An Assessment of Surface Water-Groundwater Interactions and Water Quality in Bluewater Creek New Mexico

By

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Committee

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Committee Approval

The Master of Water Resources Professional Project Report of
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Dedication

This Professional Project is dedicated to my husband and best friend, Carl F. Tollestrup. May we always be *committed* to nature and learning, to *care* for and bring *compassion* to the world we live in and to reach for our dreams…together!

Acknowledgements

I would like to acknowledge my parents who instilled the value of education in me from a very young age beginning with getting me my first library card. My parents were very proud to have been able to afford to purchase *two* sets of encyclopedias for a family of seven children. Today, the blue World Book Encyclopedia (1966 edition!!) set is in my home and I still reach for it at the spur of a moment to look up something of interest.

I would like to extend a heart felt gratitude to my husband, Carl, who never asked "when are you going to finish" but instead provided unending support and freedom which allowed me to thoroughly enjoy my work and to be successful in this journey of ours. Fortunately, our time spent in nature (i.e., fieldwork) is where we both prefer to be.

This project would not have been possible without *all of the combined support* listed below. Your support, guidance and kindness are cherished and respected. Thank you all.

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Abstract

Bluewater Creek, a spatially intermittent headwater stream and one of the main tributaries to Bluewater Lake, is located in the Zuni Mountains in Cibola National Forest approximately 100 miles west of Albuquerque, New Mexico. Annual peak discharge occurs during the spring snowmelt runoff in March and April. Average annual discharge for Bluewater Creek for the period 1989 through 2000 is approximately 9.5 cubic feet per second. The Bluewater Creek sub-watershed has a drainage area of approximately 54,300 acres (84 square miles). Watershed elevation ranges from 6650 to 9240 feet above mean sea level with a mean elevation of 8020 feet. Annually, precipitation varies across the watershed from approximately 12 to 23 inches. Land use history includes railroad logging (1800s – early 1900), uncontrolled grazing, and the removal of beaver dams. USDA Forest Service acquisition occurred in the 1940s followed by riparian area restoration in the 1980s. Today, watershed improvement is directed towards managed recreation and controlled grazing.

A surface water-groundwater interaction study was conducted along a 4 mile reach of Bluewater Creek. Hydrogeochemical findings were based on water quality measurements, groundwater elevation (30 piezometers in nests) and water temperature data. Water quality results demonstrate connectivity between the shallow alluvial aquifer and surface water. Geochemical analysis demonstrates spatial and temporal differences. Losing-gaining stream segments were identified from the groundwater elevation data and utilized to further quantify surface water-groundwater exchanges. Impairments to designated use (coldwater fishery) include temperature.

1.0 INTRODUCTION

1.1 Problem Statement

Bluewater Creek has been impacted by past land use practices such as extensive logging during 1890-1940 and uncontrolled grazing (sheep and cattle). The U.S. Forest Service acquisition of the land occurred in the early and mid 1940s. Watershed restoration treatments occurred at Bluewater during the 1980s and again during 2003-2004. Treatments during the 1980s included: exclosure fencing of the riparian areas, revetment type structures to control erosion, willow planting, elimination of streamside roads and the re-introduction of beaver.

Treatments during 2003-2004 included: exclosure fencing to study the effects of keeping the cattle out, willow planting (failed) and instrumentation and piezometers were installed to study SW-GW connectivity. These watershed restoration treatments resulted in significant initial riparian area recovery and erosion control based on visual analysis but no baseline data had been collected to perform a quantitative analysis of riparian health and water chemistry. Some existing groundwater level data had been collected but analysis had not yet been performed.

Bluewater Creek has a designated use as a coldwater aquatic habitat. In 2004, the New Mexico Surface Water Quality Bureau had identified several impairments to Bluewater Creek: exceedences in total phosphorus, nitrogren and water temperature (see http://www.nmenv.state.nm.us/swqb/RioPuerco2/summary.pdf)

1.2 Purpose

The purpose of this study was to obtain a water quality assessment of the surface water and shallow alluvial groundwater at Bluewater Creek, New Mexico to evaluate water connectivity and interaction on water quality.

1.3 Project Scope

The scope of this project is an approximately 4 mile reach of stream where 11 piezometer nests are located. Each nest contains five piezometers installed at depths that range from approximately 4 -12 feet below ground surface (bgs). The exception to this is at Nest J where there are only four piezometers. The study area is comprised of 54 piezometers in total. As shown in Figure 1, the piezometers are arranged in a quadrangle pattern with one piezometer located at each corner of the quadrangle and one centrally placed near the stream’s edge. Piezometer survey information is shown on Table 1. The nests are identified alphabetically along the stream reach beginning with the upstream location or Nest A. The farthest downstream location is identified as Nest K. For discussion purposes, Nest areas J and K are defined as Lower Bluewater. This area is riparian rich and has active beaver populations. Nests A through I are referred to as Upper Bluewater. Upper Bluewater is not riparian rich and has no active beaver areas.

1.4 Objectives

The main objective of this study was to develop an understanding of surface water - groundwater interactions. Specifically, water chemistry data, combined with groundwater elevation data and water temperature data help identify losing/gaining reaches, and the degree of connectivity, and spatial and temporal variations. The results from this study enable a better understanding of the hydrologic condition and will assist the USFS in preparing a long term management plan for developing future restoration activities on the creek. The data collected will also provide useful background information that the USFS can use to gauge the health of the creek into the future.

Figure 1: Bluewater Creek Study Area and Piezometer Locations

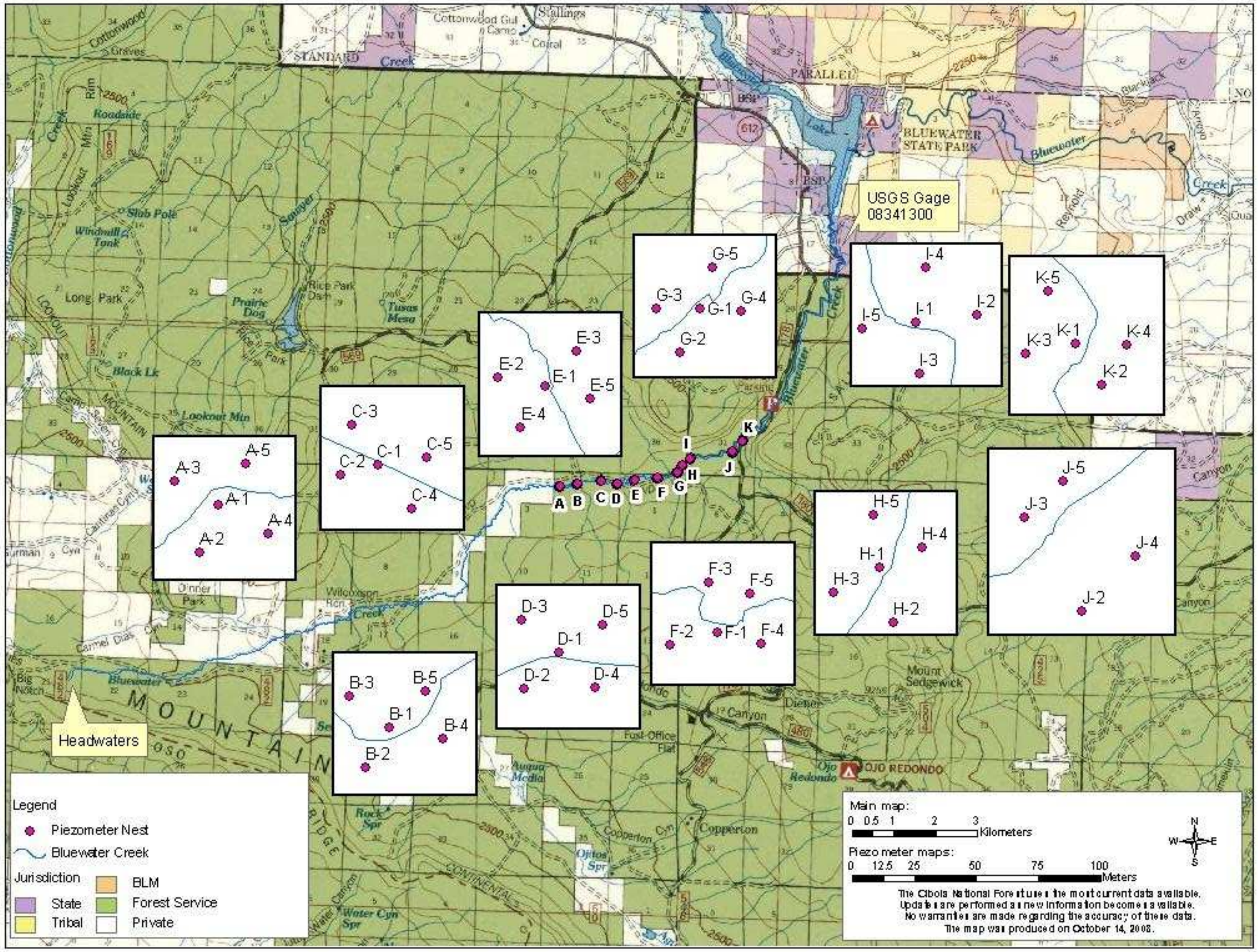


Table 1: Piezometer Survey Information and Manual Water Levels

Nest	Piezo #	Latitude	Longitude	Stick-up (m)	Elevation at TOC (m)	Piezometer Total Depth TOC (m)	Depth-to-Water December 2003 from TOC (m)	Depth-to-Water April 2004 from TOC (m)	Depth-to-Water May 2007 from TOC (m)	GW Elevation December 2003 from TOC (m)	GW Elevation April 2004 from TOC (m)	GW Elevation May 2007 from TOC (m)
A	1	3900559	756077	1.33	2329.431	3.01	2.01	-	2.11	2327.423	-	2327.319
	2	3900540	756069	1.17	2330.624	4.61	3.45	-	3.20	2327.174	-	2327.424
	3	3900569	756059	1.23	2329.734	3.01	2.26	-	2.31	2327.472	-	2327.424
	4	3900548	756097	1.21	2329.777	3.00	2.41	-	2.35	2327.366	-	2327.430
	5	3900576	756088	1.27	2330.209	4.62	2.90	-	2.92	2327.310	-	2327.289
B	1	3900650	756481	1.06	2328.110	3.03	1.51	1.51	1.72	2326.601	2326.600	2326.388
	2	3900634	756471	1.13	2328.064	3.00	1.47	1.45	1.66	2326.595	2326.614	2326.403
	3	3900663	756465	1.19	2329.272	4.65	2.76	2.75	2.93	2326.510	2326.522	2326.339
	4	3900645	756502	1.31	2328.206	3.01	1.94	1.80	2.01	2326.264	2326.406	2326.191
	5	3900665	756495	1.30	2329.067	4.68	2.99	2.90	3.01	2326.077	2326.167	2326.061
C	1	3900766	757069	1.16	2324.523	3.00	1.79	1.59	1.69	2322.734	2322.933	2322.828
	2	3900762	757054	1.07	2325.003	3.01	2.06	2.82	2.00	2322.943	2322.183	2323.007
	3	3900782	757059	1.18	2325.092	2.99	2.29	2.10	2.23	2322.803	2322.992	2322.867
	4	3900749	757083	1.02	2324.855	3.01	2.30	2.12	2.26	2322.554	2322.735	2322.593
	5	3900769	757089	1.08	2324.859	3.00	2.25	2.07	2.19	2322.610	2322.789	2322.674
D	1	3900714	757463	1.13	2321.759	2.95	1.47	1.41	1.45	2320.290	2320.349	2320.305
	2	3900699	757449	1.00	2322.267	2.98	1.99	1.92	1.93	2320.277	2320.347	2320.338
	3	3900727	757448	1.15	2322.269	2.94	1.77	1.67	1.74	2320.498	2320.599	2320.532
	4	3900700	757478	1.09	2322.198	3.00	1.92	1.87	1.91	2320.277	2320.328	2320.289
	5	3900725	757481	1.12	2321.854	3.01	1.76	1.73	1.70	2320.096	2320.124	2320.157
E	1	3900835	757871	0.74	2319.554	3.01	1.26	1.24	1.21	2318.295	2318.314	2318.341
	2	3900838	757852	0.85	2320.322	3.00	2.00	1.96	1.93	2318.322	2318.362	2318.395
	3	3900849	757883	0.92	2320.223	3.01	2.05	2.01	1.99	2318.172	2318.213	2318.236
	4	3900818	757861	1.06	2320.407	3.01	2.04	2.05	2.01	2318.368	2318.357	2318.395
	5	3900830	757888	0.91	2320.215	3.01	2.06	2.03	2.01	2318.154	2318.185	2318.206
F	1	3900904	758401	1.31	2317.351	2.73	1.62	1.26	1.69	2315.729	2316.091	2315.659
	2	3900909	758420	0.87	2316.802	3.01	2.12	1.81	2.14	2314.680	2314.992	2314.662
	3	3900929	758416	0.93	2317.379	3.01	2.20	1.92	2.27	2315.178	2315.459	2315.111
	4	3900904	758437	0.80	2317.108	2.99	2.03	1.69	2.09	2315.078	2315.418	2315.014
	5	3900925	758433	0.80	2317.319	3.01	2.27	1.99	2.28	2315.048	2315.329	2315.042

