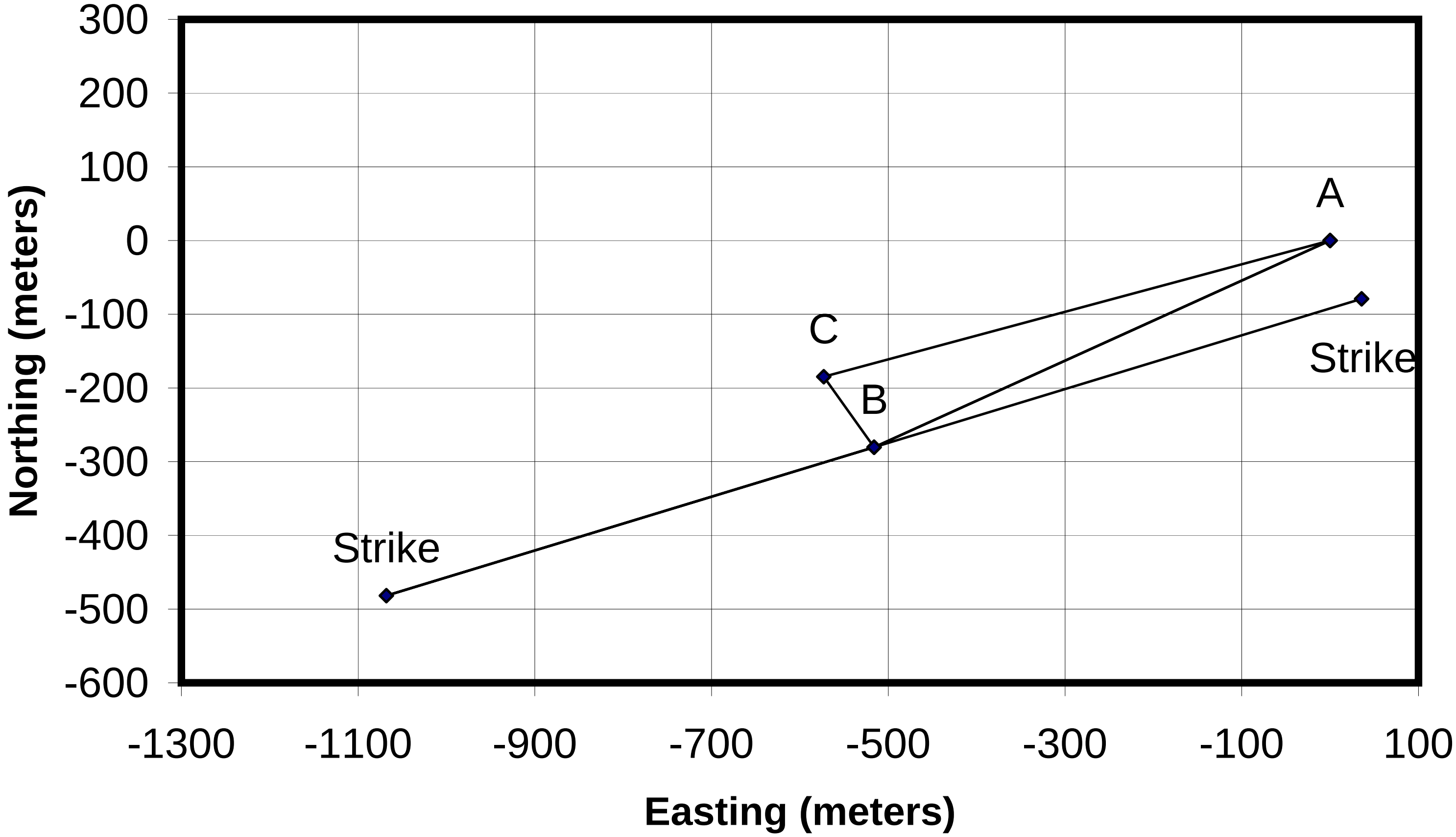
Three Point Problem



Accumulated 3-point problem solutions

	Quadrant	Quadrant					App. dip 1			App. dip 2			Theta	Cross-product			Pole	Pole	Plane
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(rad.)	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Strike & Dip

Three-Point Problem Solver

Usage

This spreadsheet calculates the strike and true dip of a structural plane given three points on the plane that h
known elevation and relative bearings and distances. Normally this is the case when a planar geologic contact c
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Angular Precision	2	Angular Field Width:	5	H/V Conversion:	1000.000	m/km	
Three Points with known elevations, relative bearings, and distance							
	Bearing	Distance	Elevation	Inclinatior	Vector attitude		
Point A	#N/A	#N/A	1200.000	#N/A	#N/A		
Point B	N 83.00 W	4148.000	950.000	3.449	N 83.00 W 3.45		
Point C	N 46.00 W	2143.000	550.000	16.873	N 46.00 W 16.87		
	Quadrant	Quadrant					
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	
South Drive	N 83.00 W 3.45	N 46.00 W 16.87	277.000	3.450	314.000	16.870	
App. dip 1			App. dip 2			Theta	
Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(radians)	
-0.991	0.122	0.060	-0.688	0.665	0.290	0.676	
Lower Hemisphere	Cross-product			Pole	Pole	Strike of	True
Flag	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Plane	Dip
-0.919	0.008	-0.394	0.919	178.906	66.821	N 88.91 E	23.18 NW
Hydraulic Flow	Gradient					Plane	
Azimuth	m/km					Strike & Dip	
358.91	428.157					N 88.91 E 23.18 NW	
Graphical Data							
X	Y	Point	Elev.				
0.000	0.000	A	1200.000				
-4117.081	505.514	B	950.000				
-1541.545	1488.653	C	550.000				
0.000	0.000	A					
-4117.081	505.514	B					
30.162	584.743	Strike	N 88.91 E 23.18 NW				
-8264.325	426.285	Strike	N 88.91 E 23.18 NW				

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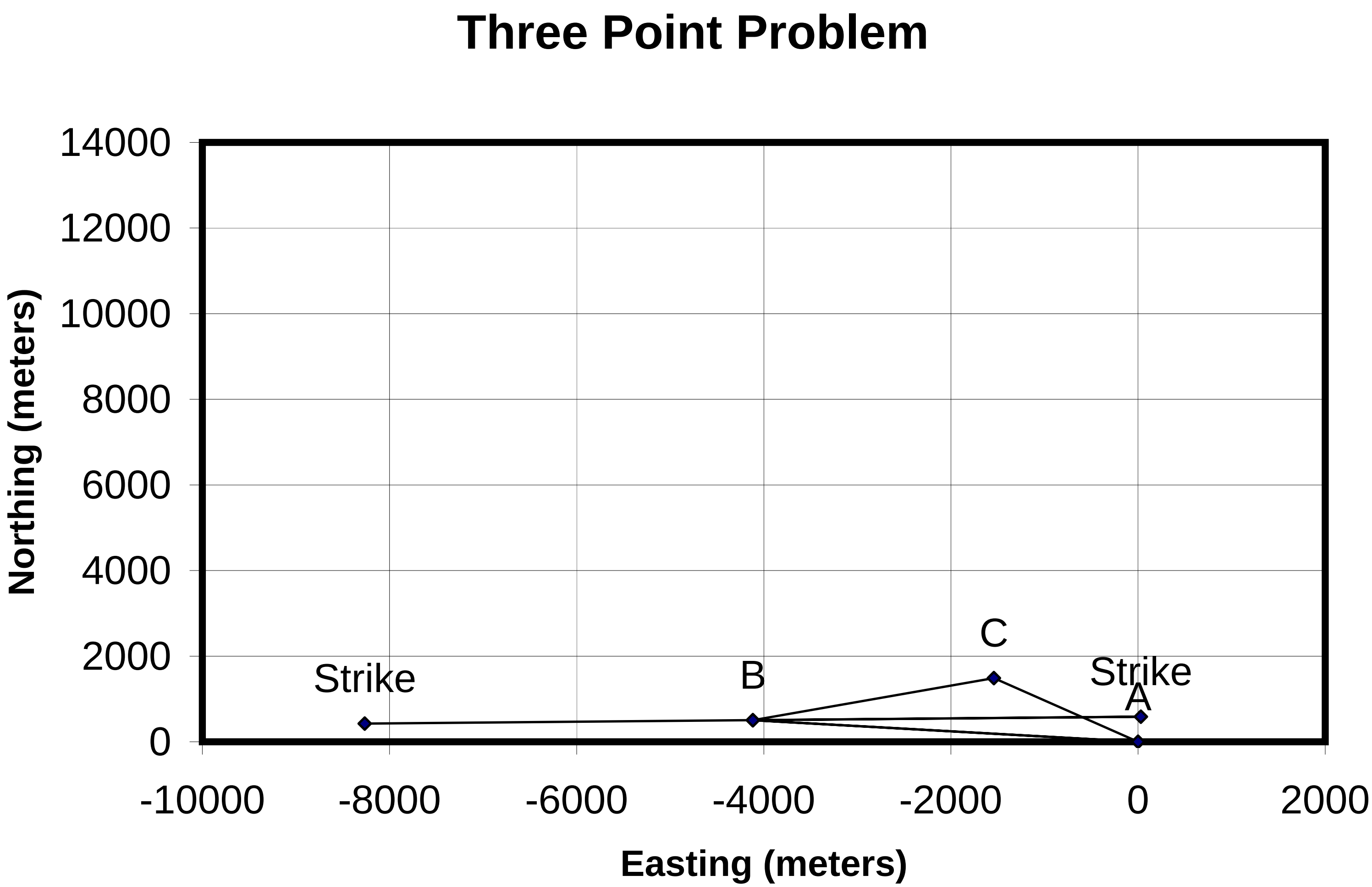

Three Point Problem
Northing (meters)
14000
12000
10000
8000
6000
4000
2000
0
Strike
B
C
Strike
A
-10000
-8000
-6000
-4000
-2000
0
2000
Easting (meters)

Accumulated 3-point problem solutions

Data Set	Quadrant App. Dip 1	Quadrant App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	App. dip 1 Cos(alpha)	Cos(beta)	Cos(gamma)	App. dip 2 Cos(alpha)	Cos(beta)	Cos(gamma)	Theta Angle(rad.)	Cross-product Cos(alpha)	Cos(beta)	Cos(gamma)	Pole Azimuth	Pole Plunge	Plane Strike & Dip
South Drive	N 83.00 W 3.45	N 46.00 W 16.87	277.000	3.450	314.000	16.870	-0.991	0.122	0.060	-0.688	0.665	0.290	0.676	0.008	-0.394	0.919	178.906	66.821	N 88.91 E 23.18 NW

Three-Point Problem Solver

Usage

This spreadsheet calculates the strike and true dip of a structural plane given three points on the plane that hav
known elevation and relative bearings and distances. Normally this is the case when a planar geologic contact ca
be traced over irregular topography. The three elevations are determined from topographic contours whereas the
bearings are measured with a protractor relative to geographic north. Distances between points are measured usin
the maps scale. Alternatively, contours of subsurface structures may be used to measure the required parameters, however
remember that this method assumes that the structure is planar! This spreadsheet may be used to determine the hydrauli
flow direction below the water table, which is the true dip direction.
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that you need to revert back to using elevation and distance measurements. The combined strike and dip attitude is displayed in green at lower rig
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Calculation Method

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vectors. In the upper portion of the spreadsheet the two vectors are converted into directional cosines, and then the cross-product is taken
The cross-product yields the attitude of the vector perpendicular to the plane that contains the original two vectors. This is analogous to th
problem of calculating a strike and dip of a plane from two given apparent dips, which are in fact simply two lines that lay within the plane
The rest of the spreadsheet converts the pole into a more familiar strike and true dip in quadrant format

Angular Precision	2	Angular Field Width:	5	H/V Conversion	1000.000	m/km	
Three Points with known elevations, relative bearings, and distances							
	Bearing	Distance	Elevation	Inclination	Vector attitude		
Point A	#N/A	#N/A	3717.000	#N/A	#N/A		
Point B	N 79.41 W	569.640	3689.000	2.814	N 79.41 W 2.81		
Point C	S 89.33 W	555.230	3716.000	0.103	S 89.33 W 0.10		
	Quadrant	Quadrant					
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	
Waylon	N 79.41 W 2.81	S 89.33 W 0.10	280.590	2.810	269.330	0.100	
App. dip 1			App. dip 2			Theta	
Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(radians)	
-0.982	0.184	0.049	-1.000	-0.012	0.002	0.202	
Lower Hemisphere	Cross-product			Pole	Pole	Strike of	True
Flag	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Plane	Dip
0.972	0.004	-0.236	0.972	178.918	76.363	N 88.92 E	13.64 NW
Hydraulic Flow	Gradient					Plane	
Azimuth	m/km					Strike & Dip	
358.92	242.611					N 88.92 E 13.64 NW	
Graphical Data							
X	Y	Point	Elev.				
0.000	0.000	A	3717.000				
-559.938	104.688	B	3689.000				
-555.192	-6.493	C	3716.000				
0.000	0.000	A					
-559.938	104.688	B					
9.601	115.447	Strike	N 88.92 E 13.64 NW				
-1129.476	93.930	Strike	N 88.92 E 13.64 NW				

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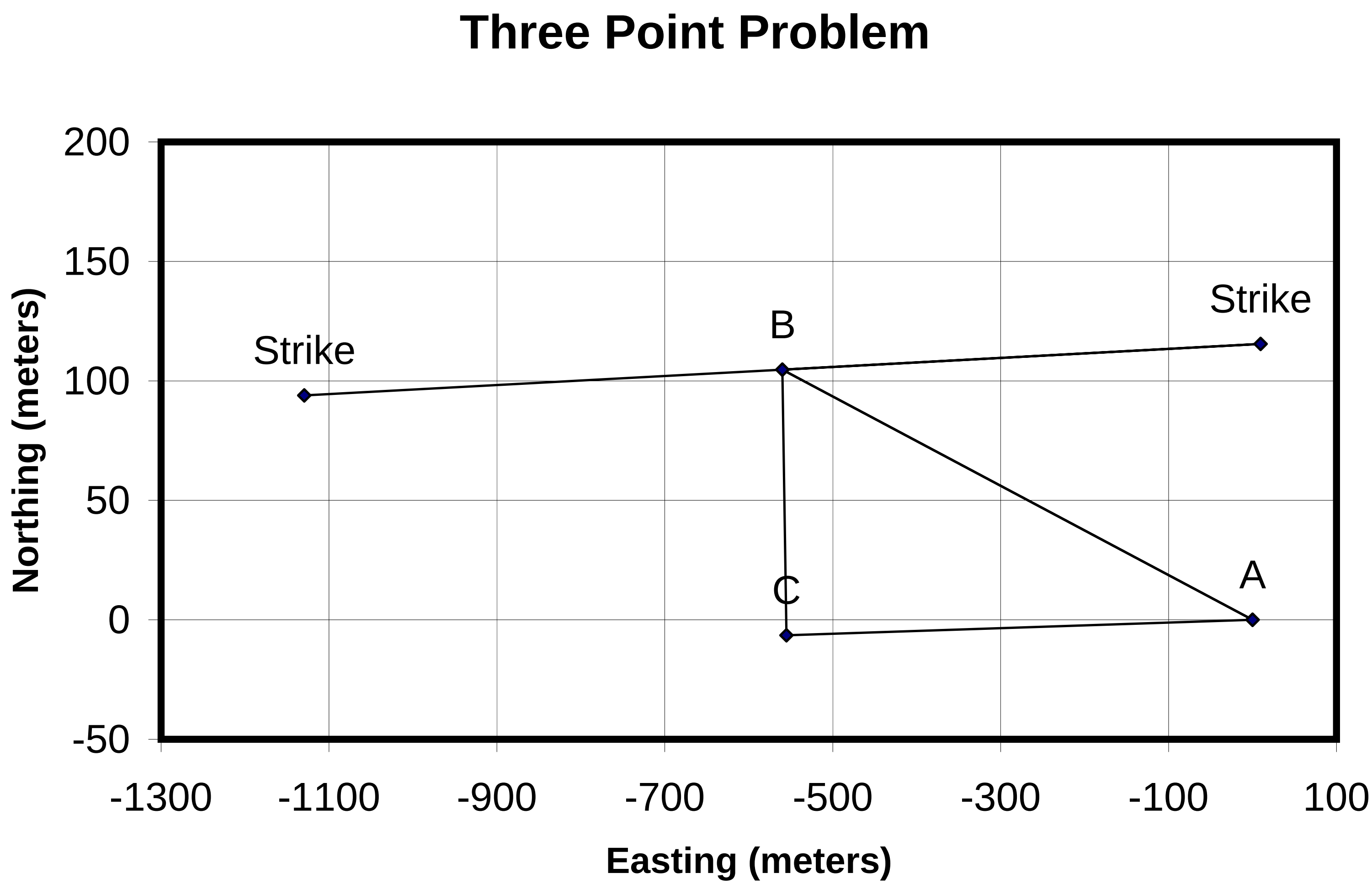
STEP 1: From the base map pick the higher elevation point and label it as "A". Label the intermediate and lowest elevation points "B" and "C"
Make sure that point A is the highest elevation, "B" is the intermediate, and that point "C" is the lowest elevation valu
STEP 2: Measure the relative bearings in quadrant format between "A>B" and "A>C". Also measure distances according to scale
Note that bearings must be entered according to the precision (I.e. decimal places) setting named "Angular Precision"
For example, a bearing measured as south 9.3 degrees west would be entered as "S 09.3 W" if angular precision = 1
STEP 3: Calculate the elevations of points A,B, and C with topographic contours or other means. Remember to convert drill depts to elevation
The worksheet assumes that units are equivalent among distance and elevation measurements. If not, convert to a consistent unit system at this ste
STEP 4: Enter the measurements from steps 1-3 into the cells in blue color below. The attitudes of the two vectors "A>B" and "A>C
will appear below the heading "Vector Attitude"
STEP 5: Read the strike and dip of the plane containing apparent dips 1 & 2 at the lower righ
of the spreadsheet. Answers appear in dark green color. Also calculated are the pole azimuth and plunge, the hydraulic flo
direction azimuth, and the gradient. The gradient horizontal vs. vertical scale conversion is controlled by the ce
right of the label "H/V conversion". Use 1000 for meters per kilometer, or 5280 for feet per mile gradient units
NOTE: Magenta and green cells contain formulae, therefore, they are by default "protected" so they are not accidentally currupted from inadvertent typin
Also note that by default the cells below App. dip 1 & App. dip 2 receive the calculated vector attitudes. If you already have the apparent d
attitudes you should over-type the formulae, however, make sure that you keep a copy of the original worksheet in the eve
that you nee to revert back to using elevation and distance measurements

Accumulation Macro

The accumulation macro is designed to copy the calculated results of the current 3-point problem to the sheet named
Accumulation". You can run the macro with the menu sequence "Tools > Macro > Macros", and then indicate th
name "AccumulateMacro" as the macro to run

Graphical Plot

The graphical diagram in the sheet "Map" displays a map view of the elements of the 3-point problem. The point
labelled "A", "B", and "C" correspond to the 3 control points in the problem. The line lablled "strike" indicates the
attitude of the strike line calculated by the algorithm. By default the X and Y axis are set to an "autoscale" tha
unfortunately will not generally set equivalent X and Y increments. After the elements of the problem are entered yo
should edit the X and Y scale settings in "manual" mode so that the grid on the graph appears as a collection o
squares" rather than rectangles. This means that the scaling is equivalent (or very close) on both axes, therefore
the graph is no longer distorted.



Three Point Problem
Northing (meters)
200
150
100
50
0
-50
-1300
-1100
-900
-700
-500
-300
-100
100
Easting (meters)
Strike
B
Strike
A
C

Accumulated 3-point problem solutions

	Quadrant	Quadrant					App. dip 1			App. dip 2			Theta	Cross-product			Pole	Pole	Plane
Data Set	App. Dip 1	App. Dip 2	Azimuth 1	Plunge 1	Azimuth 2	Plunge 2	Cos(alpha)	Cos(beta)	Cos(gamma)	Cos(alpha)	Cos(beta)	Cos(gamma)	Angle(rad.)	Cos(alpha)	Cos(beta)	Cos(gamma)	Azimuth	Plunge	Strike & Dip

APPENDIX E

GROUNDWATER DISCUSSION

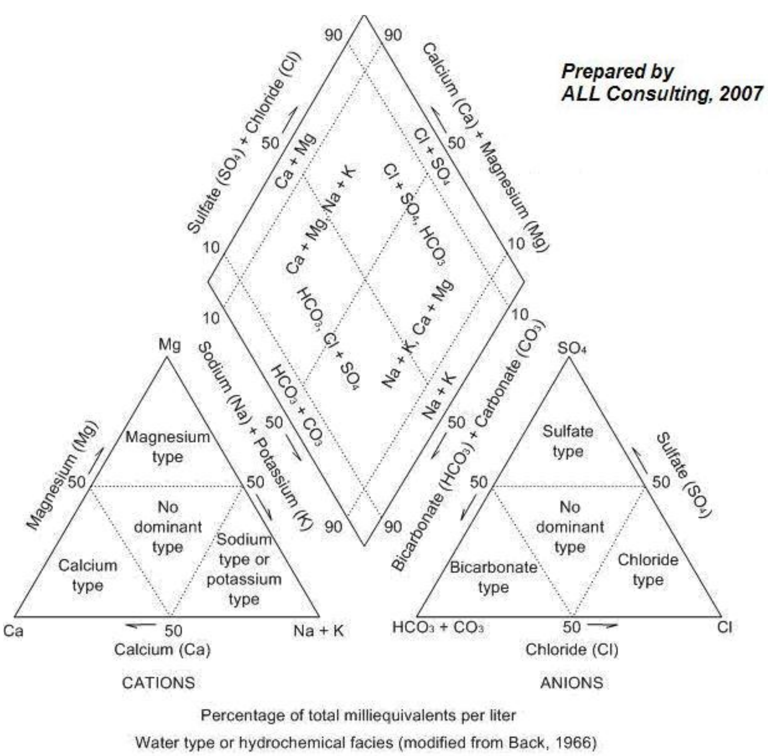
Observed Impacts to Groundwater Resulting from the Operation of CBNG Impoundments

ANALYSIS OF OBSERVED GROUNDWATER IMPACTS

Analysis of the groundwater chemistry of aquifers and of CBNG produced waters can be performed by evaluating posted analytical plots of a variety of chemical constituents present in the water. The analysis of total dissolved solids (TDS) and sodium adsorption ration (SAR) are commonly utilized to evaluate CBNG waters as a measure of suitability for agricultural uses including both livestock watering and for land application/irrigation. Other analysis performed to determine compliance with state required monitoring may focus on common and trace metals present in the waters for comparison to guidance levels. In terms of water origin analysis and evaluating water bedrock interactions, analysis is focused on the major dissolved ionic constituents including the cations of sodium, potassium, calcium, magnesium, and the anions of bicarbonate, chloride, sulfate, and carbonate.

Piper diagrams can be used to analyze the composition of most natural waters in the terms of the major cation and anion species (Hem, 1985). Figure 5-1 shows the basic layout of the Piper diagram separated into its respective water quality zones. For the groundwater analysis performed in this research, the geochemical analysis focused on evaluating water chemistry data

Figure 5-1: Generalized Piper Plot for Water Samples



in terms of the major cation and anion data as depicted on a Piper diagrams as well as the evaluation of TDS and SAR data for the samples.

Piper diagrams have long been used to study water chemistry. The two triangles at the bottom of the diagrams correspond to cations and anions, with each vertex representing 100 percent of a particular ion or groups of ions. Water quality is established by the diamond shaped area in which the two points plotted in the triangles are projected into the diamond and are plotted as a single point. Figure 5-1 shows how water quality characteristics are separated into the components of the Piper diagram. Interpretations of water quality can be made from the single point projected into the diamond. The piper plots allow for a visual comparison and thus an analysis of the quality of two or more groundwater samples. The piper plot does not however provide analysis for changes in concentrations of the major ions, other analytical methods are used to assess changes in overall ionic concentration including TDS analysis and ion plots.

Analysis of Geochemical Data from Impoundments located over Alluvial Aquifers along the Powder River of Wyoming

During the discussion of anticipated impacts associated with the infiltration of CBNG impoundment water one of the major conditions that was identified as influencing the changes in chemistry as the water infiltrates was the local geology. In an effort to in part account for this condition in this research the data analysis has been separated by aquifer type. This section presents the results of geochemical monitoring data gathered at infiltration impoundments which were sited and completed at locations over alluvial aquifers. The sites include the Jeff 3, Jeff 5, Jeff 6, Jeff 7, Arvada Phil's Pond, Arvada Cottonwood 8, Arvada Santiago, and Arvada Tietjen impoundments.

Marathon Impoundment Jeff 3 – East Arvada

CBNG produced water was initially discharged into the Jeff 3 impoundment after November 2001 and prior to January 2002. Before CBNG produced water was discharged into the impoundment, five monitoring wells were installed. The locations of these wells are shown in Figure 4-3. Background groundwater samples were collected in these well during July and November 2001 with samples from MW-1 collected in July and samples for MW-2, MW-3, MW-4, and MW-5 being collected in November. There were twenty-eight sampling events at MW-1 and a total of twenty-six sampling events occurring for the other four monitoring wells. These water quality samples represent background water quality for the shallow alluvial aquifer prior to any CBNG produced water had been discharge to the impoundment. Analysis of major ion groundwater chemistry is depicted per sampling event for each monitoring well in Figure 5-2 (Appendix G). For comparison purposes, the quality of the CBNG produced water discharged into the impoundment is also presented on Figure 5-2.

Figure 5-2 shows that the data for the Jeff 3 MW-1 and MW-2 plots between the data for Jeff MW-3, MW-4 and MW-5 toward that of CBNG produced water quality. The groundwater samples for MW-1 and MW-2 wells indicate a trend from a water with a mixed calcium/sodium cations and sulfate anion dominance to a water with a more sodium/bicarbonate dominance. This trend can be seen more clearly when the samples from the individual monitoring wells are plotted, (See Figure 5-3 and Figure 5-4, Appendix G).

The data in Figure 5-2 shows that the initial background water quality sample for MW-1 (top black circle) collected in 2001 is representative of the natural water chemistry present in an alluvial aquifer with a sodium/sulfate dominant water. Figure 5-2 also shows the quality of CBNG produced water that was discharged into the impoundment (green square); the sample was collected in April 2002 and represents typical CBNG produced water that is typically a sodium/bicarbonate water. Additionally Figure 5-2 shows plots for several simple mixing increments in which 25%, 50%, and 75% groundwater is mixed with the corresponding percentage of CBNG produced water. Groundwater quality data from Jeff 3 MW-1 collected after the initial background sample show a migration of anions away from the background sulfate dominated waters to a more carbonate dominant water. The plot of cations for these data in Figure 5-2 shows a trend which migrates away from the mixed calcium/sodium background values to a sodium dominant water.

The data in Figure 5-3 shows that the water quality samples for MW-2 collected in 2001 and 2002 are representative of the water chemistry present in an alluvial aquifer with sodium/sulfate dominant waters. Figure 5-3 also shows that the quality of the CBNG produced water that was discharged into the impoundment (green square) was a sodium/bicarbonate water. Additionally, Figure 5-3 shows plots for several simple mixing increments in which 25%, 50%, and 75% groundwater is mixed with the corresponding percentage of CBNG produced water. Groundwater quality data from Jeff 3 MW-2 collected after 2002 show a definite migration of anions away from the background sulfate dominated waters to a more carbonate dominant water. The plot of cations for these data in Figure 5-3 shows a trend which migrates from the mixed calcium/sodium background to sodium dominant water.

Jeff 3 Monitoring Well #1 Mixing – Figures 5-4 through 5-6

An evaluation of the time step sample data from the Jeff 3 MW-1 shows a mixing trend that beginning around October 2001 shifts the chemistry of the water away from the background water quality toward CBNG produced water quality. The transition mixing trend continues until around the August 2002 sampling event shown in yellow on Figure 5-4. Sampling events occurring after this date begin to reverse in direction away from the produced water quality.

Figure 5-5 shows the progression of water quality in MW-3 from January 2003 to the final sample taken in October 2004. Data collected in 2001 is also shown on the Figure 5-5 to illustrate the background water quality sampling results. The two plots (Figure 5-4 and Figure 5-5) appears to indicate that the mixing of infiltrated CBNG water with the native alluvial aquifer waters to be the factor causing the change in the MW-1 water quality samples over time.

Figure 5-6 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-1 over time. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The TDS line shows a drop of more than 3,500 mg/L in total dissolved solids between the first two sampling events. The plot shows that the mixing of the infiltrating CBNG water decreases the TDS of the alluvial groundwater by nearly 80% nearly instantly, while there is nearly a 50% increase in the SAR of the alluvial water that is drawn out over several years. The groundwater data from the Jeff 3 MW-1 indicates that CBNG produced water dominated the mixing that occurred within the alluvial aquifer near the Jeff 3 impoundment over the short term, but that the alluvial water quality started to recover in a relatively short time frame (<5 years).

Additional plots of the major cations and anions from the MW-1 samples are presented in Figures 5-7 and 5-8 (Appendix G). Figure 5-7 shows that sulfate and chloride decrease in a trend similar to that observed in the TDS concentrations. Sulfate decreased from more than 54 meq/L to a low of <5 meq/L over the duration of the sampling. The chloride concentrations over the same period decreased from 25 meq/L to a low of <2 meq/L. The smaller fluctuations that are observed in Figure 5-6 for TDS are also mimicked in the anion data for both sulfate and chloride. Conversely, the bicarbonate data shows an increase of approximately 50% occurs over the duration of sampling increasing from approximately 15 meq/L to more than 23 meq/L.

The concentrations of the three major cations (Calcium, Magnesium and Sodium) show a similar initial trend to that seen in TDS with a large decrease in all three ions (see Figure 5-8, Appendix G). Sodium decreased from 42 meq/L in the background sample to approximately 20 meq/L. Calcium decreased from 25 meq/L in the background sample to <5meq/L, while the magnesium concentration decreased from 13.5 meq/L in the background sample to <3 meq/.L. In each case there was some fluctuation in the concentration across the duration the sampling events (Figure 5-8). A comparison of the cation plots with the SAR data plotted in Figure 5-6 shows that the corresponding fluctuations in SAR are primarily a reflection of the changes in the sodium concentrations and fluctuations in sodium which occur over time. The increases in SAR seen during 2002 and 2003 are a result of decreases in calcium and magnesium while there are corresponding increases in sodium over the same time intervals (Figure 5-8, Appendix G). This data indicates that in addition to simple mixing of the existing alluvial groundwater and the infiltrating CBNG produced water, there appears to be an influx of fresh or meteoric water with sodium concentrations lower than the CBNG produced water.

Jeff 3 Monitoring Well #2 Mixing

An evaluation of the time step sample data from Jeff 3 MW-2 shows a mixing trend beginning around December 2001 which continues to shift the chemistry of the water away from the background level toward that of CBNG produced water quality. The transitional mixing trend continues until around the August 2002 sampling event shown in yellow on Figure 5-9. Figure 5-9 illustrates a mixing trend for MW-2 that does not become as dominant with respect to CBNG produced water with the water quality data staying above the 25% mixing point.

Figure 5-10 shows the progression of water quality samples from January 2003 to the final sample in October 2004. Data collected in 2001 is also shown in the plot to represent a background water quality value. The MW-2 sample data for this period show a similar mixing of infiltrated water with the alluvial aquifer as was seen at MW-1, however the MW-2 data shows the mixing to be less CBNG infiltrated water dominant and there is a more complete return of the groundwater chemistry toward background concentrations, see Figure 5-10. The groundwater data from the Jeff 3 MW-2 further illustrates that although mixing is occurring within the shallow groundwater the changes to water quality can return to background levels in a relatively short time frame (<5 years).

Figure 5-11 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-1 over time. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. A decrease in TDS of more than 1,000 mg/L occurs within the first year after the start of infiltration. The plot shows that the mixing of the infiltrating CBNG water decreases the TDS of the alluvial groundwater by more than 50% in a relatively short time frame, while the approximate 40% increase in the SAR of the alluvial water is drawn out over several years.

Additional plots of the major cations and anions from the MW-2 samples are presented in Figures 5-12 and 5-13 (Appendix G). Figure 5-12 shows that sulfate and chloride concentrations have a trend similar to that observed in the TDS concentrations. Sulfate decreased from more than 35 meq/L to a low of <10 meq/L then increased to more than

25 meq/L over the duration of the sampling. The chloride concentrations decreased from 12 meq/L to a low of <3 meq/L then increased to more than 8 meq/L over the duration of the sampling. The fluctuations that are observed in Figure 5-11 for TDS are also mimicked in the anion data for sulfate and chloride. Conversely, the bicarbonate data shows an increase of approximately 75% or 8 meq/L occurs over the duration of sampling increasing from approximately 11 meq/L to more than 18.5 meq/L.

Two of the three major cations (calcium, and magnesium) concentrations showed a similar initial trend to TDS with the large decrease in all three ions (Figure 5-13). Sodium decreased from 22.5 meq/L in the background sample to approximately 18 meq/L with some variation in calcium over the sample record. Calcium decreased from 15 meq/L in the background sample to <7 meq/L over the duration of the sampling events; there is some variation of approximately 3 to 4 meq/L after the April 2002 sampling events. Magnesium decreased from 10 meq/L in the background sample to <5 meq/L over the duration of the sampling events; there is some variation of approximately 2 to 3 meq/L. A comparison of the cation plots with the SAR data plotted in Figure 5-11 shows that the corresponding fluctuations in SAR are primarily a reflection of the changes in the sodium concentrations and the fluctuations in sodium which occur over time. This data indicates that in addition to simple mixing of the existing alluvial groundwater with infiltrating CBNG produced water, there also appears to be mixing of fresh or meteoric water with sodium concentrations lower than that of the CBNG produced water.

Monitoring Wells #3, 4, & 5

The three additional monitoring wells were installed and sampled at the Jeff 3 impoundment. None of these three monitoring wells show the same signs of mixing as was seen in MW-1 and MW-2. Sampling occurred at MW-3, MW-4, and MW-5 from 2001 to 2004 (Figure 5-14, 5-15, and 5-16). Review of the water quality for the wells MW-3 (Figure 5-14) and MW-5 (Figure 5-16) show little variation in the groundwater quality occurred over the course of the sampling events.

Data from MW-3 (Figure 5-14) is representative of a cross-gradient well which has not been influenced by the infiltrating impoundment water; the well is located cross-gradient approximately 390 feet from the impoundment. Groundwater quality represented by MW-3 is representative of the groundwater in the alluvium bordering the Powder River and shows a sodium/potassium sulfate water.

Data from MW-4 (Figure 5-15) is representative of a cross-gradient well which appears to be on the margin of influence by the infiltrating impoundment water. The well is located cross-gradient approximately 380 feet from the impoundment.

Data from MW-5 (Figure 5-16) is representative of a background well which should not be influenced by the infiltrating impoundment water because it is located up-gradient approximately 550 feet from the impoundment. Background groundwater quality represented by MW-5 shows a sodium/potassium sulfate water.

Figure 5-17 is plot of the SAR and TDS values for monitoring wells MW-3, MW-4, and MW-5. Groundwater quality represented by MW-4 appears to show a marginal mixing (up to approximately 25% CBNG infiltrated water) representative of the groundwater in the alluvium on the margins of the infiltrating water plume but still shows a sodium/potassium sulfate water. Figure 5-17 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-3, MW-4, and MW-5 over time. A decrease in TDS of more than 2,400 mg/L occurs in the last year of sampling at MW-4. The TDS data for monitoring well MW-3 increases by as much as 1,700 mg/L during 2002 then decreases to the levels shown in 2001. The TDS data for MW-5 shows approximately 600 mg/L of total variation over the sampling period. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The initial TDS values for MW-3, MW-4, and MW-5 are all greater than that of the CBNG water being discharged into the impoundment, therefore mixing of these two fluids should result in decreased TDS concentrations over time. Mixing of alluvial water and infiltrating water was indicated on the plots of data from MW-1 and MW-2, and showed decreases in TDS over time. The TDS data for MW-4 appears to show that mixing was occurring in the groundwater near this well in 2003 and 2004 as indicated by the approximate 50% decrease in TDS. The

SAR plots shown in Figure 5-17 for the three monitoring wells show little change occurs in the ratio of the three cations over the sampling interval.

Additional plots of the major cations and anions from the MW-3, MW-4, and MW-5 samples are presented in Figure 5-18 through 5-23 (Appendix G). The anion figures for each of the monitoring wells show that anion concentrations reflect similar trends to that observed in the TDS concentrations. Similarly, the fluctuations and changes in the TDS concentrations are also reflected in the cation plots presented in Appendix G.

Marathon Impoundment Jeff 5 – East Arvada

CBNG produced water was originally discharged into the Marathon Jeff 5 impoundment after November 2001 and prior to January 2002. Background groundwater samples were collected in July 2001 for MW-1 and November 2001 for MW-2, MW-3, MW-4, and MW-5. Before discharge of produced water from the impoundment took place, five monitoring wells were installed as shown in Figure 5-24. Initial groundwater sampling events took place in July 2001 for MW-1 and November 2001 for MW-2, MW-3, MW-4, and MW-5. Thirteen sampling events occurred between 2001 and November 2004. Water quality samples collected in 2001 represent background water quality in the shallow alluvial aquifer prior to any produced water discharge. Analysis of major ion groundwater chemistry is depicted per sampling event for each monitoring well in Figure 5-24. For comparison purposes, the quality of the CBNG produced water discharged into the impoundment is also presented on Figure 5-24.

Figure 5-24 shows the data for the Jeff 5 MW-1 plots between the data for Jeff 5 MW-2, MW-3, MW-4 and MW-5 toward that of CBNG produced water quality. The groundwater samples for the MW-1 well indicate a trend from water with a mixed Calcium/Sodium cation, Sulfate anion dominance to water with no dominant cation or anion. This trend can be seen more clearly when the samples from the individual monitoring wells are plotted, as indicated in Figure 5-25.

Monitoring Well # 1 Mixing

An evaluation of the time step sample data from Jeff 5 MW-1 shows a mixing trend beginning around October 2001 which continues to shift the chemistry of the water away from the background alluvial water quality toward CBNG produced water quality. The downward transition mixing trend continues until the October 2002 sampling event shown in yellow on Figure 5-26. Sampling events occurring after this date begin to reverse in direction away from the produced water quality. Figure 5-26 shows the beginning of the mixing trend in 2001 to water samples continuing the trend in 2002.

Figure 5-27 shows the progression of water quality from January 2003 to the final sample in October 2004. Data collected in 2001 is also shown on the Figure 5-27 to show the background water quality sampling results. The two plots (Figure 5-26 and Figure 5-27) appear to indicate the mixing of infiltrated CBNG water with the alluvial aquifer to be the factor causing the change in the MW-1 water quality samples. Figure 5-28 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-1 over time. The TDS line fluctuates over time varying as much as 1,000 mg/L over all the sampling events. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The plot shows that the mixing of the infiltrating CBNG water decreases the TDS of the alluvial groundwater by as much as 25%, while there is more than a 200% increase in the SAR of the alluvial water. The groundwater data from the Jeff 5 MW-1 indicates that CBNG produced water mixing occurred within the alluvial aquifer with the Jeff 5 impoundment over the short term, but that the alluvial water quality has recovered to more than 75% groundwater in a relatively short time frame (<5 years).

Additional plots of the major cations and anions from the MW-1 samples are presented in Figures 5-30 and 5-31 (Appendix G). Figure 5-30 shows that the sulfate concentration fluctuates in a trend similar to that observed in the TDS concentrations. Sulfate decreased from approximately 25 meq/L to a low of 10 meq/L then increased to over 30 meq/L over the duration of the sampling. The chloride concentrations decreased slightly from 5 meq/L to a low of <2 meq/L then increased back to 5 meq/L over the duration of the sampling. Conversely, the bicarbonate data shows an increase of approximately 300% or 15 meq/L occurs over the duration of sampling with values increasing from approximately 5 meq/L to more than 20 meq/L before returning to approximately 10 meq/L at the last sampling event.

Two of the three major cations (Calcium and Magnesium) concentrations showed a similar initial trend to TDS with variations seen reflected in the plots for the two ions (Figure 5-31, Appendix G). Sodium increased from 13 meq/L in the background sample to approximately 25 meq/L before decreasing to 17 meq/L with some variation in sodium data over the sample record. Calcium started at 12 meq/L in the background sample and decreased to <8 meq/L before returning to 12 meq/L. Magnesium started at 5 meq/L in the background sample and decreased to <3 meq/L before returning to 5 meq/L over the duration of the sampling events there is some variation of approximately 2 meq/L. A comparison of the cation plots with the SAR data plotted in Figure 5-29 shows that the corresponding fluctuations in SAR are primarily a reflection of the changes in the sodium concentrations and the fluctuations in sodium which occur over time. The increases in SAR seen during 2002 and 2003 are a result of decreases in calcium and magnesium while there are corresponding increases in Sodium over the same time intervals (see plots in Appendix D). This data indicates that in addition to simple mixing of the existing alluvial groundwater and the infiltrating CBNG produced water, there also appears to be mixing of fresh or meteoric water with sodium concentrations lower than CBNG produced water.

Monitoring Wells #2, 3, 4, & 5

The four additional monitoring wells drilled at the Jeff 5 impoundment are MW-2 (Figure 5-32), MW-3 (Figure 5-33), MW-4 (Figure 5-34), and MW-5 (Figure 5-35), which were sampled between 2001 to 2004 in a manner similar to MW-1. The data from these four monitoring wells did not show signs of mixing between infiltrating CNNG produced water and alluvial groundwater. The data for each of the monitoring wells does show some variation from sample to sample, but the overall data seems to be indicative of a pattern with little migration in water character.

Figure 5-36 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-2, MW-3, MW-4, and MW-5 over time. A decrease in TDS of more than 1,200 mg/L occurs at MW-2, while the TDS data for monitoring well MW-3 shows increases by as much as 400 mg/L. The TDS data for both MW-4 and MW-5 shows approximately 500 mg/L of total variation over the sampling period. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The initial TDS values for MW-2, MW-3, MW-4, and MW-5 are all greater than that of the CBNG water being discharged into the impoundment, therefore mixing of these two fluids should result in decreased TDS concentrations over time. The TDS and SAR plots shown in Figure 5-36 for the four monitoring wells at the Jeff 5 impoundment show only minor changes in the water chemistry over the sampling interval, with less than one unit of SAR variation in three of the wells (MW-3, MW-4, and MW-5), and approximately two units of SAR variation in the other well.

Additional plots of the major cations and anions from the MW-2, MW-3, MW-4, and MW-5 samples are presented in Figures 5-37 through 5-44 (Appendix G). The anion figures for each of the monitoring wells show that anion concentrations reflect similar trends to that observed in the TDS concentrations. Similarly, the fluctuations and changes in the TDS concentrations are also reflected in the cation plots presented in Appendix G.

Marathon Impoundment Jeff 6 – East Arvada

CBNG produced water was originally discharged into the Marathon Jeff 6 impoundment after October 2001 and prior to January 2002. Background groundwater samples were collected in July 2001 for MW-1. The monitoring well Jeff 6 MW-1 was installed the previous summer in 2001, with the first groundwater sampling event occurring in July 2001. Groundwater monitoring data has been collected from Jeff 6 MW-1 from July 2001 to November 2004 with thirteen sampling events occurring over that timeframe. Water quality samples collected in 2001 represent background water quality in the shallow alluvial aquifer prior to any produced water discharge. Analysis of major ion groundwater chemistry is depicted per sampling event for each monitoring well in Figure 5-45. For comparison purposes, the quality of the CBNG produced water discharged into the impoundment is also presented on Figure 5-45.

Figure 5-45 shows the background water quality to represent a sodium/potassium sulfate water type. Figure 5-45 shows that the CBNG produced water (green square) that is discharged into the impoundment is representative of sodium bicarbonate water. The data from Jeff 6 MW-1 presented in Figure 5-45 shows the change in shallow alluvial groundwater quality that occurred over the sampling interval. Figure 5-45 shows the mixing transition over time as the infiltrating CBNG water mixes with the shallow alluvium water. Figure 5-45 shows the anion migration from sulfate dominated waters in the background sample to a mixed sulfate/carbonate water type.

The downward mixing trend shown on Figure 5-46 occurs from July 2001 to May 2003; around the May 2003 sampling event, the trend appears to reverse as subsequent samples become more sulfate rich. Figure 5-47 shows the evolution of water quality from July 2003 to the date of the final sample in November 2004. The transition from July 2003 to November 2004 could be the result of decreasing infiltration or an influx of alluvial water. The groundwater data from the Jeff 6 MW-1 monitoring well shows that mixing was occurring within the shallow groundwater but the water quality started to recover in a relatively short time frame (<5 years).

Figure 5-48 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-1 over time. A decrease in TDS of more than 2000 mg/L occurs at MW-1 between July 2001 and January 2002. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The TDS values for MW-1 from the January 2002 sample until sampling ended in 2004 are all within 500 mg/L of the CBNG water discharged to the impoundment; this low TDS concentration could be indicative of the mixing of two waters with CBNG water dominating the volume of water being mixed. The SAR plots shown in Figure 5-48 show a similar CBNG water dominance in the mixing as is reflected by the increased SAR values in the samples collected after January 2002.

Additional plots of the major cations and anions from the MW-1 samples are presented in Figure 5-49 and 5-50 (Appendix D). Figure 5-49 shows that sulfate exhibits a trend similar to that observed in the TDS concentrations. Sulfate levels decreased from a high of approximately 57 meq/L to a low of 8 meq/L then fluctuated around 5 meq/L over the duration of the sampling. The chloride concentrations seemed to be constant at about 1 meq/L with less than 0.5 meq/L of variation over the duration of the sampling. Conversely, the bicarbonate data shows an increase of approximately 200% or 13 meq/L occurs over the duration of sampling increasing from approximately 6 meq/L to approximately 20 meq/L before returning to approximately 18 meq/L at the last sampling event.

The three major cations (Calcium, Magnesium, and Sodium) concentrations showed an initial trend similar to TDS with variations reflected in the plots for the two ions (Figure 5-50, Appendix G). Sodium decreased from 33 meq/L in the background sample to approximately 20 meq/L before increasing to 22 meq/L with some fluctuation in sodium data over the sample record. Calcium started at 12 meq/L in the background sample and decreased to < 3 meq/L with minor fluctuation of approximately 1 meq/L for the remainder of the sampling events. Magnesium started at 8 meq/L in the background sample and decreased to <3 meq/L; for the duration of the sampling events there is some variation of approximately 0.5 meq/L. A comparison of the cation plots with the SAR data plotted in Figure 5-48 shows that the corresponding fluctuations in SAR are primarily a reflection of the changes in the sodium concentrations and the fluctuations in sodium which occur over time. The increases in SAR seen during 2002 and 2003 appear to result from decreases in calcium and magnesium while there are corresponding increases in sodium over the same time intervals (Appendix G). This data indicates that in addition to simple mixing of the existing alluvial groundwater and the infiltrating CBNG produced water, there also appears to be mixing of fresh or meteoric water with sodium concentrations lower than CBNG produced water.

Marathon Impoundment Jeff 7 – East Arvada

CBNG produced water was originally discharged into the Marathon Jeff 7 impoundment between November 2001 and January 2002. Before discharge of produced water from the impoundment took place, four monitoring wells were installed (see Figure 4-3). Initial groundwater sampling events took place in July 2001 for MW-1 and November 2001 for MW-2 with a total of twenty-seven sampling events and during November 2001 for MW-3, and MW-4, with twenty-six sampling events occurring. Water quality samples collected in 2001 represent background water quality for the shallow alluvial aquifer prior to any produced water discharge. The Piper diagram shown in Figure 5-51 exhibits sampling results for each of the monitoring wells and the CBNG produced water discharged into the impoundment.

The data for the Jeff 7 MW-4, plotted on Figure 5-52, shows the start of a mixing trend toward that of CBNG produced water quality similar to trends seen in previously discussed impoundments. The data shows that background water quality samples (black circles) were collected in 2001 and represent the water quality of alluvial groundwater. The groundwater data shows background groundwater quality to be representative of sodium/potassium sulfate water. Sampling of the CBNG produced water quality (green square) occurred in April 2002 and is a sodium bicarbonate water type. Migration of anions of the background sulfate dominance to a water with a more sodium/bicarbonate dominance is apparent in Figure 5-52. This trend can be seen more clearly when the samples from MW-4 are plotted separately, see Figure 5-53 and 5-54. Figure 5-52 also shows several simple mixing increments in which 25%, 50%, and 75% groundwater is mixed with the corresponding percentage of CBNG produced water. Samples of groundwater from Jeff 7 MW-4 collected after the initial background sample show a migration of anions away from the background sulfate dominated waters to a more carbonate dominant water. The plot also shows a migration trend of cations away from the mixed calcium/sodium background toward a sodium water.

Monitoring Well #4 Mixing

An evaluation of the time step sample data from Jeff 7 MW-4 shows a mixing trend beginning around October 2001 which continues to shift the chemistry of the water away from the background alluvial water quality toward CBNG produced water quality. Figure 5-54 shows the beginning of the mixing trend in 2003 with water samples continuing the trend through the last sampling event in 2004. Figure 5-55 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples collected from MW-4 over time. The TDS line shows little migration from November 2001 until the June 2003 the sampling event. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The plot shows that the mixing of the infiltrating CBNG water decreases the TDS of the alluvial groundwater by as much as 50%.

Additional plots of the major cations and anions from the MW-4 samples are presented in Figures 5-56 and 5-57 (Appendix G). Figure 5-56 shows that the sulfate concentrations trend in the same observed pattern as the TDS concentrations. Sulfate levels decreased from approximately 55 meq/L to a low of 20 meq/L over the duration of the sampling. The chloride concentrations seemed to be similar to sulfate but at a reduced scale over the duration of the sampling. Conversely, the bicarbonate data shows an increase of approximately 100% or 10 meq/L occurs over the duration of sampling increasing from approximately 11 meq/L to approximately 21 meq/L at the last sampling event.

The three major cations (Calcium, Magnesium, and Sodium) concentrations showed a similar initial trend to TDS with variations seen in the plots for the three ions (Figure 5-57, Appendix G). Sodium levels decreased from 33 meq/L in the background sample to approximately 22 meq/L with fluctuation in sodium data over the sample record. Calcium concentrations started at 27 meq/L in the background sample and decreased to 13 meq/L with fluctuations of approximately 4 meq/L over the course of the sample record. The initial Magnesium concentration was at 15 meq/L in the background sample and decreased to <8 meq/L, during the duration of the sampling events with some variation of approximately 1.5 meq/L. A comparison of the cation plot (Figure 5-57) with the SAR data plotted in Figure 5-55 shows the corresponding fluctuations in cation concentrations are also displayed in the SAR plot. The fluctuations seen in SAR's data points during the duration of the sampling rounds are corresponding to changes seen in all three cations over the same time intervals.

Jeff 7 MW-1, MW-2, and MW-3

The three additional monitoring wells drilled at the Jeff 7 impoundment did not show signs of mixing. Sampling for MW-1, MW-2, and MW-3 occurred from 2001 to 2004, and was similar to that for MW-4 (Figures 5-58, 5-59, and 5-60). Water quality for the three remaining wells did not present the same downward trend which could mean infiltrating water from the impoundment has not migrated laterally into the alluvial aquifer. Data shows background groundwater quality to represent sodium/potassium sulfate water. Data collected in the subsequent years did not show the infiltrating impoundment CBNG produced water to be affecting groundwater in any significant way, as can be seen by the grouping of the data for these wells on the appropriate Piper diagram. Figures 5-58, 5-59, and 5-60 show the Piper diagrams for the Jeff 7 MW-1, MW-2 and MW-3, respectively.

Figure 5-61 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-1, MW-2, and MW-3 over time. The TDS data for MW-1 shows approximately 700 mg/L of total variation over the sampling period. A decrease in TDS of more than 1,200 mg/L occurs at MW-2. The TDS data for monitoring well MW-3 increases by as much as 1,200 mg/L. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The initial TDS values for MW-1, MW-2, and MW-3 were all greater than that of the CBNG water being discharged into the impoundment, therefore mixing of these two fluids should result in decreased TDS concentrations over time. The TDS and SAR plots presented in Figure 5-61 for the three monitoring wells at the Jeff 7 impoundment show minor changes in the water chemistry occurred over the sampling interval. The plot shows there was less than two units of SAR variation at the three monitoring wells (MW-1, MW-2, and MW-3).

Additional plots of the major cations and anions from the MW-1, MW-2, and MW-3 samples are presented in Figures 5-62 through 5-67 (Appendix G). The anion figures for each of the monitoring wells show that anion concentrations reflect similar trends to that observed in the TDS concentrations. Similarly, the fluctuations and changes in the SAR concentrations are also reflected in the cation plots presented in Appendix G.

Marathon Impoundment Phil's Pond – West Arvada

CBNG produced water was originally discharged into the Marathon Phil's Pond impoundment after November 2001 and prior to January 2002. Before CBNG produced water was discharged into the impoundment, one groundwater monitoring well was installed. Background groundwater samples were collected in April 2001 and October 2001. Water quality samples collected in 2001 represent background water quality in the shallow alluvial aquifer prior to any produced water discharge. Samples of the monitoring well were taken from April 2001 to November 2004, with a total of fifteen sampling events. The Piper diagram showing sampling events for each well and the CBNG produced water discharged into the impoundment is shown in Figure 5-68.

Monitoring Well #1Mixing

An evaluation of the time step sample data from Phil's Pond MW-1 shows a mixing trend beginning around December 2001 which continues to shift the chemistry of the water away from the background water quality toward that of CBNG produced water quality. As shown on Figure 5-68 the transition mixing trend continues for the entire sampling record. This plot also shows that the mixing trend at MW-1 does not become as CBNG produced water dominant as some of the previously analyzed impoundments, with the sample data staying above the 50% mixing point. The mixing trend is not as readily apparent in the early years of discharge to the impoundment in comparison to the data from the other impoundments such as the Jeff 3 or Jeff 6 data. Figure 5-69 shows the 2001-2002 data for MW-1, with a trend which appears to be reflective of the scatter seen on some of the background wells. A slight shift away from the dominant sulfate to bicarbonate anion can be observed from the diagram. However, the geochemical change shown in Figure 5-69 does not appear to reflect mixing with a water of a different chemical signature such as that reflected in the CBNG produced water data point. It is not until the data from the 2003-2004 sampling events is plotted and reviewed, Figure 5-70, that the mixing trend in the alluvial water under Phil's Pond is apparent. The Phil's Pond data does not appear to show the end point of the mixing timeline, additional sampling would be needed to determine if additional mixing is occurring or if the alluvial groundwater will return to its background chemistry. Based on the data collected for the Phil's Pond MW-1, it is not possible to determine if the aquifer would recover to background quality in a relatively short time frame (<5 years), as has been observed for the other impoundments in the area.

Figure 5-71 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-1 over time. The TDS data plotted shows a 1,600 mg/L decrease over the duration of the sampling events. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The plot shows that the mixing of the infiltrating CBNG water decreases the TDS and increases the SAR of the alluvial groundwater.

Additional plots of the major cations and anions from the MW-1 samples are presented in Figures 5-72 and 5-73 (Appendix G). Figure 5-72 shows that sulfate concentration trends dominate the observed pattern seen in the TDS concentrations. Sulfate levels decreased from approximately 55 meq/L to a low of 20 meq/L over the duration of the sampling. The chloride concentrations seemed to be relatively consistent at approximately 1 meq/L over the duration of the sampling. Conversely, the bicarbonate data shows an increase of approximately 100% or 9 meq/L occurs over the duration of sampling increasing from approximately 9 meq/L to approximately 18 meq/L at the last sampling event.

The three major cations (Calcium, Magnesium, and Sodium) concentrations showed a similar initial trend then diverged in 2002 with variations seen in the plots for the three ions (Figure 5-73, Appendix G). Sodium increased from 23 meq/L in the background sample to approximately 29 meq/L with fluctuation in sodium data over the sample record. Calcium concentrations started at 25.5 meq/L in the background sample and decreased to 19 meq/L with fluctuations of approximately 5 meq/L over the course of the sample record. The initial magnesium concentration was 24 meq/L in the background sample and decreased to 17 meq/L during the duration of the sampling events with some variation of approximately 5 meq/L. A comparison of the cation plots with the SAR data plotted in Figure 5-71 shows the corresponding fluctuations and changes in the sodium concentrations are reflected in the SAR's data. The increases seen in SAR during the duration of the sampling rounds are corresponding to changes seen in all three cations over the same time intervals (see plots in Appendix G).

Marathon Impoundment Candida 2 – West Arvada

CBNG produced water was initially discharged into the Candida 2 impoundment after June 2001 and prior to October 2001. Before CBNG produced water was discharged into the impoundment, one monitoring well was installed. Background groundwater samples were collected in April and June 2001 for MW-1. There were a total of 15 sampling events at MW-1. The water quality samples collected in 2001 represent background water quality for the shallow alluvial aquifer prior to any CBNG produced water being discharge. Analysis of major ion groundwater chemistry is depicted per sampling event for each monitoring well at the Candida 2 site in Figure 5-74. For comparison purposes, the water chemistry of the CBNG produced water discharged into the impoundment is also presented on Figure 5-74.

Monitoring Well #1Mixing

An evaluation of the time step sample data from Candida 2 MW-1 shows a mixing trend beginning in early 2001 which resulted in a shifting of the chemistry of the water away from that of background groundwater quality toward the quality of the CBNG produced water discharged into the impoundment. The mixing trend appears to continue for the entire sampling record, see Figure 5-74. Figure 5-75 shows that the mixing trend at MW-1 is nearly 50% CBNG produced water by the October 2001 sampling event, the first sample after produced water was discharged to the impoundment. The 2001-2002 data for MW-1 shows the mixing transition from 50% to approximately 75% CBNG water chemistry. Figure 5-76 reflects the further migration toward CBNG infiltration water chemistry with greater than 80% CBNG water chemistry present in the 2004 samples.

The Candida 2 data does not appear to show the end point of the mixing timeline. Additional sampling would be needed to determine if additional mixing is occurring or if the alluvial groundwater will return to its background chemistry. Based on the data collected for the Candida 2 MW-1, it is not possible to determine if the aquifer would recover to background quality in a relatively short time frame (<5 years), as has been observed for the other impoundments in the area.

Figure 5-77 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-1 over time. The TDS data plotted shows a 2,000 mg/L decrease over the duration of the sampling events, with TDS levels below the level of the CBNG water discharged into the impoundment during two of the sampling events. The 1,810 mg/L plotted on the chart that represents the TDS concentration of the CBNG water that was discharged into the impoundment. The plot shows that the mixing of the infiltrating CBNG water decreases the TDS. The SAR data plotted on Figure 5-77 shows that the mixing of the CBNG water resulted in a 100% increase of SAR values for the alluvial groundwater.

Additional plots of the major cations and anions from the MW-1 samples are presented in Figures 5-78 and 5-79 (Appendix G). Figure 5-78 shows that sulfate concentration trends dominate the observed pattern seen in the TDS concentrations. Sulfate levels decreased from approximately 39 meq/L to a low of <5 meq/L over the duration of the sampling. The chloride concentrations seemed to decrease from approximately 9 meq/L to less than 2 meq/L over the duration of the sampling. Conversely, the bicarbonate data shows an increase of approximately 300% or 19 meq/L occurs over the duration of sampling increasing from approximately 7 meq/L to approximately 26 meq/L at the last sampling event. There appears to be some mixing with meteoric water as the TDS concentrations of the mixed waters decrease below TDS concentrations for CBNG produced water in 2004.

The combined trends of the three major cations (Calcium, Magnesium, and Sodium) concentrations can be seen in the TDS data (Figure 5-79, Appendix G). Sodium fluctuated from 18 meq/L to approximately 33 meq/L with fluctuations in sodium data over the sample record trending in a similar pattern to TDS. Calcium concentrations started at 17 meq/L in the background sample and decreased to 5 meq/L with fluctuations of approximately 0.5 meq/L over the course of the sample record. The initial Magnesium concentration was at 8 meq/L in the background sample and decreased to 3 meq/L for the duration of the sampling events with some variations of approximately 0.5 meq/L. A comparison of the cation plots with the SAR data plotted in Figure 5-77 shows the corresponding fluctuations in the sodium concentrations are reflected in the SAR's data. The increases and decreases seen in SAR during the duration of the sampling rounds correspond to changes seen in all three cations over the same time intervals (see plots in Appendix G).

Marathon Impoundment Santiago 3 – West Arvada

CBNG produced water was initially discharged into the Santiago 3 impoundment after June 2001 and prior to October 2001. Before CBNG produced water was discharged into the impoundment, one monitoring well was installed. As shown in Figure 5-80 background groundwater samples were collected in April and June 2001 for MW-1. There were a total of 15 sampling events at MW-1. The water quality samples collected in 2001 represent background water quality for the shallow alluvial aquifer prior to any CBNG produced water being discharge. Analysis of major ion groundwater chemistry is depicted per sampling event for each monitoring well in Figure 5-80. For comparison purposes, the water chemistry of the CBNG produced water discharged into the impoundment is also presented on Figure 5-80.

Monitoring Well #1 Mixing

An evaluation of the time step sample data from Santiago 3 MW-1 shows a mixing trend beginning in early 2001 which resulted in a shifting of the chemistry of the water away from that of background water quality toward the quality of the CBNG produced water discharged into the impoundment. The mixing trend appears to continue into 2003, see Figure 5-81. Figure 5-81 shows that the mixing trend at MW-1 is less than 75% alluvial water by the October 2001 sampling event, the first sample taken after produced water was discharged to the impoundment. Figure 5-81 also shows the 2001-2002 data for MW-1, which shows the mixing transition from 75% alluvial water to approximately 50% alluvial water chemistry. Figure 5-82 reflects the further migration toward the CBNG infiltration water chemistry with less than 25% alluvial water chemistry present in the July 2003 sample. The data in Figure 5-82 does show the start of the recovery of the alluvial water beginning with the late 2003 and 2004 data. In these sampling events the water chemistry is observed to be changing from less than 25% alluvial water to more than 50% alluvial water by the time of the last sample.

Figure 5-83 shows the changes that occur to the TDS and SAR concentrations in the groundwater samples from MW-1 over time. The TDS data plotted shows a 3,000 mg/L decrease over the duration of the sampling events. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The plot shows that the mixing of the infiltrating CBNG water decreased the TDS. The SAR data plotted on Figure 5-83 shows that the mixing of the CBNG water resulted in a 3 unit increase of SAR in the alluvial groundwater.

Additional plots of the major cations and anions from the MW-1 samples are presented in Figures 5-84 and 5-85 (Appendix G). Figure 5-84 shows that sulfate concentration trends dominate the observed pattern seen in the TDS concentrations. Sulfate level decreased from approximately 78 meq/L to a low of 14 meq/L before increasing to 38 meq/L at the final sampling event. The chloride concentrations decreased from approximately 4 meq/L to less than 2 meq/L over the duration of the sampling. Conversely, the bicarbonate data shows an increase of approximately 200% or 17 meq/L occurs over the duration of sampling increasing from approximately 12 meq/L to approximately 29 meq/L at the last sampling event.

The combined trends of the three major cations (Calcium, Magnesium, and Sodium) concentrations can be seen in the TDS data (Figure 5-85, Appendix G). Sodium fluctuated from 33 meq/L to approximately 27 meq/L with fluctuations in sodium data over the sample record trending in a similar pattern to TDS. Calcium concentrations started at 22 meq/L in the background sample and decreased to 8 meq/L with fluctuations over the course of the sample record. Magnesium concentrations started at 27 meq/L in the background sample and decreased to 7 meq/L for the duration of the sampling events with some variation in concentrations. A comparison of the cation plots with the SAR's data plotted in Figure 5-83 shows the corresponding fluctuations in the sodium concentrations are reflected in the SAR data. The increases and decreases seen in SAR during the duration of the sampling rounds correspond to changes seen in all three cations over the same time intervals (see plots in Appendix G).

Marathon Impoundment Cottonwood 8 – West Arvada

CBNG produced water was initially discharged into the Cottonwood 8 impoundment after June 2001 and prior to October 2001. Before CBNG produced water was discharged into the impoundment, one monitoring well was installed as shown in Figure 5-86. Background groundwater samples were collected in April and June 2001 for MW-1. There were a total of fourteen sampling events at MW-1. The water quality samples collected in 2001 represent background water quality for the shallow alluvial aquifer prior to any CBNG produced water being discharge. Analysis of major ion groundwater chemistry is depicted per sampling event for each monitoring well in Figure 5-86. For comparison purposes, the water chemistry of the CBNG produced water discharged into the impoundment is also presented on Figure 5-86.

Figure 5-87 shows the TDS and SAR concentrations in the groundwater samples from MW-1 over time. The TDS data plotted shows a 900 mg/L decrease over the duration of the sampling events. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The plot does not show evidence of mixing of infiltrating CBNG water in the TDS data. The SAR data plotted on Figure 5-87 shows only a 1.5 unit variation in SAR in the alluvial groundwater over the sample events.

Additional plots of the major cations and anions from the MW-1 samples are presented in Figure 5-88 and 5-89 (Appendix G). Figure shows that sulfate concentration trends dominate the observed pattern seen in the TDS concentrations. Sulfate decreased from approximately 95 meq/L to a low of 84 meq/L before increasing to 88 meq/L at the final sampling event. The chloride concentrations decreased from approximately 4 meq/L to less than 2 meq/L over the duration of the sampling. Conversely, the bicarbonate data shows a constant concentration of approximately 8 meq/L over the duration of the sampling.

The combined trends of the three major cations (Calcium, Magnesium, and Sodium) concentrations can be seen in the TDS data (Figure 5-89, Appendix G). Sodium fluctuated from 33 meq/L to approximately 42 meq/L. Calcium began at 22 meq/L in the background sample and fluctuated around 20 meq/L over the course of the sample record. Magnesium started at 30 meq/L in the background sample and fluctuated around 30 meq/L over the course of the sample record. A comparison of the cation plots with the SAR's data plotted in Figure 5-87 shows the corresponding fluctuations in the sodium concentrations were not reflected in the SAR data (see plots in Appendix G).

Marathon Impoundment Tietjen – West Arvada

CBNG produced water was initially discharged into the Tietjen impoundment after June 2001 and prior to October 2001. Before CBNG produced water was discharged into the impoundment, two monitoring wells were installed as shown in Figure 4-3. Background groundwater samples were collected in April and June 2001 for MW-1 and MW-2. There were a total of sixteen sampling events at MW-1 and MW-2. The water quality samples collected in 2001 represent background water quality for the shallow alluvial aquifer prior to any CBNG produced water having been discharge. Analysis of major ion groundwater chemistry is depicted per sampling event for each monitoring well in Figure 5-90 and 5-91. For comparison purposes, the quality of the CBNG produced water discharged into the impoundment is also presented on Figure 5-90 and 5-91.

Tietjen MW-1, and MW-2

The two monitoring wells drilled at the Tietjen impoundment did not show signs of mixing. Sampling for MW-1 and MW-2 occurred from April 2001 to November 2004. Water quality for the two wells did not present the mixing trend which has been seen at other alluvial impoundments; this could mean infiltrating water from the impoundment has not migrated laterally into the alluvial aquifer near these wells. Data shows background groundwater quality to represent sodium/potassium sulfate water. As can be seen by the grouping of data points on Figures 5-90 and 5-91 data collected in the subsequent years did not show that CBNG produced water infiltrating from this impoundment had affected groundwater in any significant way.

Figure 5-92 shows the TDS and SAR concentrations in the groundwater samples from MW-1 and MW-2 over time. The TDS data plotted shows a 5,000 mg/L increase over the duration of the sampling events for MW-1. The bottom boundary line on the plot represents the TDS concentration of the CBNG water that was discharged into the impoundment. The plot does not show evidence of mixing of infiltrating CBNG water in the TDS data; MW-1 shows a trend opposite what would be expected of simple mixing between the two waters. The SAR data plotted on Figure 5-92 mirrors the increase in TDS that is seen over the record of sampling events. The increase in SAR is the result of a 125% increase in Sodium between the first sampling event (896 mg/L) and the final sample (2,040). The increase in SAR does not reflect the complete increase in Sodium as there was also an 85% increase Magnesium noted between the first sampling event (336 mg/L) and the final sample (622 mg/L. There was also a 50% increase in both Sulfate, which increased from 4,060 mg/L to 6,790 mg/L, and in Bicarbonate which saw an increase from 506 mg/L to 762 mg/L.

Figure 5-92 also presents the sampling results form Tietjen MW-2. The MW-2 sample data shows only minor variation over the duration of the sampling event. The TDS data from MW-2 varies by 800 mg/L and shows a steady rise over the duration of the sampling interval. A similar trend can be seen in the SAR data for the same period with a total of 1.4 units of variation between all of the samples, see Figure 5-92.

Analysis of Geochemistry Data from Impoundments over Non-Alluvial Aquifers along the Powder River of Wyoming

During the discussion of anticipated impacts associated with the infiltration of CBNG impoundment water one of the major conditions that were identified as influencing the changes in chemistry as the water infiltrates was the local geology. This section presents the results of monitoring chemical data for impoundments which were completed over non-alluvial aquifers. The lithologic composition of the materials present below these impoundments is described in the geology discussion in Section 4.3 of this document.

JM Huber Impoundment Lori – Prairie Dog Creek

CBNG produced water was initially discharged into the Lori impoundment in 2001. Since CBNG produced water was discharged into the impoundment, four monitoring wells were installed. Groundwater chemistry, as shown in the piper diagram in Figure 5-93, shows the Lori PD#1, Lori MW-1, and Lori MW-4 waters to be characterized as sodium/sulfate waters. The groundwater sample from the Lori MW-3 is characterized as sodium/carbonate and bicarbonate water. Water chemistry representing average CBNG produced water quality is also plotted in Figure 5-93 for comparison, and is characterized as having a predominant sodium/carbonate and bicarbonate chemical signature. Groundwater was encountered in the Lori MW-3 in a coal stringer formation at an approximate elevation of 3,504.4 feet amsl. Groundwater collected from Lori MW-4 was interpreted to be from the same coal stringer, where it was encountered at an approximate elevation of 3,515.6 amsl. The proximal distance and structural similarities between the subsurface materials in the boreholes of MW-3 and MW-4 would indicate these two wells are producing water from a similar water bearing zone while chemical analysis shows these two wells to have differing chemistries. Based on the simple mixing data shown on Figure 5-93 and the geographic location of PD-1, MW-3 and MW-4 it is possible that the chemistry of the water in coal stringer aquifer screened in MW-3 and MW-4 is being altered by infiltration of CBNG water from the Lori impoundment. Lori PD-1 and MW-1 contained groundwater originating in a siltstone aquifer. Lori MW-3 and MW-4 contained groundwater originating a coal stringer aquifer.

Figure 5-94 presents the major cation and anion composition of the wells installed near the Lori impoundment on a stiff diagram. A comparison of the major cation and anion chemistry shown on the stiff diagram in Figure 5-94 to the general formation quality data shown in Figure 2-5 shows the influence of CBNG infiltration water at Lori MW-3. The migration/influence of the CBNG infiltration water for the sodium and magnesium/sulfate water in Lori PD-1, to the sodium/bicarbonate water of Lori MW-3 and MW-4 is also apparent on Figure 5-94.

JM Huber Impoundment Sandy – Prairie Dog Creek

CBNG produced water was initially discharged into the Sandy impoundment in 2001. Since CBNG produced water was discharged into the impoundment, three monitoring wells were installed. Groundwater chemistry, as shown in the Piper diagram in Figure 5-95, shows the Sandy MW-1 and Sandy MW-2 waters to be characterized as sodium/sulfate waters, and water samples from the Sandy MW-3 to be characterized as calcium and sodium/sulfate water. Water chemistry representing average CBNG produced water quality is also plotted in Figure 5-95 for comparison, and is characterized as having a predominant sodium/carbonate and bicarbonate chemical signature. Groundwater was encountered in the Sandy MW-1 and MW-2 in Upper Roland Coal aquifer. Groundwater collected from Sandy MW-3 was interpreted to be from shallow alluvial zone and was encountered at an elevation of 3,614 ft amsl. The alluvial aquifer sampled in MW-3, however, contained water enriched in calcium and magnesium, suggesting an influence from gypsum within that particular alluvium. The water chemistry analysis indicates that none of these monitoring wells are positioned structurally down-gradient from the impoundment or are not being influenced by infiltrating CBNG water.

Figure 5-96 presents the major cation and anion composition of the wells installed near the Sandy impoundment on a stiff diagram. A comparison of the major cation and anion chemistry shown on the stiff diagram in Figure 5-96 to the general formation quality data shown in Figure 2-5 shows that none the wells exhibit water of similar to the average CBNG water quality observed elsewhere in the PRB. Figure 5-96 appears to show the lack of influence of the CBNG infiltration water for the sodium and magnesium/sulfate water in Lori PD-1, to the sodium/bicarbonate water of Lori MW-3 and MW-4.

JM Huber Impoundment Joe Draw Jr. – Prairie Dog Creek

CBNG produced water was initially discharged into the Joe Draw Jr. impoundment in 2000. Since CBNG produced water was discharged into the impoundment, three monitoring wells were installed. Groundwater chemistry, as shown in the Piper diagram in Figure 5-97, shows the Joe Draw Jr. MW-1, MW-2, and MW-3 waters to be characterized sodium/bicarbonate water. Water chemistry representing average CBNG produced water quality is also plotted in Figure 5-97 for comparison, and is characterized as having a predominant sodium/bicarbonate chemical signature. Groundwater that was encountered in the three Joe Draw Jr. monitor wells plots very closely to that of CBNG produced water on the Piper Diagrams. The water chemistry analysis appears to indicate that the three Joe Draw Jr. monitoring wells are all affected by CBNG infiltration, or are completed in an aquifer of similar quality to that of CBNG produced water. The lack of returns during the drilling of these three boreholes makes the interpretation of the geologic nature of the water producing formation more difficult, however, based on the returns that were seen, it appears to be a siltstone between two coal seams.

Figure 5-98 presents the major cation and anion composition of the wells installed near the Joe Draw Jr. impoundment plotted on a stiff diagram. A comparison of the major cation and anion chemistry shown on the stiff diagram in Figure 5-98 to the general formation quality data shown in Figure 2-5 shows that none the wells exhibit water of a quality similar to average CBNG produced water in the PRB.

Yates Impoundment Yates State – LX Bar Creek

CBNG produced water was initially discharged into the Yates State impoundment in 2001. Since CBNG produced water was discharged into the impoundment, two monitoring wells were installed. Groundwater chemistry, as shown in the Piper diagram in Figure 5-99, shows the water samples from the Yates State MW-1 to be characterized as calcium, magnesium/sulfate waters and while waters from MW-2 to be characterized as calcium, magnesium, sodium/bicarbonate water. Water chemistry representing average CBNG produced water quality is also plotted in Figure 5-99 for comparison, and is characterized as having a predominant sodium/bicarbonate chemical signature. The MW-1 well is screened in a sandy silt. MW-2 is screened in the Anderson Coal seam aquifer. The MW-2 sample is comparatively rich in sodium and bicarbonate while the MW-1 sample is richer in calcium, magnesium, and sulfate. It is unclear whether the difference in water chemistry is caused by the difference in lithology of the aquifers or infiltration from the impoundment.

The stiff diagram shown in Figure 5-100 presents the major cation and anion composition of the wells installed near the Yates State impoundment. A comparison of the major cation and anion chemistry shown on this diagram to the general formation quality data shown in Figure 2-5 shows that MW-1 data exhibits water of a quality similar to average Wasatch Formation water quality. Figure 5-100 also shows that the water quality shown at MW-2 appears to be influenced by CBNG produced water quality.

Additionally, it is unknown the extent the two aquifers sampled by the two monitoring wells are connected. The shallow sandy silt aquifer has limited head and may be a perched aquifer of very limited extent. This perched aquifer may outcrop beneath the impoundment if it extends that far, although the direction of water flow within the aquifer is unknown. Communication between the perched aquifer and the impoundment is likely; however, it is unknown whether flow is into the aquifer or into the impoundment.

On the other hand, the Anderson Coal aquifer, seen in MW-2, is extensive over much of the area. Water in the Anderson Coal aquifer is likely to drain both to the west, into the buttes, and to the east, toward the creek, following the dip of the coal seam. The

Anderson Coal may outcrop in the LX Bar Creek or in the alluvium under the creek to the north-east of the impoundment. The bottom of the impoundment is likely to be more than 40 feet above the Anderson, suggesting that infiltration into this aquifer is not probable.

Yates Impoundment Bounty Hunter – LX Bar Creek

CBNG produced water was initially discharged into the Bounty Hunter impoundment in 2001. Since CBNG produced water was discharged into the impoundment, three monitoring wells were installed. Groundwater chemistry, as shown in the Piper diagram in Figure 5-101, shows that the Bounty Hunter MW-1 contains a sodium-calcium-magnesium bicarbonate water, MW-2 contains a sodium-calcium-magnesium bicarbonate sulfate water, and MW-3 contains a magnesium-sodium-sulfate-bicarbonate water. Water chemistry representing average CBNG produced water quality is also plotted in Figure 5-101 for comparison and is characterized as having a predominant sodium/bicarbonate chemical signature. Anderson coal aquifer sampled at MW-1 contains a sodium-calcium-magnesium bicarbonate water. Alluvial water in MW-2 is similar to the coal aquifer but is enriched in sulfate. Alluvial water from MW-3 is similar to MW-2 water but is more enriched with sulfate ion. No indication of infiltration out of the impoundment into the alluvial aquifers is apparent from the sampling data.

Figure 5-102 presents the major cation and anion composition of the wells installed near the Bounty Hunter impoundment as plotted on a stiff diagram. A comparison of the major cation and anion chemistry shown on this diagram to the general formation quality data shown in Figure 2-5 indicates an apparent chemical change occurring from the water in MW-1 to MW-2 and MW-3. That change being a gradual decline in the sulfate concentration.

Termo Impoundment Termo – LX Bar Creek

CBNG produced water was initially discharged into the Termo impoundment in 2002. Since CBNG produced water was discharged into the impoundment, three monitoring wells were installed. Groundwater chemistry, as shown in the Piper diagram in Figure 5-103, shows the Termo MW-1, MW-2, and MW-3 contain a calcium-magnesium-sodium sulfate water. Water chemistry representing average CBNG produced water quality is also plotted in Figure 5-103 for comparison, and is characterized as having a predominant sodium/bicarbonate chemical signature. MW-1 was screened through the Anderson Coal and overlying sandy siltstone. MW-2 was screened through the Anderson Coal and overlying silty clays. MW-3 is screened through the Anderson Coal and overlying sand. Water samples from these wells are approximately the same and no indication is seen for the occurrence of infiltration out of the impoundment into the alluvial aquifers.

Figure 5-104 presents the major cation and anion composition of the wells installed near the Termo impoundment as plotted on a stiff diagram. A comparison of the major cation and anion chemistry shown on the stiff diagram in Figure 5-104 to the general formation quality data shown in Figure 2-5 shows the quality of water to differ from the average water quality of the shallow aquifers in the PRB.

Yates Impoundment Waylon – LX Bar Creek

CBNG produced water was initially discharged into the Waylon impoundment in 2002. Since CBNG produced water was discharged into the impoundment, three monitoring wells were installed. Groundwater chemistry, as shown in the Piper diagram in Figure 5-105, shows the Waylon MW-1, MW-2, and MW-3 contains calcium-magnesium-sodium sulfate water. Water chemistry representing average CBNG produced water quality is also plotted in Figure 5-105 for comparison, and is characterized as having a predominant sodium/bicarbonate chemical signature. MW-1 is screened in the Lower Cook Coal and an overlying silt. MW-2 is screened in a silty sand below the Lower Cook Coal. MW-3 is screened in the Lower Cook Coal aquifer. MW-3 is structurally down-gradient while MW-1 and MW-2 are up-gradient of the impoundment. It appears that the Lower Cook becomes only slightly enriched in magnesium and sulfate ions, suggesting that the aquifer is less influenced by CBNG water. If MW-1 and MW-3 are screened in the same aquifer, then there seems to be no evidence of infiltration out of the impoundment. All three of the water samples appear to be surface water related, not influenced by CBNG water.

Figure 5-106 presents the major cation and anion composition of the wells installed near the Waylon impoundment as plotted on a stiff diagram. A comparison of the major cation and anion chemistry shown on the stiff diagram in Figure 5-106 to the general formation quality data shown in Figure 2-5 shows there appears to be a chemical change occurring from the water in MW-1 to MW-3 as a gradual decline in the magnesium and sulfate concentration occurs.

J.M. Huber Impoundment Golden Eagle – LX Bar Creek

CBNG produced water was initially discharged into the Golden Eagle impoundment in 2000. Since CBNG produced water was discharged into the impoundment, three monitoring wells were installed. Groundwater chemistry, as shown in the Piper diagram in Figure 5-107, shows the Waylon MW-1, MW-2, and MW-3 contains calcium-magnesium-sodium sulfate water. All three samples are mixed ion sulfate waters that are similar to each other and are similar to alluvial water seen elsewhere. These samples do not appear to have been impacted by infiltration of CBNG water. No up-gradient alluvial aquifer sample point appears to be available at this reservoir. MW-2 and MW-3 appear to be free of impact from infiltrate coming from the impoundment. Water chemistry representing average CBNG produced water quality is also plotted in Figure 5-107 for comparison, and is characterized as having a predominant sodium/bicarbonate chemical signature. MW-1 is screened in Felix Coal and underlying bedrock. MW-2 and MW-3 are screened in shallow alluvium below the impoundment. Water samples are approximately the same and no indication is seen for the occurrence of infiltration out of the impoundment into the alluvial aquifers.

Figure 5-108 presents the major cation and anion composition of the wells installed near the Golden Eagle impoundment on a stiff diagram. A comparison of the major cation and anion chemistry shown on the stiff diagram in Figure 5-108 to the general formation quality data shown in Figure 2-5 shows there appears to be a chemical change occurring to the cations from MW-1 to MW-3 as a gradual increase in magnesium concentration occurs.