Table 1: Piezometer Survey Information and Manual Water Levels (Continued)

Nest	Piezo #	Latitude	Longitude	Stick-up (m)	Elevation at TOC (m)	Piezometer Total Depth TOC (m)	Depth-to-Water December 2003 from TOC (m)	Depth-to-Water April 2004 from TOC (m)	Depth-to-Water May 2007 from TOC (m)	GW Elevation December 2003 from TOC (m)	GW Elevation April 2004 from TOC (m)	GW Elevation May 2007 from TOC (m)
G	1	3901073	758893	1.11	2315.307	3.00	1.71	1.30	1.64	2313.597	2314.007	2313.670
	2	3901055	758884	1.05	2315.833	4.61	2.21	1.78	2.10	2313.623	2314.053	2313.729
	3	3901073	758875	0.87	2315.740	3.00	2.18	1.73	2.07	2313.561	2314.010	2313.667
	4	3901072	758909	0.39	2315.113	3.00	1.61	1.16	1.49	2313.503	2313.953	2313.619
	5	3901089	758897	0.92	2315.433	3.01	2.06	1.61	1.93	2313.373	2313.823	2313.504
H	1	3901257	758993	0.82	2314.916	4.61	2.23	1.90	2.13	2312.685	2313.016	2312.786
	2	3901235	758999	0.84	2314.949	3.02	2.26	1.88	2.08	2312.687	2313.069	2312.864
	3	3901247	758974	0.22	2314.299	3.00	1.51	1.19	1.42	2312.790	2313.109	2312.878
	4	3901265	759010	1.09	2315.140	4.65	2.48	2.17	2.38	2312.659	2312.970	2312.763
	5	3901278	758990	0.24	2314.188	2.99	1.50	1.18	1.40	2312.688	2313.008	2312.785
I	1	3901431	759182	1.07	2314.437	2.98	2.23	1.92	1.90	2312.206	2312.517	2312.541
	2	3901434	759207	1.09	2314.380	2.86	2.22	1.90	1.72	2312.161	2312.480	2312.661
	3	3901411	759184	1.05	2314.515	2.37	2.25	1.97	1.97	2312.266	2312.545	2312.543
	4	3901453	759187	1.09	2314.418	3.02	2.25	1.94	1.88	2312.168	2312.478	2312.537
	5	3901429	759161	1.04	2314.540	2.71	2.25	1.96	1.97	2312.291	2312.580	2312.568
J	2	3901605	760180	1.18	2309.281	3.01	1.17	1.32	1.14	2308.111	2307.961	2308.138
	3	3901642	760158	1.26	2309.484	2.99	1.37	0.56	1.36	2308.116	2308.924	2308.125
	4	3901627	760202	1.24	2309.347	3.03	1.46	1.55	1.36	2307.887	2307.797	2307.987
	5	3901657	760173	1.19	2309.396	3.00	1.47	1.55	1.46	2307.927	2307.846	2307.933
K	1	3901930	760426	1.15	2307.186	3.01	1.27	1.20	1.39	2305.915	2305.986	2305.799
	2	3901915	760435	1.19	2307.469	3.00	1.58	1.12	1.61	2305.890	2306.349	2305.863
	3	3901926	760407	1.08	2307.937	3.00	2.15	1.96	2.07	2305.788	2305.977	2305.864
	4	3901930	760444	1.16	2307.254	2.99	1.41	0.71	1.40	2305.843	2306.544	2305.852
	5	3901950	760415	1.18	2307.195	3.33	1.64	1.49	1.48	2305.555	2305.705	2305.720

Stick-up: Length of 2-inch PVC from ground surface to top of casing (TOC)

The primary hypothesis of this study is that Bluewater Creek exhibits variable temporal and spatial patterns in its gaining and losing character across the study area and that water quality parameters will reflect these variations.

1.5 Audience

This project will benefit Cibola National Forest through active discussion and natural resource planning in developing a long term management plan for the Bluewater Creek ecosystem.

2.0 PHYSICAL SETTING

2.1 Location

Bluewater Creek is located in the Zuni Mountains in Cibola National Forest approximately 100 miles west of Albuquerque, New Mexico and drains a watershed with an area of approximately 54,300 acres (84 square miles). The Continental Divide marks the southwestern edge of the watershed. Bluewater Creek is an intermittent stream that becomes perennial in nature downstream and is one of the main tributaries to Bluewater Lake (Figure 2) or Bluewater Dam which was built in 1927 to provide water storage for irrigation in the Grants-Bluewater area. Watershed elevation ranges from 6650 to 9240 feet above mean sea level. The entire length of the stream from the headwaters to Bluewater Lake is approximately 18 miles.

Gentle hills predominate (slopes < 15%) with 3 % having slopes >40% (USDA, 2003). Mesas combined with broad valley bottoms cut by arroyos complete the topography (Figure 3).

2.2 Precipitation and Weather Patterns

Average day time temperature ranges from 85 degrees (F) during the summer to 46 degrees (F) during the winter season. Seasonal minimum temperatures range from 48 degrees (F) to 12 degrees (F) (www.wrcc.edu).

Two Remote Acquisition Weather Stations (RAWS) were installed and became operational in the watershed in July 2003. The Bluewater Creek station is located in the valley bottom centrally located in the study near piezometer Nest H. The other station, located in the upper watershed, is referred to as the Bluewater Ridge station. This station is approximately 2 miles due south of the Bluewater Creek station. Both RAWS record precipitation data via a tipping bucket rain gauge. The complete monthly RAWS data can be found in Appendix 11.1.

Figure 2: Location of Bluewater Creek

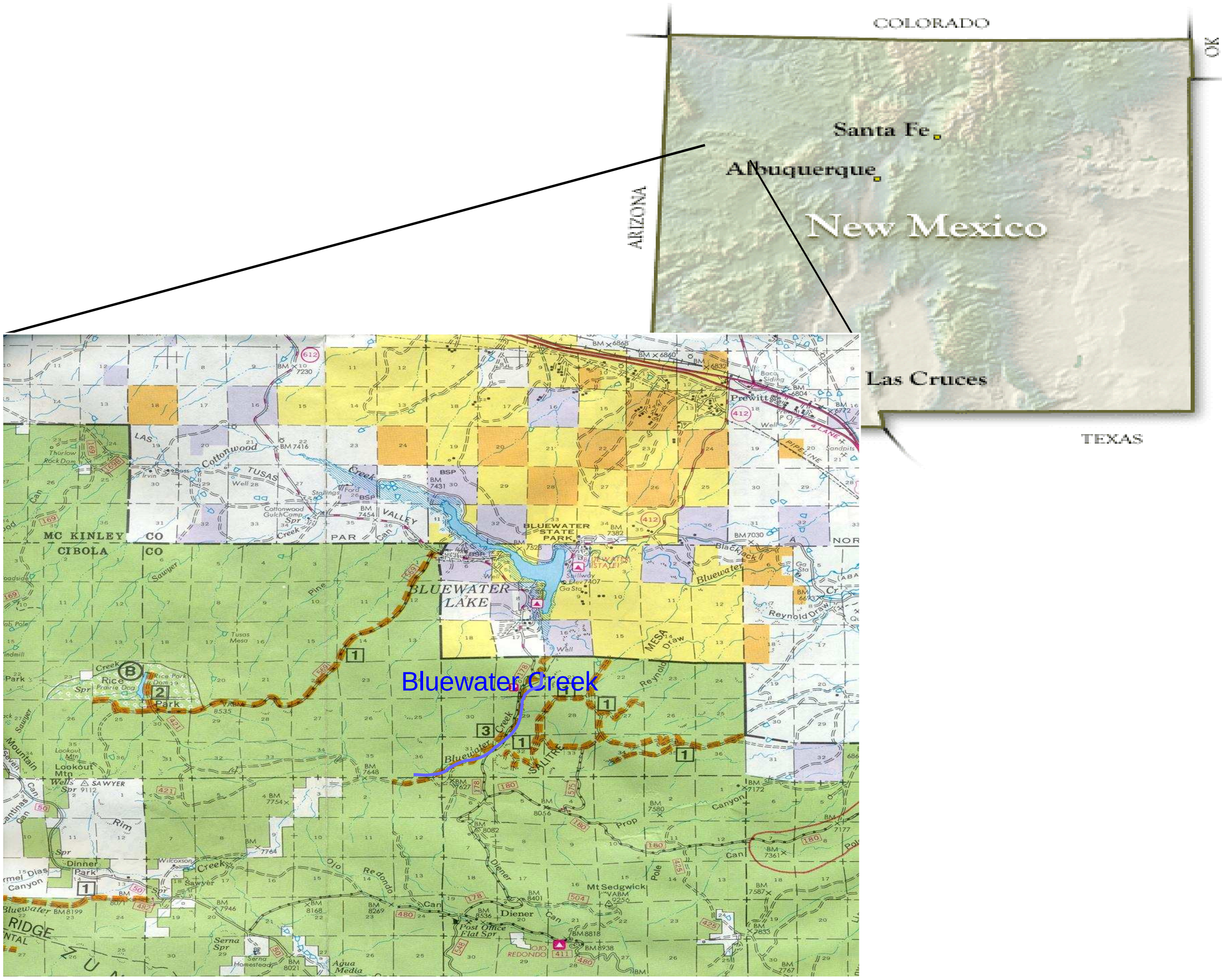
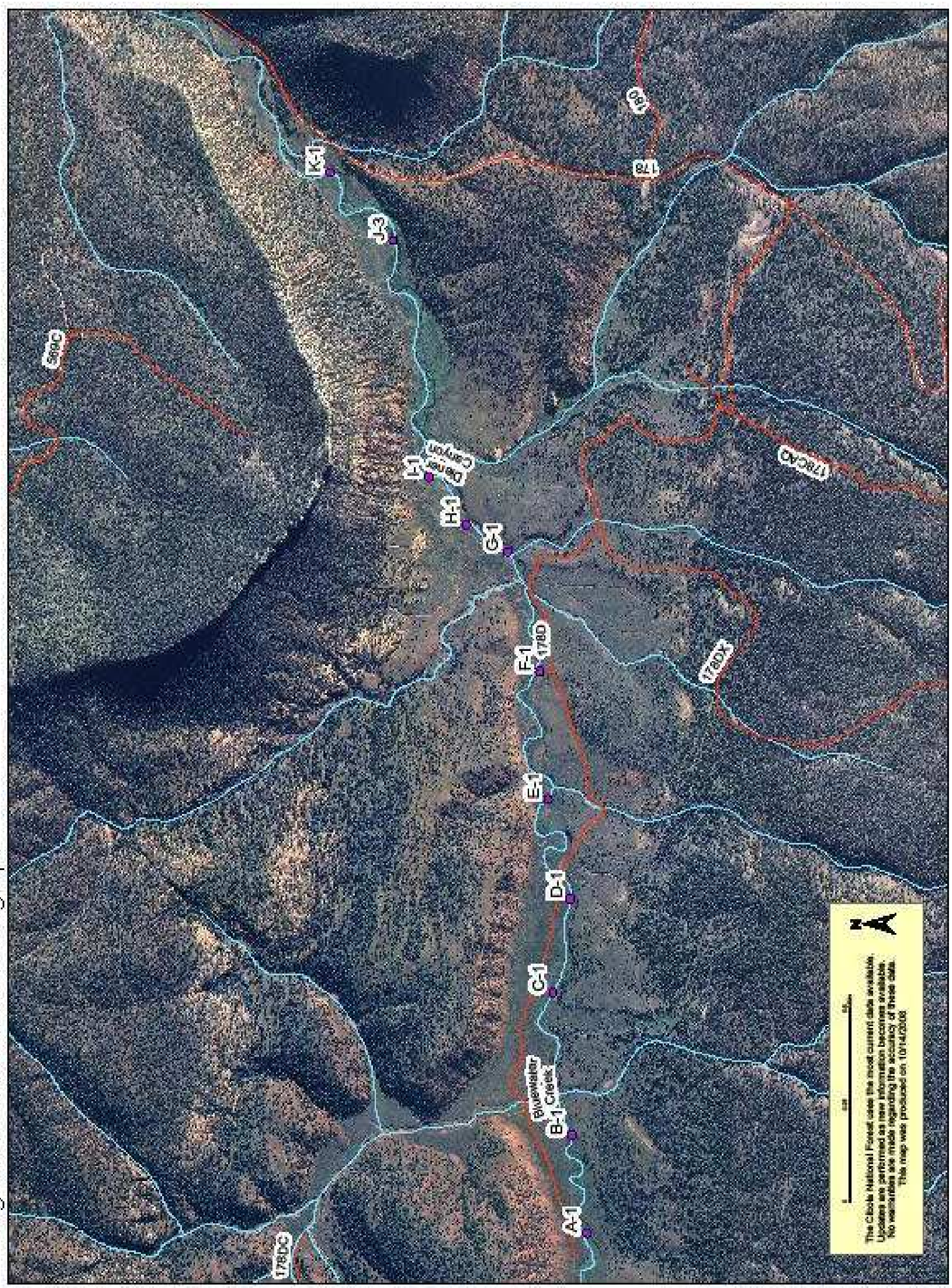