APPENDIX F

FIGURES

Figure 5-1: Piper Plot for Water Samples Collected from the Jeff 3 Impoundment Monitoring Wells

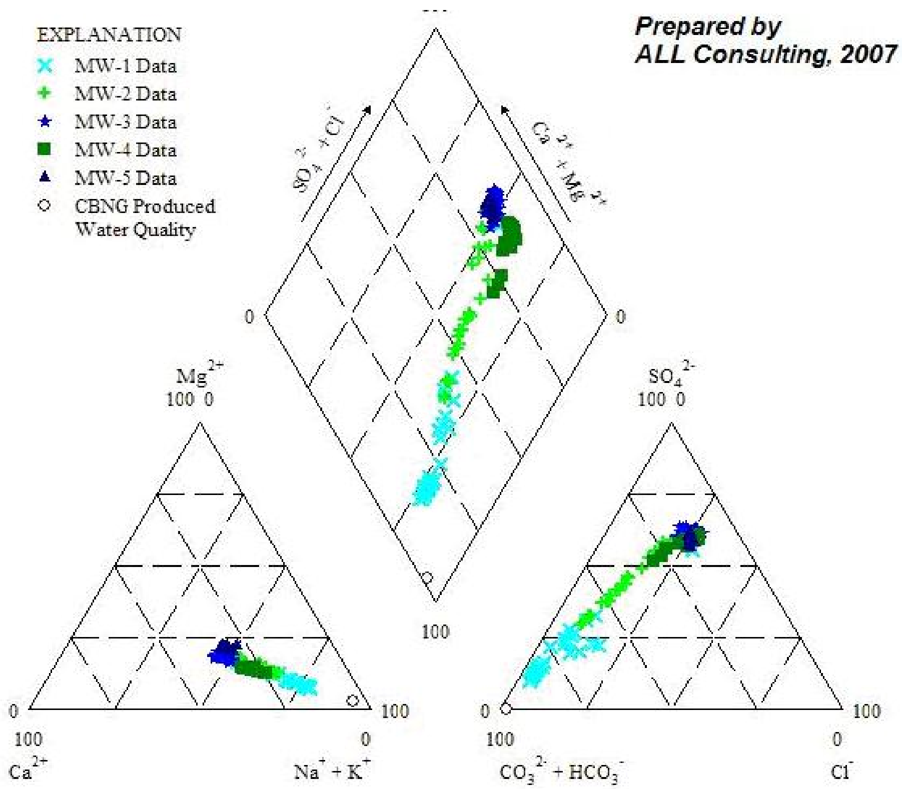


Figure 5-2: Piper Plot for Jeff 3 MW-1

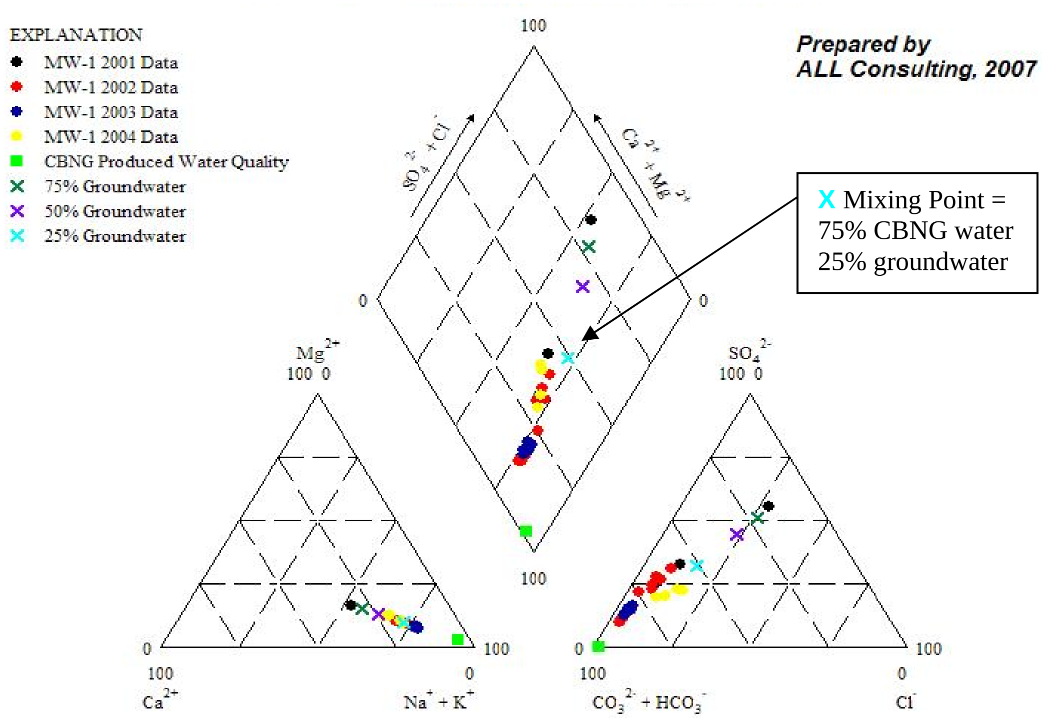


Figure 5-3: Piper Plot for Jeff 3 MW-2

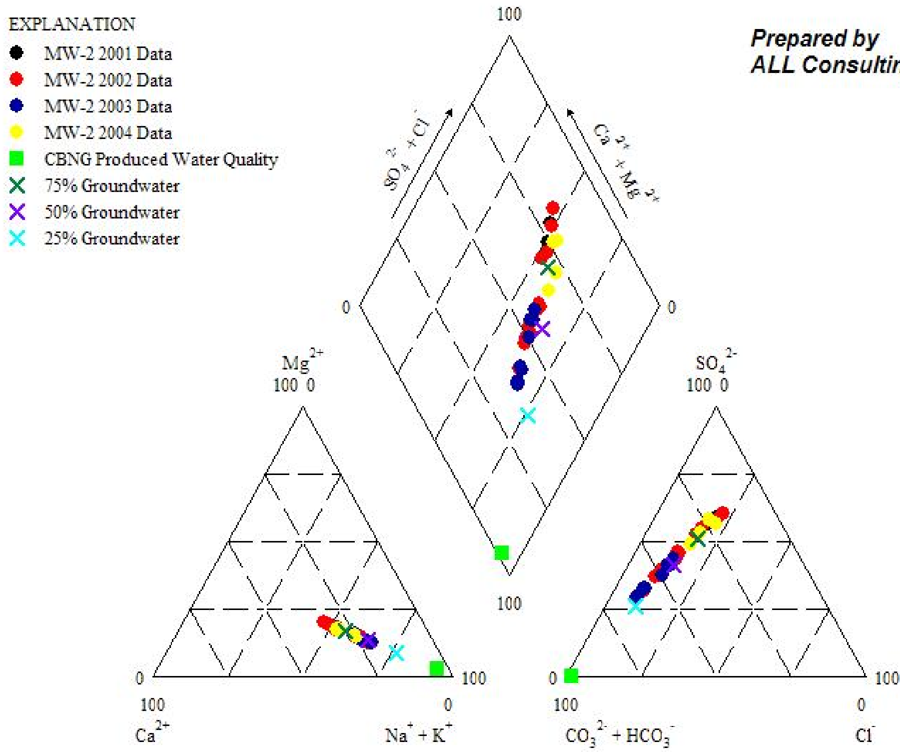


Figure 5-4: Piper Plot for Jeff 3 MW-1 Years 2001-2002

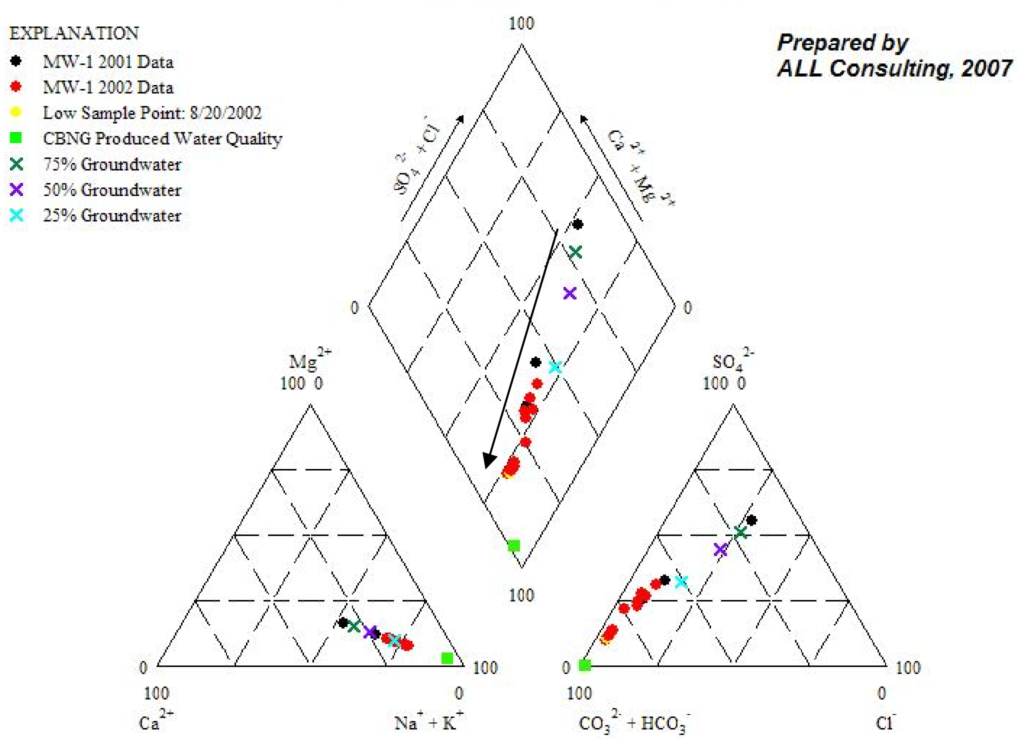


Figure 5-5: Piper Plot for Jeff 3 MW-1 Years 2003-2004

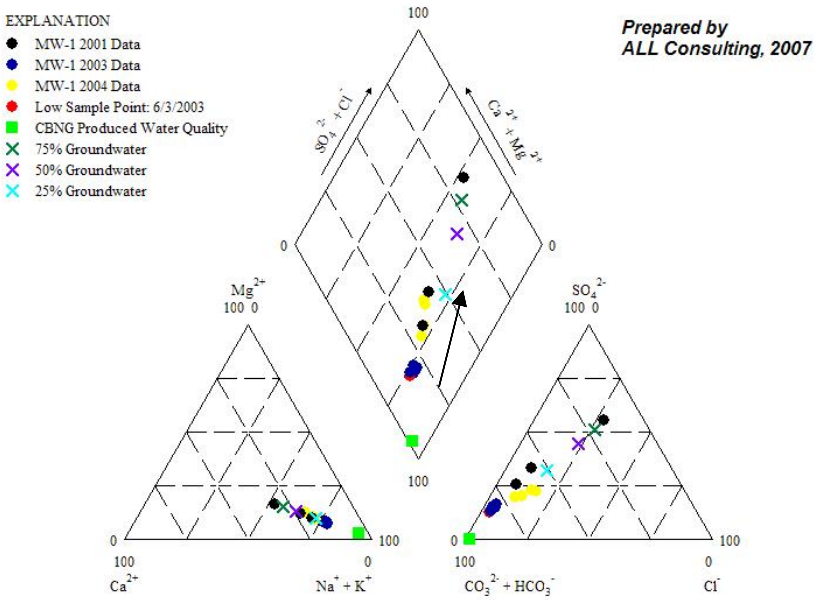


Figure 5-6: SAR and TDS Trends for Jeff 3 MW-1

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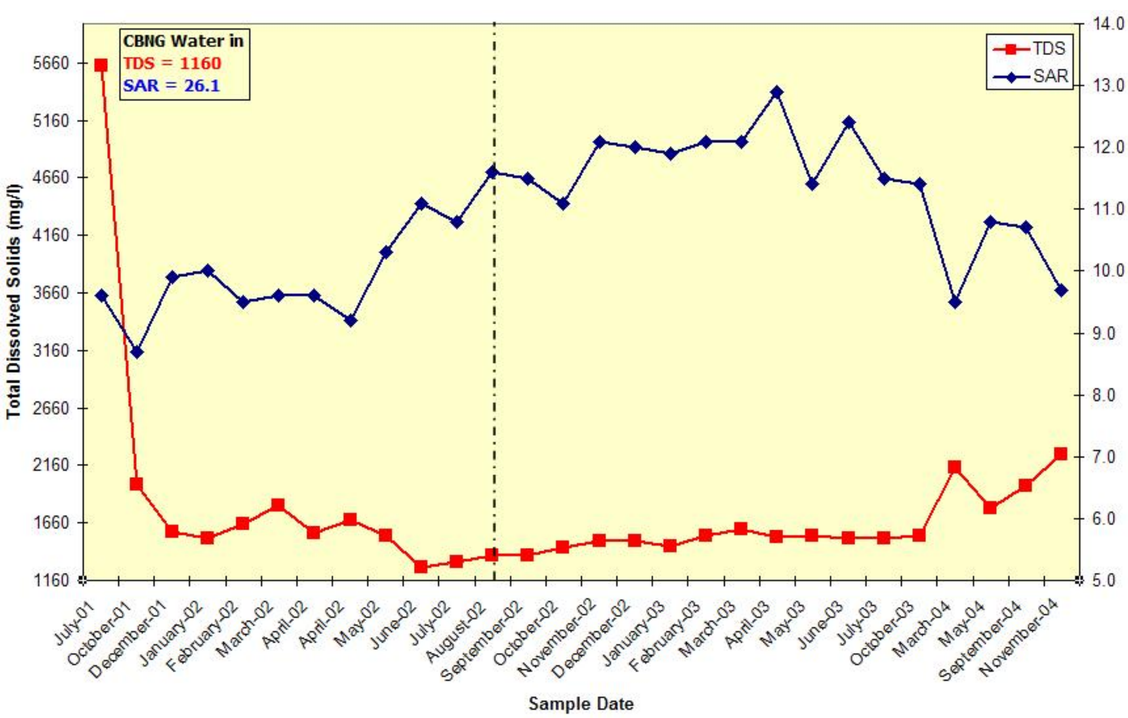
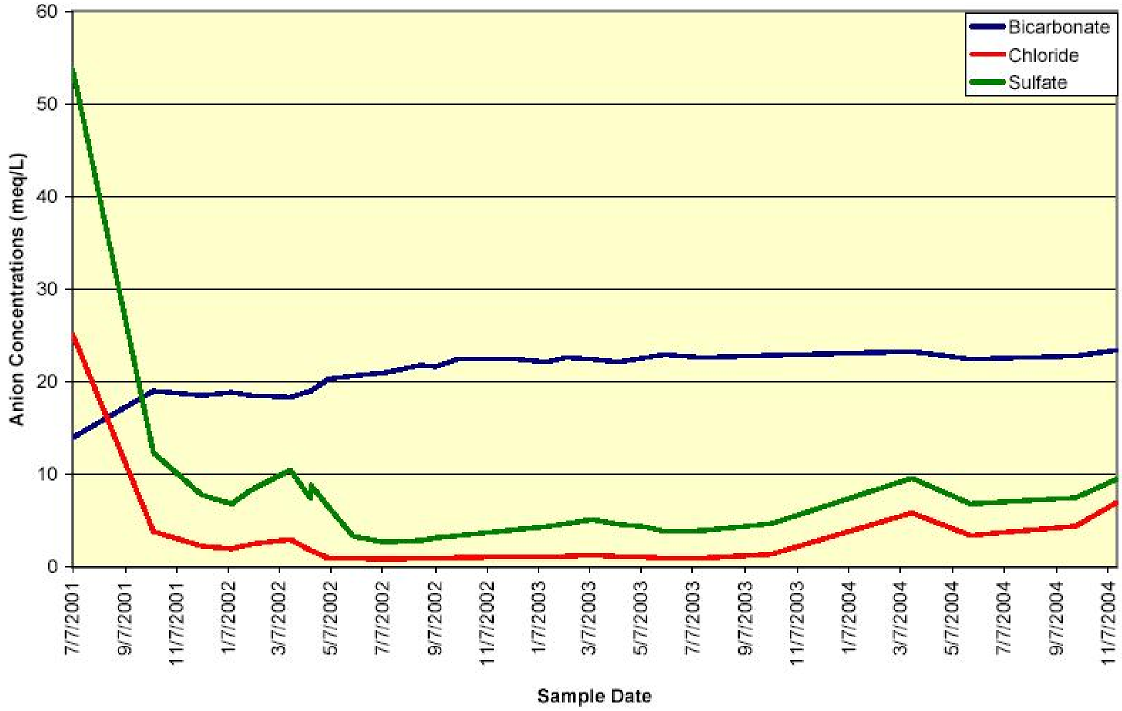