Figure 3: Ortho Quad Photograph

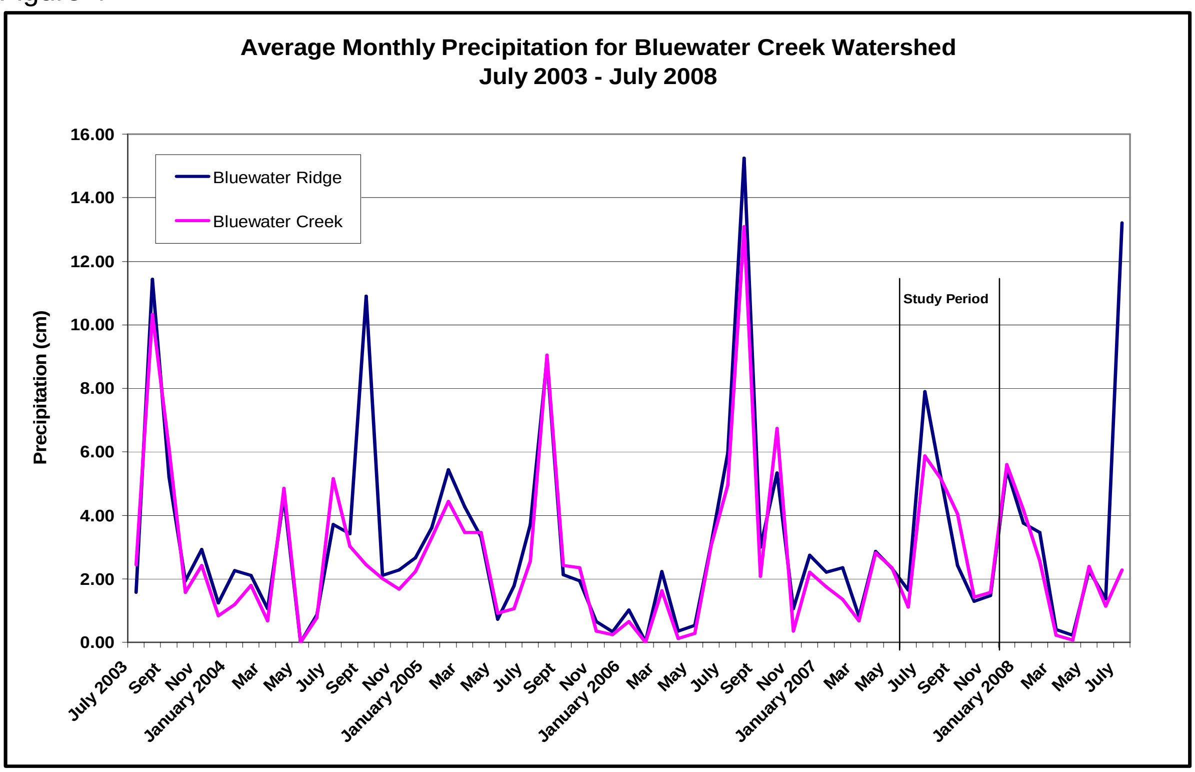


The 2004 rainfall was below average (25.9 cm) but recovered in 2006 with an annual total of 35.2 cm to the valley bottom.

Historic records from 1961-1990 indicate that precipitation varies annually across the watershed from approximately 30.5 to 58.4 centimeters (or 12-23 inches). The precipitation data recorded at RAWS during 2004 - 2007 also shows annual variability from a minimum of 25.9 cm (during 2004) along Bluewater Creek to a maximum of 40.6 cm (during 2006) recorded at Bluewater Ridge.

Figure 4 summarizes the average monthly precipitation data obtained from these two stations between July 2003 and July 2008. Both stations received little or no precipitation in May 2004 and February 2006. However, in August 2006, above average monthly precipitation of 13.1 cm and 15.2 cm was recorded at Bluewater Creek and Bluewater Ridge, respectively. During this study, Bluewater Creek averaged 2.7 cm a month in precipitation while Bluewater Ridge was slightly higher with a monthly average precipitation of 3.3 cm. The 7 month period during which this study took place (June – December 2007) is also shown on this figure.

Figure 4



2.3 Vegetation

Ponderosa Pine covers the majority of the watershed. The upland areas are dominated by Piñon-Juniper to mixed conifer. Along the valley bottoms and alluvial terraces, a variety of grasses and rabbitbrush are the predominant vegetation type.

2.4 Land Use

Land use history includes logging (1890 – 1940), and uncontrolled grazing of both sheep and cattle. US Forest Service acquisition occurred in 1947 followed by riparian area restoration in the 1980s. These restoration activities included items such as a building a designated camp ground and picnic area, 1.5 miles of stream channel fenced, exclusion of cattle and vehicles, road closures, gully head cut control, and the planting of willows and trees (USDS, 2003). Revetment structures to reduce bank erosion and beaver reintroduction also occurred during this time.

3.0 HYDROGEOLOGY

3.1 Geology

The bedrock geology exposed at the surface consist of undifferentiated Precambrian rocks, carbonate rocks, clastic sedimentary rocks, undifferentiated volcanic rocks, and unconsolidated alluvium. The primary geologic formations (from youngest to oldest) within the watershed are identified in Table 2 (USDA, 2003; state geologic map of New Mexico (http://geoinfo.nmt.edu/publications/maps/geologic/gome.html).

Table 2: Primary Geologic Formations

Geologic Formation	Description	Age
Qal	*Alluvium*; surficial deposit, eolian deposits	Quaternary
Qb	*Basalt*; undifferentiated flows, ash, cinder cones	Quaternary
TRc	*Wingate Sandstone* and *Chinle Formation*; fluvial siltstone, mudstone, sandstone and bedded channel sandstones. Some limestone in the upper part of the Chinle Formation	Triassic
Psa	*San Andres Limestone*; marine fossiliferous limestone with some interbedded sandstone	Permian
Pg	*Glorieta Sandstone*; massive-bedded, fine to medium-grained, well cemented intertidal sandstone	Permian
Py	*Yeso Formation*; Gypsiferours shale, siltsone, silty sandstone with some thin-bedded limestone	Permian
Pa	*Abo Formation*; reddish-brown sandstone and siltsone with some limestone interbedded	Permian
PC	*Precambrian rocks*, undifferentiated. Composed of granite, gneiss, metarhyolite, schist and quartzite	Precambrian

3.2 Soils

Five major soil types are found in the watershed and include Alfisols, Mollisols, Entisols, Inceptisols, and Vertisols. Mollisols are primarily dominant and are exposed in the incised channels along Bluewater Creek in the immediate study area (soil survey available at http://www.nm.nrcs.usda.gov/technical/fotg/section-2/soils-info.html).

3.3 Groundwater

Groundwater is found in two aquifers in the Bluewater Creek watershed. The primary aquifer is located inthe Permian San Andres Limestone and the underlying Glorieta Sandstone (commonly referred to as the San Andres-Glorieta Aquifer due to their good hydraulic connection). Depth-to-water ranges from 200 – 500 feet (Gordan, 1965) and most water in the aquifer is conveyed in solution channels, cavernous zones and fractures in the San Andres Limestone (USGS, 1993).

Groundwater moves in a northeast direction and then east toward the Rio Grande.

The San Andreas Limestone and the Glorieta sandstone both outcrop and recharge on the flanks of the Zuni Mountains with recharge primarily coming from direct precipitation and spring snow melt. Recharge can also occur from leakage from Bluewater Lake and Bluewater Creek.

The Quaternary valley fill alluvium and basalt is a secondary shallow aquifer commonly referred to as the Alluvial Aquifer. It can be up to 100 feet thick and yields an adequate supply of water for irrigation, domestic and stock use (Gordan, 1961). Groundwater in the alluvium moves primarily northeast and then east toward the Rio San Jose. Well depths completed in the alluvial aquifer range from 30 - 370 feet deep with depth-to-water from 10 -170 feet below ground surface (Gordan, 1961).

The Triassic rocks of the Chinle formation can act as a confining unit between the underlying San Andres-Glorieta aquifer and overlying alluvial aquifer. There are some isolated outcrops of the Chinle Formation in the Bluewater Watershed. However, the Chinle formation appears to be absent in the 4 mile stream stretch that defines this study area (USGS, 1993) which would indicate that the San Andres-Glorieta aquifer and the alluvial aquifer are hydraulically connected here.

Recharge of the alluvial aquifer is from direct precipitation, surface runoff, streamflow leakage, and leakage from the underlying rocks of the San Andres-Glorieta aquifer (USGS, 1992).

Dames and Moore (1981) performed aquifer tests on wells in the Bluewater area and found hydraulic conductivity in the alluvial aquifer to range from 40 to 60 feet per day.

3.4 Stream flow

The headwaters of Bluewater Creek are located in the Zuni Mountains on the northeast side of the continental divide. Bluewater Creek is considered an intermittent – perennial stream. The creek flows in a northerly direction and then east toward its confluence with the Rio San Jose. Annual peak flow occurs during the spring snowmelt in March and April.

The USGS gaging station, 08341300, is located above the Bluewater dam (Sec.16, T12N, R12W). The watershed above this gage which includes Bluewater Creek covers a drainage area of 75 square miles. Periods of record include 1953 – 1978 and again from 1989 – 2000. Figure 5 shows a maximum daily average discharge for 1989-2000 to be 845 cubic feet per second recorded on March 25, 1998. Average annual discharge from Bluewater Creek for the period 1989 through 2000 is approximately 9.5 cubic feet per second (cfs). Kundargi (2005) recorded discharge during spring 2005 to be 8.1 cfs.

For the Bluewater Creek area, historical records (1913 – present) obtained from the Western Regional Climate Center (www.wrcc.dri.edu) show the annual snowfall recorded at Thoreau, New Mexico in 1996 and 1998 to be 18.7 inches and 41 inches, respectively. Thoreau is located about 13 miles north of Bluewater Creek. These snow amounts, viewed as a good snow year (1998) and a poor snow year (1996) are shown in Figure 6 in terms of discharge amounts during the March snow melt.

4.0 BACKGROUND – WATER QUALITY STUDIES

Few surface water quality studies have been performed at Bluewater Creek beginning in 1984. Four groundwater samples were collected in 2005.

Jacobi and Smolka in their Reconnaissance Survey of Bluewater Creek (1983) collected two water samples from Bluewater Dam to the mouth of Bluewater Canyon and concluded that there was a downstream increase for temperature, turbidity, TSS, sulfate and alkalinity. It should be noted that these sample locations are not on USFS property.

Figure 5

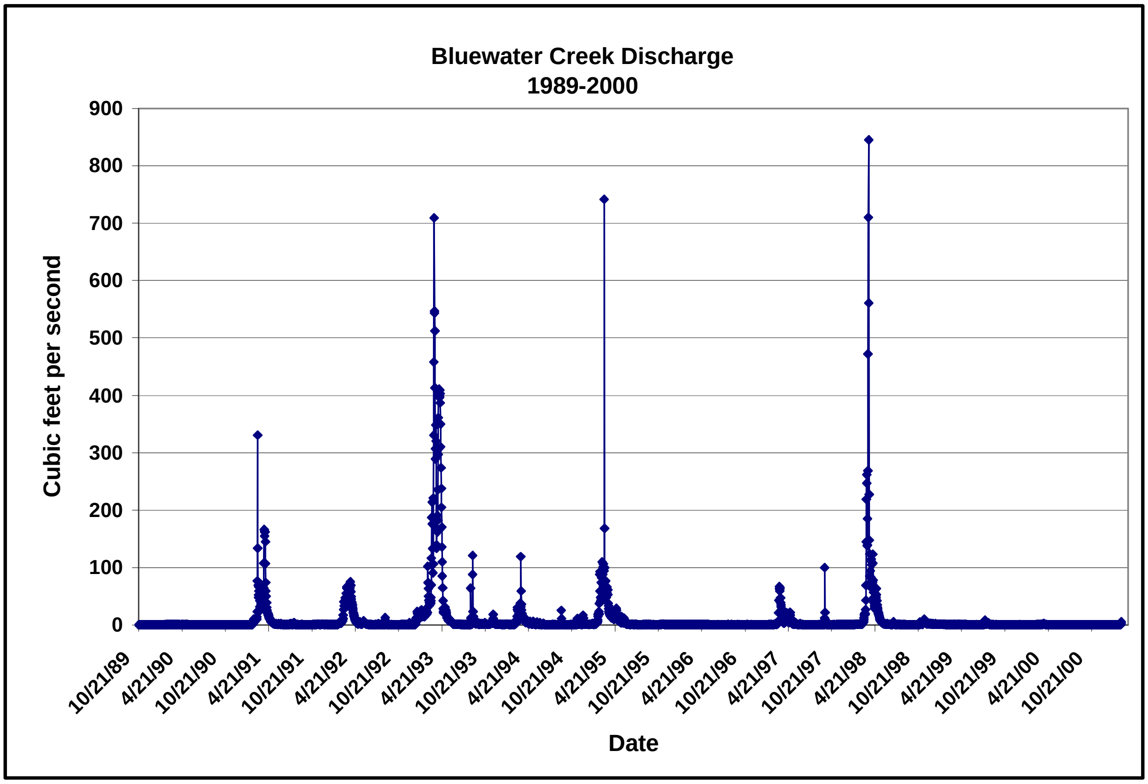
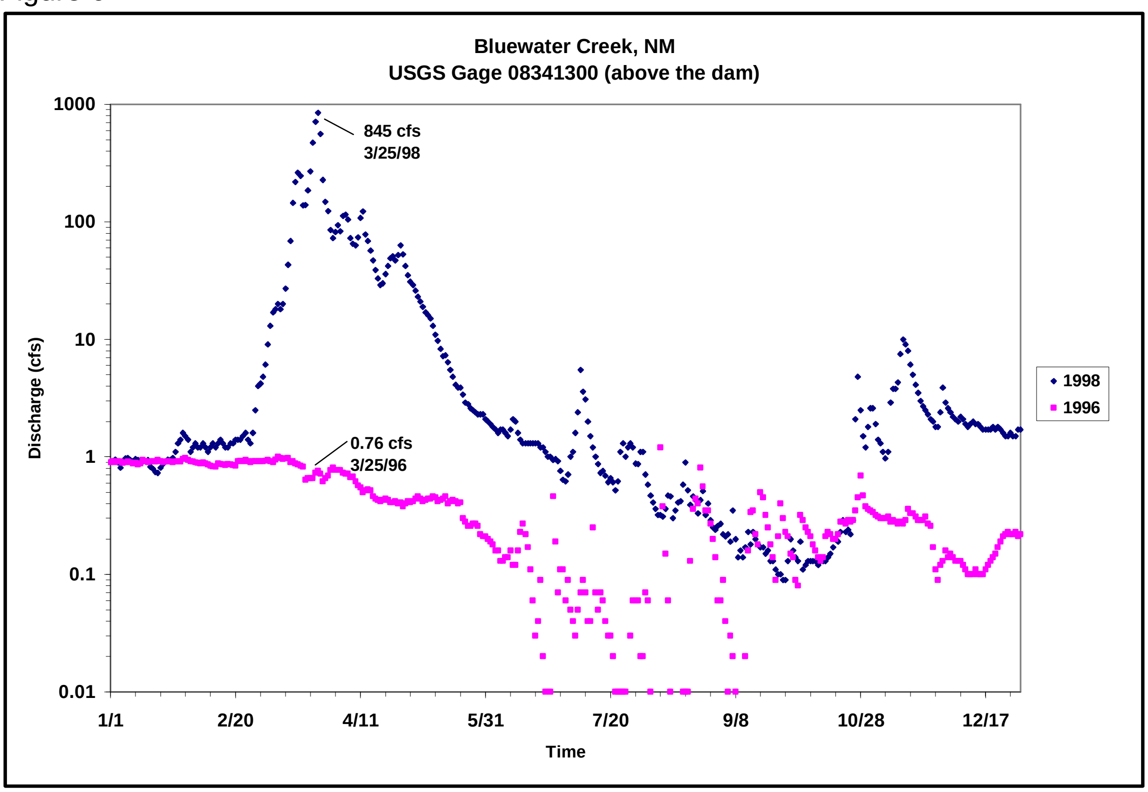


Figure 6



DuBey (2003) collected six surface water samples for alkalinity, hardness, nitrates and sulfates. Sample locations are shown in Figure 7. Field measurements were also collected for water temperature, dissolved oxygen, specific conductance, pH and turbidity (Table 3). Results indicated turbidity exceeded the NMED standard of < 25 NTU at two locations located upstream on private property. Results also showed the stream to be moderately oxygenated, alkaline, moderately cold, and containing moderates amounts of nutrients (DuBey, 2003).

The New Mexico Environment Department (NMED) collected water samples from Bluewater Lake and along Bluewater Creek (above and below the dam) during a six month period in 2004 as part of the Total Maximum Daily Load Report (TMDL) for the Rio Puerco Watershed Report – Part 2 (NMED, 2007). Bluewater Creek is considered a tributary to the Rio Puerco Watershed. The designated uses for Bluewater Creek as set forth in the New Mexico Standards for Interstate and Intrastate Surface Waters (NM Administrative Code 20.6.4) are the following: coldwater aquatic life, domestic water supply, fish culture, irrigation, livestock watering, and wildlife habitat States are required to develop a TMDL under Section 303(d) of the Federal Clean Water Act. A TMDL is defined as a “written plan and analysis established to ensure that a waterbody will attain and maintain water quality standards including consideration of existing pollutant loads and reasonably foreseeable increase in pollutant loads” (USEPA 1999)

NMED sample collection occurred on April 5, May 3, June 8, July 13, August 10 and November 15, 2004. Their findings showed Bluewater Creek from the lake to the headwaters to be impaired due to temperature and nutrients (exceedences in total nitrogen and phosphorus).Temperature was recorded from June 10 – December 8, 2004. Bluewater Creek exceeded the temperature criterion (>20 ^{0}C) 15% of the time during this period with a maximum temperature of 27.86 ^{0}C Pertinent to this study, only those samples collected above the dam near USGS gaging station 08341300 (see Figure 7) are summarized and shown on Table 4 due to its close proximately to this study area or approximately 2.5 miles downstream from piezometer Nest K.

Valdez (2006) performed a surface water monitoring study along Bluewater Creek during 2004-2006. Three of the six designated sample locations are located on USFS lands above Bluewater dam. This study showed that water temperature, pH, turbidity and dissolved oxygen exceeded the New Mexico Standards for Interstate and Intrastate Surface Waters (NM Administrative Code 20.6.4) during the study period.

These exceedances are listed below, with the corresponding standard shown in parenthesis.