Prepared by
ALL Consulting, 2007

Figure 5-7: Anion Trend Data for the Jeff 3 MW-1



Prepared by
ALL Consulting, 2007

Figure 5-8: Cation Trend Data for the Jeff 3 MW-1

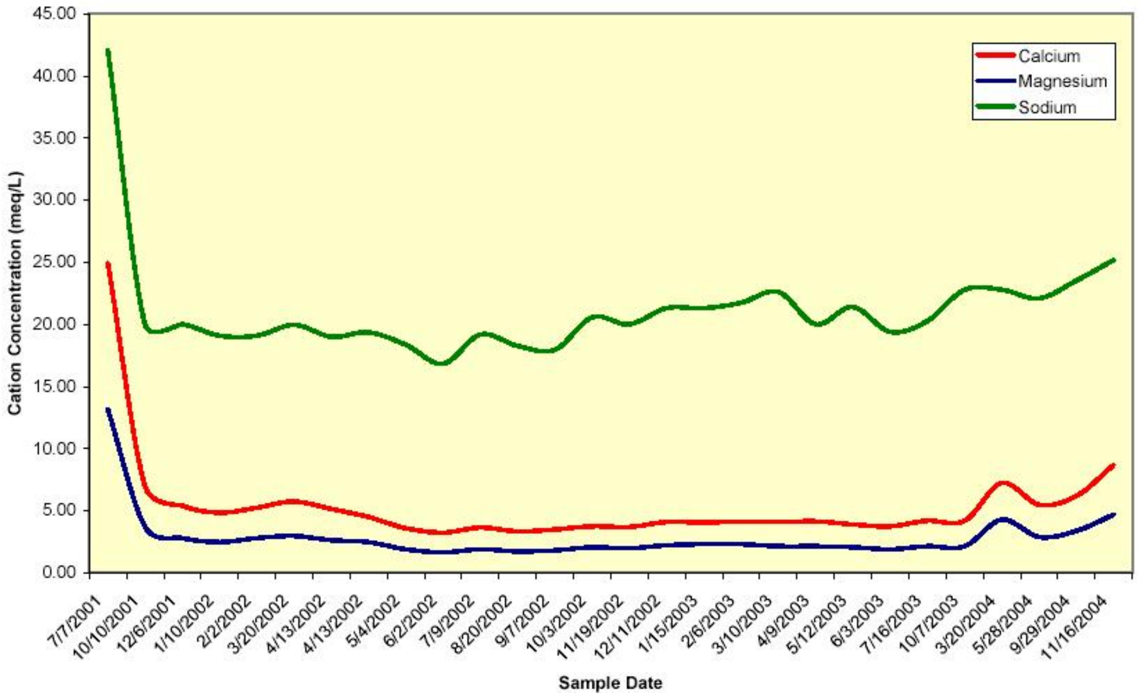


Figure 5-9: Piper Plot for Jeff 3 MW-2 Years 2001-2002

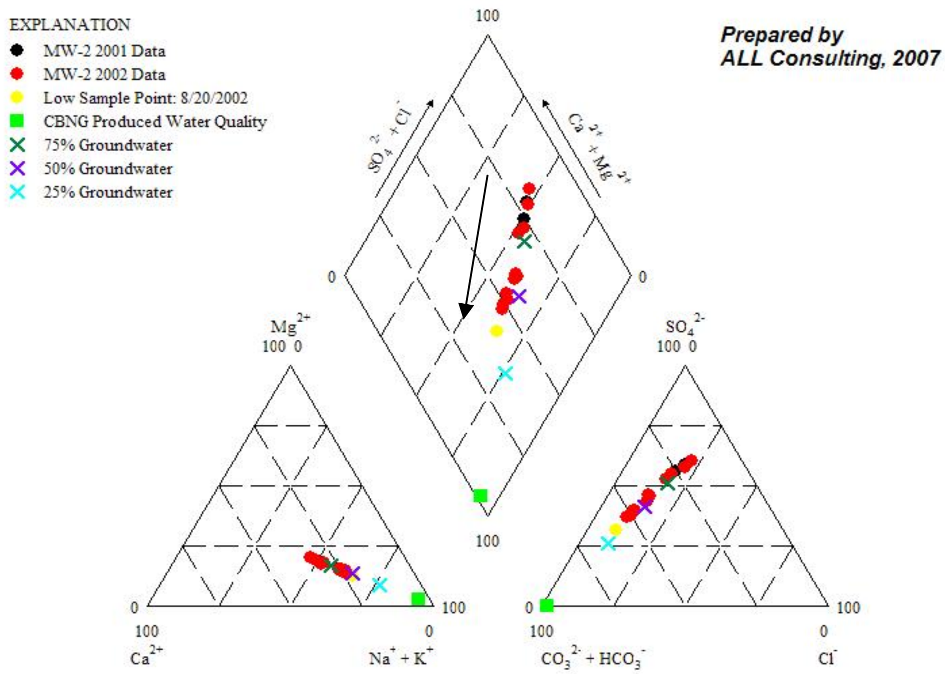


Figure 5-10: Piper Plot for Jeff 3 MW-2 Years 2003-2004

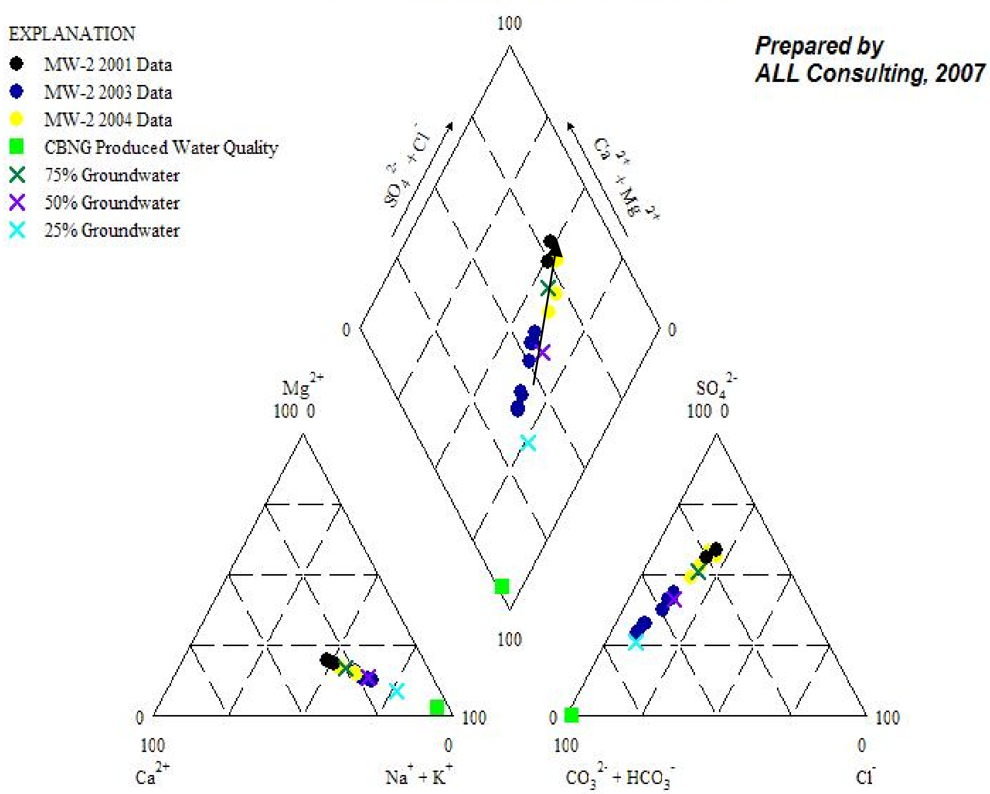


Figure 5-11: SAR and TDS Trends for Jeff 3 MW-2

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ALL Consulting, 2007

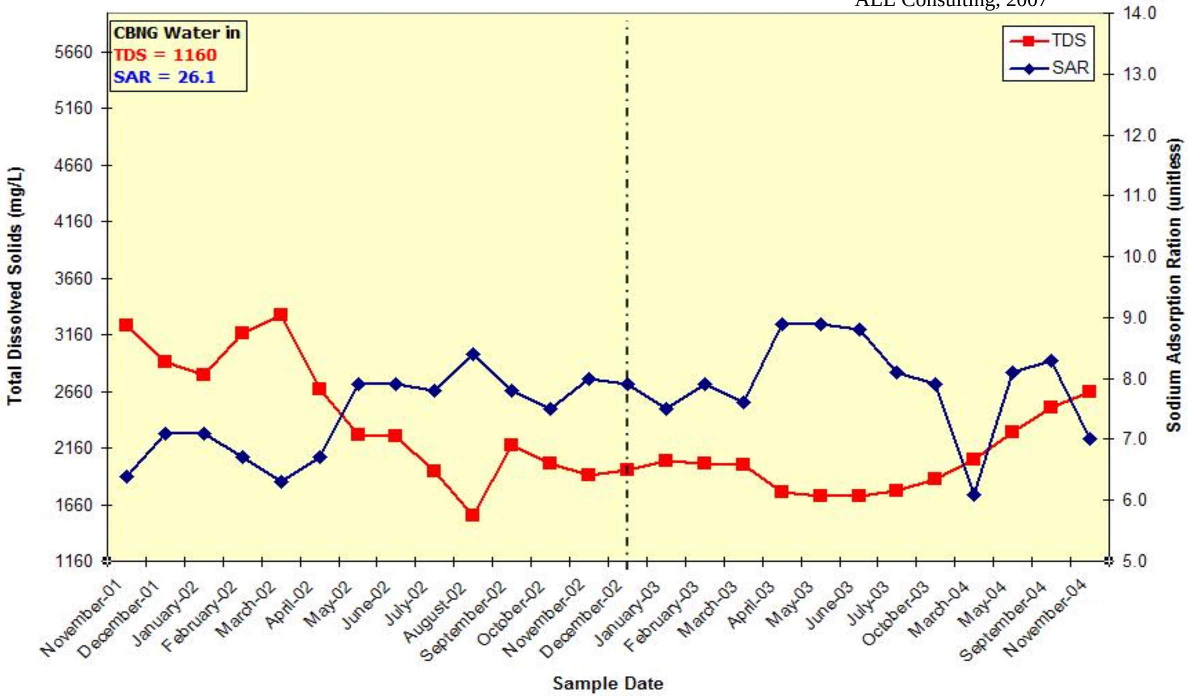

Figure 5-12: Anion Trend Data for the Jeff 3 MW-2

Prepared by
ALL Consulting, 2007

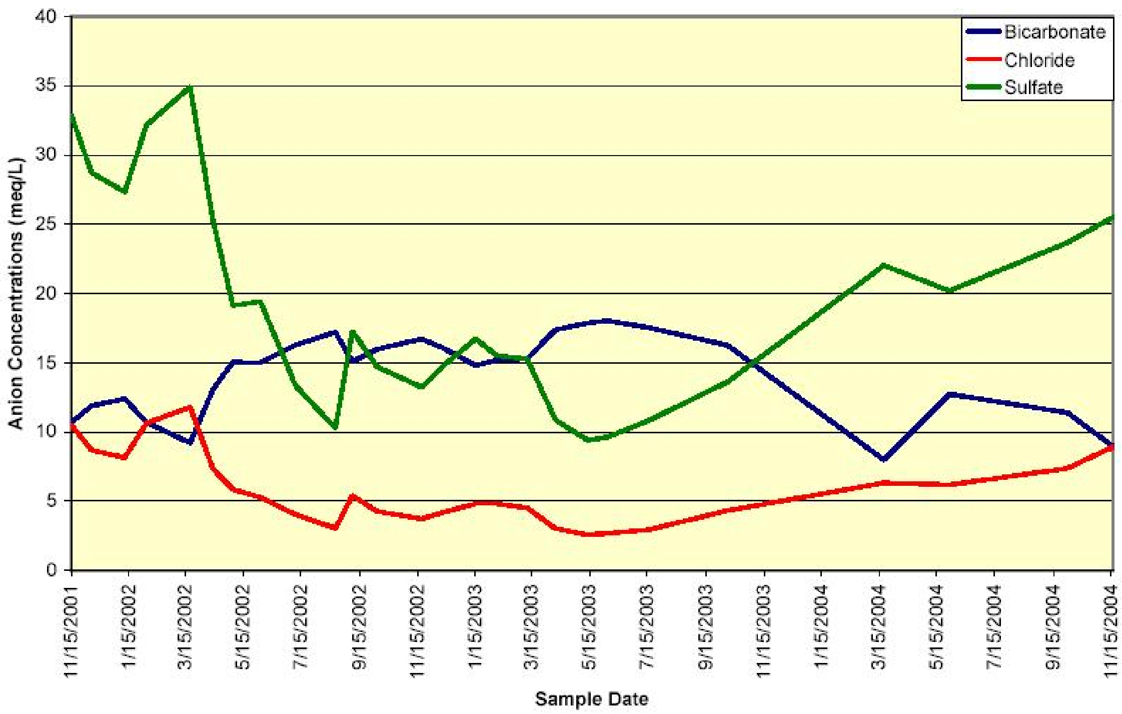

Figure 5-13: Cation Trend Data for the Jeff 3 MW-2

Prepared by
ALL Consulting, 2007

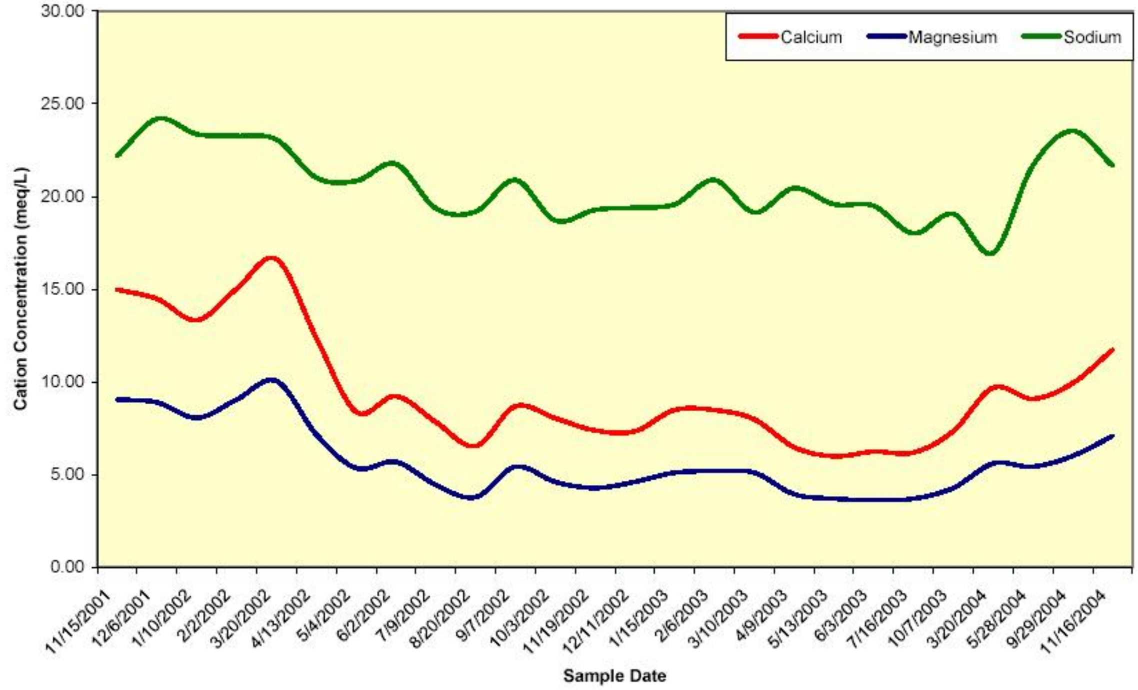

Figure 5-14: Piper Diagram of Water Samples Collected from Jeff 3 MW-3

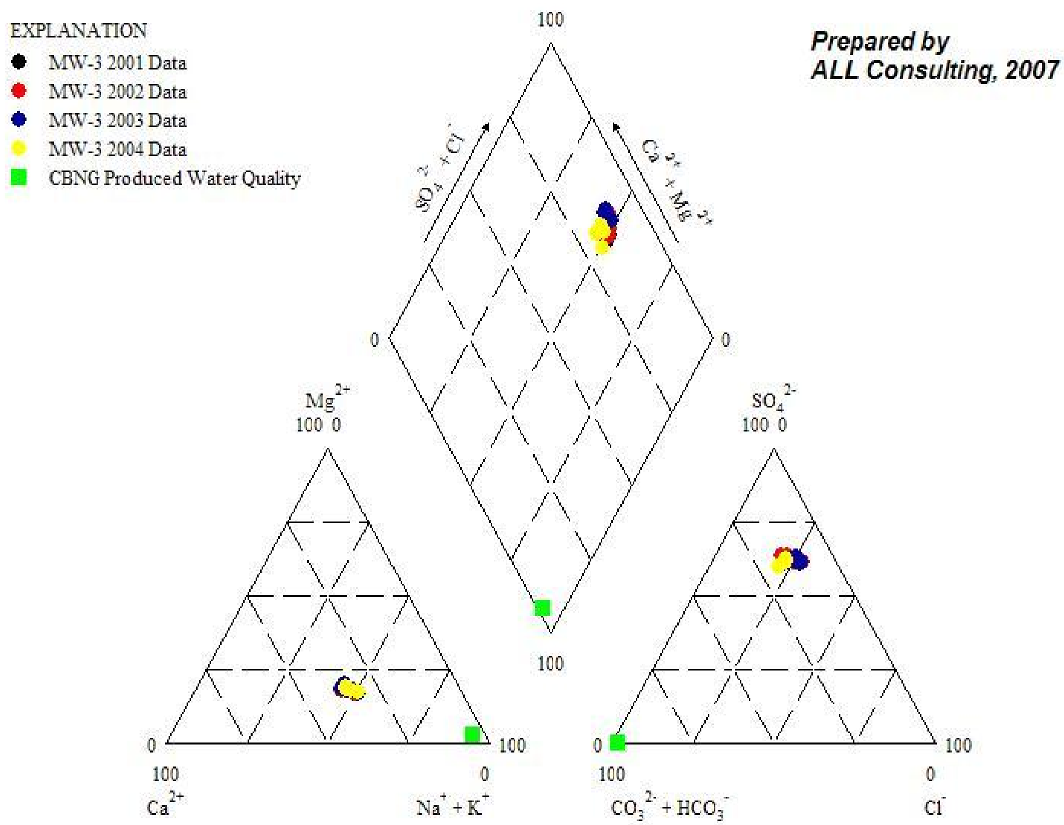

Figure 5-15: Piper Diagram of Water Samples Collected from Jeff 3 MW-4

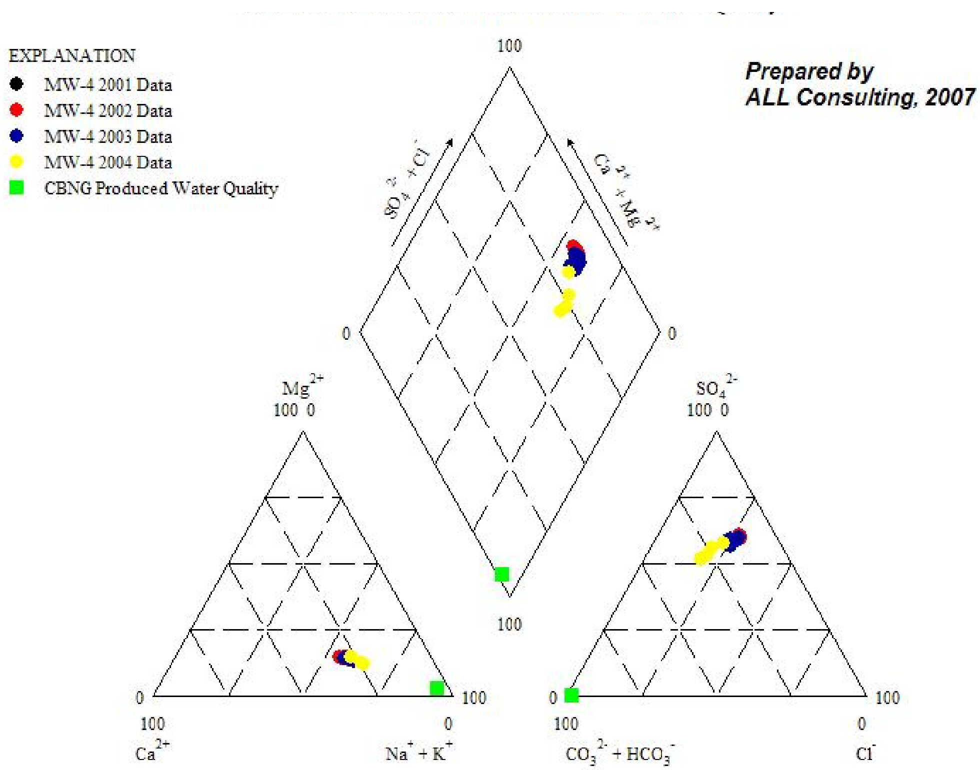

Figure 5-16: Piper Diagram of Water Samples Collected from Jeff 3 MW-5

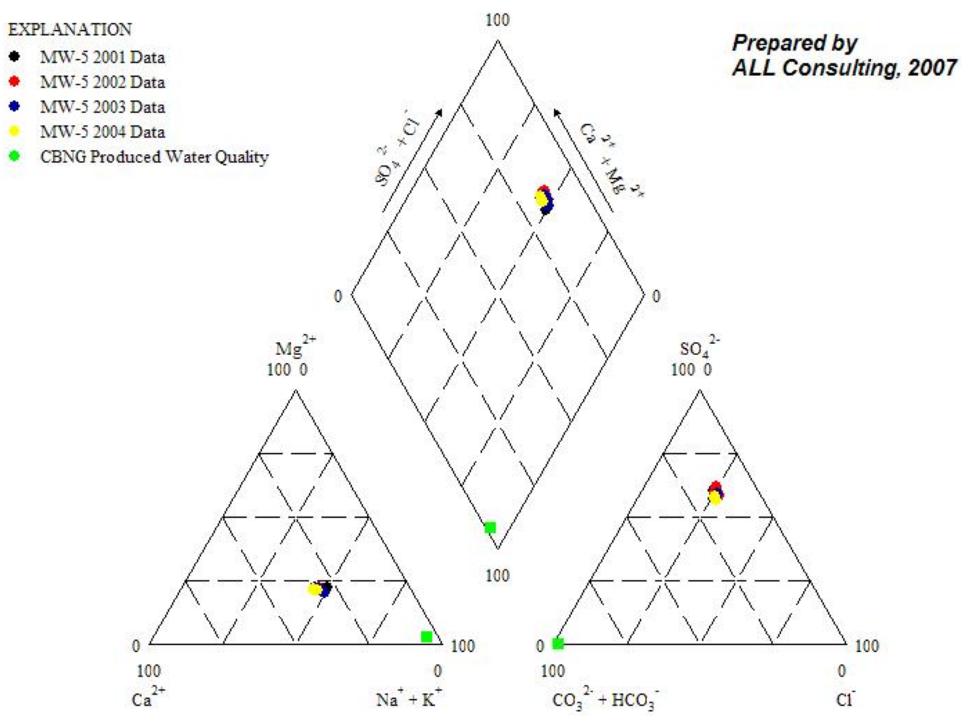

Figure 5-17: SAR and TDS Trends for Jeff 3 MW-3, MW-4, and MW-5

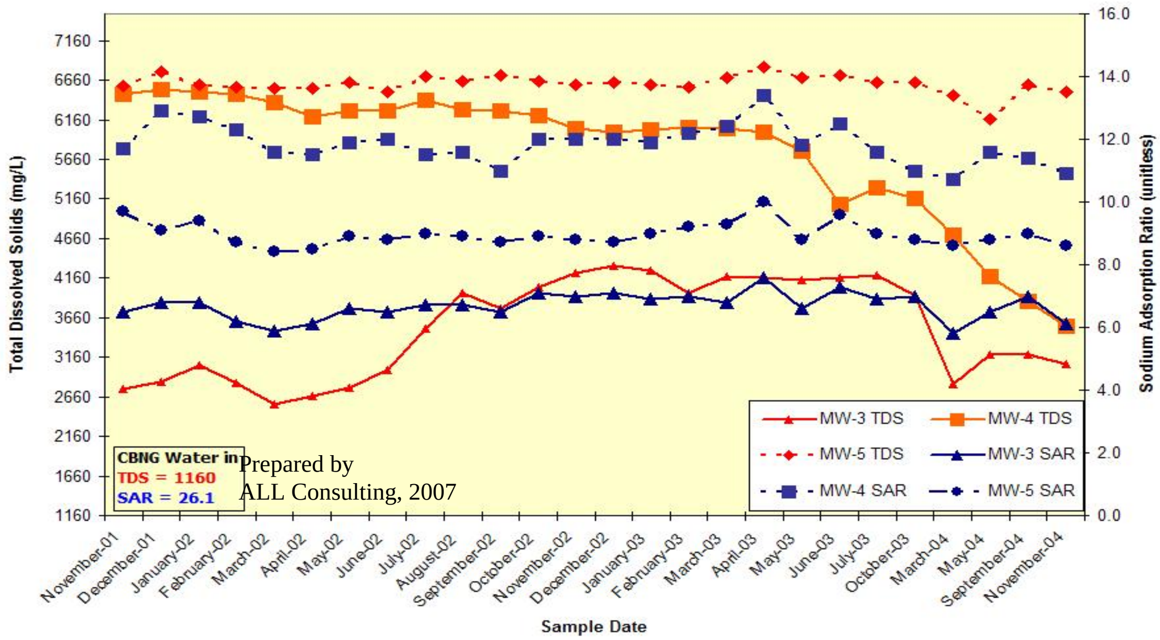

Figure 5-18: Anion Trend Data for the Jeff 3 MW-3

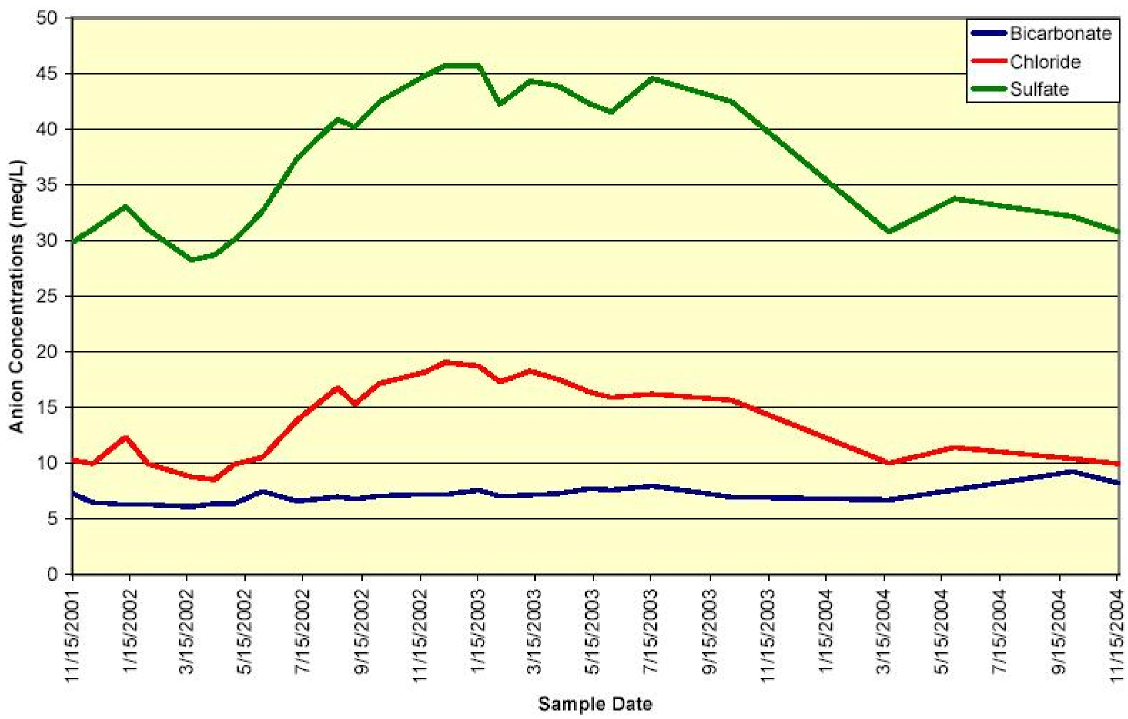

Figure 5-19: Anion Trend Data for the Jeff 3 MW-4

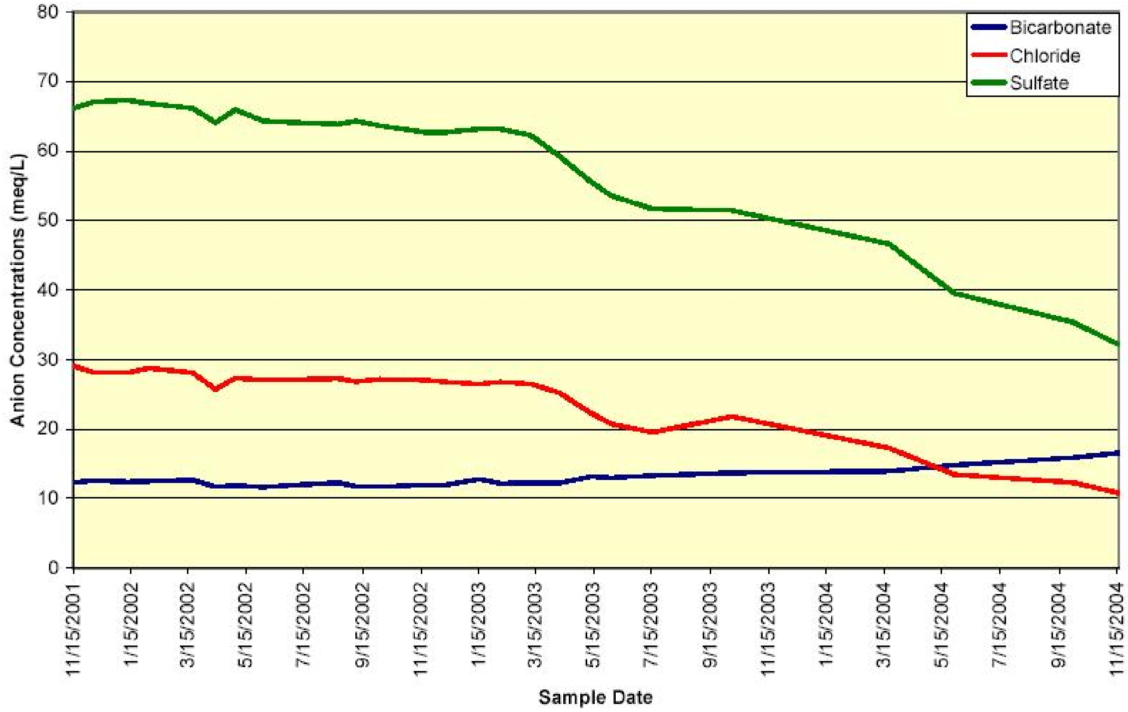

Figure 5-20: Anion Trend Data for the Jeff 3 MW-5

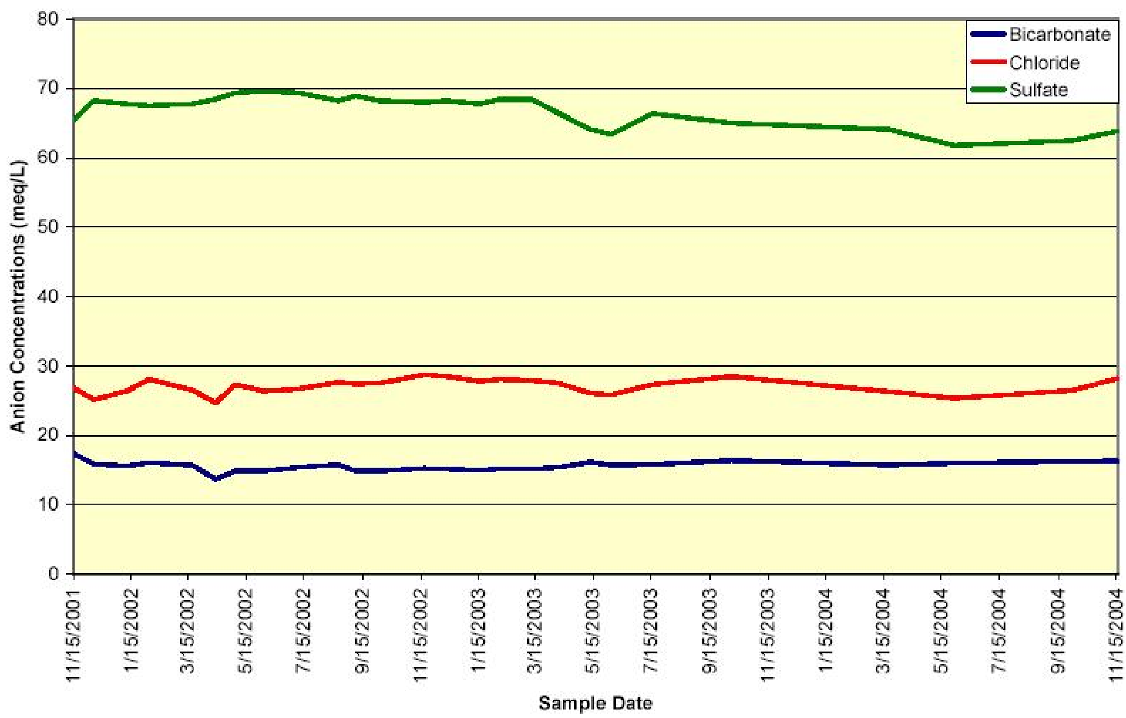

Figure 5-21: Cation Trend Data for the Jeff 3 MW-3

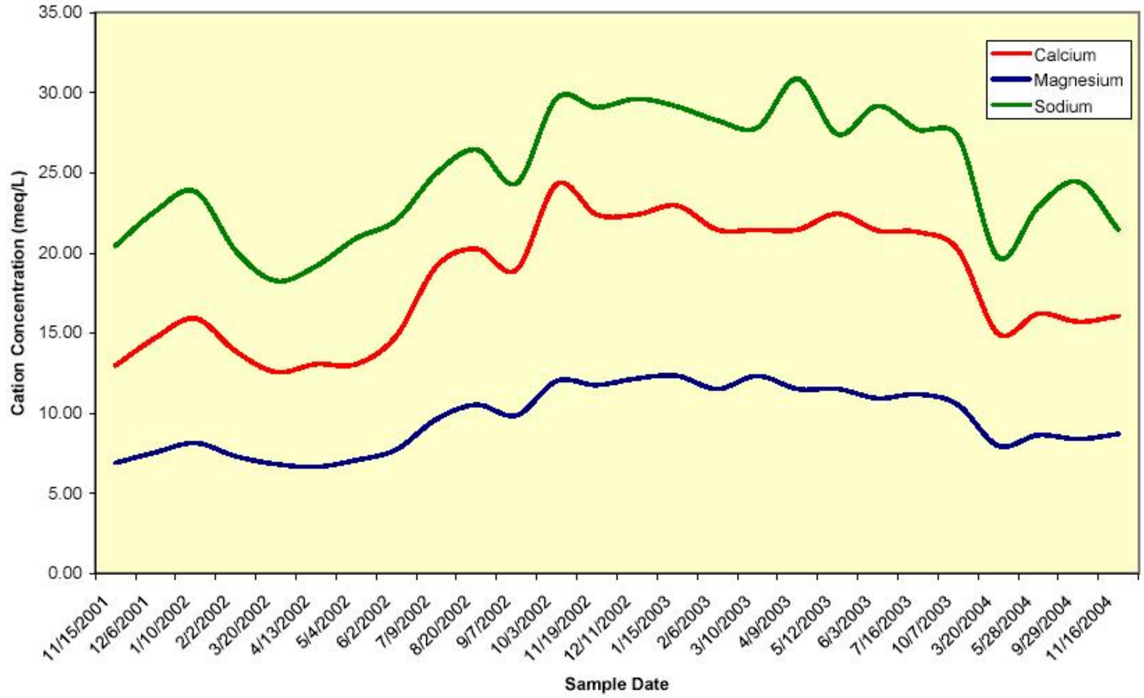

Figure 5-22: Cation Trend Data for the Jeff 3 MW-4

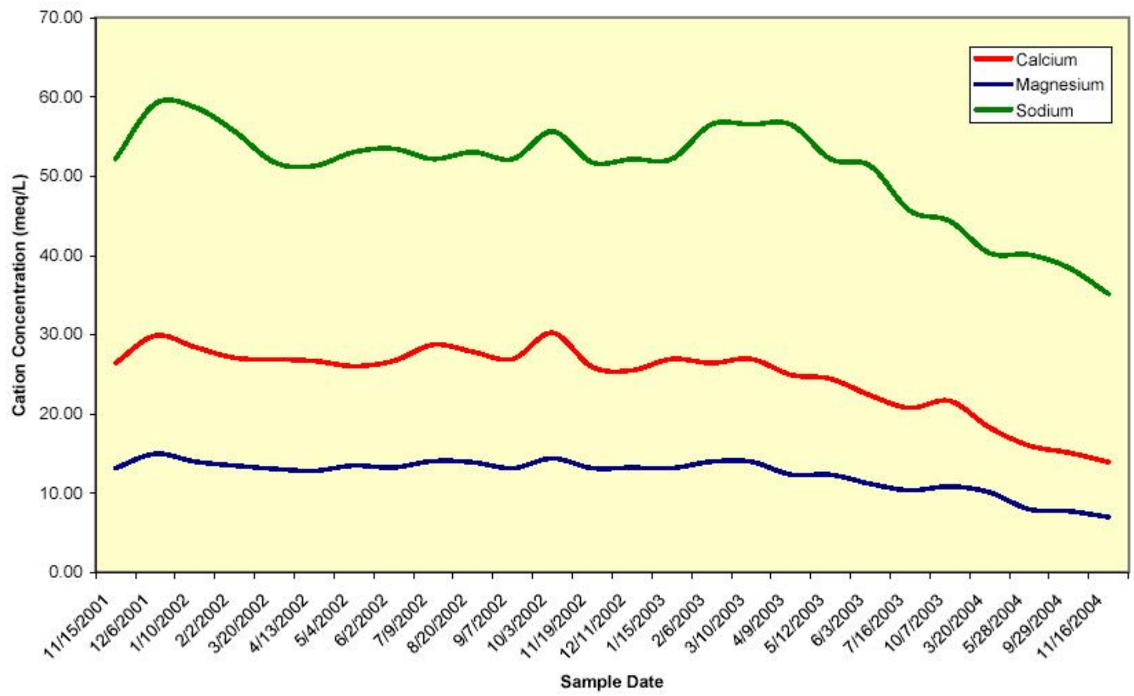

Figure 5-23: Cation Trend Data for the Jeff 3 MW-5

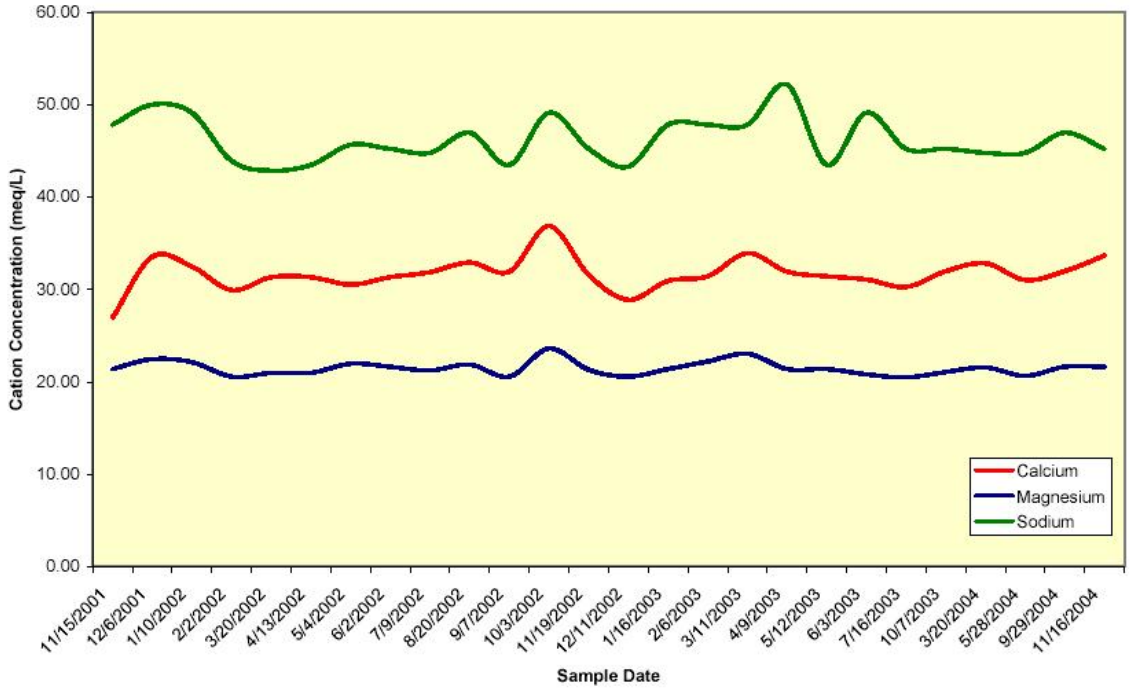

Figure 5-24: Piper Plot for Water Samples Collected from the Jeff 5 Impoundment Monitoring Wells

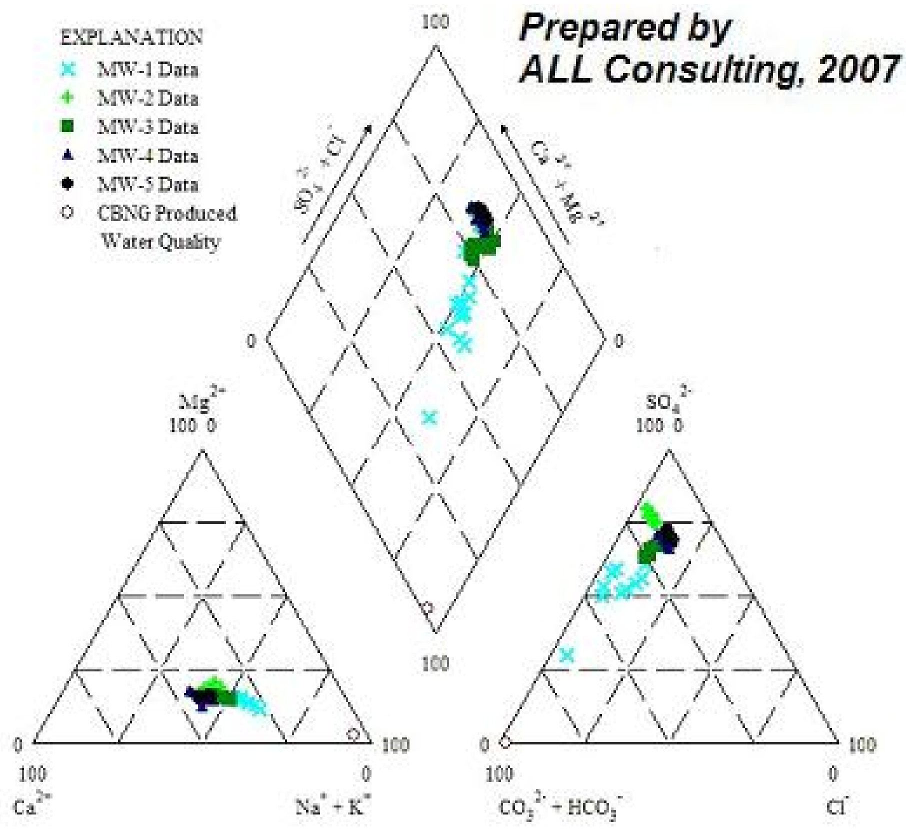

Figure 5-25: Piper Plot for Jeff 5 MW-1

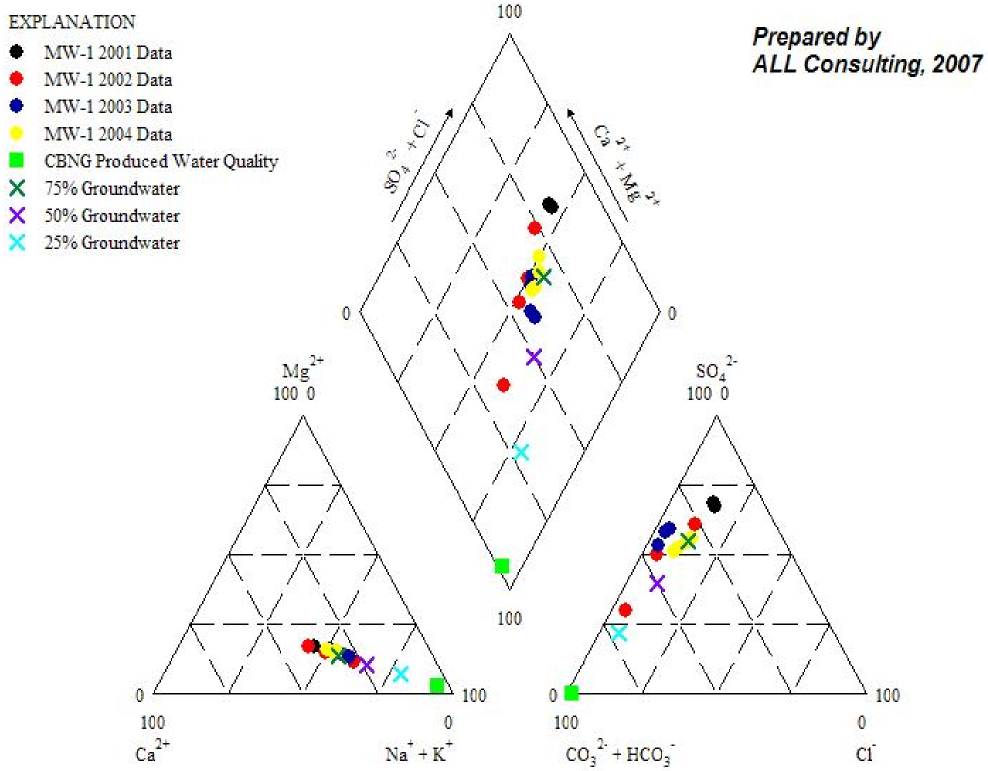

Figure 5-26: Piper Plot for Jeff 5 MW-1 Years 2001-2002

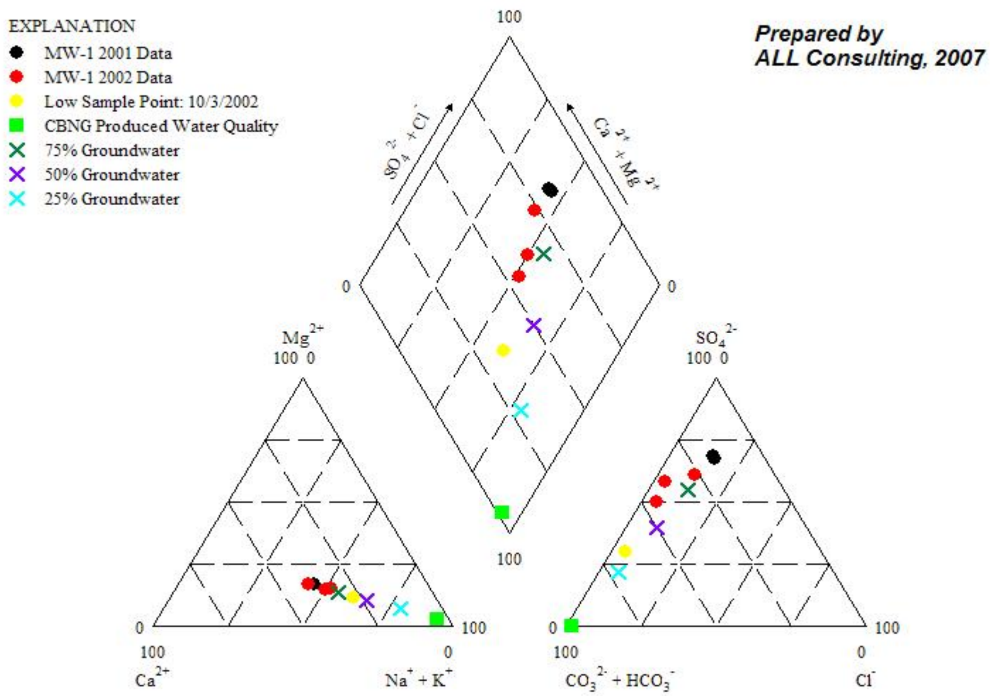

Figure 5-28: Piper Plot for Jeff 5 MW-1 Years 2003-2004

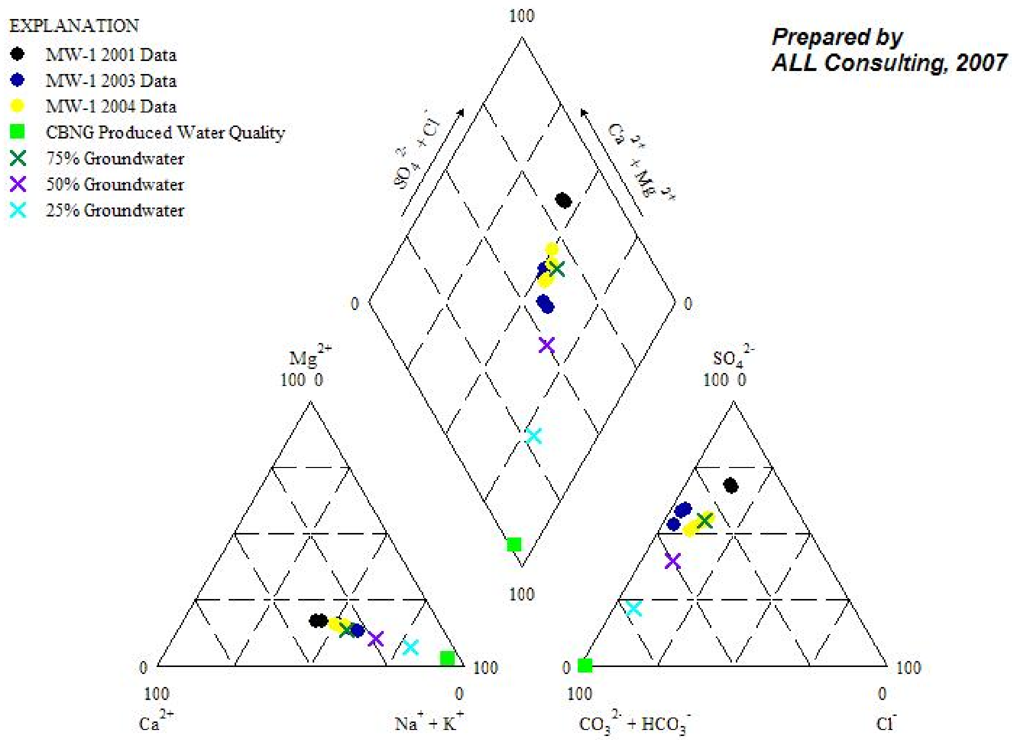

Figure 5-29: SAR and TDS Trends for Jeff 5 MW-1

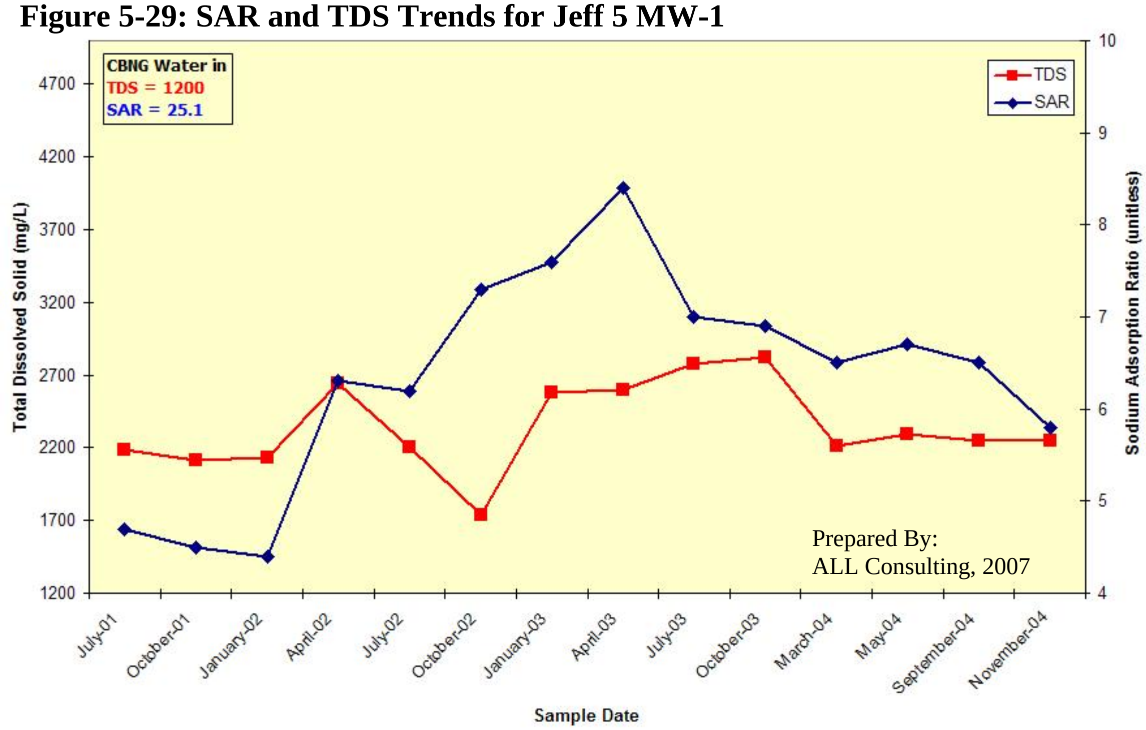

Figure 5-30: Anion Trend Data for the Jeff 5 MW-1

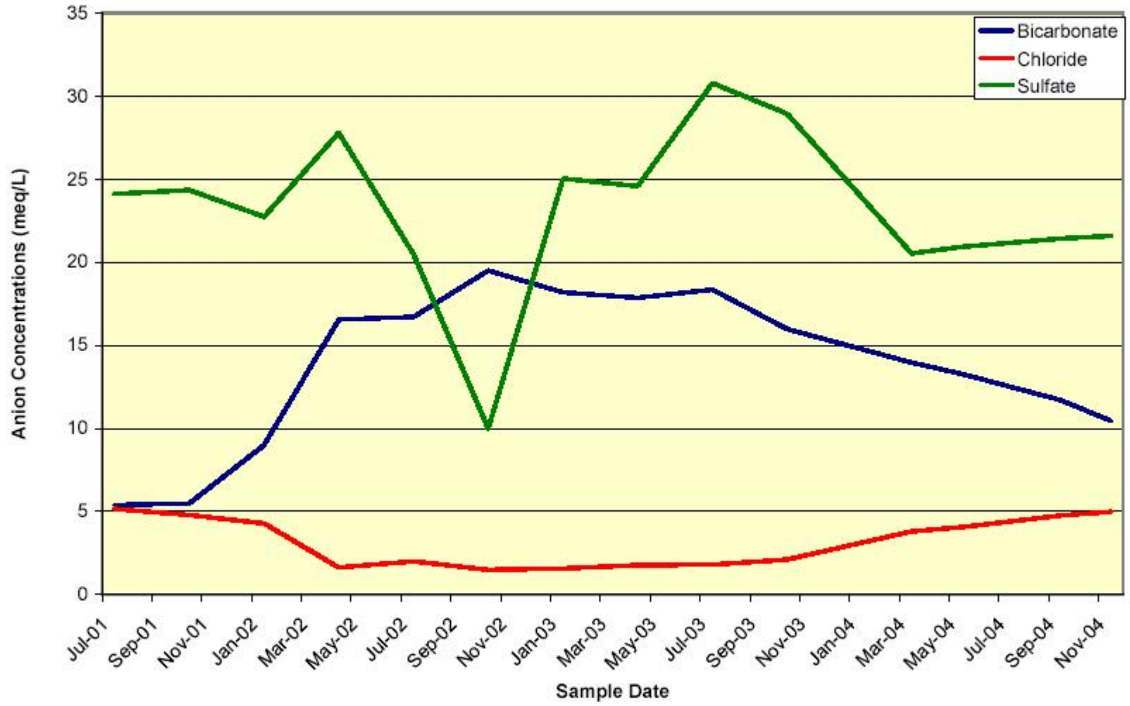

Figure 5-31: Cation Trend Data for the Jeff 5 MW-1

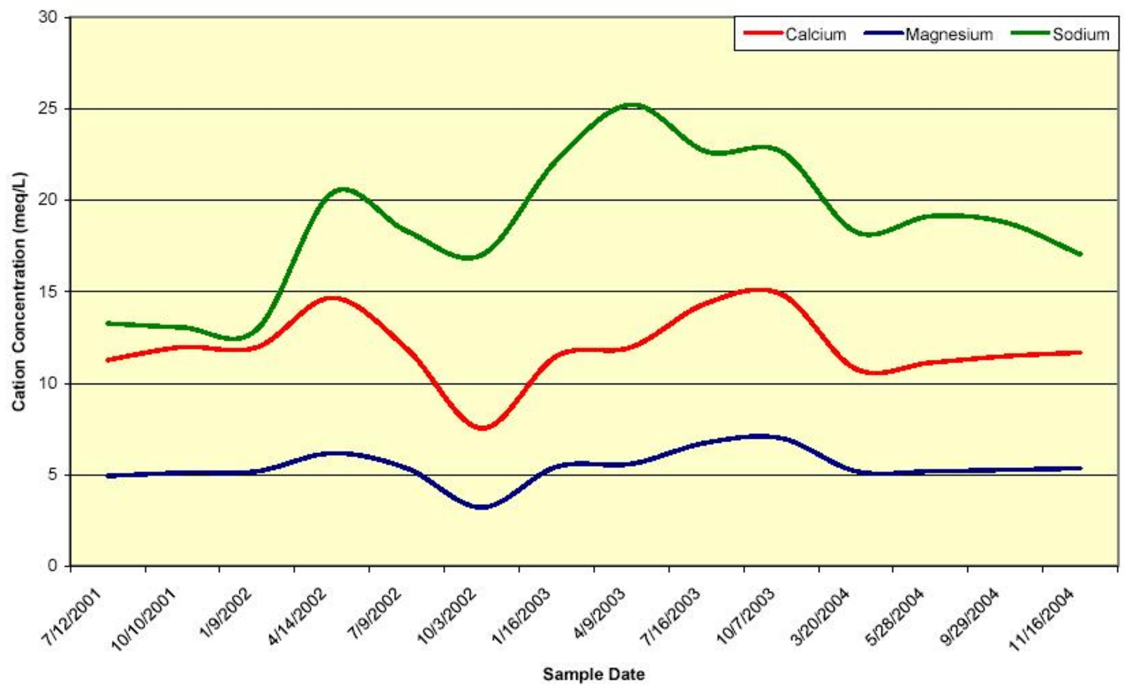

Figure 5-32: Piper Plot of Water Samples Collected from Jeff 5 MW-2

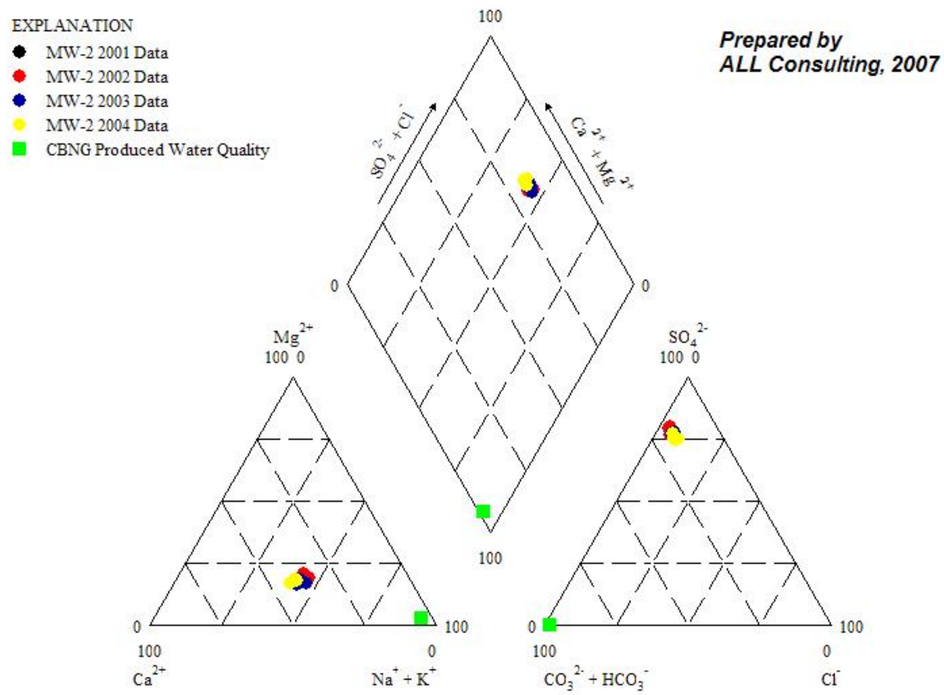

Figure 5-33: Piper Plot of Water Samples Collected from Jeff 5 MW-3

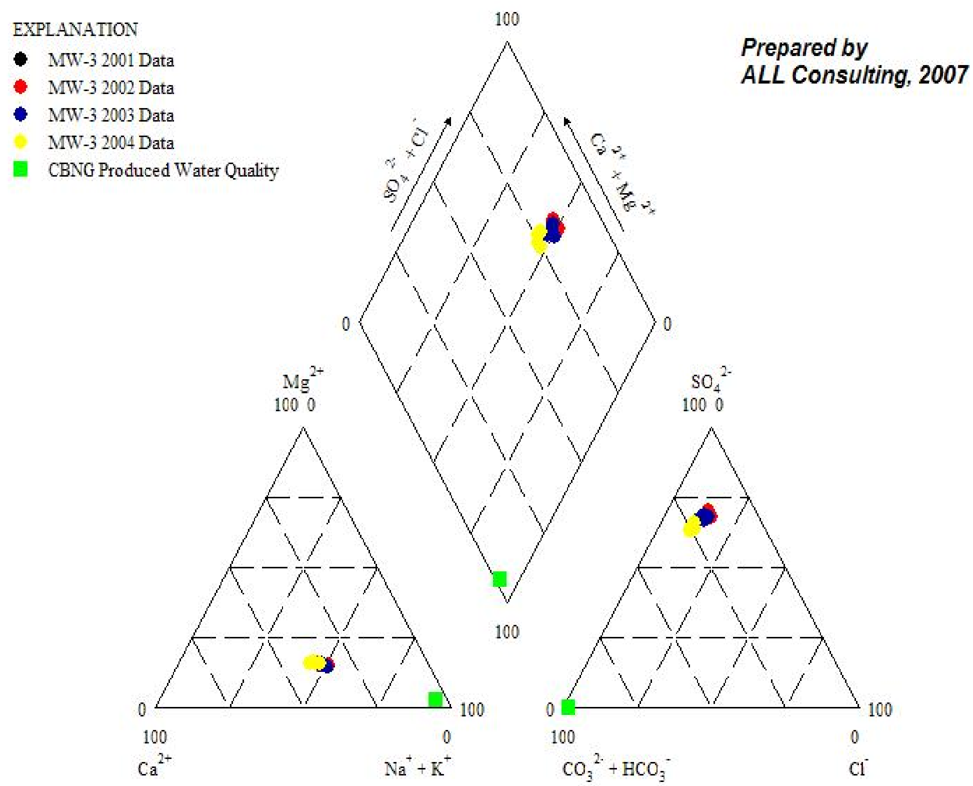

Figure 5-34: Piper Plot of Water Samples Collected from Jeff 5 MW-4

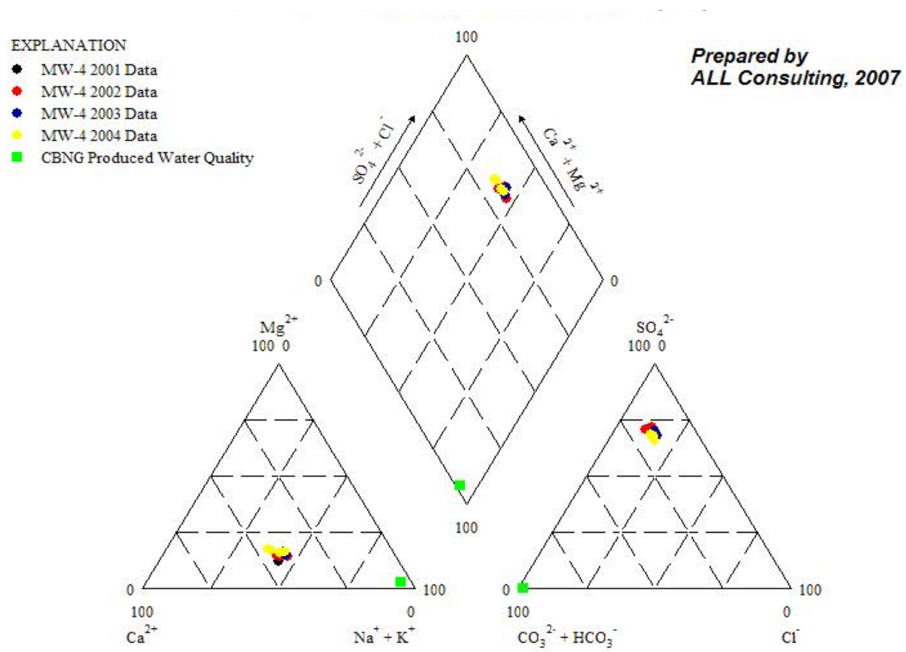

Figure 5-35: Piper Plot of Water Samples Collected from Jeff 5 MW-5

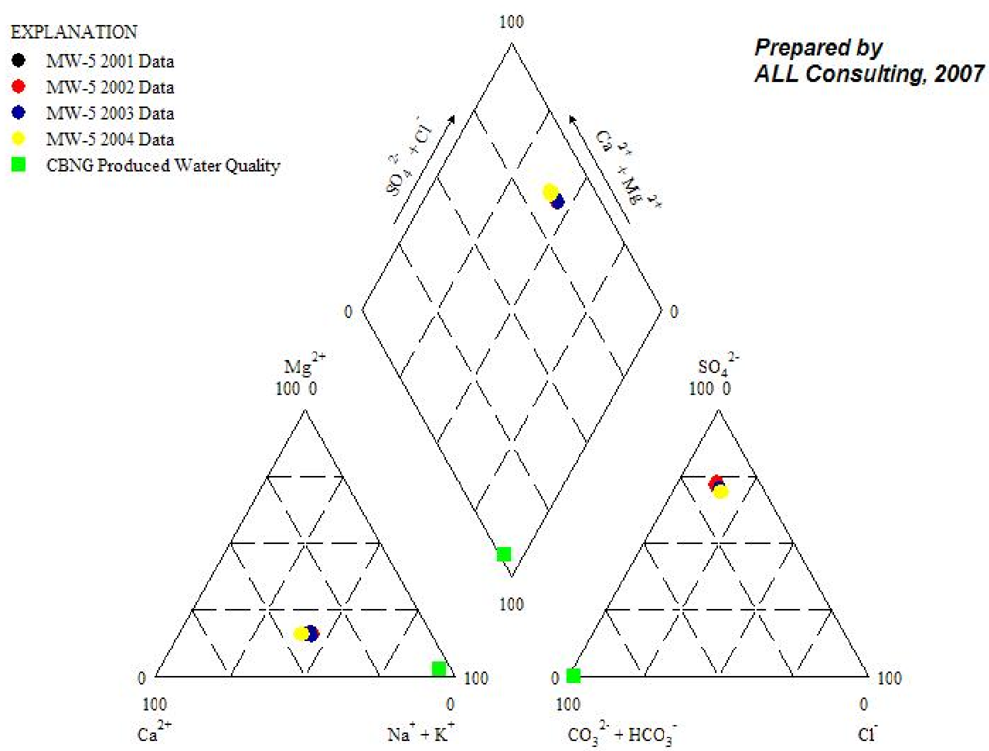

Figure 5-36: SAR and TDS Trends for Jeff 5 MW-2, MW-3, MW-4, and MW-5

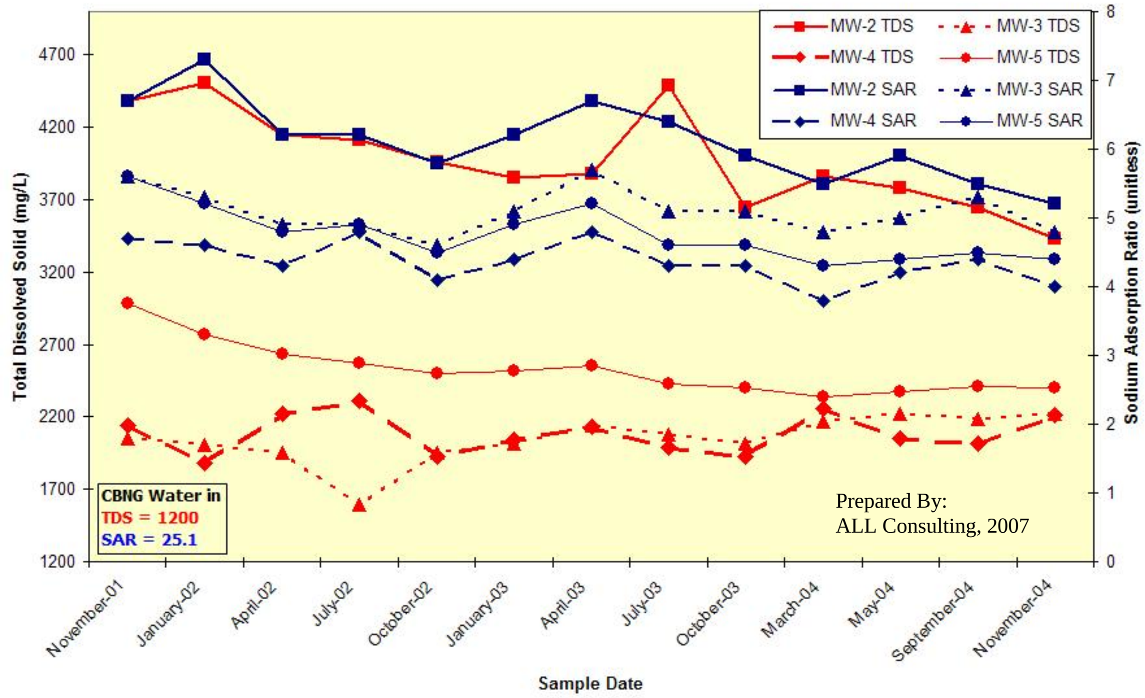

Figure 5-37: Anion Trend Data for the Jeff 5 MW-2

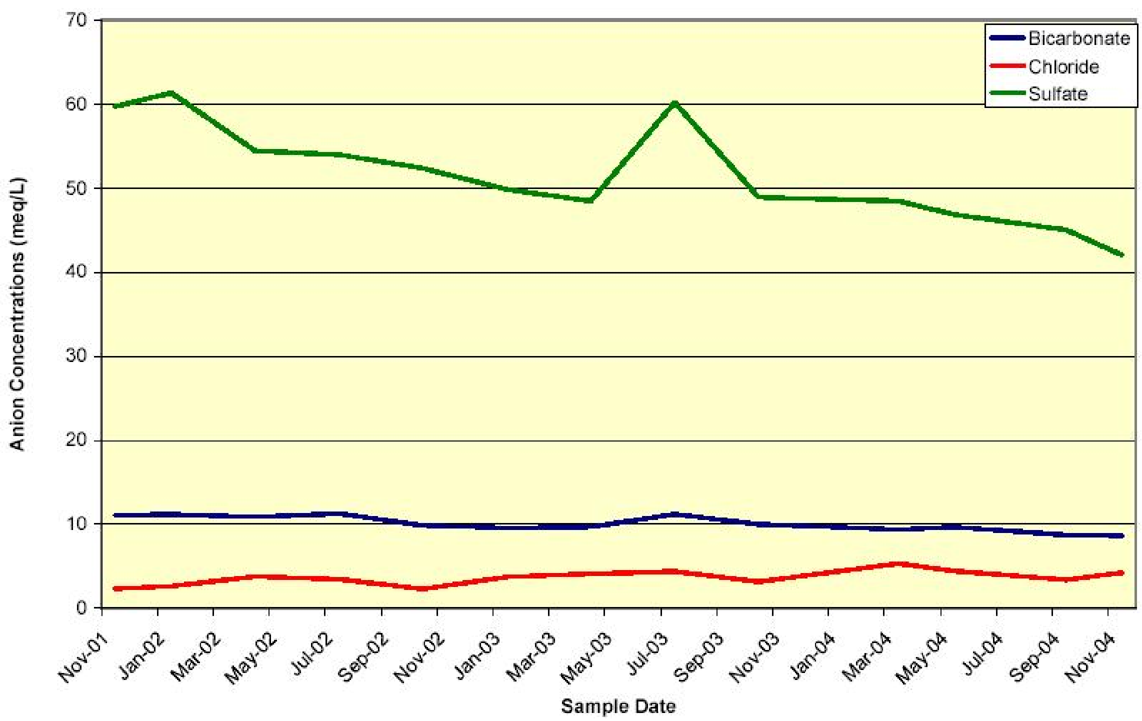

Figure 5-38: Anion Trend Data for the Jeff 5 MW-3

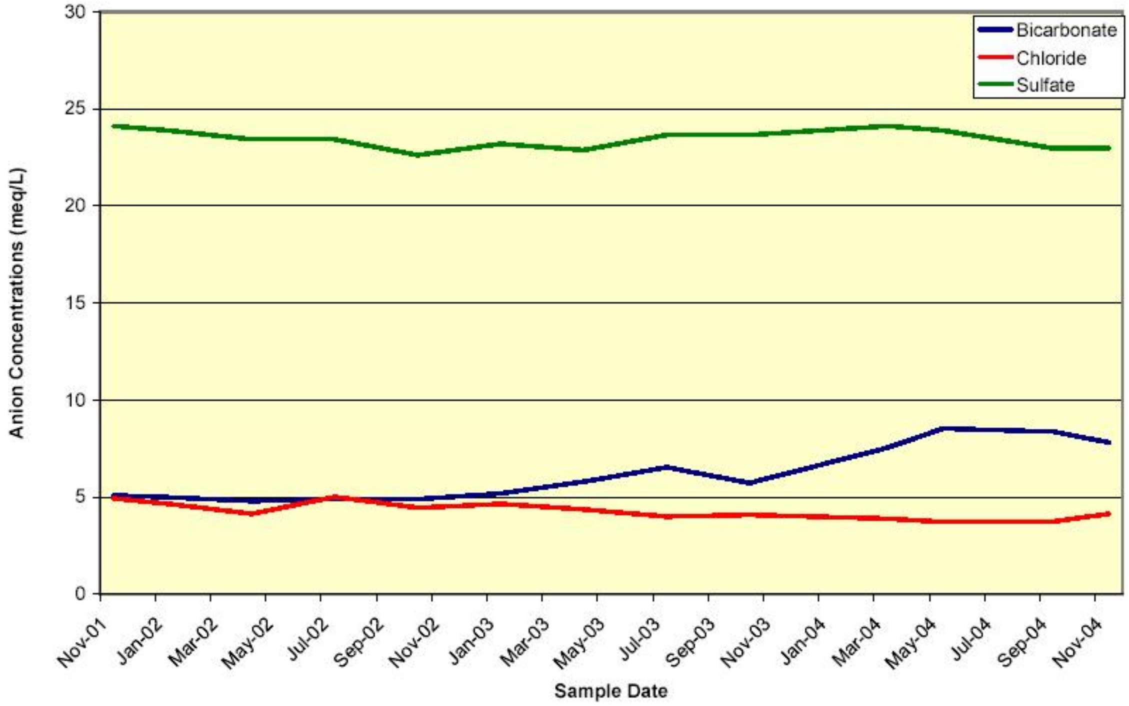

Figure 5-39: Anion Trend Data for the Jeff 5 MW-4

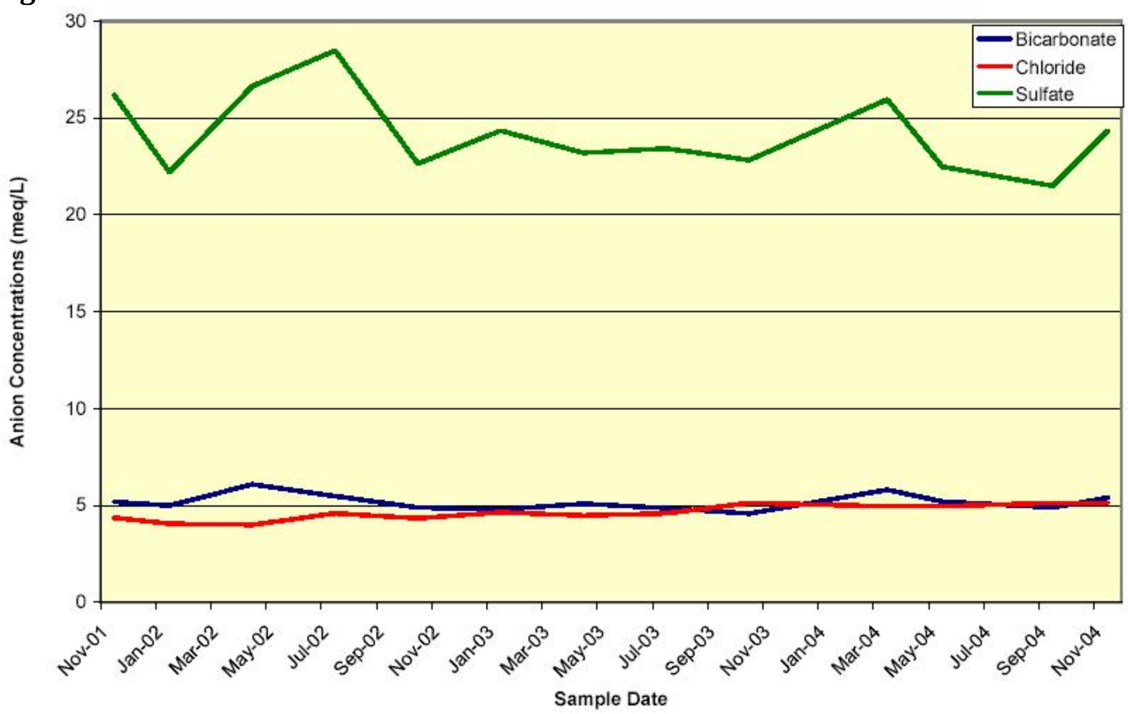

Figure 5-40: Anion Trend Data for the Jeff 5 MW-5

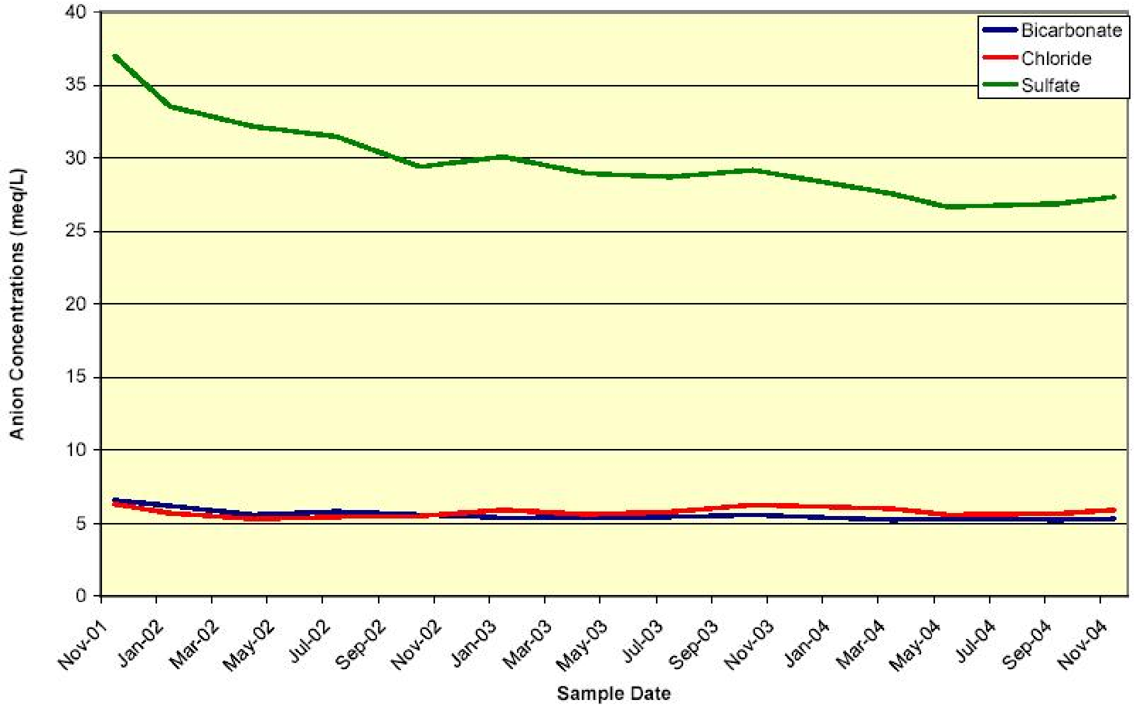

Figure 5-41: Cation Trend Data for the Jeff 5 MW-2

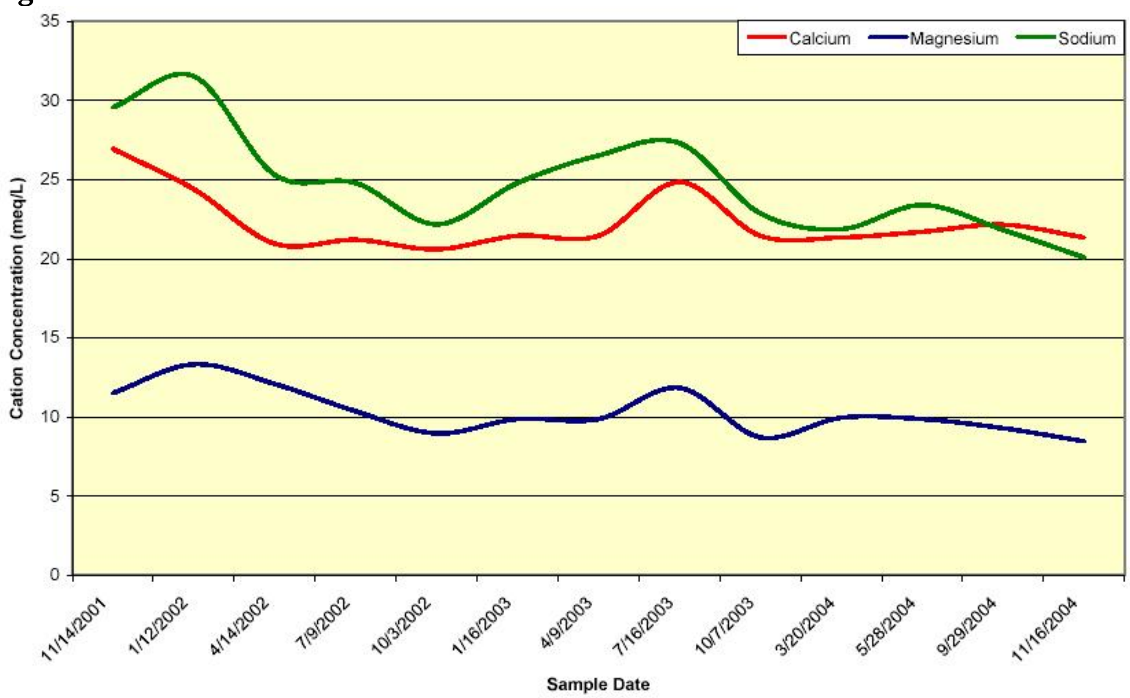

Figure 5-42: Cation Trend Data for the Jeff 5 MW-3

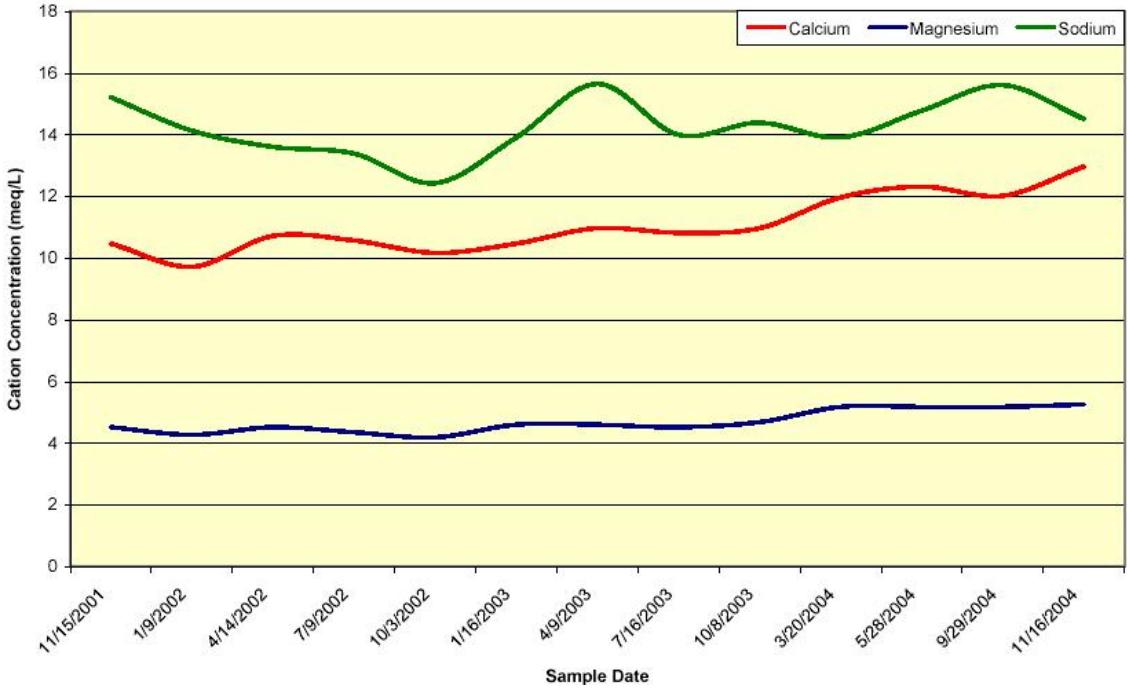

Figure 5-43: Cation Trend Data for the Jeff 5 MW-4

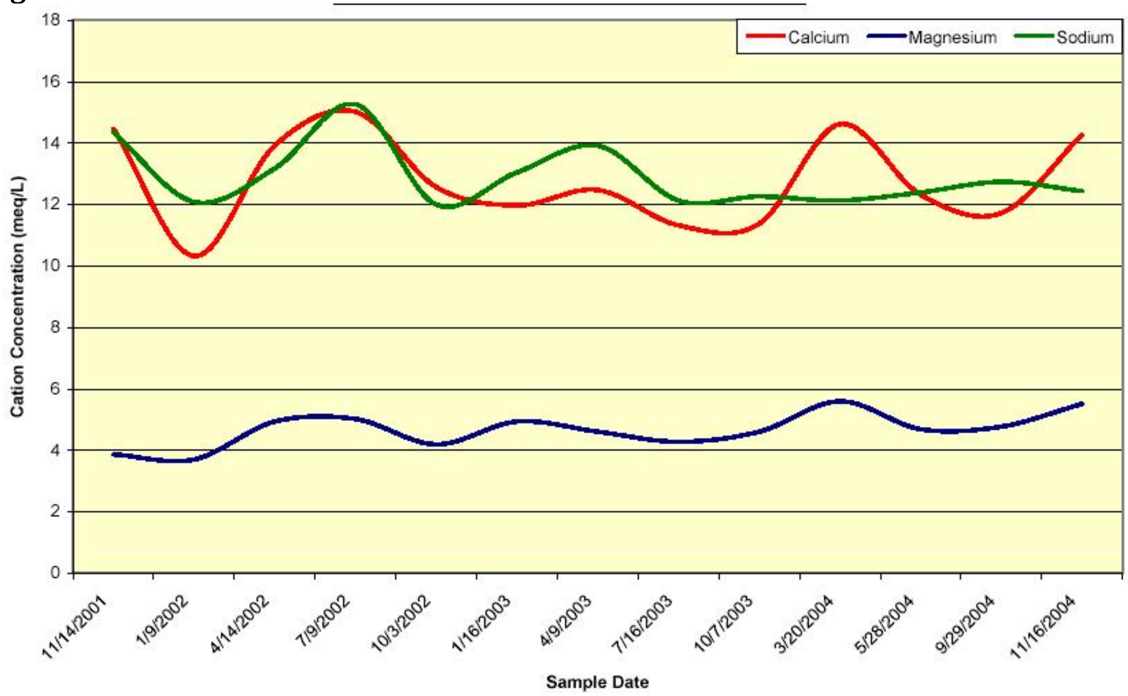

Figure 5-44: Cation Trend Data for the Jeff 5 MW-5

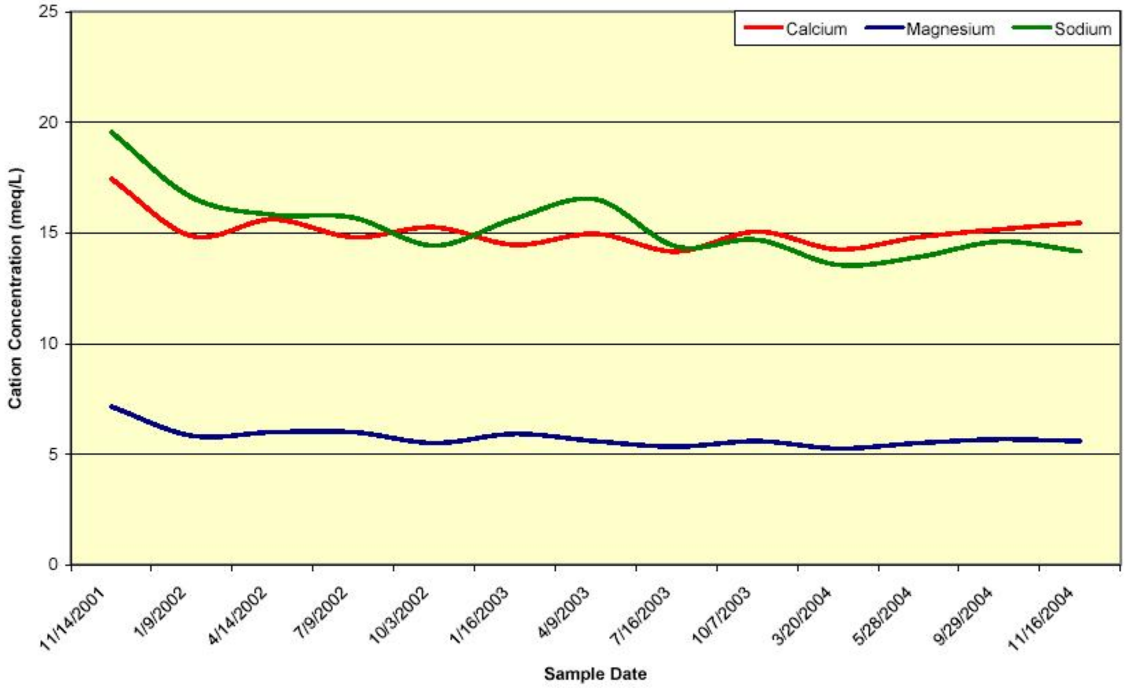

Figure 5-45: Piper Plot of Water Samples Collected from Jeff 6 MW-1

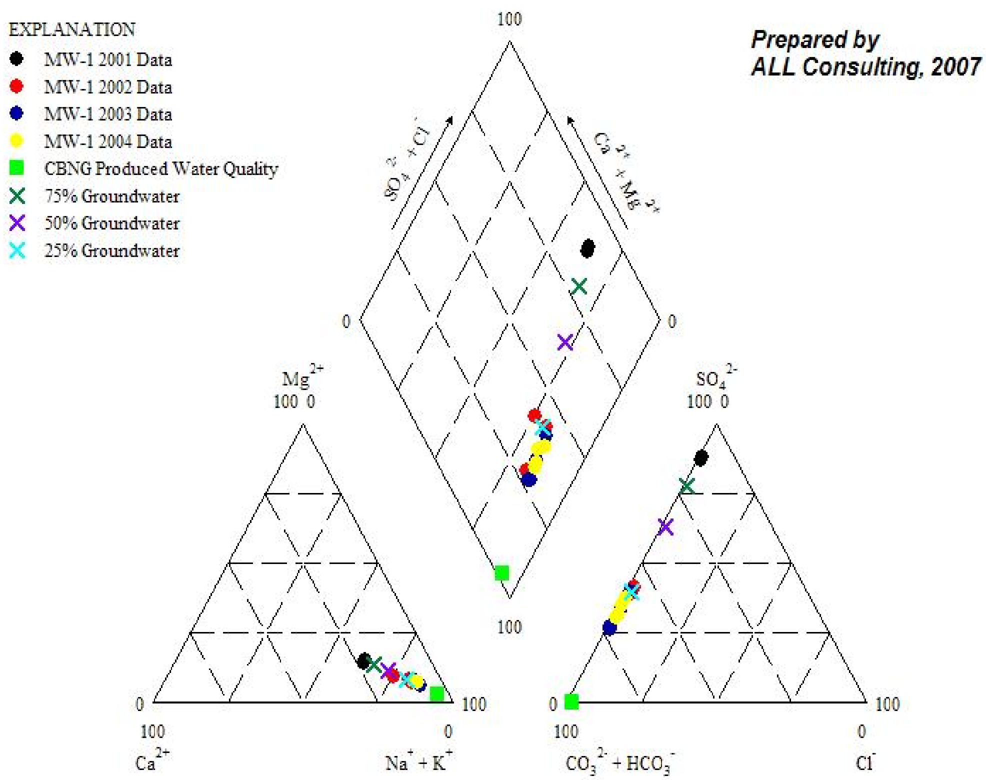

Figure 5-46: Piper Plot for Jeff 6 MW-1 Years 2001-2002

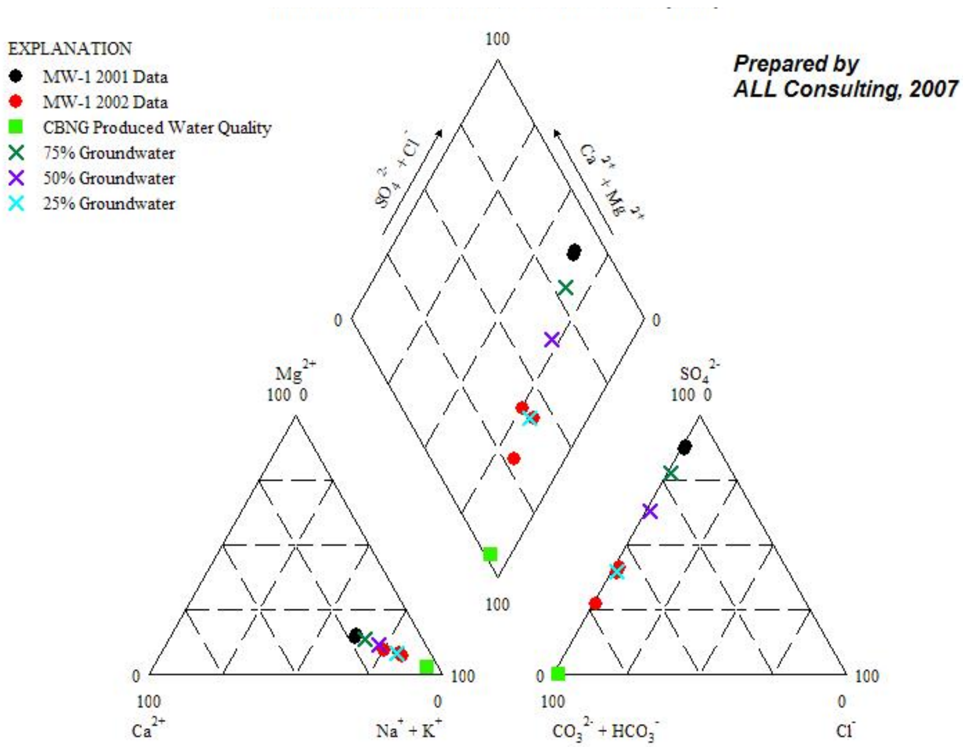

Figure 5-47: Piper Plot for Jeff 6 MW-1 Years 2003-2004

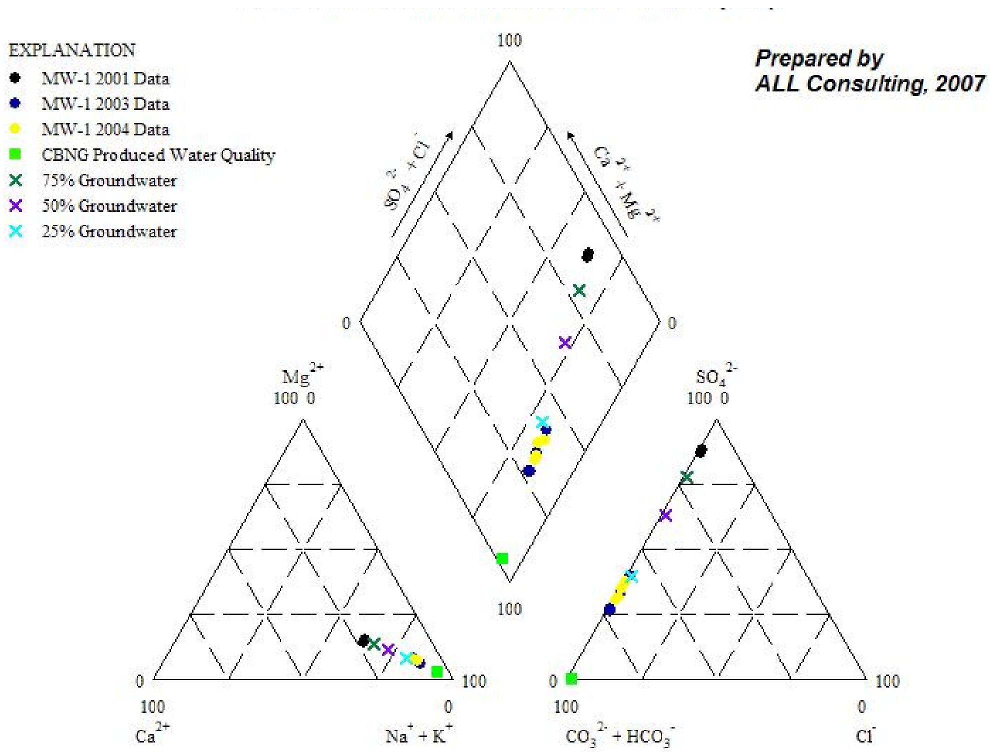

Figure 5-48: SAR and TDS Trends for Jeff 6 MW-1

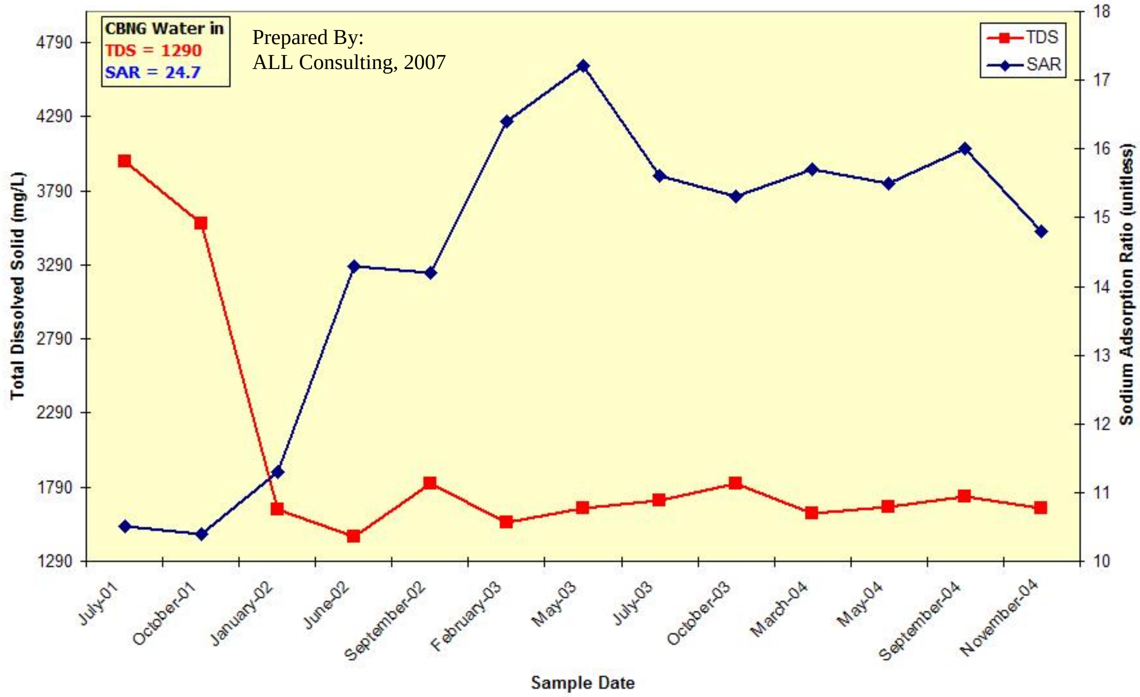

Figure 5-49: Anion Trend Data for the Jeff 6 MW-1

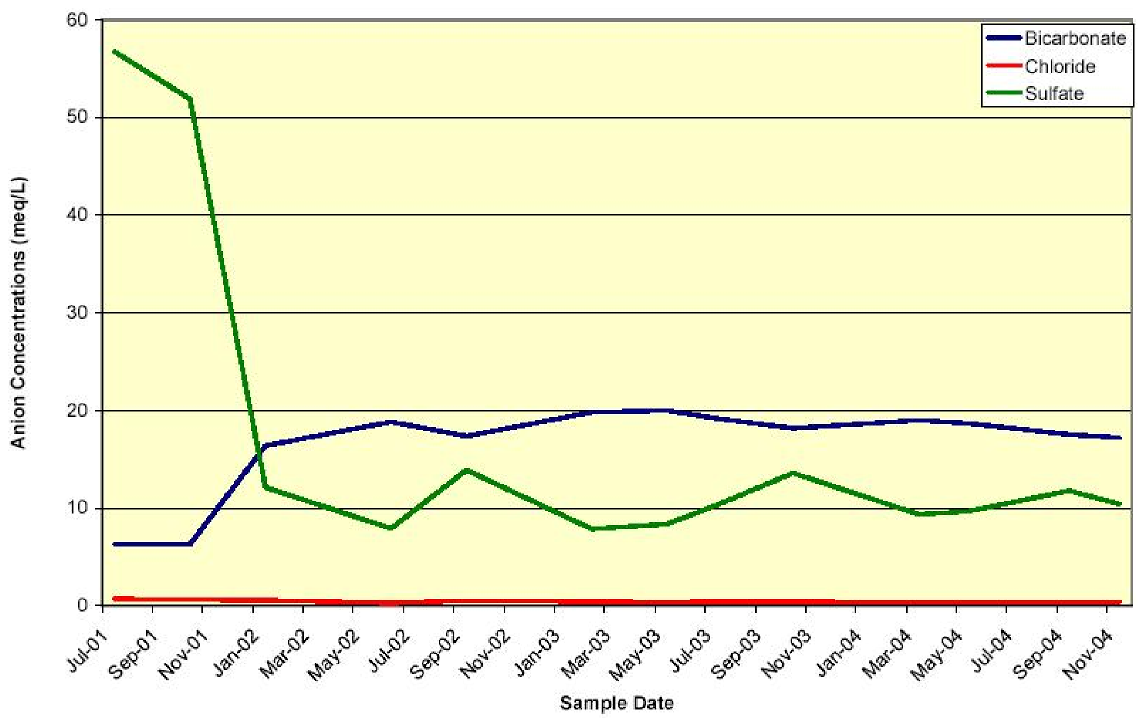