•Water temperature: 1.7 – 22.8 ^{0}C (< 20 ^{0}C)

•pH: 6.47 – 8.5 (6.6 to 8.8)

•Conductivity: 112 – 1047 µS/cm (no designated standard)

•Turbidity: 1.1 – 257.8 NTU (< 25 NTU)

•Dissolved Oxygen: 2.2 – 6.7 mg/L (above 6 mg/L)

Table 3: Surface Water Quality Results from DuBey Study (2003)

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
D.O. mg/l	5.5	6.2	7.0	5.2	4.0	5.0
pH	8.2	8.6	8.9	8.3	8.1	8.9
H_2O Temperature C^o	10.9	15.7	16.7	19.7	19.7	15.7
Alkalinity $CaCO_3$	280	280	280	280	220	200
Nitrate NO_3 –N mg/l	1.8	1.3	1.8	7.7	4.2	5.2
Sulfate SO_4^{-2} mg/l	27	20	28	27	33	27
Turbidity NTU	1.5	5.0	21.0	10.0	51.0	35.0
Conductivity uohms	410	417	486	481	439	354
Survey Information (UTM 83)	(x)760331 (y) 3902161	(x)759192 (y) 3901688	(x)758770 (y) 3901770	(x)758353 (y) 3901113	(x)755476 (y) 3900721	(x)754888 (y) 3900666

Figure 7:DuBey (2003) and NMED (2004) Sample Locations

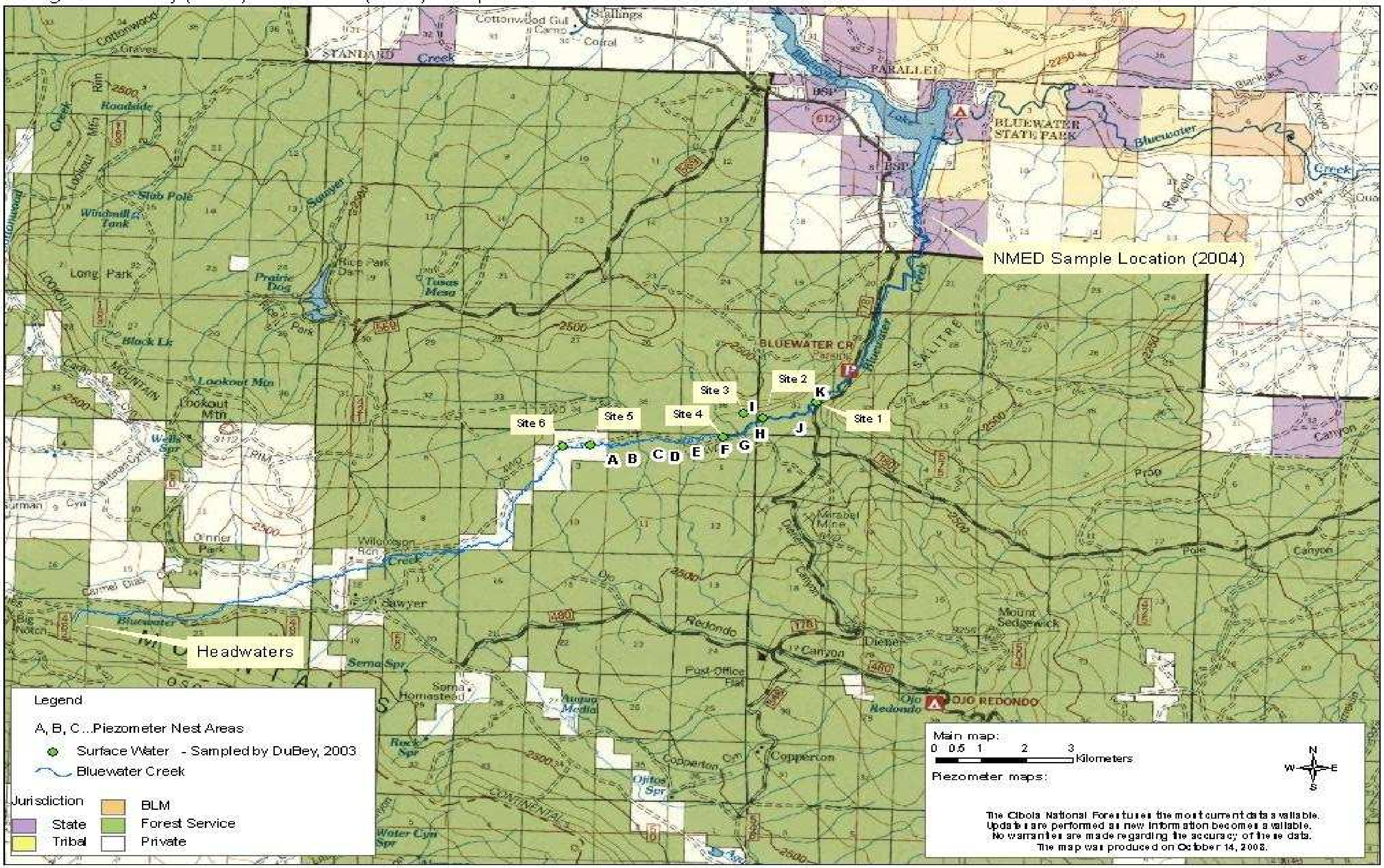


Table 4: Surface Water Quality Results from NMED study (2004)

Major Cation and Anion Chemistry (mg/l)

Date	F	Cl	SO_4	HCO_3	Ca	K	Mg	Na	TDS
4/5/04	0.52	-	-	-	38.0	-	10.0	-	220
5/3/04	0.32	10.0	804	175	290	5.00	62.0	16.4	1360
6/8/04	0.58	10.0	33.6	264	64.0	5.00	17.0	11.2	324
7/13/04	0.63	-	-	-	74.4	-	19.1	-	328
8/10/04	0.62	-	-	-	76.0	-	20.0	-	344
11/15/04	0.48	10.0	56.3	267	41.5	5.00	18.9	10.2	328

Field Parameters

Date	pH	EC	Temp C	DO (mg/l)	DO (%sat)	Turbidity
4/5/04	7.64	281	8.95	11.2	126	31.8
5/3/04	7.66	405	12.7	9.20	113	3.10
6/8/04	7.75	300	25.1	5.75	90.0	1.30
7/13/04	7.83	310	28.3	9.21	145	9.70
8/10/04	7.16	543	20.6	4.07	57.4	4.10
11/15/04	8.02	485	5.45	11.3	115	-

Total Nutrients (mg/l)

Date	Total Phosphorous	Total Nitrogen
4/5/04	0.0344	0.459
5/3/04	<0.03	0.513
6/8/04	0.03035	0.434
7/13/04	<0.03	0.33
8/10/04	0.0334	0.42
11/15/04	0.022	0.27

Kundargi (2005) measured the effects of excluding cattle from three fenced areas on water quality and vegetative conditions through use of three exclosures. Sixteen surface water samples were collected during three separate sample events (fall 2004, winter 2004 and spring 2005). These samples were collected at various grazed and ungrazed sections along the creek between piezometer Nest A and piezometer Nest H (Figure 1). All water samples were analyzed for total phosphorous, nitrate-nitrite, fecal coliform, dissolved oxygen, temperature, pH, conductivity, and turbidity. Kundargi (2005) concluded that there were no significant differences in surface water quality between the ungrazed and grazed areas. One explanation for this is that cattle had only been absent for a year prior to the study. Surface water quality results, however, did indicate a seasonal trend which was expected. Turbidity results showed a significant increase downstream.

Four groundwater samples were collected from piezometers A1, D1, G1 and H1 during the spring 2005 sample event only. Overall results showed differences in surface water chemistry for dissolved oxygen, temperature, conductivity, pH and nitrogen. Total phosphorous was absent from the groundwater samples but was present in the surface water at a mean value of 0.02 mg/L (Kundargi, 2005). Major cation and anion analyses were not included in this study.

5.0 RESTORATION ACTIVITIES IN THE 1980s AND 1990s

Watershed restoration treatments occurred at Bluewater during the 1980s and again during 2003-2004. Treatments during the 1980s included exclosure fencing of the riparian areas, revetment type structures to control erosion, willow planting, elimination of streamside roads and the re-introduction of beaver.

Treatments during 2003-2004 included activities such as exclosure fencing to study the effects of keeping the cattle out, willow planting (failed) and instrumentation and piezometers were installed to study SW-GW connectivity. These watershed restoration treatments resulted in significant initial riparian area recovery and erosion control based on visual analysis but no baseline data had been collected to perform a quantitative analysis of riparian health and water chemistry.

6.0 PROJECT METHOD AND DESIGN

A combination of measurements for physical and chemical properties were used in this assessment and include temperature and water level monitoring, water chemistry analysis for major cation/anions and selected trace elements, field parameter and alkalinity measurements. These methods helped identify subsurface flow paths, chemistry differences and/or similarities, and areas where the interaction between the surface water and groundwater are significant.

6.1 Field

6.1.1 Water Temperature Monitoring

Temperature monitoring in streams and shallow wells can be used as a screening tool for identifying gaining and losing reaches (Silliman & Booth, 1993; Stonestrom and Constanz, 2003). Bluewater Creek has been identified impaired for Temperature > 20^{o} C according to the recent TMDL report by the New Mexico Bureau of Surface Water Quality. Warm summer stream temperatures are due partly to low flows, high air temperature and lack of riparian vegetation. This can lead to other water quality problems, too.

Onset Hobo Temperature Loggers (model: water temp Pro v2) were installed on June 29, 2007 at two locations (adjacent to piezometer nest D and K) along Bluewater Creek to record surface water temperature variability. Forest service personnel also installed a third temperature logger downstream of the study area in proximity to the USGS gage 08341300. Only the temperature data collected from Nest D and K were evaluated as part of this study.

Subsurface temperature patterns can provide information about the velocity and direction of water movement at the interface between surface water and groundwater systems. Subsurface temperature was recorded at each piezometer nest in the piezometer located closest to the stream bank.

6.1.2 Groundwater and Surface Water Level Monitoring

The direction of groundwater flow is based upon static water-level data. Three miniTROLL pressure transducer data loggers obtained from In-Situ, Inc. were installed in June 2007 at each piezometer nest to record water level data at 30 minute intervals with exception to Nest B, E and J. At these nests only two dataloggers were installed to record water levels. A total of 30 dataloggers were installed to collect groundwater level data. Past water level data collected from 2004-2006 were also evaluated. Pressure transducer installation at Nest F is shown in Figure 8. Transducers were checked frequently and data were downloaded in the field Figure 9.

Figure 8: Pressure transducer Installation (Nest F)

Figure 9: Downloading pressure transducer in the field

Water levels can show either downward or upward gradients and with this information losing and gaining segments along Bluewater Creek were able to be determined.

6.1.3 Water Quality Sample Collection and Analysis

Prior to this study, sample collection was performed in March 2007 to capture a snowmelt event and to supplement this study. These results are summarized below.

Initial Headwater and Snowmelt Sample collection

Surface water samples were collected during the spring snowmelt event in March 2007 from seven select locations; five from the headwaters (SW 001 – 005) and two further downstream along the active perennial portion of Bluewater Creek (SW-006 and SW-007). Sample locations are shown in Figure 10. In-stream measurements for pH, temperature, and flow were recorded at the time of sample collection. Laboratory analyses included alkalinity, dissolved organic carbon (DOC), particulate organic carbon (POC), and major cation and anions.

Results indicate an increase in concentration for sulfate, chloride and alkalinity in a downstream direction. Similarly, dissolved organic carbon follows this same trend. These results are expected for the headwaters where there is an abundance of allochthonous material. Also, quantitatively, DOC is the largest organic carbon term in most aquatic systems and appears to be true for Bluewater Creek. It is expected that these DOC values would decrease during baseflow conditions. Alkalinity concentrations indicated that these waters are dominated by inorganic carbon or specifically HCO_3. Data can be found in Table 5.

PHREEQC (Parkhurst, D.L., et al, 1980) analysis was performed using major chemistry cation and anion laboratory results. A charge balance showed a < 8.5 % error. Major species include cations Ca, Na, Mg, K and $S0_4$ and anion HCO_3 for the headwaters.

Calcium is the dominant cation and bicarbonate is the major anion; all waters from this study are calcium-bicarbonate type water.