Figure 5-50: Cation Trend Data for the Jeff 6 MW-1

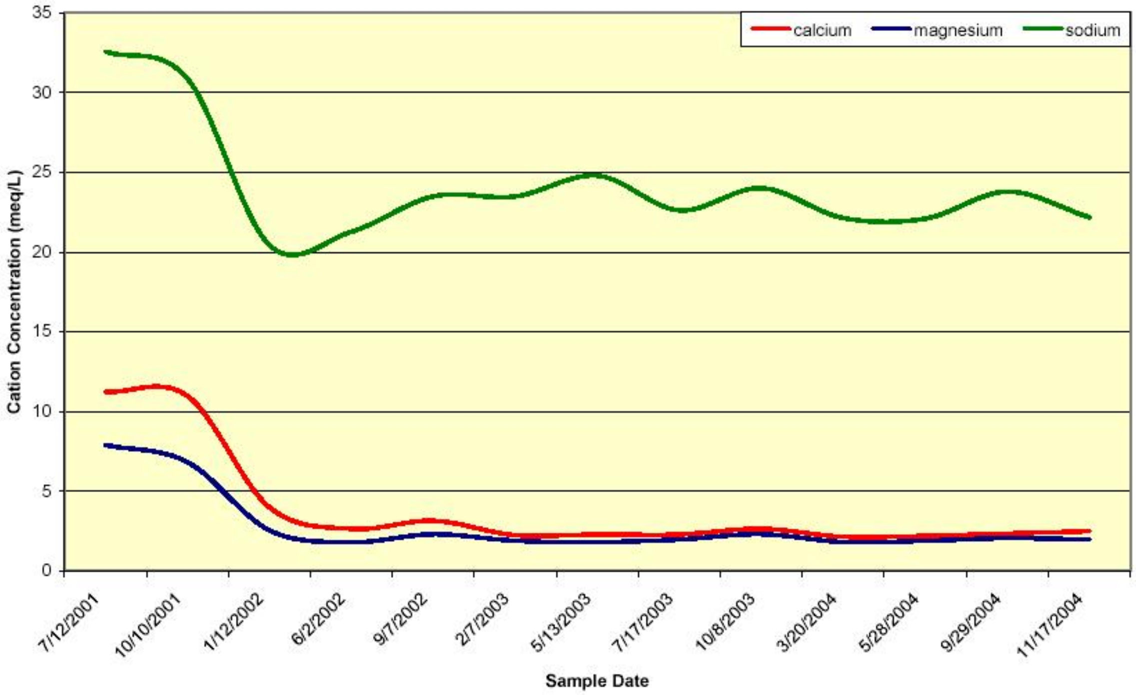

Figure 5-51: Piper Plot of Water Samples Collected from Jeff 7 Monitoring Wells

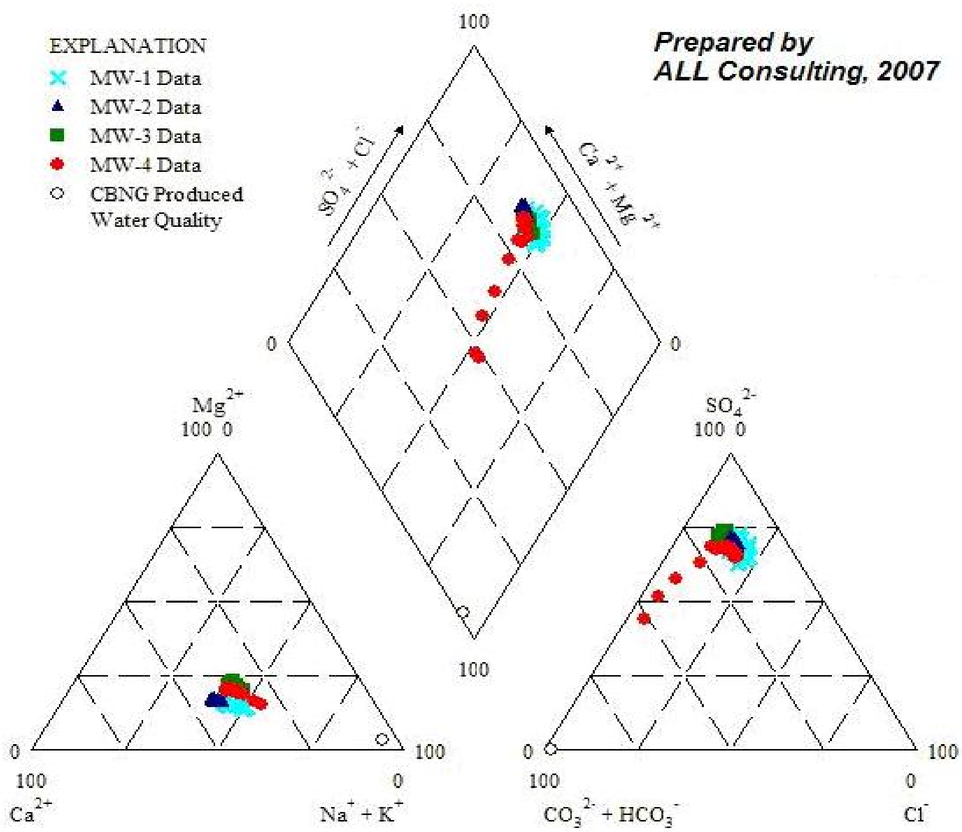

Figure 5-52: Piper Plot for Jeff 7 MW-4

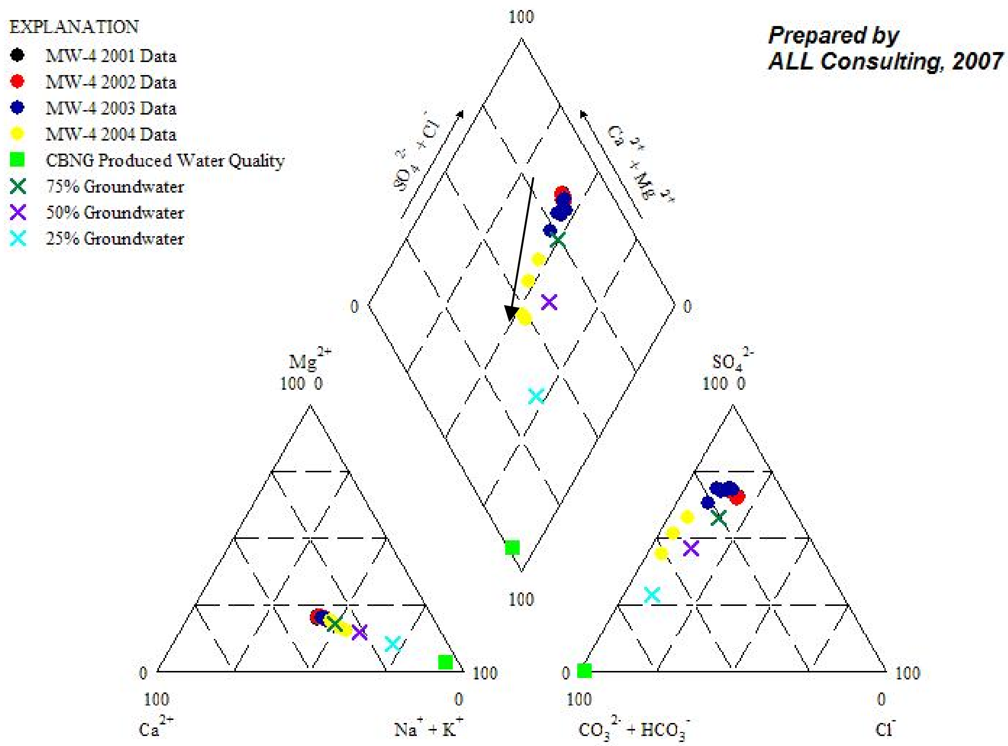

Figure 5-53: Piper Plot for Jeff 7 MW-4 Years 2001-2002

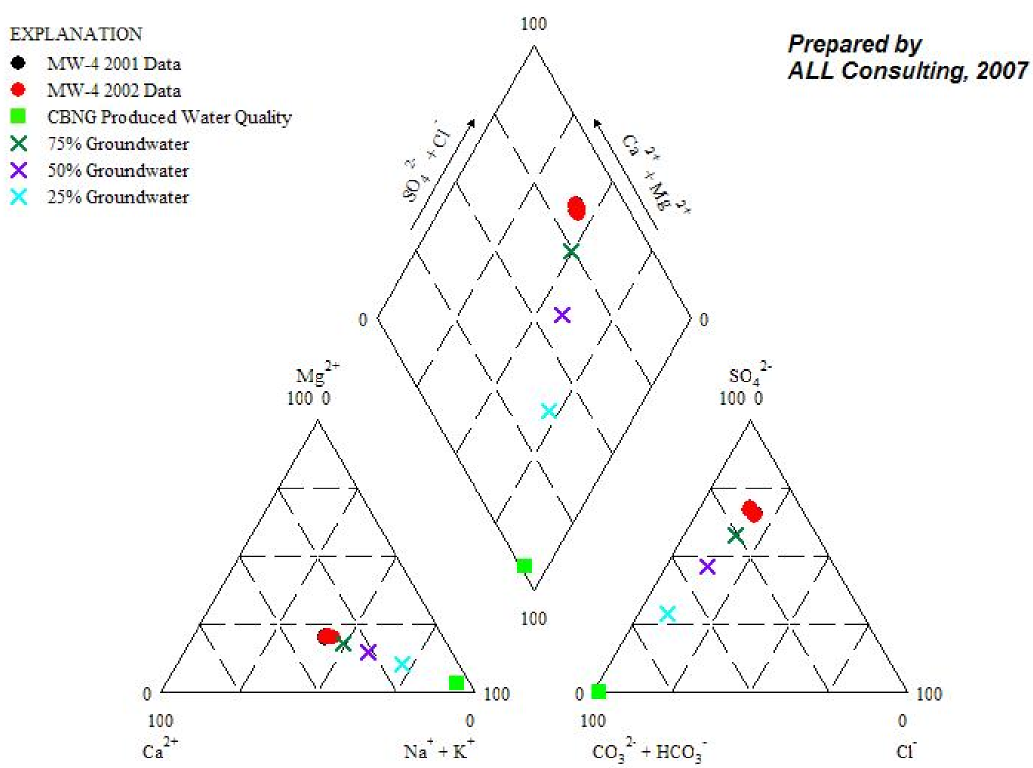

Figure 5-54: Piper Plot for Jeff 7 MW-4 Years 2003-2004

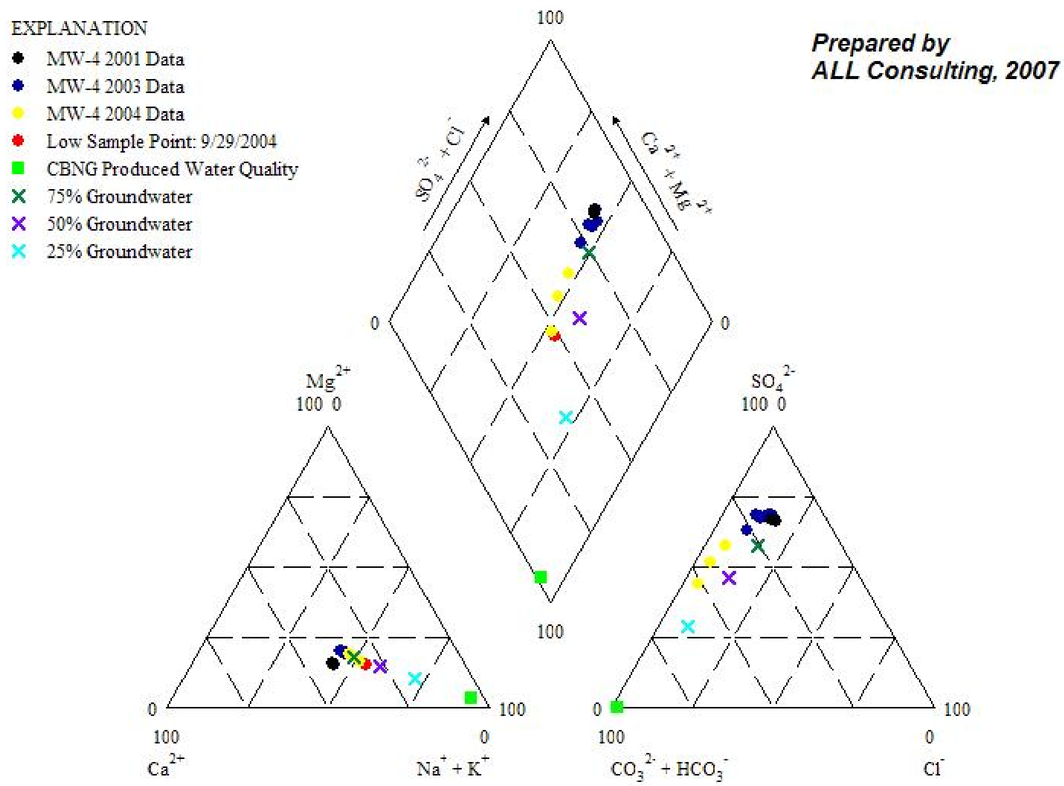

Figure 5-55: SAR and TDS Trends for Jeff 7 MW-4

Prepared By:
ALL Consulting, 2007

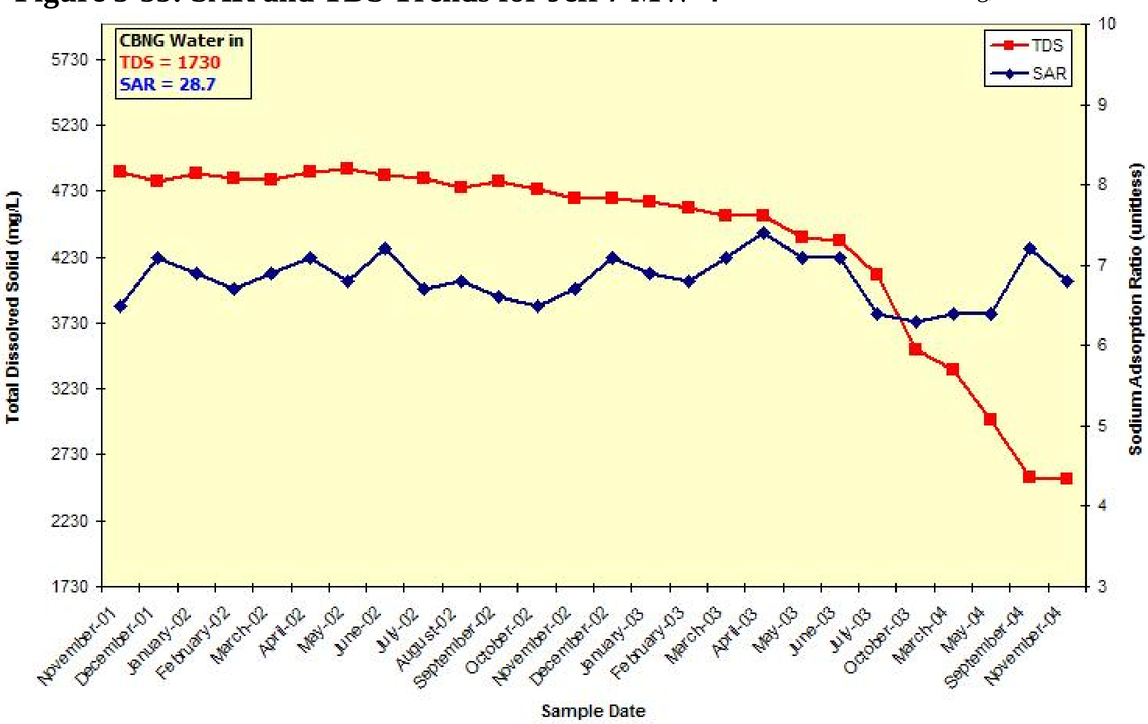

Figure 5-56: Anion Trend Data for the Jeff 7 MW-4

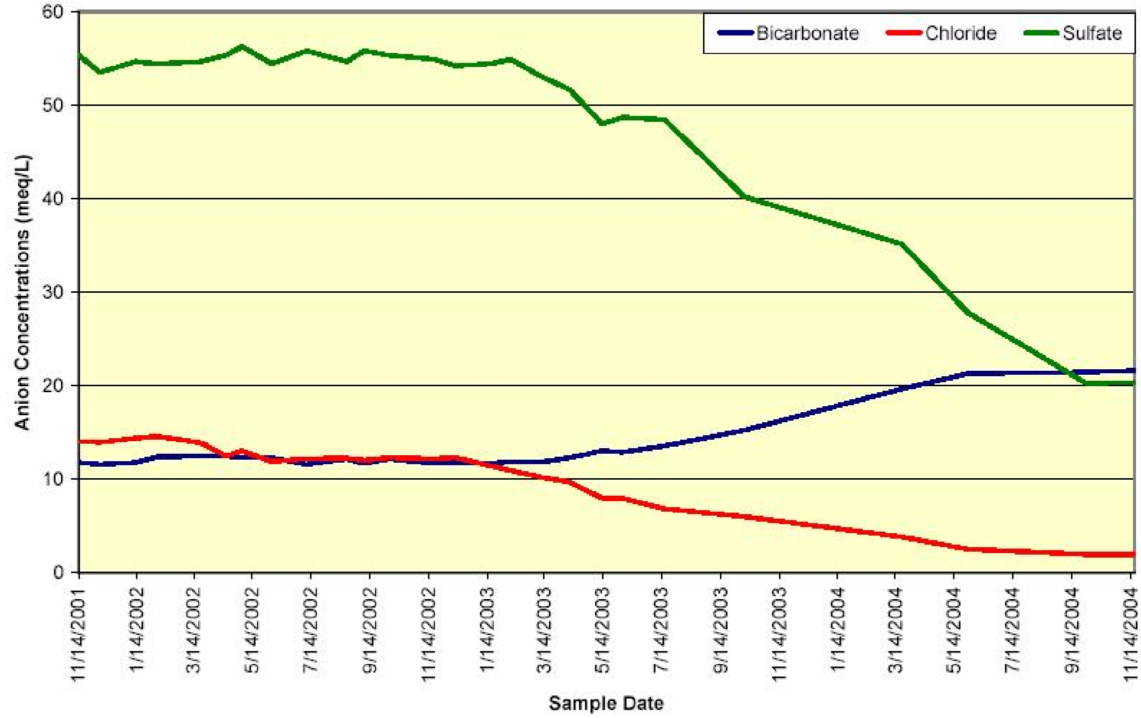

Figure 5-57: Cation Trend Data for the Jeff 7 MW-4

Figure 5-58: Piper Plot for Jeff 7 MW-1

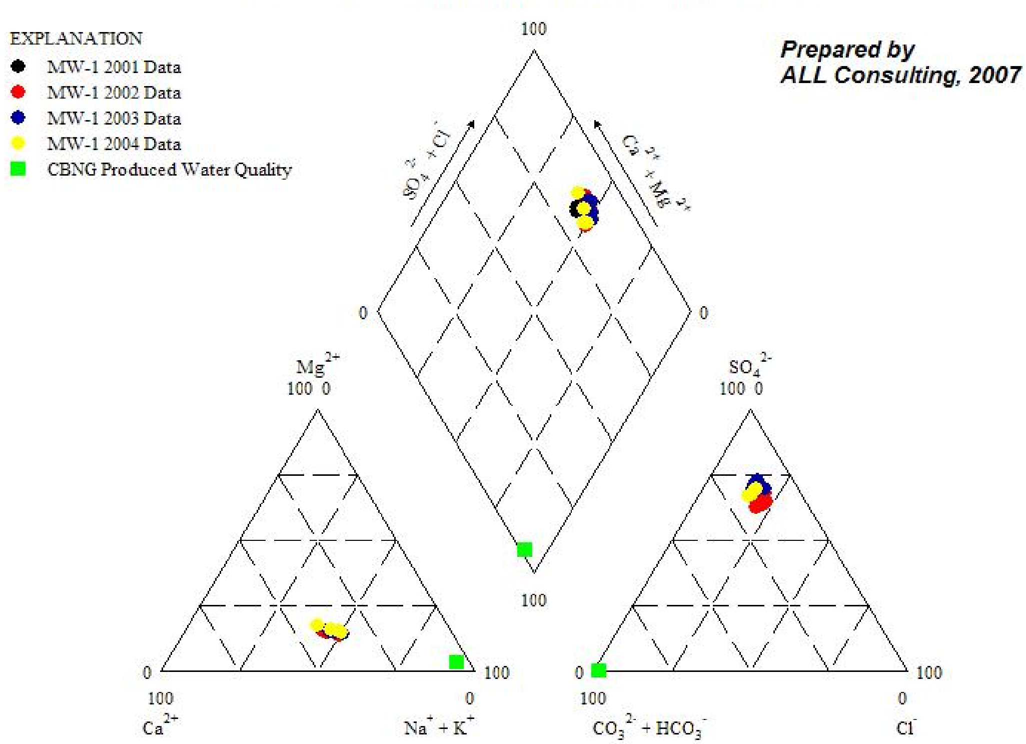

Figure 5-59: Piper Plot for Jeff 7 MW-2

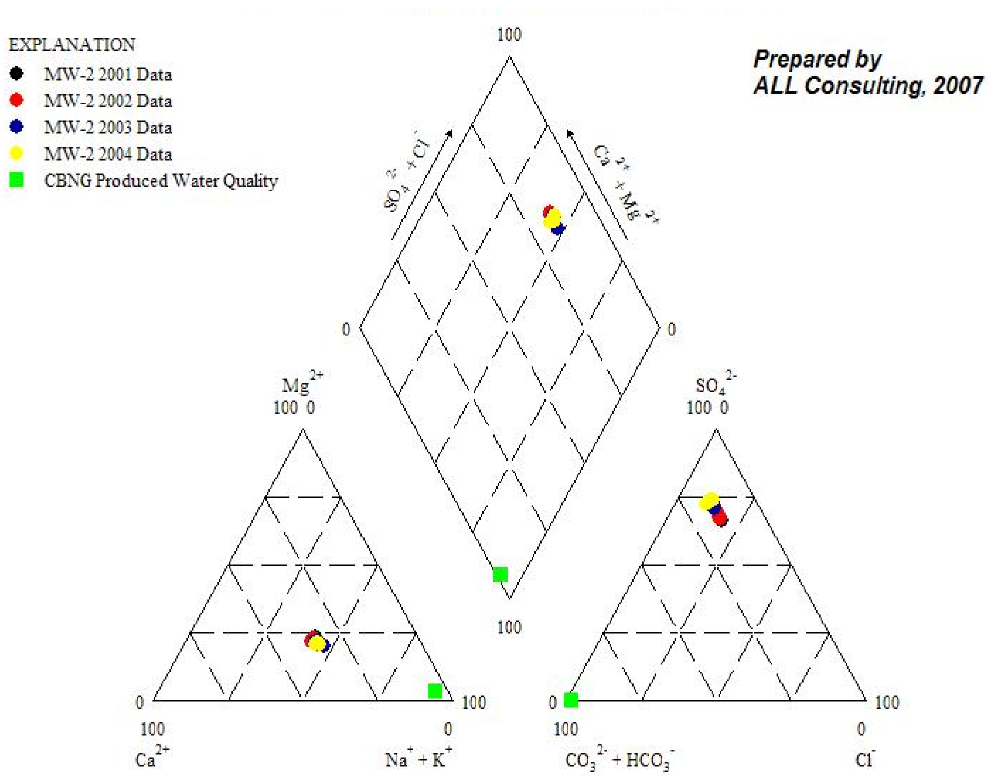

Figure 5-60: Piper Plot for Jeff 7 MW-3

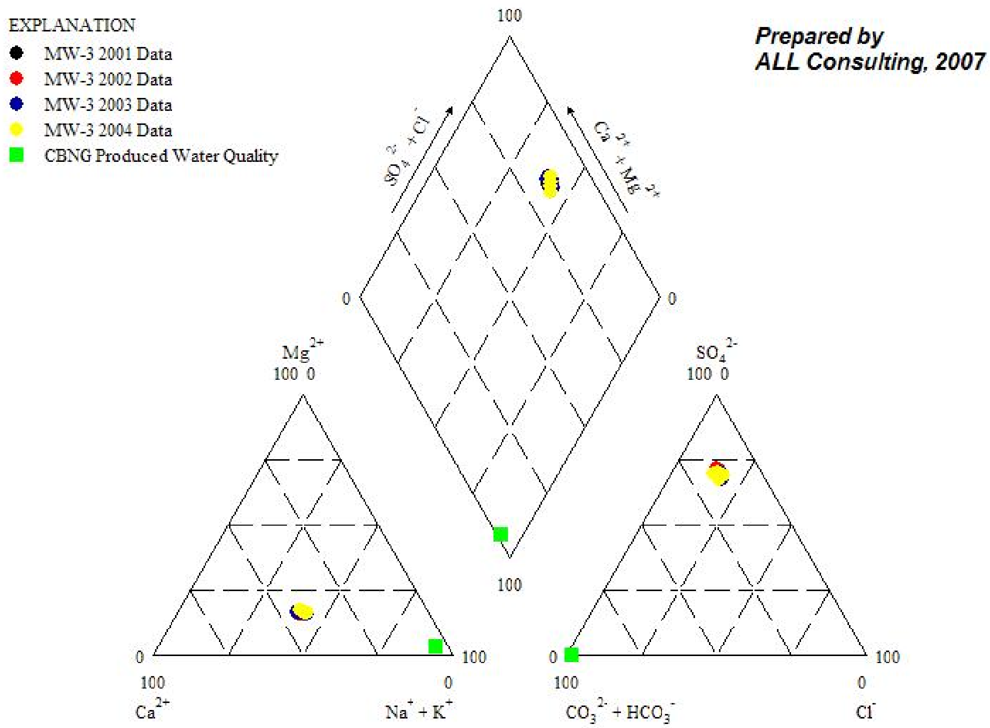

Figure 5-61: SAR and TDS Trends for Jeff 7 MW-1, MW-2, and MW-3

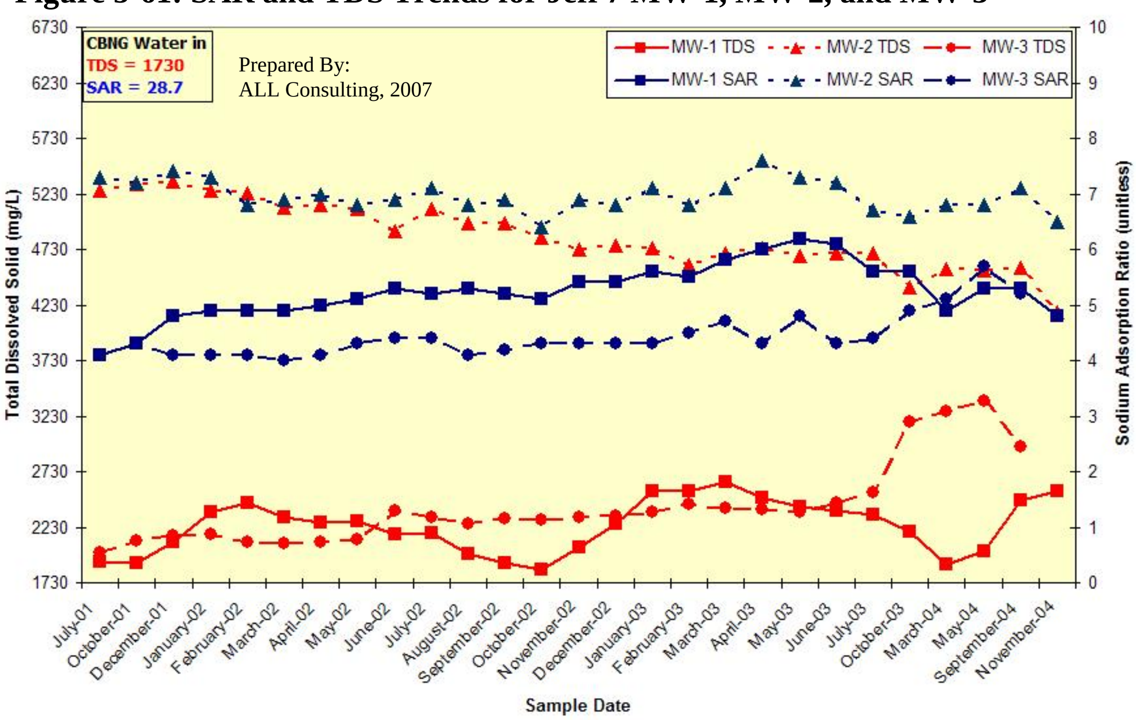

Figure 5-62: Anion Trend Data for the Jeff 7 MW-1

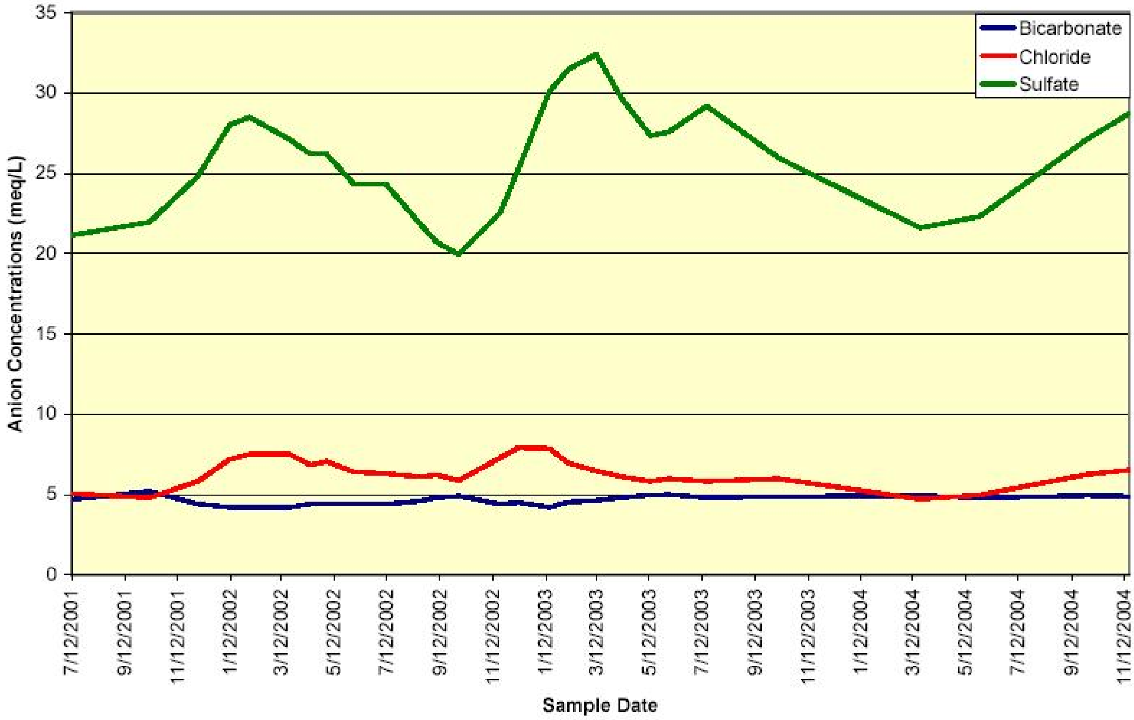

Figure 5-63: Anion Trend Data for the Jeff 7 MW-2

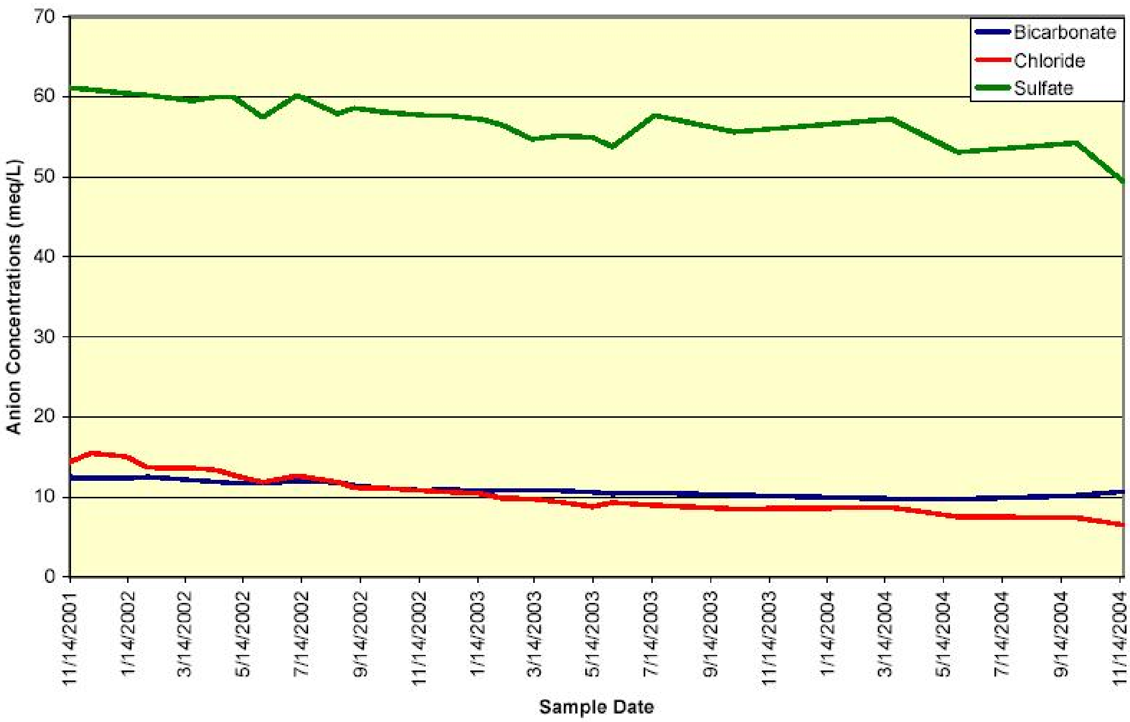

Figure 5-64: Anion Trend Data for the Jeff 7 MW-3

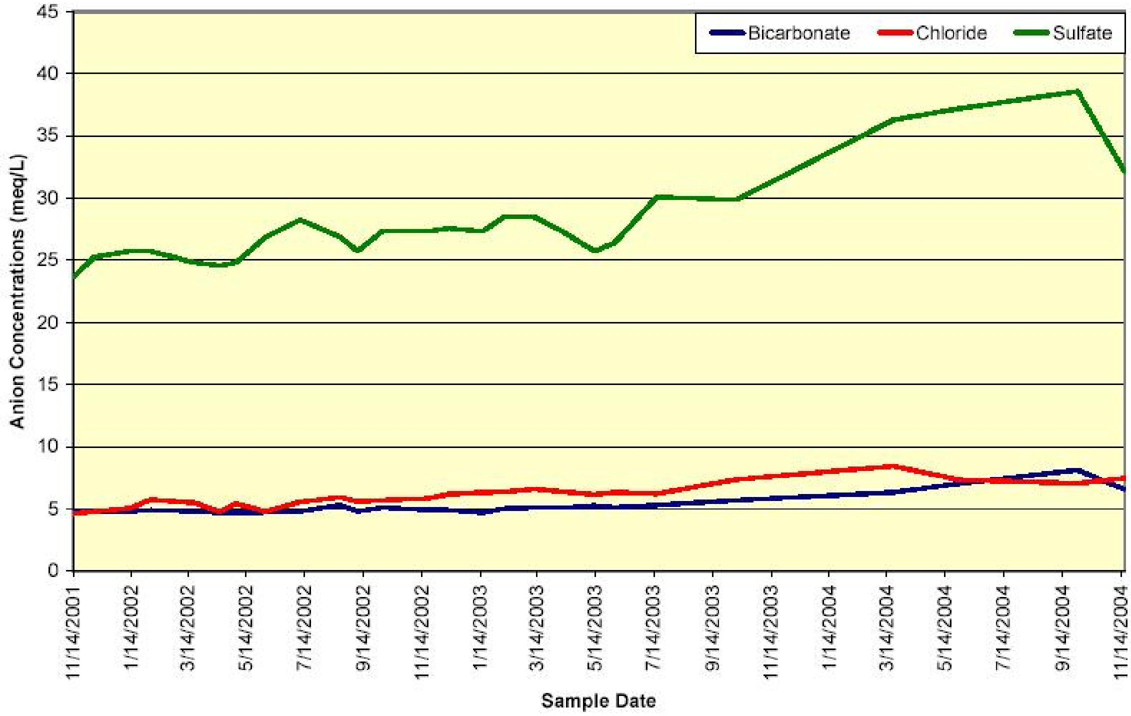

Figure 5-65: Cation Trend Data for the Jeff 7 MW-1

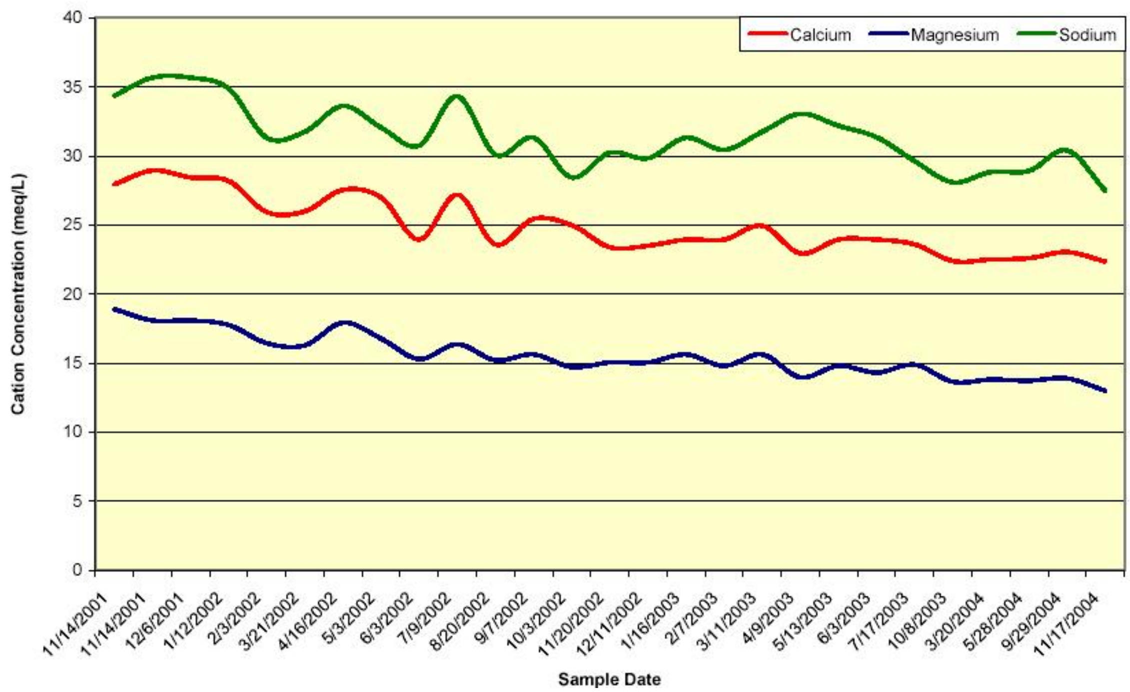

Figure 5-66: Cation Trend Data for the Jeff 7 MW-2

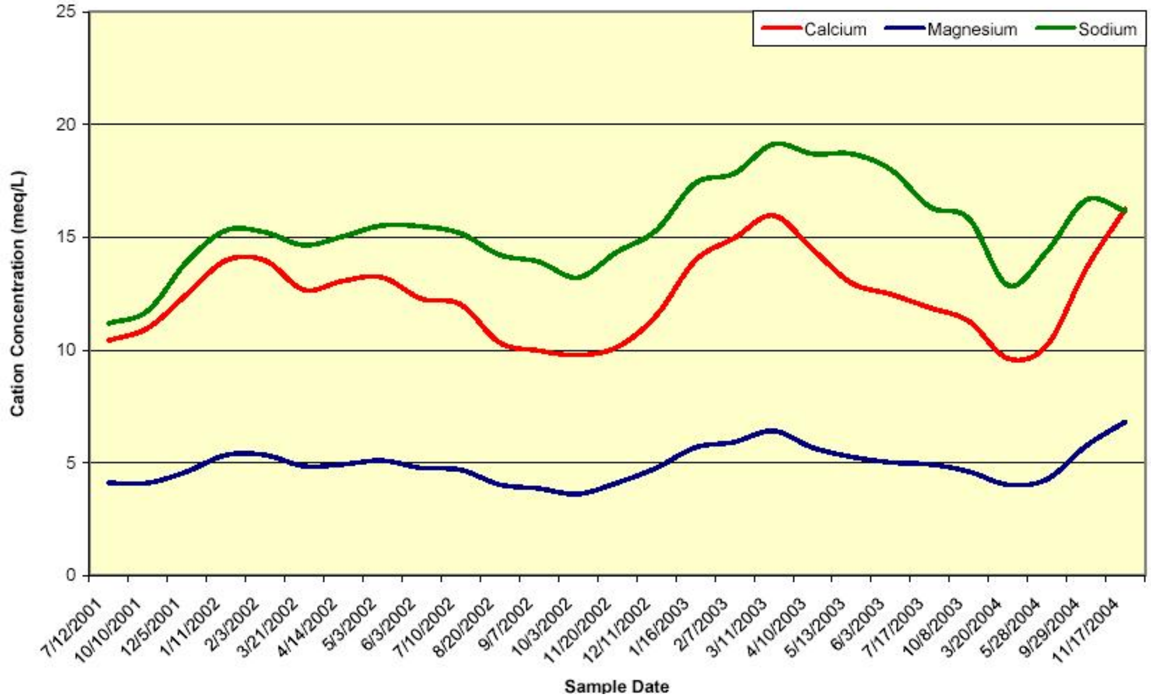

Figure 5-67: Cation Trend Data for the Jeff 7 MW-3

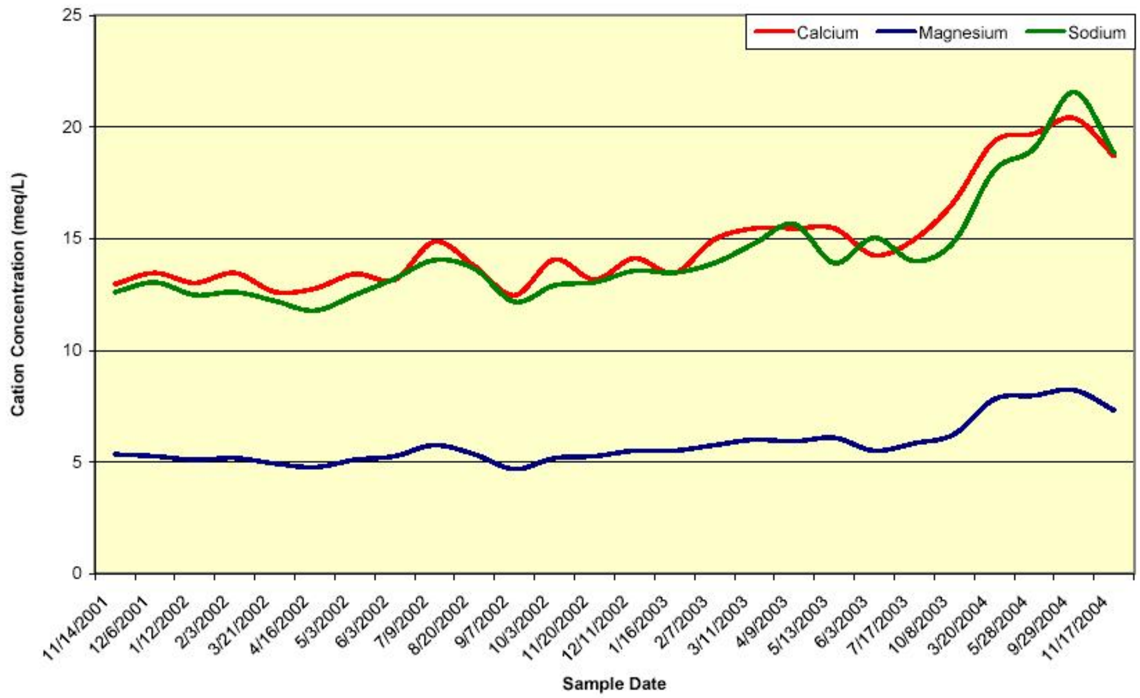

Figure 5-68: Piper Diagram of Water Samples Collected from the Phil's Pond MW-1

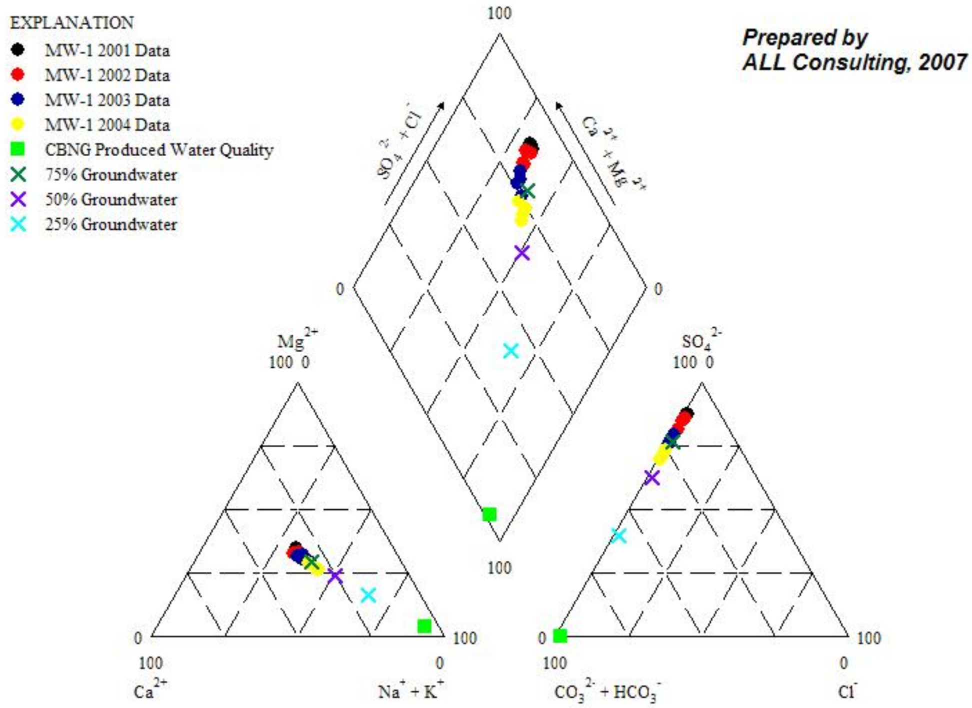

Figure 5-69: Piper Plot for Phil's Pond MW-1 Year 2001-2002

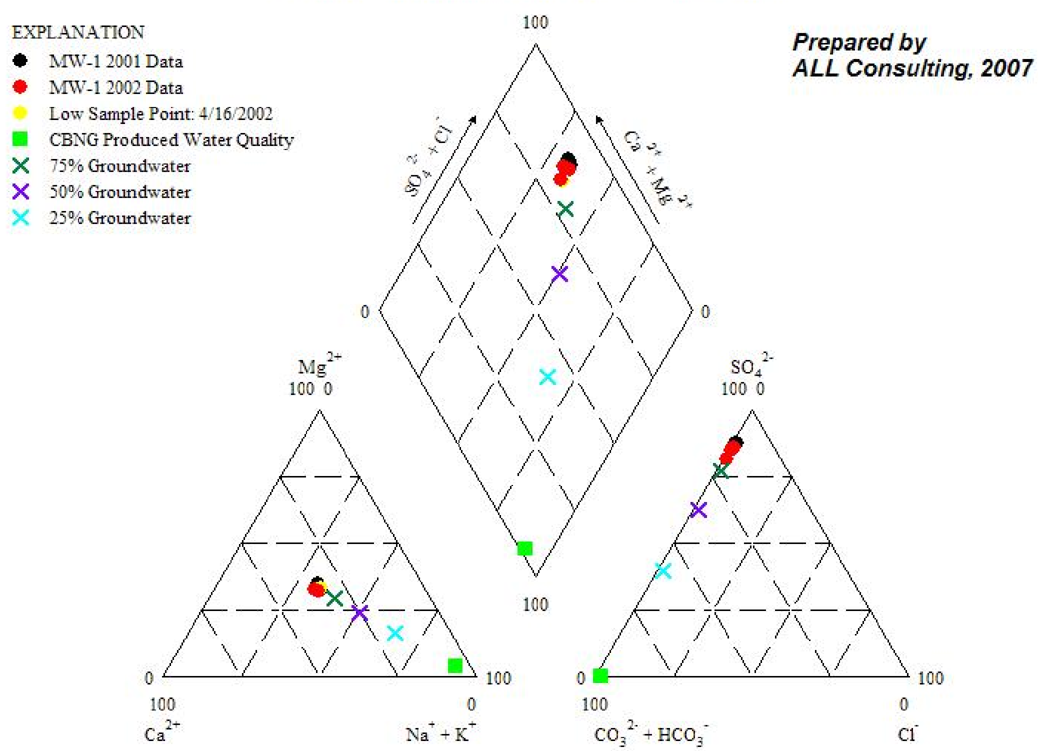

Figure 5-70: Piper Plot for Phil's Pond MW-1 Year 2003-2004

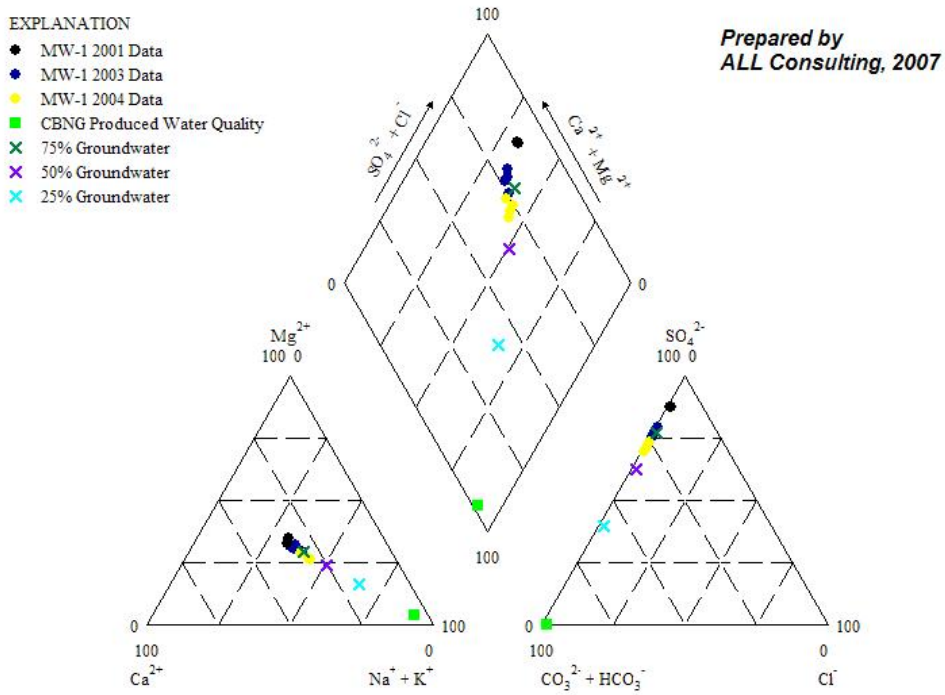

Figure 5-71: SAR and TDS Trends for Phil's Pond MW-1

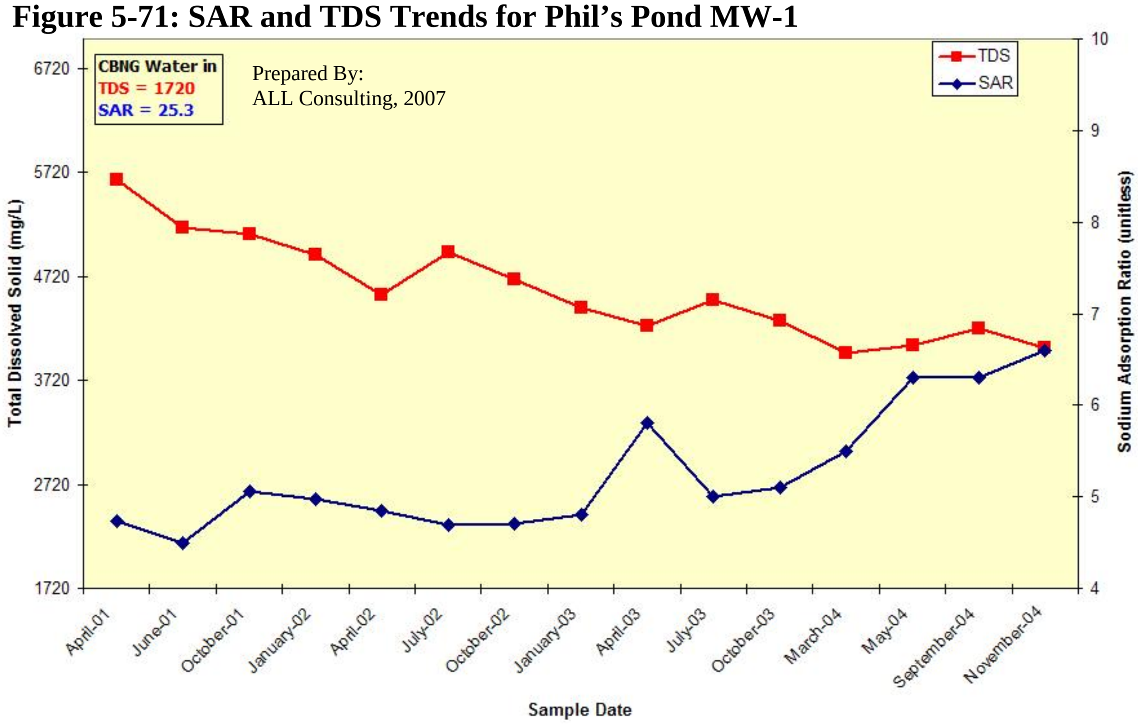

Figure 5-72: Anion Trend Data for the Phils Pond MW-1

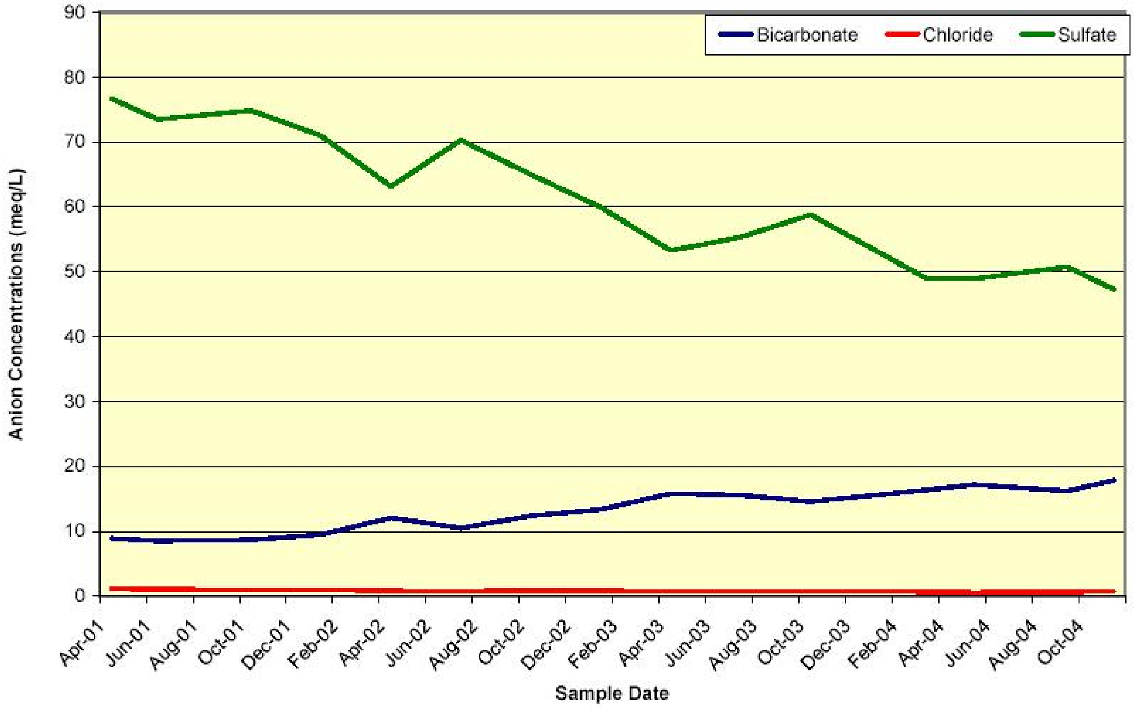

Figure 5-73: Cation Trend Data for the Phils Pond MW-1

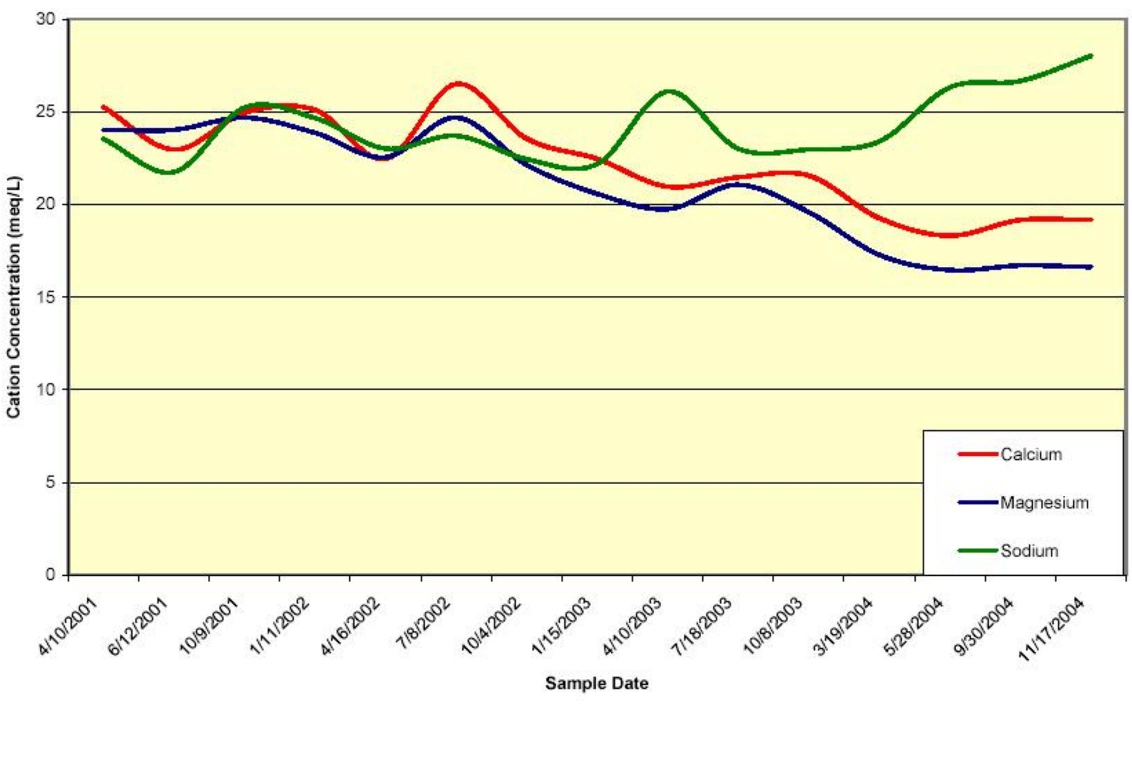

Figure 5-74: Piper Plot Diagram of Water Samples Collected from the Candida 2 MW-1