Figure 10: March 2007 Sample Locations During Spring Discharge (snowmelt)

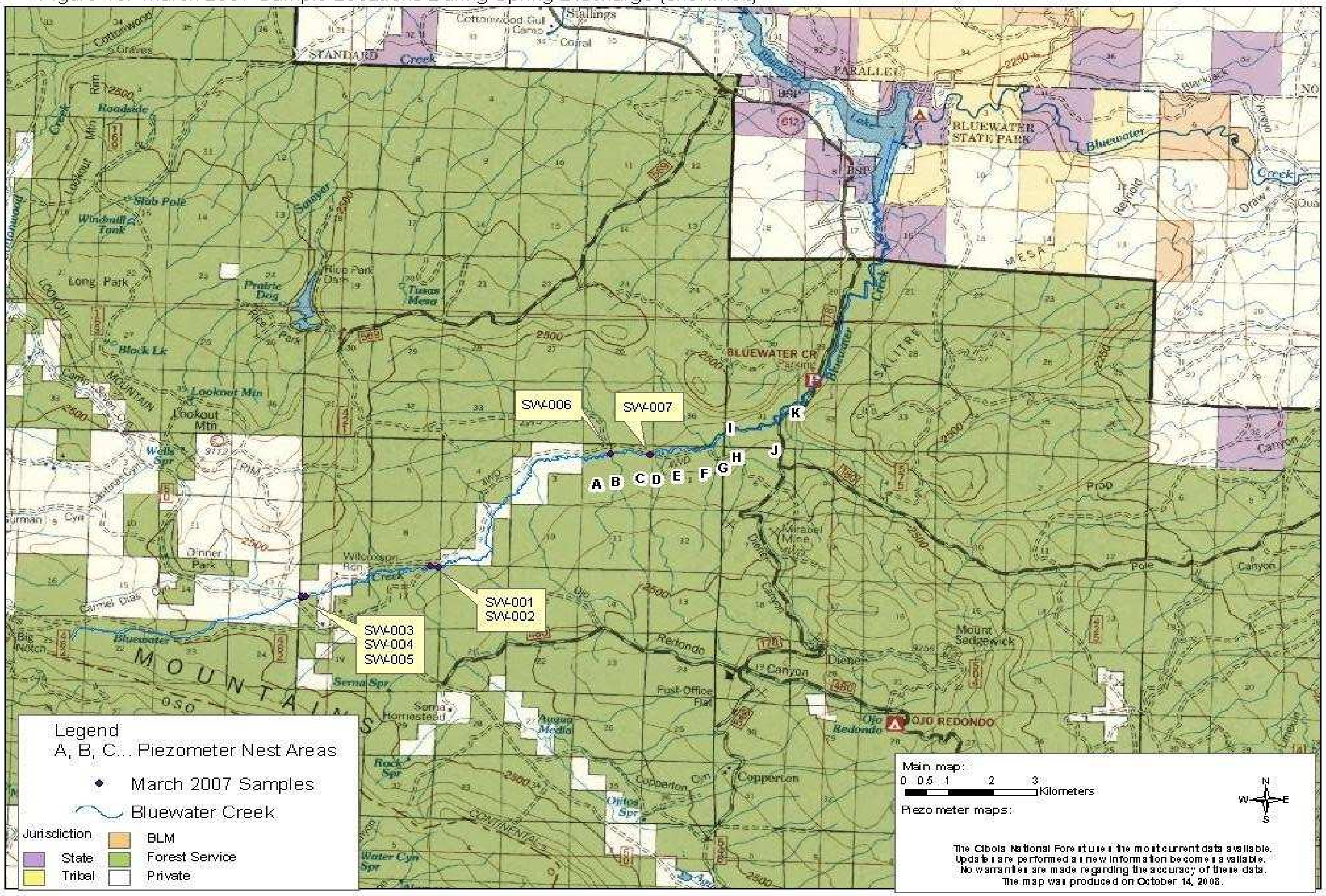


Table 5: Surface Water Quality Results for March 2007

Major Chemistry

ID Number	Location	Date	F	Cl	$N0_2$	Br	NO_3	PO_4	SO_4	HCO_3	Ca	K	Mg	Na	TDS	% balance
SW-001	headwaters	March	0.18	3.73	0.01	0.03	0.35	0.03	15.5	167	41.6	0.84	11.8	16.2	257	8.44
SW-002	headwaters	March	0.38	4.37	0.01	0.06	1.24	0.03	13.1	146	34.5	1.11	9.30	15.4	224	5.82
SW-003	headwaters	March	0.06	3.36	ND	0.01	0.28	0.03	7.57	67.1	17.6	0.70	3.90	3.42	104	0.29
SW-004	headwaters	March	0.07	2.65	0.02	0.04	0.31	0.04	7.24	62.2	16.6	0.69	3.55	3.64	96.6	1.58
SW-005	headwaters	March	0.10	2.55	0.02	0.02	0.52	0.03	7.04	58.6	17.1	0.75	4.12	3.93	94.0	7.28
SW-006	valley	March	0.51	4.34	0.01	0.03	0.33	0.04	13.3	124	30.5	1.10	7.35	17.5	198.5	8.26
SW-007	valley	March	0.51	4.43	0.04	0.01	0.56	0.02	13.1	122	30.1	1.22	7.25	16.7	194.9	7.97

ND = not detected

Field Parameters and DOC/POC*

ID Number	Location	Date	Lat.	Long.	pH	Temp C	Flow (ft/sec)	DOC (mg/l)	POC (mg/l)
SW-001	headwaters	March	3897584	752626	8.32	8.8	0.78	5.78	0.01
SW-002	headwaters	March	3897539	752810	8.33	10.4	0.56	6.52	0.37
SW-003	headwaters	March	3896578	749728	7.88	11.0	0.01	7.50	0.20
SW-004	headwaters	March	3896617	749732	8.17	14.8	0.5	8.02	1.41
SW-005	headwaters	March	3896605	749813	8.05	14.7	0.7	7.91	0.81
SW-006	valley	March	3900714	757443	8.50	15.0	-	6.41	1.62
SW-007	valley	March	3900692	756547	-	-	-	6.37	0.95

*DOC = Dissolved Organic Carbon (Laboratory analysis)

*POC = Particulate Organic Carbon (Laboratory analysis)

Trace Element

ID Number	Location	Date	Al	B	Ba	Fe	Si	Sr	V
SW-001	headwaters	March	0.359	0.497	0.066	0.169	8.97	0.142	0.002
SW-002	headwaters	March	0.035	0.244	0.042	<0.1	8.74	0.107	0.007
SW-003	headwaters	March	0.032	0.303	0.002	<0.1	10.49	0.053	0.010
SW-004	headwaters	March	0.044	0.324	0.016	<0.1	9.27	0.049	0.006
SW-005	headwaters	March	0.065	0.323	0.017	<0.1	9.45	0.053	0.001
SW-006	valley	March	0.060	0.291	0.042	<0.1	9.74	0.107	0.001
SW-007	valley	March	0.044	0.352	0.044	<0.1	9.36	0.114	0.003

Surface water and Groundwater Sample Collection

Groundwater and surface water samples were collected on three separate occasions in 2007 and include August 7, September 29 and November 2. The sample collection strategy is summarized in Table 6.

Table 6: Sample Collection Strategy

Piezometer Nest	GW Sample (piezometer)	SW Sample	8/7/2007	9/29/2007	11/2/2007
Nest A	A-1 and A-2	Adjacent to Piezometer A-1 in Thalweg	X	X	X
Nest D	D-1 and D-2	Adjacent to Piezometer D-1 in Thalweg	X	X	X
Nest F	F-1 and F-2	Adjacent to Piezometer F-1 in Thalweg	X	X	X
Nest I	I-1 and I-2	Adjacent to Piezometer I-1 in Thalweg	X	X	X
Nest K	K-1 and F-3	Adjacent to Piezometer K-1 in Thalweg	X	X	X

Surface Water

Surface water samples were collected in the thalweg adjacent to the center piezometer from five different piezometer nest locations or Nest A, D, F, I and K. The center piezometer is located closest to the stream bed and is identified with a “1” within any given piezometer nest such as A-1, B-1, C-1, etc (Figure 1).

Two surface water samples were collected in a 150-ml polyethylene bottle at each location; a filtered water sample for cation and trace metal analysis and an unfiltered water sample for anion and alkalinity analysis.

Prior to sample collection, each bottle and the 60-ml syringe were rinsed with sample water. Also, with the filter attached to the syringe, a small amount of the sample water was drawn through the filter and used to rinse the sample bottle before the actual water sample was drawn for the sample bottle.

Filtering was performed in the field using a .045 µm filter and a filtered sample was acidified with nitric acid. All samples were placed on ice during field collection activity. Upon delivery to the laboratory, samples were refrigerated.

Groundwater

The piezometer network was utilized to characterize shallow groundwater chemistry. Groundwater samples were collected from two piezometers at the same nest locations where surface water samples were collected or Nest A, D, F, I, and K (Table 5). For each sample event, one groundwater sample was obtained from the piezometer closest to the stream bed and another sample was collected from the farthest up gradient piezometer in relation to the stream bed piezometer.

Three borehole volumes of water were removed prior to groundwater sample collection. The volume of water in the well was calculated from information obtained for casing diameter, total well depth and depth-to-water measurements as shown in the following formula (USGS 2006):

$V = r^2h\ (0.163)$

Where:

V = static volume of water in well (in gallons)

r = inner radius of well casing (in inches)

h = length of water column (in feet) which equals to the total well depth minus depth to water.

0.163 = a constant conversion factor that compensates for the conversion of the casing radius from inches to feet for a 2-inch diameter piezometer and the conversion of cubic feet to gallons, and pi.

A 1-inch dedicated PVC bailer was used to remove the water from the piezometer (Figure 11). Field parameters (pH, temp, DO, EC) were measured and recorded at the end of purging the piezometer of stagnant water. Once three borehole volumes had been removed, the piezometer was given a minimum “recharge” time of one hour before a groundwater sample was collected. A manual water level measurement was taken prior to sample collection to record the static water level and to ensure recharge conditions had been met. A separate 1-inch dedicated PVC bailer was used for sample collection purposes only. After each use, both the purge and sample collection bailer was thoroughly cleaned with an alconox type solution followed by a de-ionized water rinse.

Groundwater samples were collected in 2 150-ml polyethylene bottle from each piezometer; a filtered water sample for cation and trace metal analysis and an unfiltered water sample for anion and alkalinity analysis. Prior to sample collection, each bottle and the 60-ml syringe were rinsed with the actual sample water. Also, with the filter attached to the syringe, a small amount of the sample water was drawn through the filter and used to rinse the sample bottle before the actual water sample was drawn for the sample bottle.

Filtering was performed in the field using a .045 µm filter and a filtered sample was acidified with nitric acid. All samples were placed on ice during field collection activity. Upon delivery to the laboratory, samples were refrigerated.

Figure 11: 1-inch bailer is placed in piezometer to purge 3 borehole volumes

6.1.4 Field Parameters

Measurement were made in the field for specific conductivity, dissolved oxygen, water temperature and pH with a water quality field instrument from YSI, Inc (556 MPS probe). Proper calibration for all field parameters were performed prior to use and rechecked throughout the course of the day during sample collection activities.

Flow was only able to be measured during the November sample collection event. Flow was measured using a March-McBirney portable electronic flow meter (FLO-MATE - Model 2000) in combination with a top-setting rod. Two stream profile sections were established at Nest F and at Nest I. Nest I profile section is shown on Figure 10.

Discharge measurement procedures followed guidance set forth by the USGS (USGS, 1965). A cross-sectional profile was established and divided into sections where average velocity was obtained using the six-tenths-depth method. This method is recommended for depths less than 2.5 feet deep or greater than 0.3 feet. At this depth, it can be assumed that average velocity occurs at six-tenths of the total depth. After the average velocity was measured at each subsection along the established stream profile, discharge (q) for each subsection was calculated using the equation $q=v*a$. The individual section discharge values (q) were then added together to determine the total stream discharge or flow (Q) where $Q = \sum q_i$

Figure 12: Stream Discharge Profile at Nest I

6.2 Laboratory Analyses: Water Quality

An Ion Chromatograph (IC) and an Inductive Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) were used to determine concentrations of major anions and cations in the water samples, respectively. Standard methods from the American Society for Testing and Materials (ASTM) were used and include method 200.7 (ICP-AES) and method 4010B (IC).

Laboratory alkalinity was performed within 48-72 hours of sample collection by acid titration by using .020N sulfuric acid solution. Laboratory procedures are in accordance to Standard Methods for the Examination of Water and Wastewater, 1976.

Table 7 provides an overview of parameters measured and methods of analysis.

Table 7: Measured Parameters and Methods of Analysis

Parameter	Method
Major Cations	IC (4010B) and ICP-AES (200.7)
Major Anions	IC (4010B) and ICP-AES (200.7)
Trace Elements	IC (4010B) and ICP-AES(200.7)
Dissolved Oxygen	YSI Inc. 556 MPS probe
Temperature	YSI Inc. 556 MPS probe
pH	YSI Inc. 556 MPS probe
Conductivity	YSI Inc. 556 MPS probe
Alkalinity	Acid titration using .020N sulfuric acid solution
Flow Rate	Marsh-McKinney FlowMate™ 2000

6.3 Quality Assurance

Quality assurance is a system of measures taken to ensure that a desired product meets a defined level of quality. For this study, we employed a field and laboratory component to quality assurance for data integrity purposes.

During water sample collection, measurements were obtained from field parameters and recorded on a data collection form. This included pH, specific conductivity, temperature, and dissolved oxygen. Repeated measurements at select locations were also recorded. Manual water level measurements were taken and recorded from those piezometers that are without a pressure transducer data logger.

A manual water level measurement was also obtained from those piezometers with a dedicated pressure transducer data logger where a groundwater sample will be collected. Any discrepancy between the datalogger water level and the manual water level measurement is referred to as “drift correction”. Once the water level data from each of the pressure transducer datalogger is downloaded and accessible for viewing in Microsoft Excel will the “drift correction” be evaluated and the data adjusted accordingly.

Measurement duplicate samples can determine the precision of the sampling technique. Therefore, one surface water and groundwater duplicate field sample were collected during each sample collection event.

Laboratory Instrument calibration consisted of preparing one blank and three calibration blanks. For accuracy measures, two solutions were prepared to verify calibration accuracy; these are called Initial Calibration Blank Verification (ICBV) and an Initial Calibration Verification (ICV) solution. Additionally, matrix spikes were performed to check for any interference during analysis. Last, sample and matrix spike duplicates were used to verify precision accuracy.

7.0 RESULTS

7.1 Surface Water Chemistry

Field Parameters

Surface water (SW) field parameter results for each sample collection event are shown in Table 8a, 8b, and 8c. A summary is outlined below for each nest area where sample collection occurred.

Table 8a: Sample Collection Locations and Field Parameters August 7, 2007

Sample ID	Latitude	Longitude	Piezometer Total Depth TOC (m)	Depth-to-water (TOC) prior to sampling (m)	Temp - C	pH	Conductivity (µs/cm)	DO (mg/l)	DO (%)	TDS (ppm)	Elevation TOC (m)	Ground Water Elevation TOC (m)
NEST A												
SW A-1	NA	NA	NA	NA	17.58	7.13	166	7.0	73.4	115	NA	NA
GW A-1	3900559	756077	3.01	2.076	16.10	6.63	1000	3.0	31	391	2329.431	2327.356
GW A-2	3900540	756069	4.61	3.508	11.10	6.43	987	-	-	478	2330.624	2327.116
GW A-3	3900569	756059	3.01	2.591	-	-	-	-	-	-	2329.734	2327.143
GW A-4	3900548	756097	3.00	2.856	-	-	-	-	-	-	2329.777	2326.921
GW-A-5	3900576	756088	4.62	3.365	-	-	-	-	-	-	2330.209	2326.844
NEST D												
SW D-1	NA	NA	NA	NA	18.50	7.39	221	6.71	72.2	136	NA	NA
GW D-1	3900714	757463	2.95	1.442	16.00	6.61	1414	2.65	30	526	2321.759	2320.317
GW D-2	3900699	757449	2.98	1.948	13.77	6.79	1103	4.45	50	580	2322.267	2320.320
GW D-3	3900727	757448	2.94	1.996	-	-	-	-	-	-	2322.269	2320.273
GW D-4	3900700	757478	3.00	1.902	-	-	-	-	-	-	2322.198	2320.296
GW-D-5	3900725	757481	3.01	1.862	-	-	-	-	-	-	2321.854	2319.992
NEST F												
SW F-1	NA	NA	NA	NA	19.08	7.48	314	5.85	65.3	205	NA	NA
GW F-1	3900904	758401	2.73	1.615	16.70	7.34	756	6.15	68	217	2317.351	2315.735
GW F-2	3900909	758420	3.01	2.112	14.20	7.17	904	2.85	29	417	2316.802	2314.690
GW F-3	3900929	758416	3.01	2.176	-	-	-	-	-	-	2317.379	2315.202
GW F-4	3900904	758437	2.99	1.999	-	-	-	-	-	-	2317.108	2315.108
GW F-5	3900925	758433	3.01	2.237	-	-	-	-	-	-	2317.319	2315.082
NEST I												
SW I-1	NA	NA	NA	NA	20.25	7.62	350	4.23	47.1	218	NA	NA
GW I-1	3901431	759182	2.98	1.935	17.00	7.19	883	2.60	27.5	418	2314.437	2312.502
GW I-2	3901434	759207	2.86	1.954	16.15	7.06	1184	2.46	25	449	2314.380	2312.426
GW I-3	3901411	759184	2.37	1.990	-	-	-	-	-	-	2314.515	2312.525
GW I-4	3901453	759187	3.02	1.981	-	-	-	-	-	-	2314.418	2312.437
GW I-5	3901429	759161	2.71	2.027	-	-	-	-	-	-	2314.540	2312.513
NEST K												
SW K-1	NA	NA	NA	NA	20.90	7.94	meter error	-	-	429	NA	NA
GW K-1	3901930	760426	3.01	1.740	16.53	7.70	meter error	-	-	604	2307.186	2305.446
GW K-2	3901915	760435	3.00	1.951	-	-	-	-	-	-	2307.469	2305.519
GW K-3	3901926	760407	3.00	2.432	13.53	7.60	meter error	-	-	557	2307.937	2305.504
GW K-4	3901930	760444	2.99	1.731	-	-	-	-	-	-	2307.254	2305.523
GW K-5	3901950	760415	3.33	1.743	-	-	-	-	-	-	2307.195	2305.452

TOC = Top of Outer Casing
NA = Not Applicable
TDS = Computed from sum of major ions (ppm)

Table 8b: Sample Collection Locations and Field Parameters September 29, 2007

Sample ID	Latitude	Longitude	Piezometer Total Depth TOC (m)	Depth-to-water (TOC) prior to sampling (m)	Temp - C	pH	Conductivity (µs/cm)	DO (mg/l)	DO (%)	TDS (ppm)	Elevation TOC (m)	Ground Water Elevation TOC (m)
NEST A												
SW A-1	NA	NA	NA	NA	12.89	8.20	305	-	-	325	NA	NA
GW A-1	3900559	756077	3.01	2.219	13.01	7.79	448	4.2	40	338	2329.431	2327.212
GW A-2	3900540	756069	4.61	3.527	12.75	7.67	600	2.04	21	475	2330.624	2327.098
GW A-3	3900569	756059	3.01	2.618	-	-	-	-	-	-	2329.734	2327.116
GW A-4	3900548	756097	3.00	2.780	-	-	-	-	-	-	2329.777	2326.998
GW A-5	3900576	756088	4.62	3.380	-	-	-	-	-	-	2330.209	2326.828
NEST D												
SW D-1	NA	NA	NA	NA	14.34	7.98	442	9.0	90	475	NA	NA
GW D-1	3900714	757463	2.95	1.640	13.87	7.84	555	2.2	22	508	2321.759	2320.119
GW D-2	3900699	757449	2.98	2.134	13.50	7.69	451	2.0	20	483	2322.267	2320.134
GW D-3	3900727	757448	2.94	2.030	-	-	-	-	-	-	2322.269	2320.239
GW D-4	3900700	757478	3.00	2.100	-	-	-	-	-	-	2322.198	2320.097
GW D-5	3900725	757481	3.01	1.884	-	-	-	-	-	-	2321.854	2319.971
NEST F												
SW F-1	NA	NA	NA	NA	14.31	7.65	418	9.00	90	458	NA	NA
GW F-1	3900904	758401	2.73	1.713	12.46	8.02	477	6.37	60	441	2317.351	2315.638
GW F-2	3900909	758420	3.01	2.164	12.20	7.69	390	1.75	17	423	2316.802	2314.638
GW F-3	3900929	758416	3.01	2.310	-	-	-	-	-	-	2317.379	2315.068
GW F-4	3900904	758437	2.99	2.140	-	-	-	-	-	-	2317.108	2314.968
GW F-5	3900925	758433	3.01	2.316	-	-	-	-	-	-	2317.319	2315.003
NEST I												
SW I-1	NA	NA	NA	NA	14.76	7.71	420	9.89	95	468	NA	NA
GW I-1	3901431	759182	2.98	2.109	14.14	7.35	513	2.1	25	461	2314.437	2312.328
GW I-2	3901434	759207	2.86	2.146	12.79	7.32	436	2.84	25	483	2314.380	2312.234
GW I-3	3901411	759184	2.37	2.134	-	-	-	-	-	-	2314.515	2312.382
GW I-4	3901453	759187	3.02	2.158	-	-	-	-	-	-	2314.418	2312.260
GW I-5	3901429	759161	2.71	2.161	-	-	-	-	-	-	2314.540	2312.379
NEST K												
SW K-1	NA	NA	NA	NA	11.37	7.72	448	8.25	75.6	536	NA	NA
GW K-1	3901930	760426	3.01	1.484	13.05	7.43	497	2.4	23	560	2307.186	2305.702
GW K-2	3901915	760435	3.00	1.682	-	-	-	-	-	-	2307.469	2305.787
GW K-3	3901926	760407	3.00	2.140	14.17	7.55	556	1.99	19.5	479	2307.937	2305.797
GW K-4	3901930	760444	2.99	1.548	-	-	-	-	-	-	2307.254	2305.706
GW K-5	3901950	760415	3.33	1.503	-	-	-	-	-	-	2307.195	2305.692

TOC = Top of Outer Casing
NA = Not Applicable
TDS = Computed from sum of major ions (ppm)