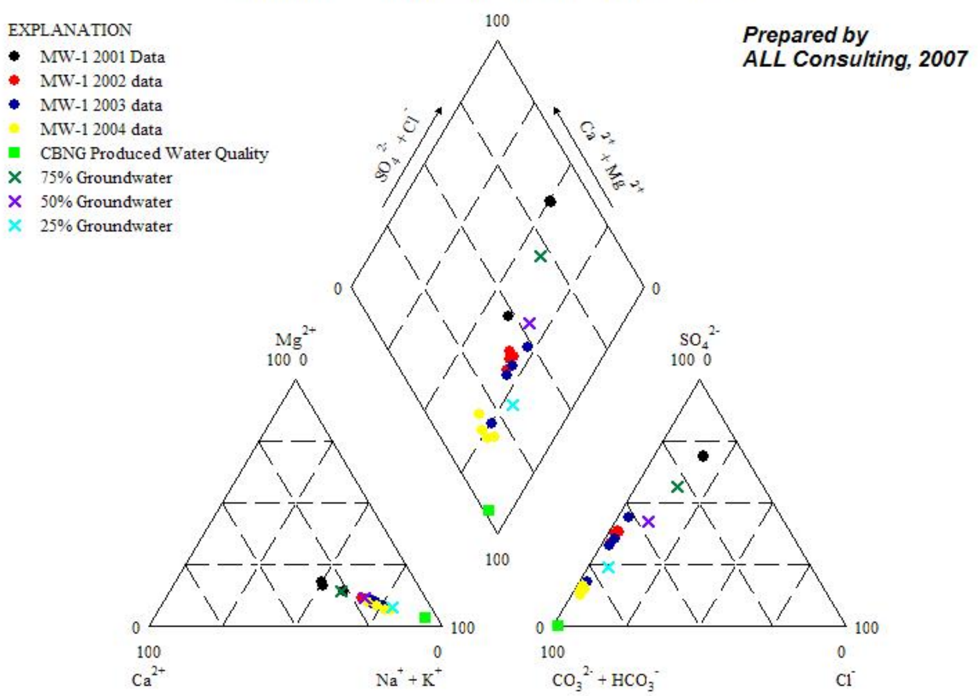

Figure 5-75: Piper Plot for Candida 2 MW-1 Years 2001-2002

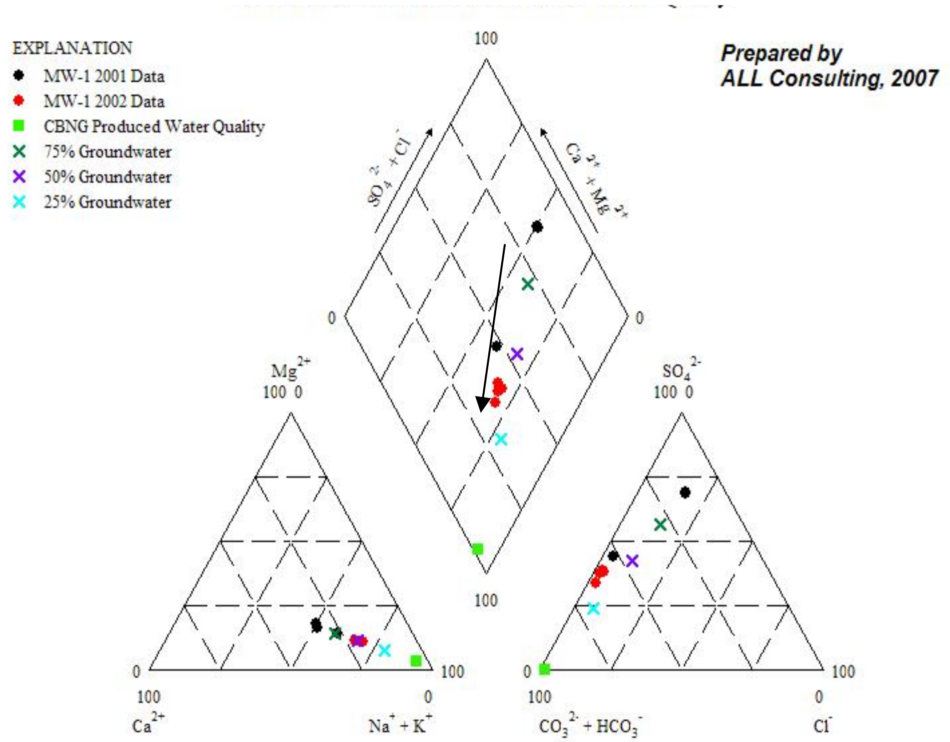

Figure 5-76: Piper Plot for Candida 2 MW-1 Years 2003-2004

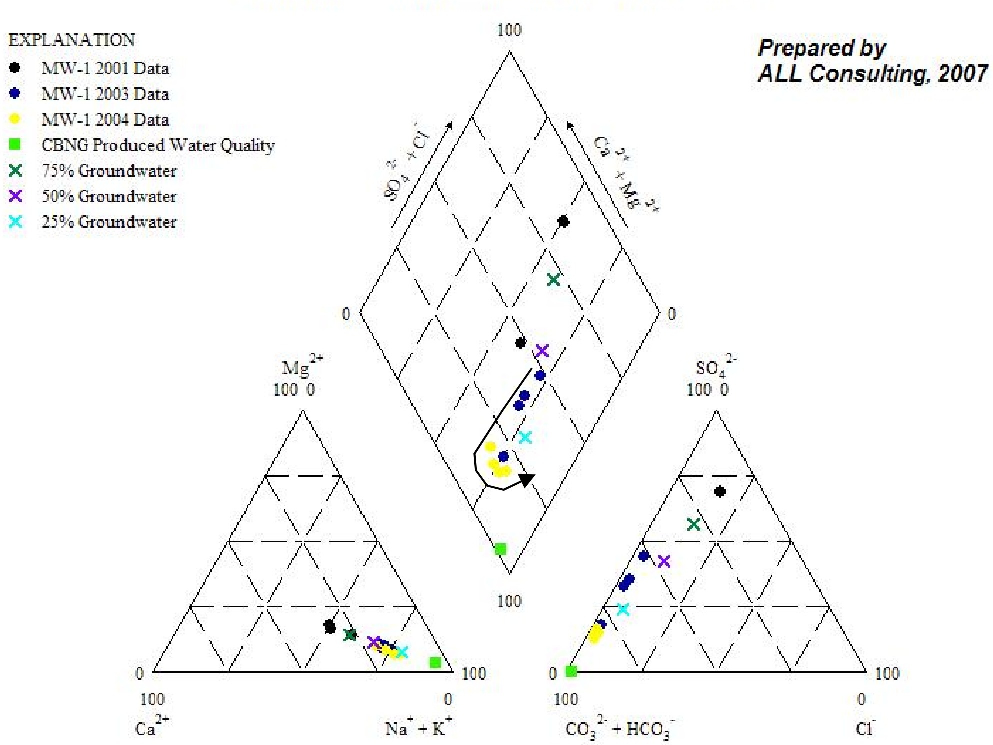

Figure 5-77: SAR and TDS Trends for Candida 2 MW-1

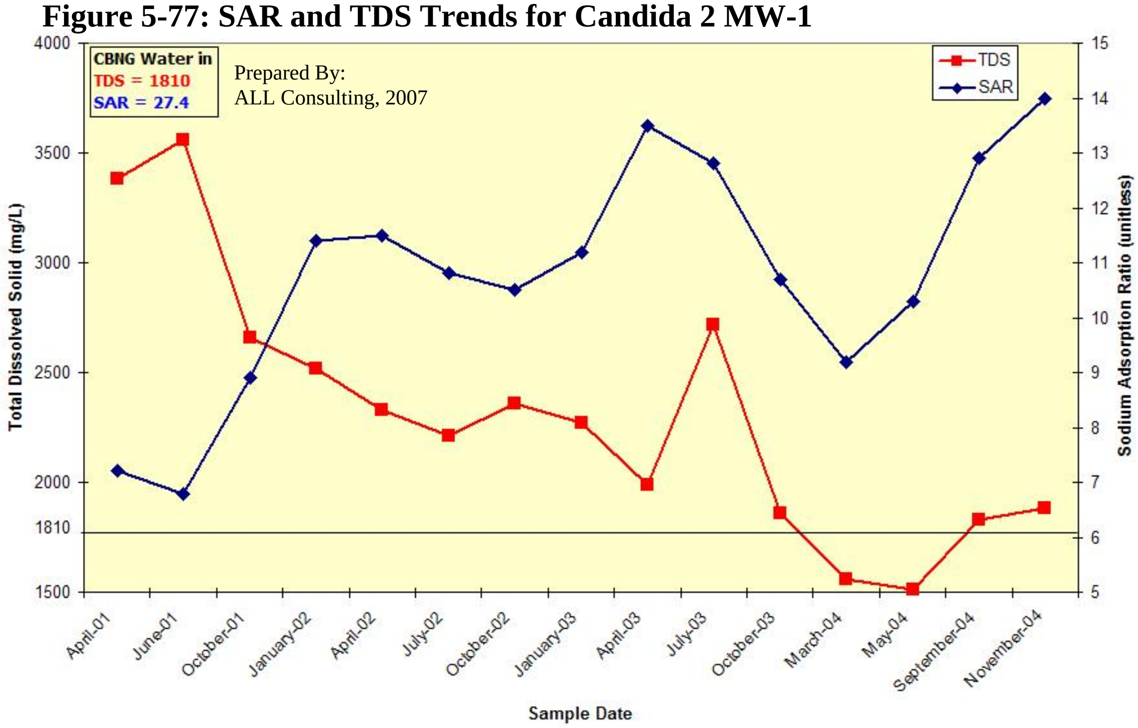

Figure 5-78: Anion Trend Data for the Candida 2 MW-1

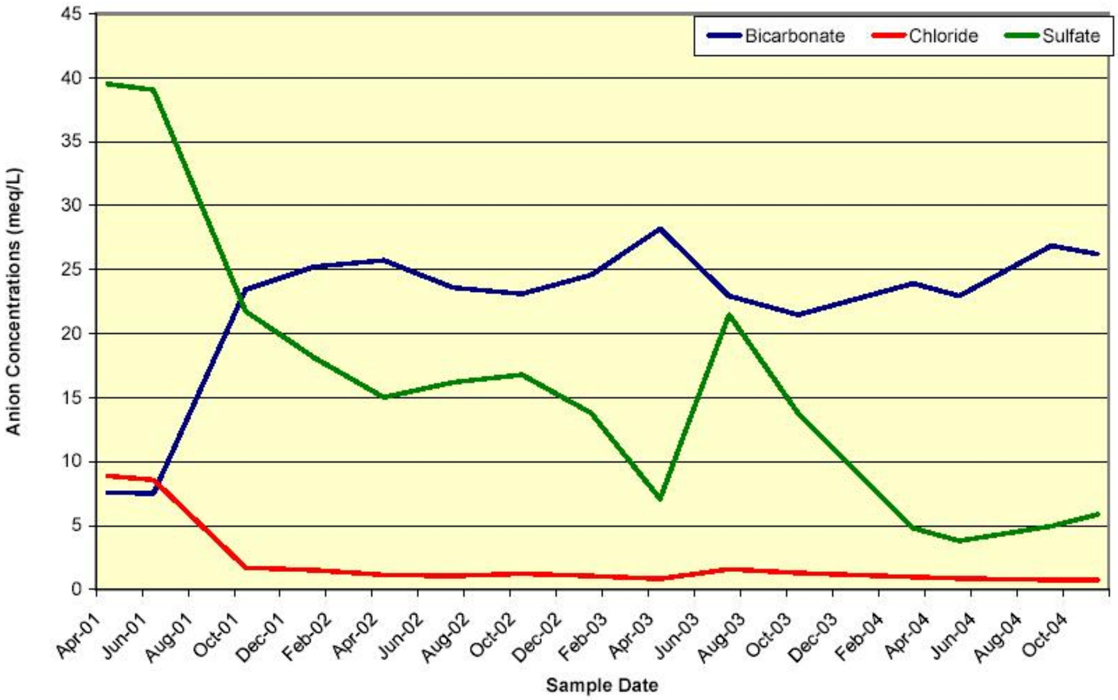

Figure 5-79: Cation Trend Data for the Candida 2 MW-1

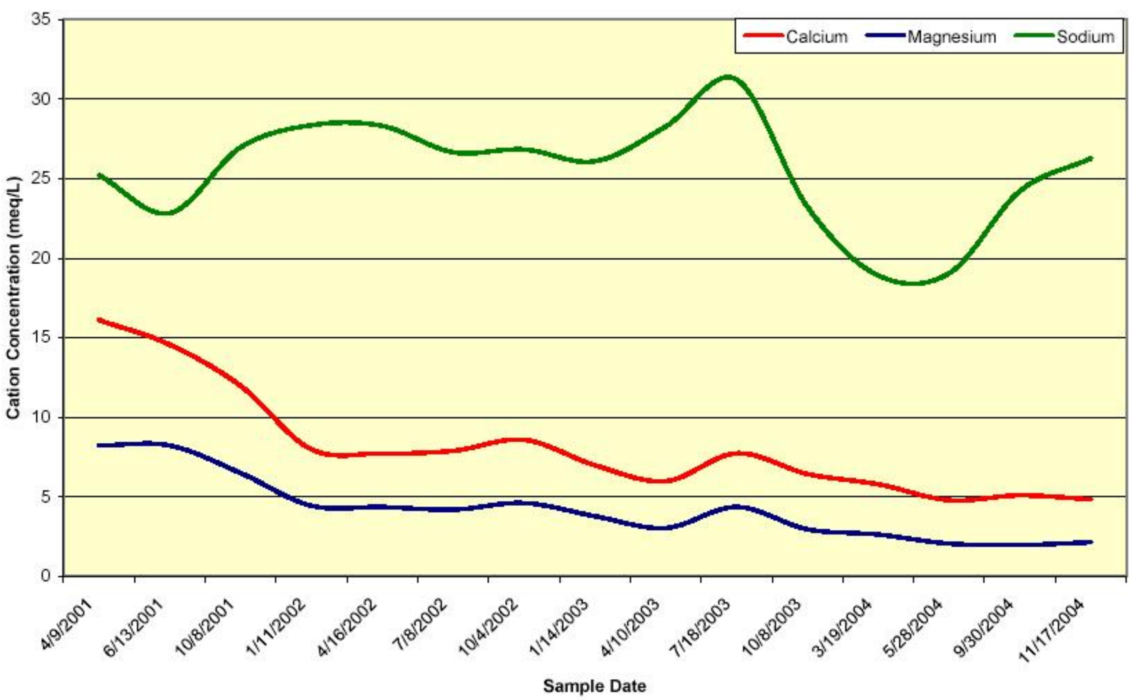

Figure 5-80: Piper Plot for Water Samples Collected from the Santiago 3 Impoundment Monitoring Wells

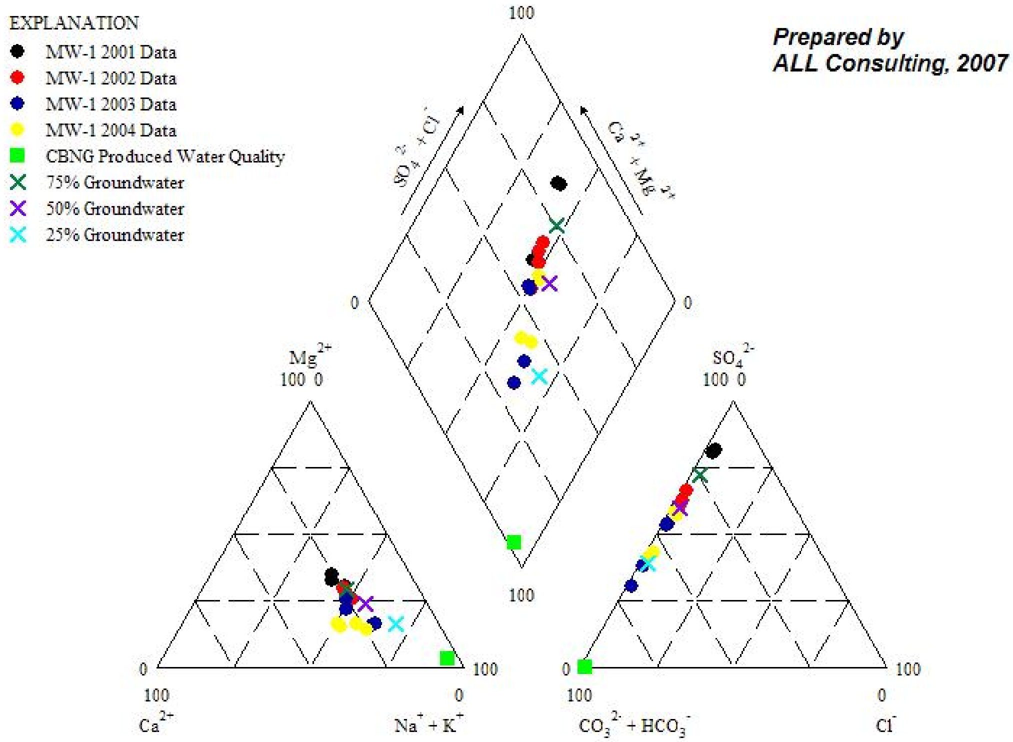

Figure 5-81: Piper Plot for Santiago 3 MW-1 Years 2001-2002

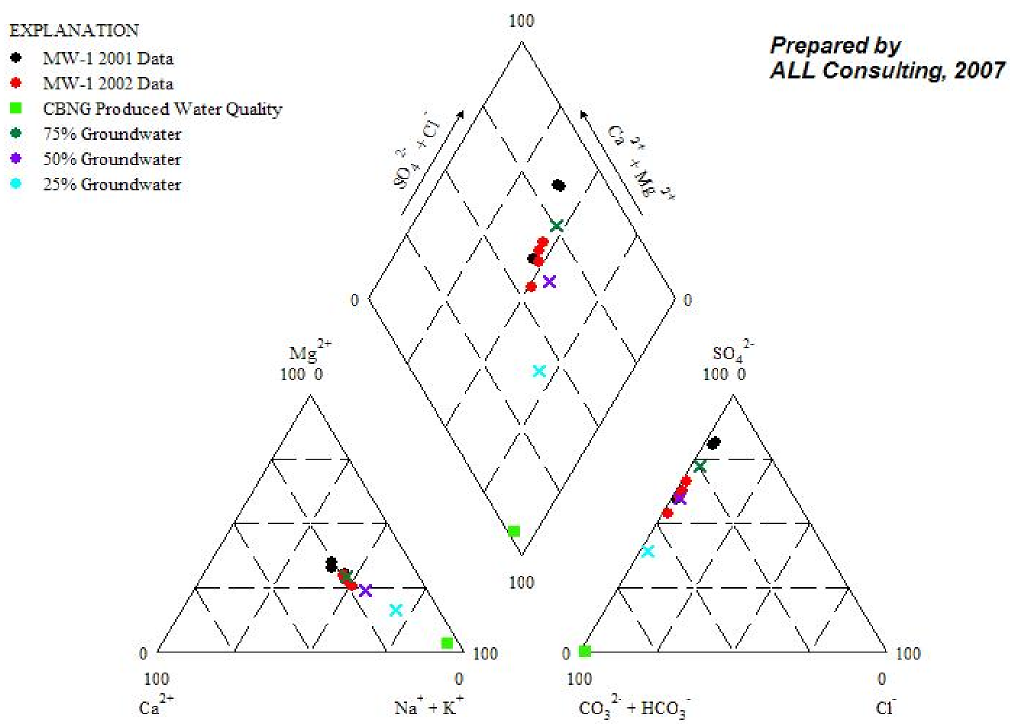

Figure 5-82: Piper Plot for Santiago 3 MW-1 Years 2003-2004

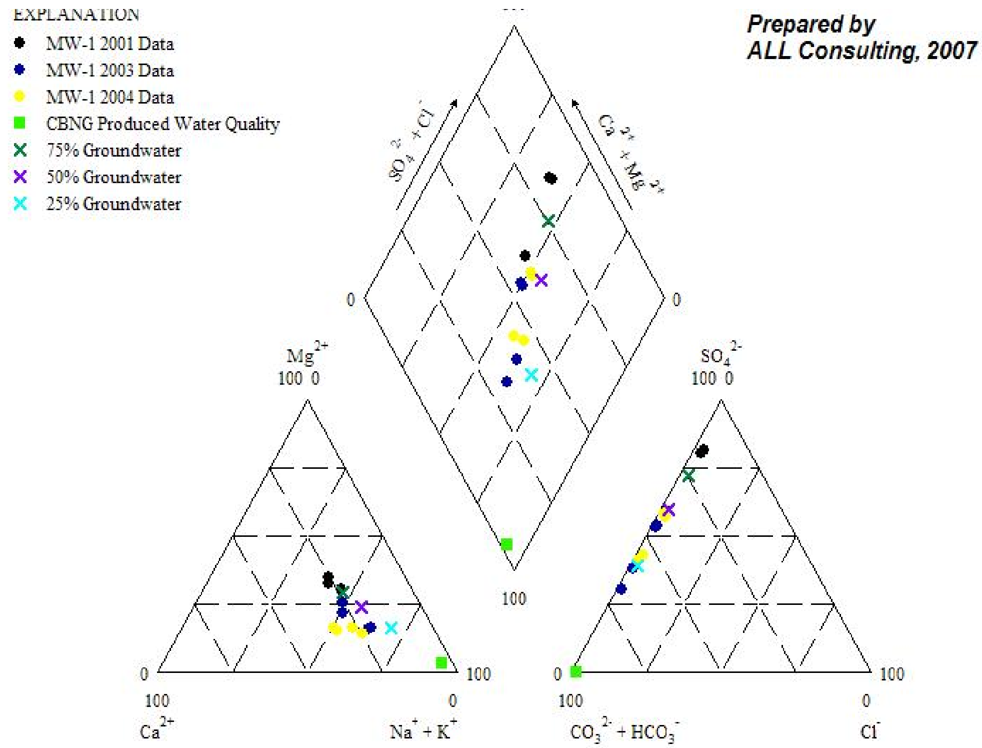

Figure 5-83: SAR and TDS Trends for Santiago 3 MW-1

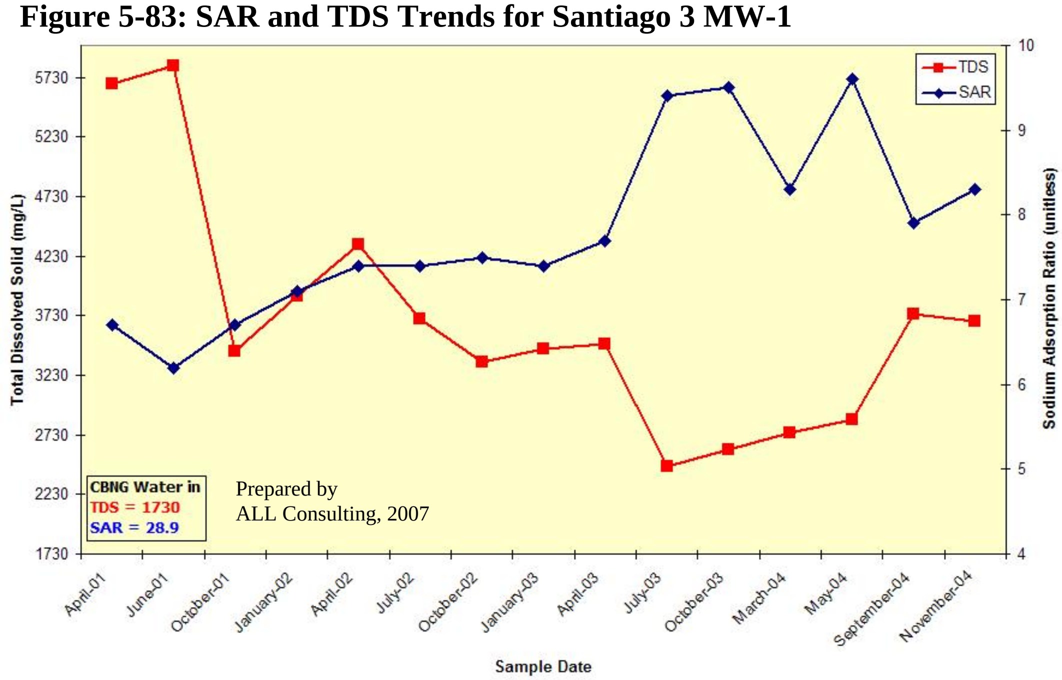

Figure 5-84: Anion Trend Data for the Santiago 3 MW-1

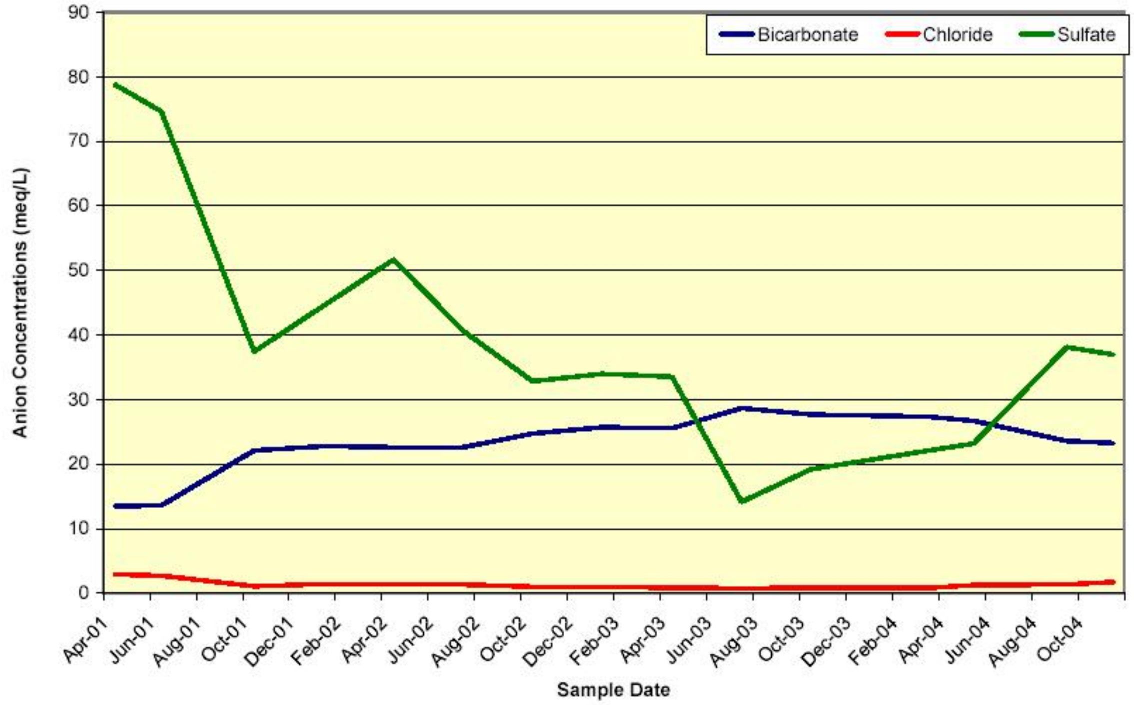

Figure 5-85: Cation Trend Data for the Santiago 3 MW-1

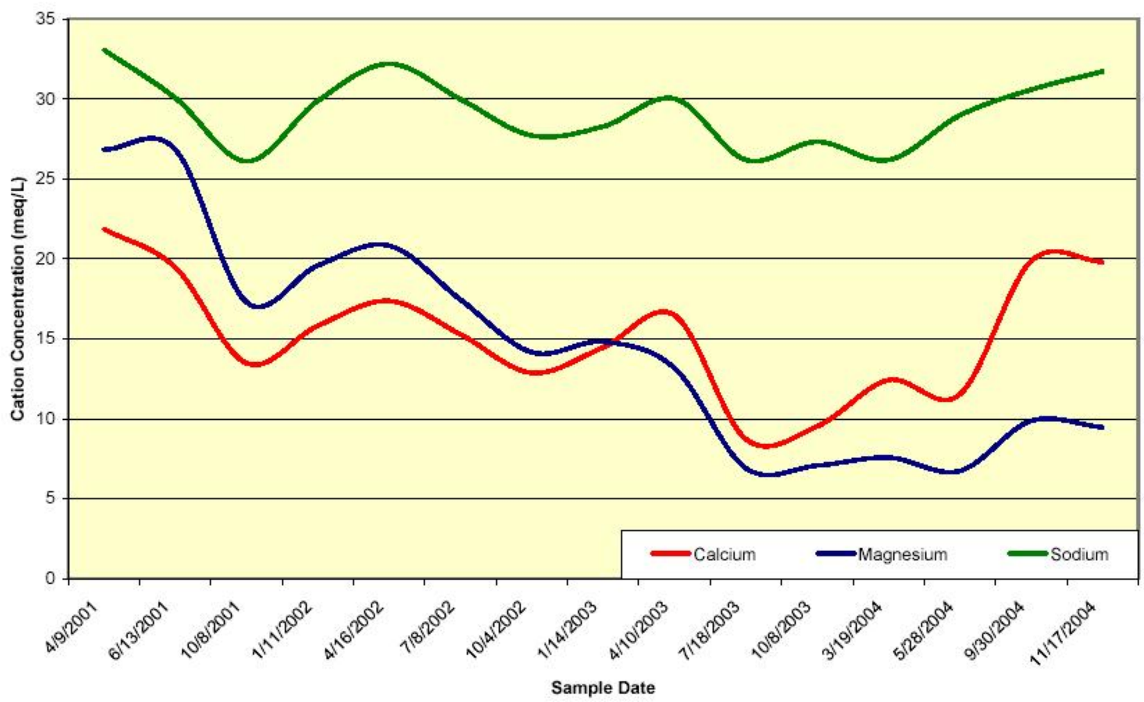

Figure 5-86: Piper Diagram of Water Samples Collected from the Cottonwood 8 MW-1

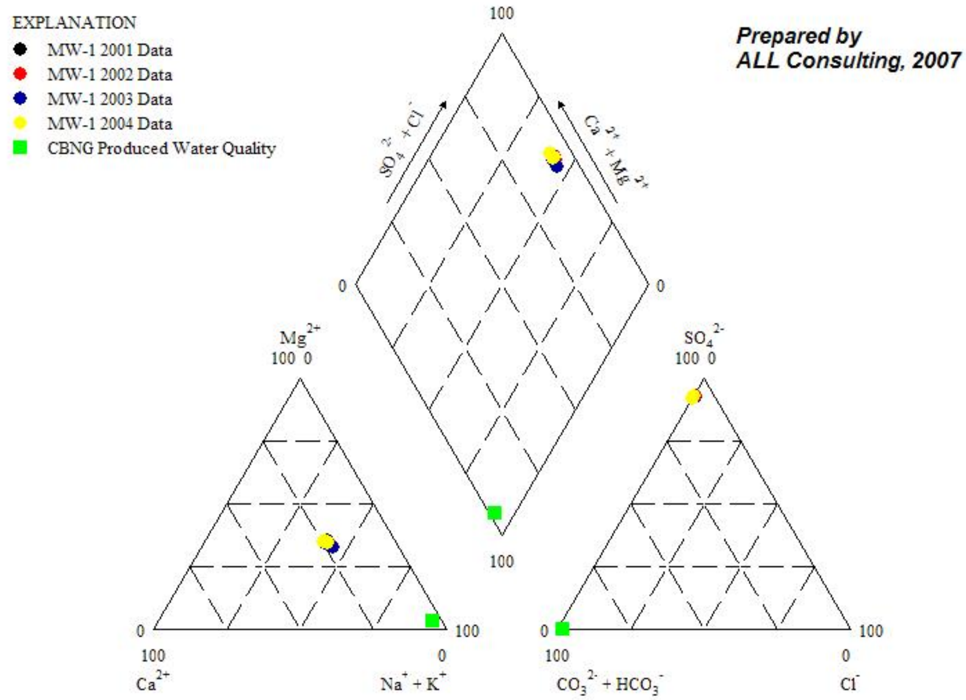

Figure 5-87: SAR and TDS Trends for Cottonwood 8 MW-1

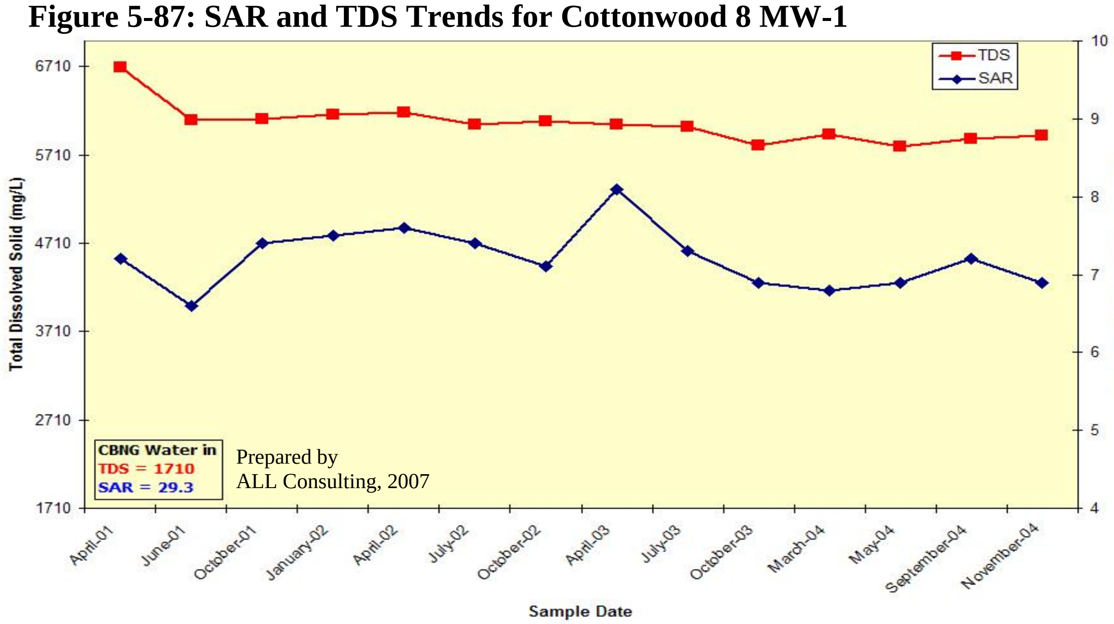

Figure 5-88: Anion Trend Data for the Cottonwood 8 MW-1

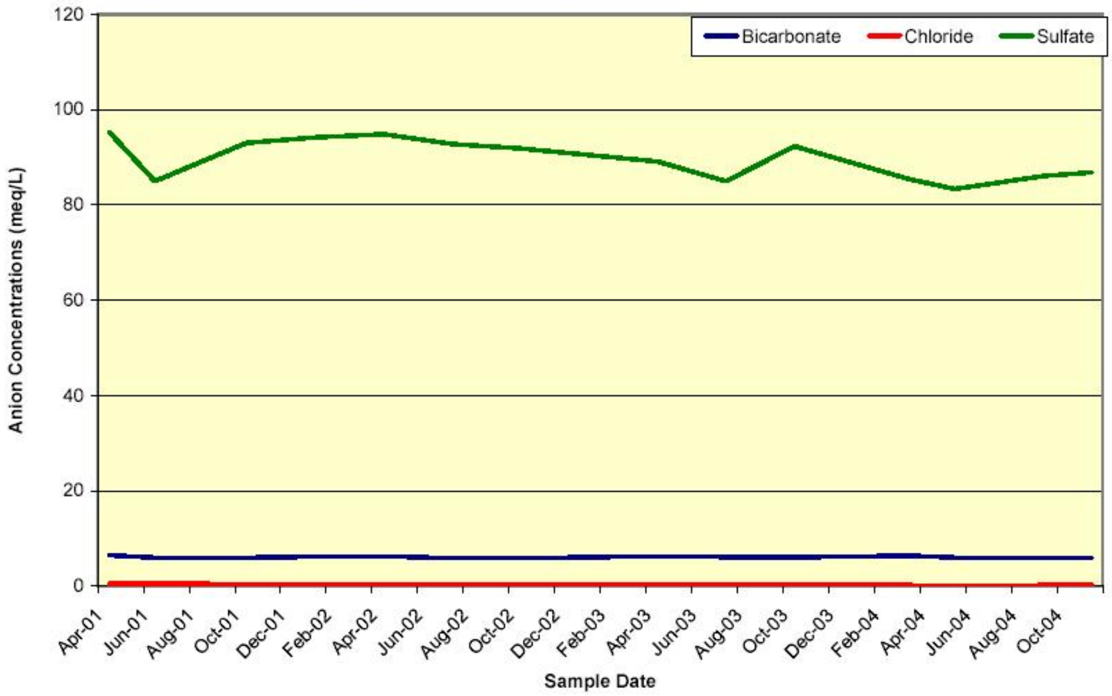

Figure 5-89: Cation Trend Data for the Cottonwood 8 MW-1

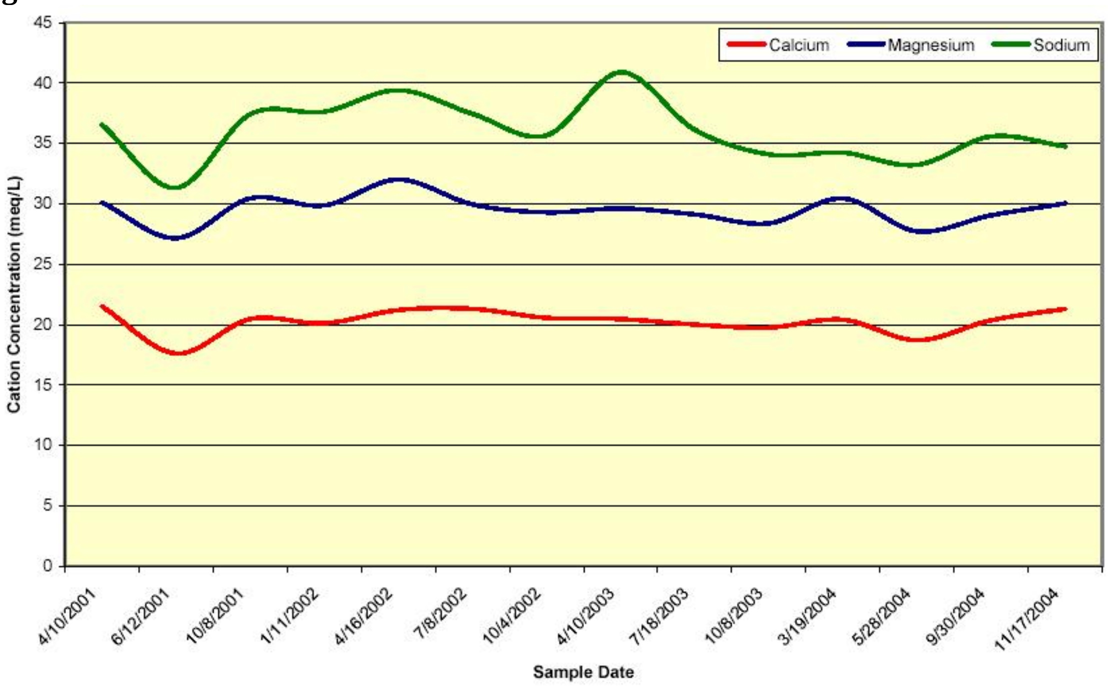

Figure 5-90: Piper Diagram of Water Samples Collected from the Tietjen Impoundment MW-1

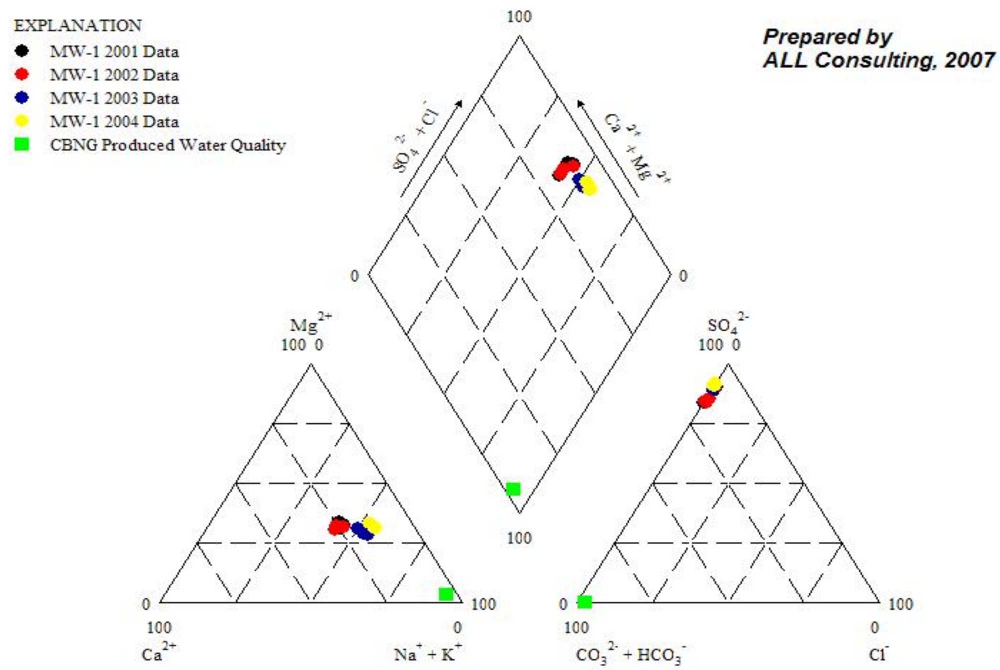

Figure 5-91: Piper Diagram of Water Samples Collected from the Tietjen Impoundment MW-2

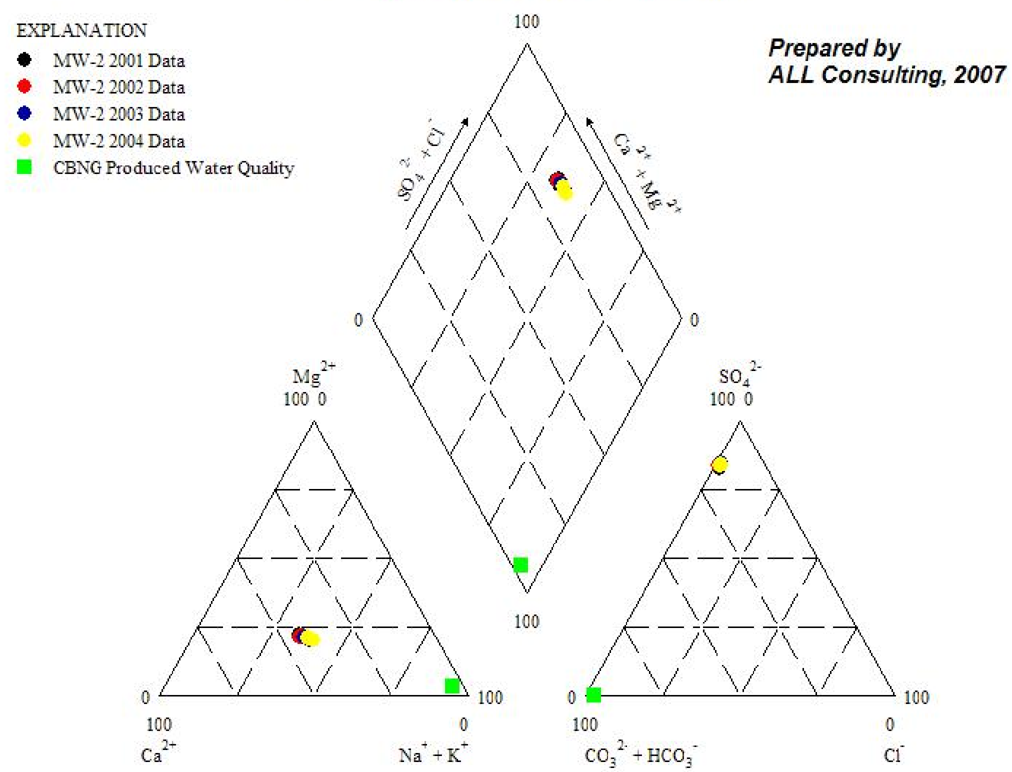

Figure 5-92: SAR and TDS Trends for Tietjen MW-1 and MW-2

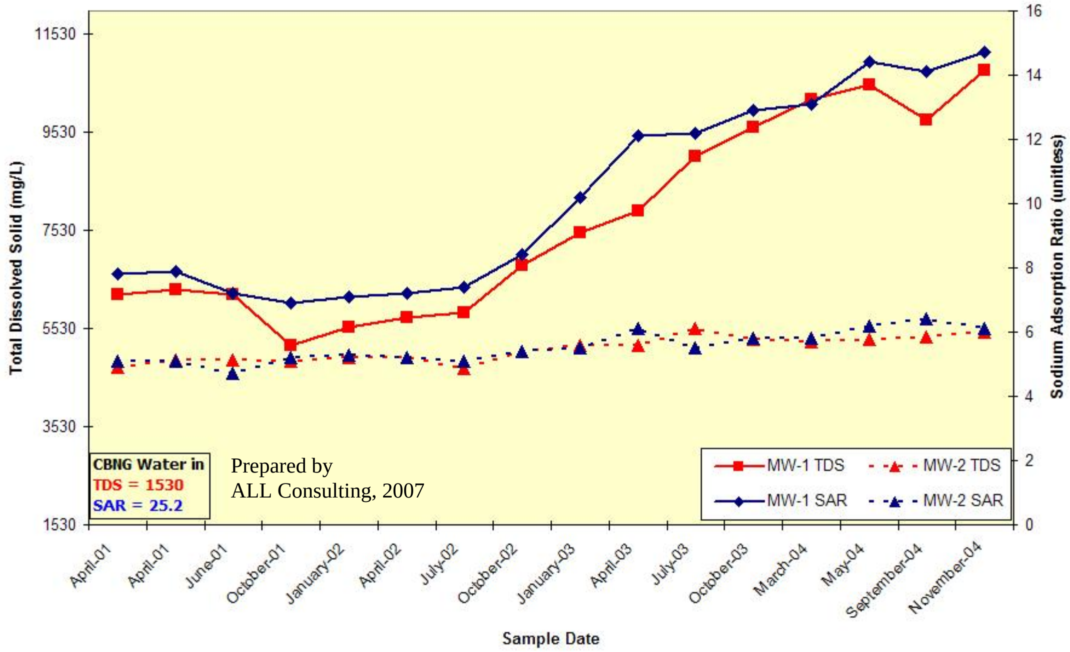

Figure 5-93: Piper Diagram of Water Samples Collected from the Lori Impoundment Monitoring Wells

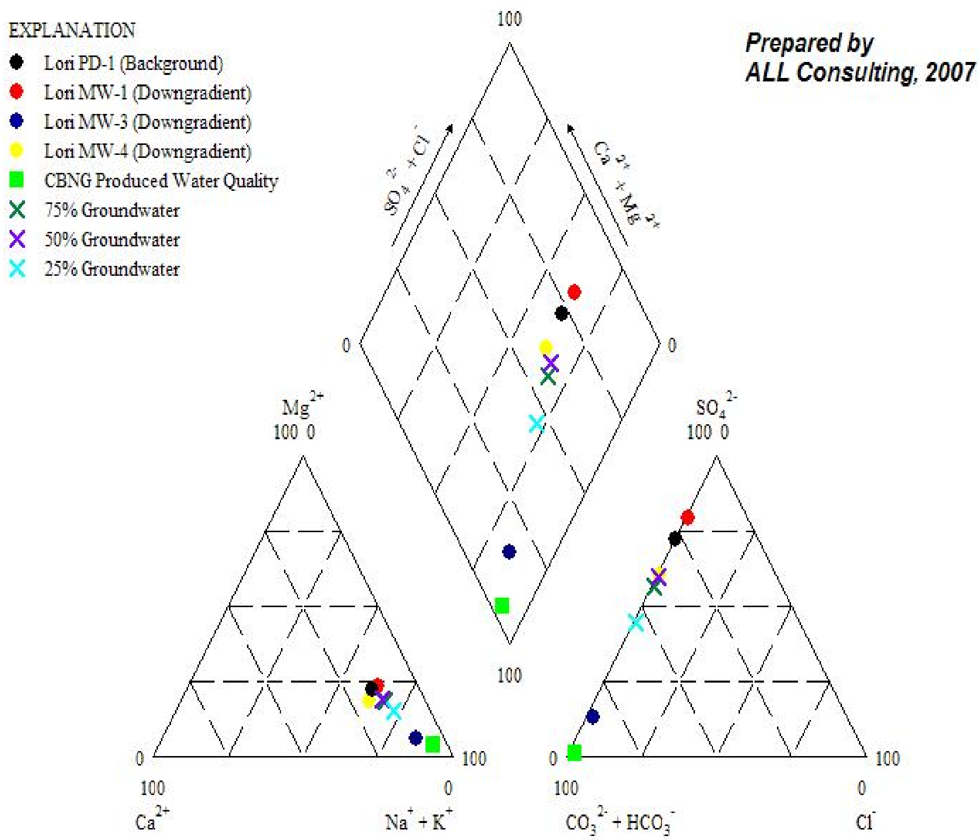

Figure 5-94: A Stiff Diagram Displaying Water Quality for the Lori impoundment

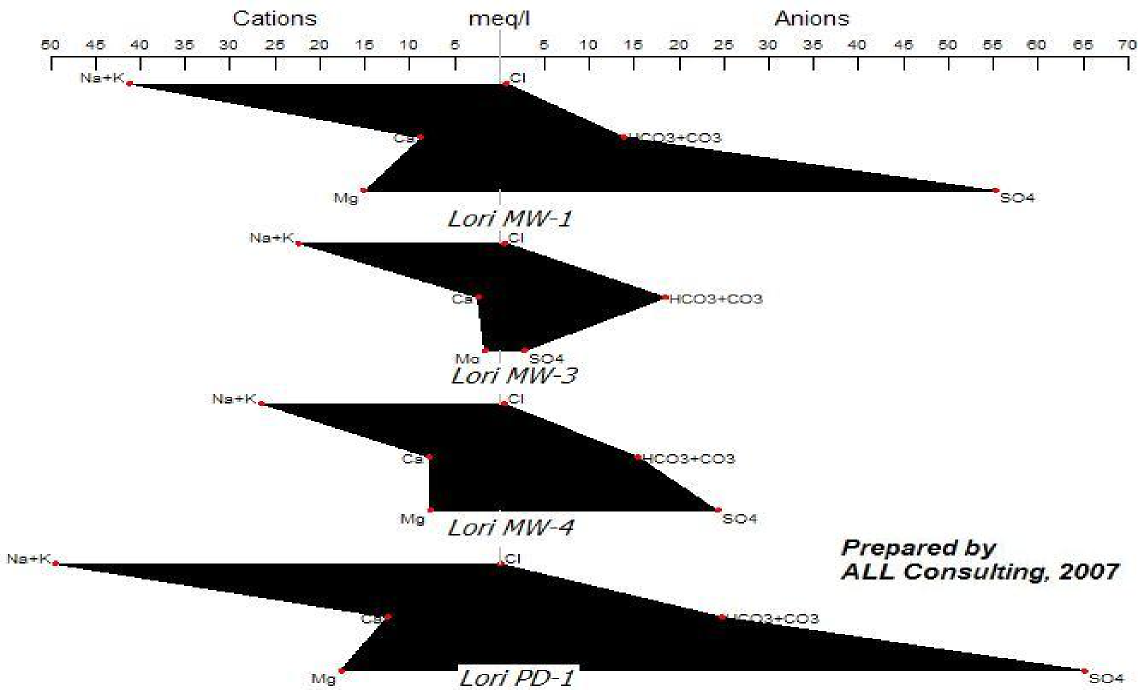

Figure 5-95: Piper Diagram of Water Samples Collected from the Sandy Impoundment Monitoring Wells

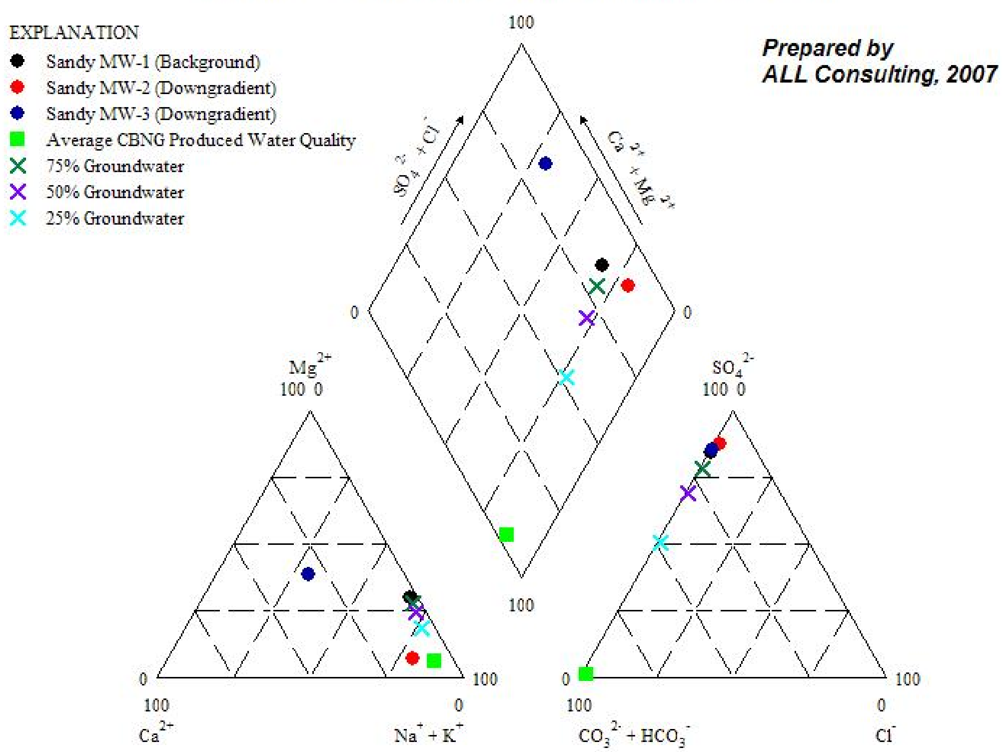

Figure 5-96: A Stiff Diagram Displaying Water Quality for the Sandy impoundment

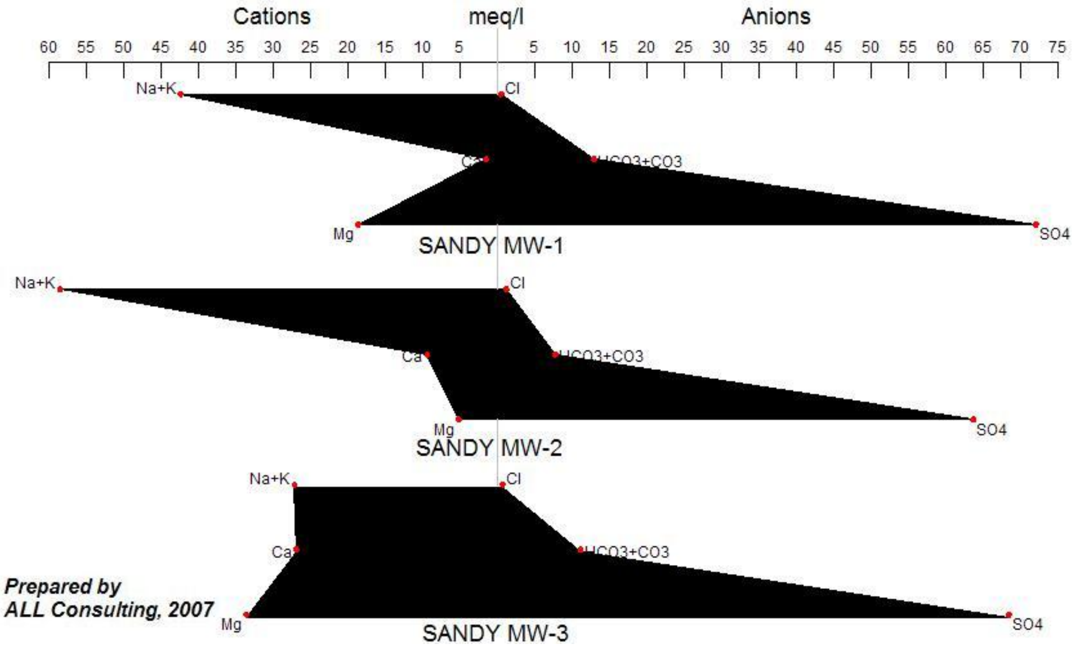

Figure 5-97: Piper Diagram of Water Samples Collected from the Joe Draw Jr. Impoundment Monitoring Wells

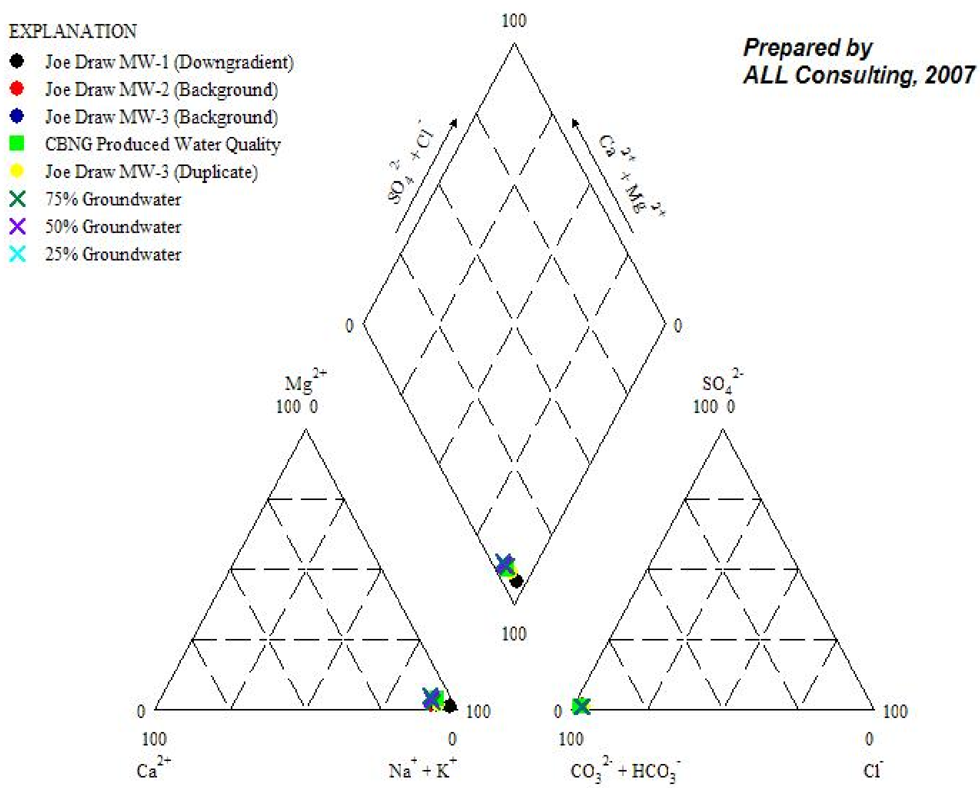

Figure 5-98: A Stiff Diagram Displaying Water Quality for the Joe Draw Jr. impoundment

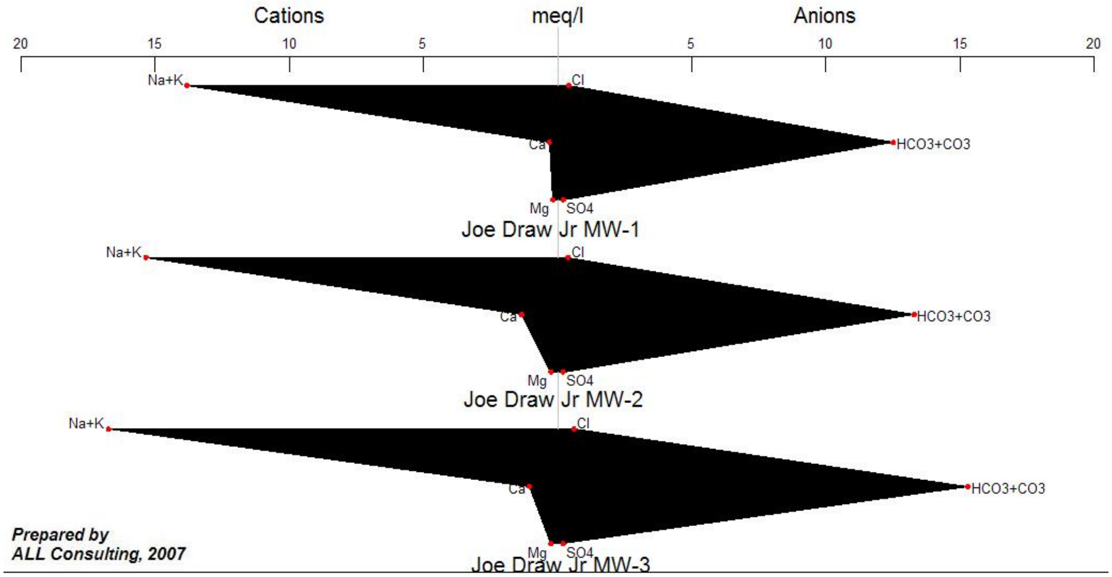

Figure 5-99: Piper Diagram of Water Samples Collected from the Yates State Impoundment Monitoring Wells

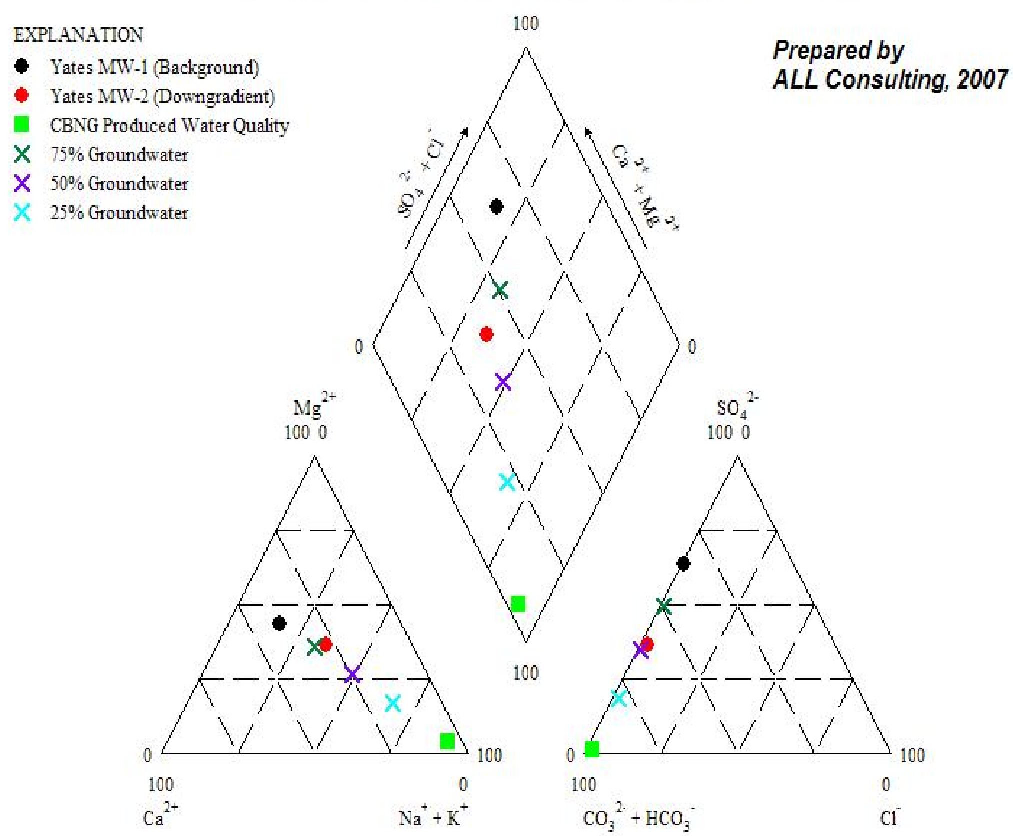

Figure 5-100: A Stiff Diagram Displaying Water Quality for the Yates State impoundment

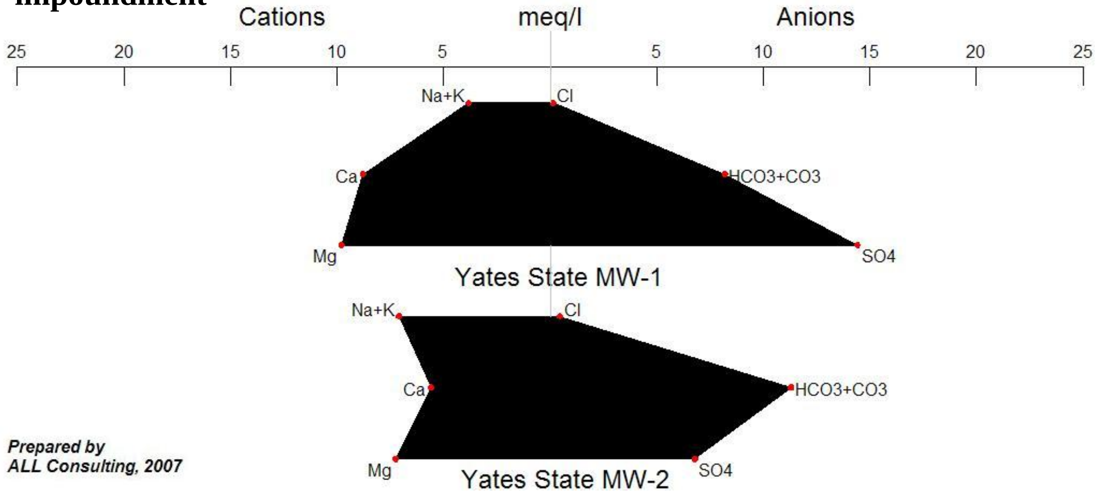

Figure 5-101: Piper Diagram of Water Samples Collected from the Bounty Hunter Impoundment Monitoring Wells

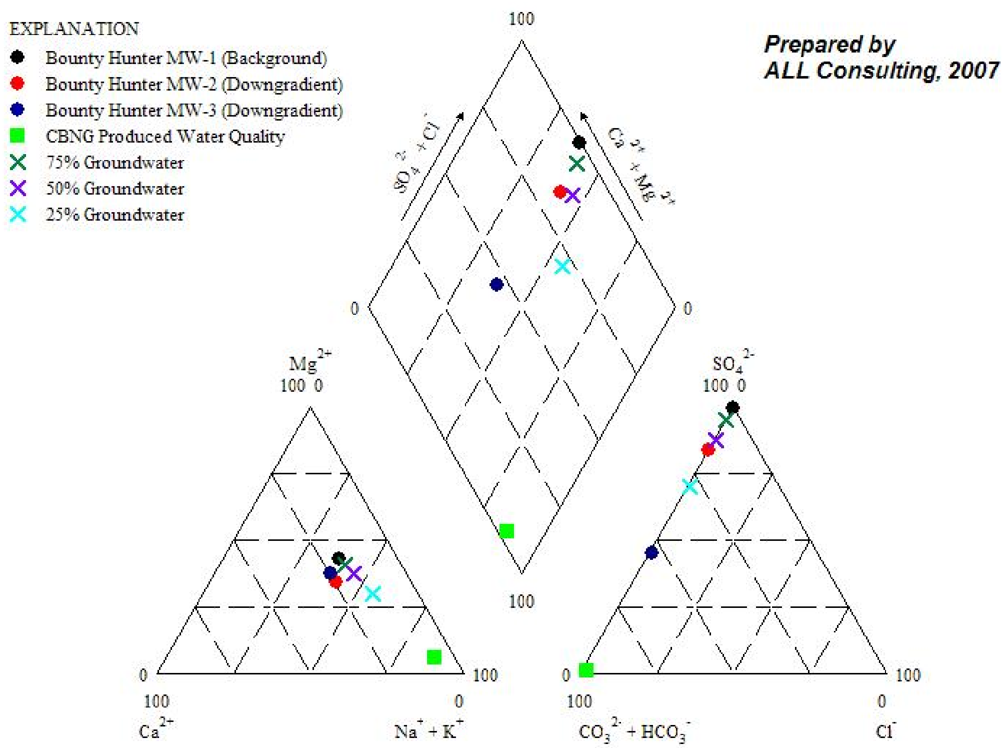

Figure 5-102: A Stiff Diagram Displaying Water Quality for the Bounty Hunter impoundment

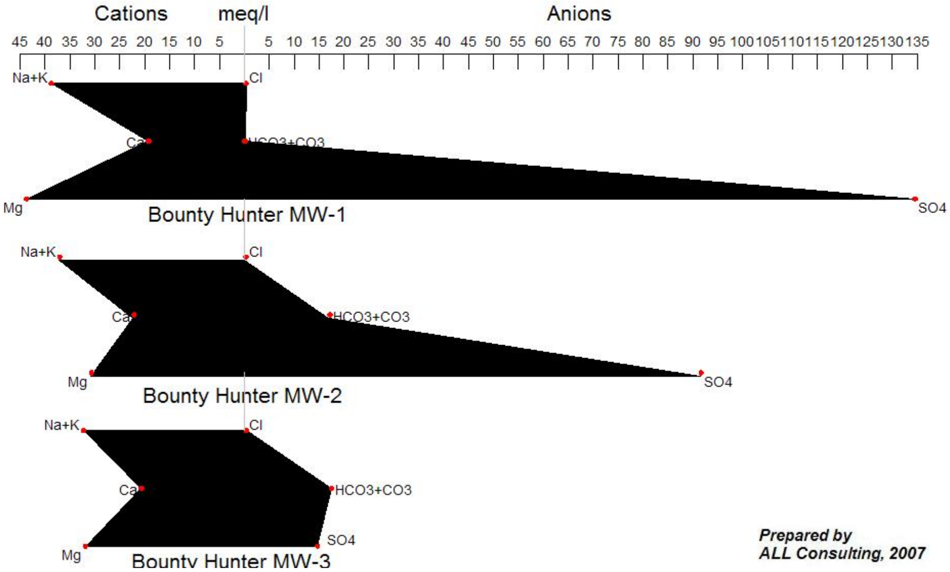

Figure 5-103: Piper Diagram of Water Samples Collected from the Termo Impoundment Monitoring Wells

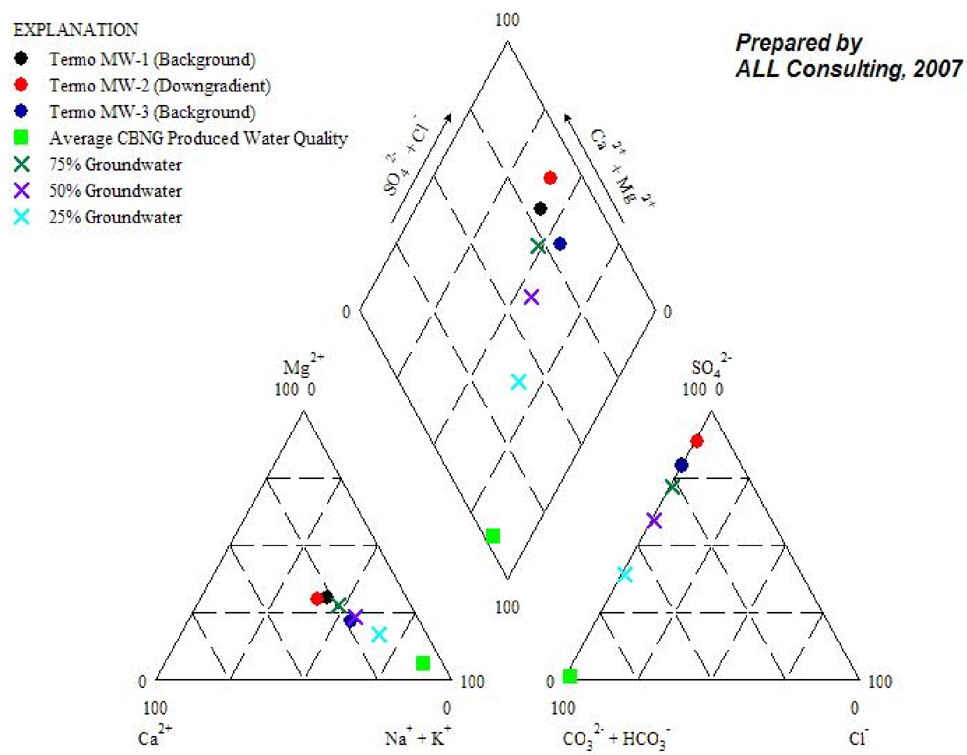

Figure 5-104: A Stiff Diagram Displaying Water Quality for the Termo impoundment

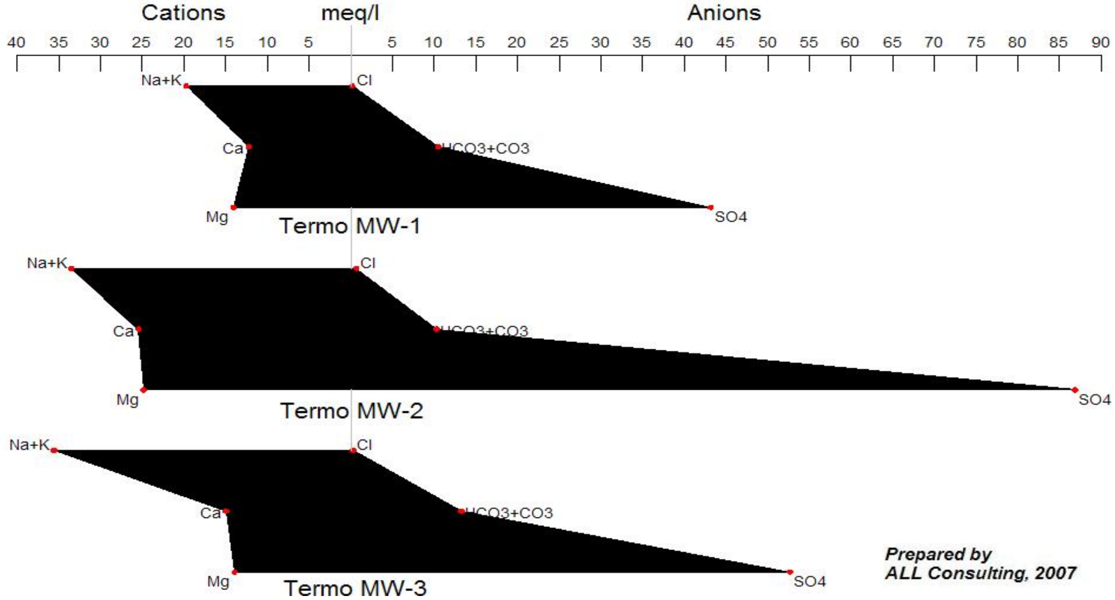

Figure 5-105. Piper Diagram of Water Samples Collected from the Waylon Impoundment Monitoring Wells

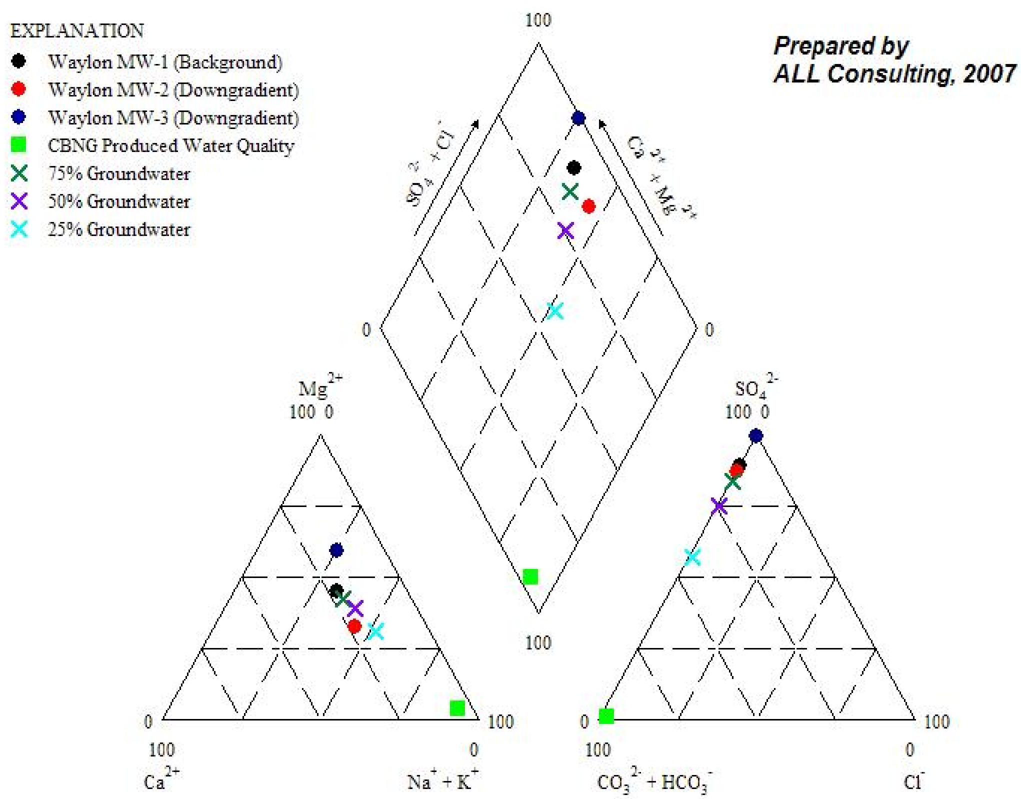

Figure 5-106: A Stiff Diagram Displaying Water Quality for the Waylon impoundment

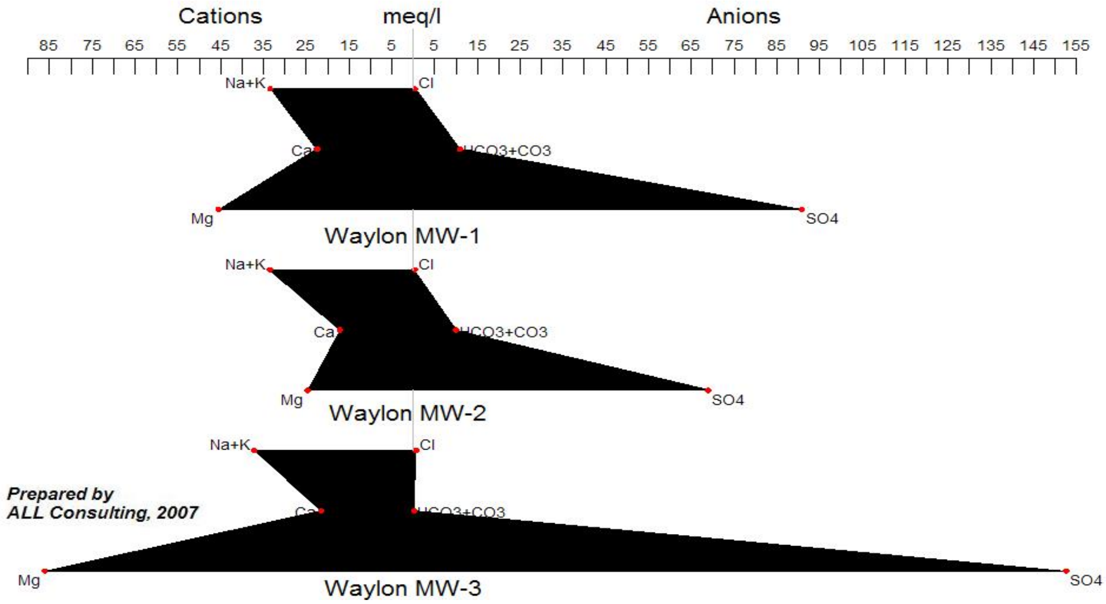

Figure 5-107. Piper Diagram of Water Samples Collected from the Golden Eagle Impoundment Monitoring Wells

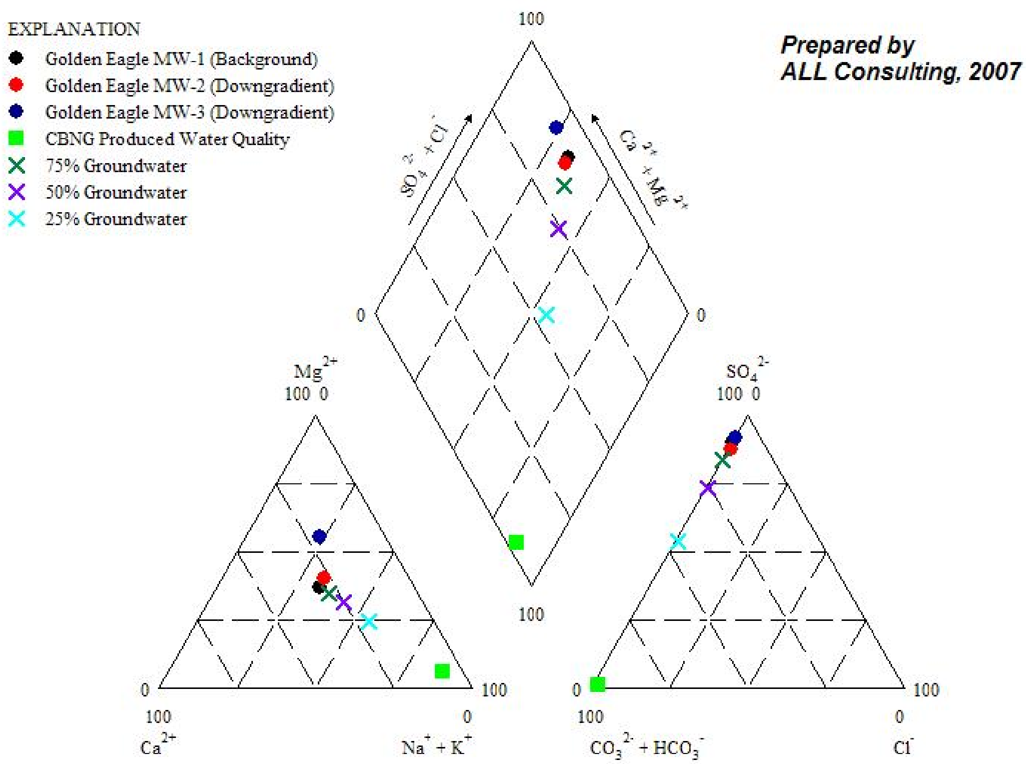

Figure 5-108: A Stiff Diagram Displaying Water Quality for the Golden Eagle impoundment