Table 8c: Sample Collection Locations and Field Parameters November 2, 2007

Sample ID	Latitude	Longitude	Piezometer Total Depth TOC (m)	Depth-to-water (TOC) prior to sampling (m)	Temp - C	pH	Conductivity (µs/cm)	DO (mg/l)	DO (%)	TDS (ppm)	Elevation TOC (m)	Ground Water Elevation TOC (m)
NEST A												
SW A-1	NA	NA	NA	NA	5.41	7.57	275	12.24	97	343	NA	NA
GW A-1	3900559	756077	3.01	2.210	8.38	7.82	448	2.81	25	365	2329.431	2327.222
GW A-2	3900540	756069	4.61	3.505	11.55	7.37	497	1.72	16.5	437	2330.624	2327.119
GW A-3	3900569	756059	3.01	2.560	-	-	-	-	-	-	2329.734	2327.174
GW A-4	3900548	756097	3.00	2.789	-	-	-	-	-	-	2329.777	2326.988
GW A-5	3900576	756088	4.62	3.307	-	-	-	-	-	-	2330.209	2326.902
NEST D												
SW D-1	NA	NA	NA	NA	3.83	7.05	397	11.04	84.1	517	NA	NA
GW D-1	3900714	757463	2.95	1.731	10.09	7.17	497	3.97	33.7	515	2321.759	2320.027
GW D-2	3900699	757449	2.98	2.239	9.81	7.61	575	3.09	26	513	2322.267	2320.028
GW D-3	3900727	757448	2.94	2.140	-	-	-	-	-	-	2322.269	2320.130
GW D-4	3900700	757478	3.00	2.198	-	-	-	-	-	-	2322.198	2320.000
GW D-5	3900725	757481	3.01	1.951	-	-	-	-	-	-	2321.854	2319.904
NEST F												
SW F-1	NA	NA	NA	NA	5.28	7.87	364	9.83	77.7	457	NA	NA
GW F-1	3900904	758401	2.73	1.707	7.50	7.87	373	9.70	78	455	2317.351	2315.644
GW F-2	3900909	758420	3.01	2.143	13.65	7.69	680	2.23	21	425	2316.802	2314.659
GW F-3	3900929	758416	3.01	2.274	-	-	-	-	-	-	2317.379	2315.105
GW F-4	3900904	758437	2.99	2.121	-	-	-	-	-	-	2317.108	2314.986
GW F-5	3900925	758433	3.01	2.304	-	-	-	-	-	-	2317.319	2315.015
NEST I												
SW I-1	NA	NA	NA	NA	7.92	7.22	394	9.53	81	460	NA	NA
GW I-1	3901431	759182	2.98	2.015	10.14	7.50	568	2.48	23	443	2314.437	2312.422
GW I-2	3901434	759207	2.86	2.051	9.44	7.64	537	2.20	20	498	2314.380	2312.328
GW I-3	3901411	759184	2.37	2.027	-	-	-	-	-	-	2314.515	2312.488
GW I-4	3901453	759187	3.02	2.060	-	-	-	-	-	-	2314.418	2312.357
GW I-5	3901429	759161	2.71	2.067	-	-	-	-	-	-	2314.540	2312.474
NEST K												
SW K-1	NA	NA	NA	NA	7.78	7.38	469	10.85	92	548	NA	NA
GW K-1	3901930	760426	3.01	1.719	7.79	7.28	562	2.99	26	541	2307.186	2305.467
GW K-2	3901915	760435	3.00	1.914	-	-	-	-	-	-	2307.469	2305.555
GW K-3	3901926	760407	3.00	2.377	11.05	7.63	540	2.13	20	493	2307.937	2305.559
GW K-4	3901930	760444	2.99	1.710	-	-	-	-	-	-	2307.254	2305.544
GW K-5	3901950	760415	3.33	1.753	-	-	-	-	-	-	2307.195	2305.442

TOC = Top of Outer Casing
NA = Not Applicable
TDS = Computed from sum of major ions (ppm)

Nest A

Surface water temperature at Nest A ranged from 5.41 - 17.58 ^{0}C. Conductivity values ranged from 166 - 305 µs/cm and pH was from 7.13 - 8.20. Dissolved oxygen ranged from 7.0 – 12.2 mg/l. And total dissolved solids values were found to range from 115 - 343 mg/l.

Nest D

Surface water temperature at Nest D ranged from 3.83 - 18.5 ^{0}C. Conductivity values ranged from 221 - 442 µs/cm and pH was from 7.05 - 7.98. Dissolved oxygen ranged from 6.7 – 11.0 mg/l. Total dissolved solids ranged from 136-517 mg/l.

Nest F

Surface water temperature at Nest F ranged from 5.28 - 19.08 ^{0}C. Conductivity values ranged from 314 - 418 µs/cm and pH was from 7.48 – 7.87. Dissolved oxygen ranged from 5.9 – 9.83 mg/l. And total dissolved solids values were found to range from 205 - 458 mg/l.

Nest I

Surface water temperature at Nest I ranged from 7.92 - 20.25 ^{0}C. Conductivity values ranged from 350 - 420 µs/cm and pH was from 7.22 - 7.71. Dissolved oxygen ranged from 4.2 – 9.9 mg/l. Total dissolved solids ranged from 218-460 mg/l.

Nest K

Surface water temperature at Nest K ranged from 7.78 - 20.90 ^{0}C. Conductivity values ranged from 448 - 469 µs/cm and pH was from 7.72 - 7.94. Dissolved oxygen ranged from 8.3 – 10.9 mg/l. Total dissolved solid values ranged from 429 - 548 mg/l.

Site wide, surface water at Nest A had the highest pH and dissolved oxygen value of 8.20 and 12.2 mg/l, respectively. Surface water at Nest K had the highest conductivity and total dissolved solid value of 469 µs/cm and 548 mg/l. And the surface water collected and analyzed at Nest I and Nest K from the August sample event exceeded New Mexico Standards for Interstate and Intrastate Surface Waters (NM Administrative Code 20.6.4) for temperature (or <20 ^{0}C) at values of 20.25 ^{0}C and 20.90 ^{0}C, respectively. Surface water also exceeded the standard for dissolved oxygen of 6 mg/l at all sample locations. Overall, surface water DO concentrations ranged from 4.23 mg/l to 12.2 mg/l.

Major Cations and Anions

There were no major fluctuations found in the surface water at the study site. However, seasonal and spatial differences in surface water quality were detected. Chemistry results are presented below for each surface water location (i.e., piezometer nest area). This section summarizes by location whether a cation and/or anion was identified as the overall site wide minimum and/or maximum concentration based on three sample events and at what period of time (Aug, Sept or Nov) the peak concentration was detected in Bluewater creek.

Overall, low concentrations (TDS < 429 mg/l) of cations and anions were observed in surface water during August, 2007. The August sampling event was preceded by a significant rainstorm as recorded by the site Remote Area Weather Station.

Table 9 is the complete summary of the major chemistry analytical results for surface water and groundwater. It is arranged in order from the up gradient site or Nest A to the down gradient site (Nest K).

With exception to four charge balance errors between 5.79 - 7.99%, the rest of the surface water samples (or 73%) had a charge balance error of < 5%. Surface water chemistry graphs for each of the major cation and anions are displayed alongside the groundwater chemistry graphs for comparison purposes and are shown in Figures 13a through Figures 25b.

Nest A

The range of concentrations at Nest A are presented in Table 9.

Chloride, sodium, bromide, fluoride, bicarbonate, calcium, magnesium, and TDS were found to represent an overall site wide minimum and/or maximum concentration value for the entire study area.

Chloride was detected in the surface water during August at a minimum concentration of 1.54 mg/l and during November at a maximum concentration of 11.7 mg/l. Sodium was also detected and identified as the overall minimum and maximum concentration of 3.61 mg/l and 50.4 mg/l, respectively, in the Creek during August.

Fluoride was detected in the November surface water sample at a maximum concentration of 3.11 mg/l.

Minimum concentrations of bicarbonate (80.5 mg/l), calcium (17.2 mg/l), magnesium (4.22 mg/l), bromide (0.03 mg/l) and TDS (115 mg/l) were all detected in the surface water at Nest A during August.

Nest D

The range of concentrations for Nest D is presented in Table 9.

Nitrite, bromide, phosphate, and sulfate were found to represent an overall site wide minimum and/or maximum concentration for the entire study area.

Maximum concentrations of nitrite (0.38 mg/l), bromide (0.58 mg/l), phosphate (0.56 mg/l), and sulfate (63.4 mg/l) were all detected during November in the surface water at Nest D. Phosphate was also detected in the surface water but at an overall minimum concentration of 0.06 mg/l during August.

Phosphate is a component of phosphorus. Phosphorus was determined by first calculating the formula mass of the phosphate ion. Then, multiply this ratio (31/95) by the November phosphate concentration of 0.56 mg/l. This results in a phosphorus concentration of 0.18 mg/l during November and exceeds the NM standard of 0.1 mg/l.

Nest F

The range of concentrations for Nest F is presented in Table 9.

Nitrite, potassium, and magnesium represent an overall minimum and/or maximum concentration value for the entire study area. Nitrite was not detected in the surface water during November and therefore represents the overall minimum concentration of 0 mg/l. Potassium was detected in the surface water at a maximum concentration of 4.36 mg/l during August and at a minimum concentration of 2.03 mg/l during September. Finally, magnesium was detected in the surface water at a maximum concentration of 24.8 mg/l during September.

Phosphate is a component of phosphorus. Phosphorus was determined by first calculating the formula mass of the phosphate ion. Then, multiply this ratio (31/95) by the November phosphate concentration of 0.33 mg/l. This results in a phosphorus concentration of 0.11 mg/l during November and exceeds the NM standard of 0.1 mg/l.

Nest I

The range of concentrations for Nest I are presented in Table 9.

Only nitrate was found to represent the overall minimum surface water concentration value of 0.18 mg/l during August for the entire study area.

Phosphate is a component of phosphorus. Phosphorus was determined by first calculating the formula mass of the phosphate ion. Then, multiply this ratio (31/95) by the November phosphate concentration of 0.48 mg/l. This results in a phosphorus concentration of 0.16 mg/l during November and exceeds the NM standard of 0.1 mg/l.

Nest K

The range of concentrations for Nest K is presented in Table 9.

Fluoride, nitrite, sulfate, bicarbonate, calcium, and TDS represent an overall site wide minimum and/or maximum concentration value for the study area. Fluoride and sulfate were both detected at minimum concentrations of 0.11 mg/l and 3.78 mg/l, respectively, in the surface water during November.

Nitrate (4.52 mg/l), bicarbonate (396 mg/l), calcium (86.0 mg/l) and TDS (548 mg/l) all represent the maximum concentration levels found in the surface water during November.

Phosphate is a component of phosphorus. Phosphorus was determined by first calculating the formula mass of the phosphate ion. Then, multiply this ratio (31/95) by the November phosphate concentration of 0.46 mg/l. This results in a phosphorus concentration of 0.15 mg/l during November and exceeds the NM standard of 0.1 mg/l.

In summary, Table 10 shows which analyte at a given location (i.e., nest) was shown to be the overall site wide minimum and/or maximum concentration based on three sample events.

Table 9: Major Chemistry Analytical Results (mg/l)

ID Number	Nest	Date	F	Cl	NO_2	Br	NO_3	PO_4	SO_4	HCO_3	Ca	K	Mg	Na	TDS *	% balance
SW A-1	A	Aug	0.15	1.54	0.33	0.06	1.44	0.07	4.97	80.5	17.2	3.37	4.22	3.61	115	-1.99
SW A-1	A	Sept	2.94	10.2	0.24	0.26	1.07	0.22	21.1	204	37.8	2.84	9.08	39.9	325	2.12
SW A-1	A	Nov	3.11	11.7	0.05	0.03	0.45	0.09	37.9	199	32.7	2.41	8.6	50.4	343	0.48
GW A-1	A	Aug	1.97	10.6	0.04	0.06	1.00	0.08	47.5	232	52.0	3.32	9.42	36.8	391	-1.46
GW A-1	A	Sept	2.39	8.30	0.14	1.00	0.43	0.16	19.5	221	46.5	2.06	8.83	31.2	338	0.39
GW A-1	A	Nov	1.59	11.4	0.72	0.42	0.77	0.48	26.1	223	43.3	2.22	8.70	49.7	365	4.56
GW A-2	A	Aug	0.88	6.24	0.01	0.10	0.22	0.10	17.8	340	74.3	1.84	18.68	18.8	478	-0.44
GW A-2	A	Sept	1.64	5.21	0.14	0.33	0.43	0.14	12.9	329	77.3	1.80	18.13	29.9	475	6.19
GW A-2	A	Nov	1.42	5.63	0.00	0.21	0.70	0.37	10.0	315	65.6	0.00	15.43	25.5	437	0.45
SW D-1	D	Aug	0.20	1.95	0.23	0.06	2.35	0.06	7.75	92.1	20.1	3.94	4.97	4.79	136	-1.64
SW D-1	D	Sept	1.32	5.56	0.24	0.28	0.75	0.22	43.9	301	70.5	2.91	20.1	30.6	475	3.75
SW D-1	D	Nov	0.29	5.86	0.38	0.58	0.97	0.56	63.4	313	69.5	3.42	24.8	37.0	517	3.81
GW D-1	D	Aug	0.48	6.35	0.19	0.09	0.90	0.11	67.1	325	81.8	2.32	22.3	21.0	526	-0.41
GW D-1	D	Sept	1.09	4.41	0.14	0.23	0.45	0.14	35.1	343	71.8	2.18	22.4	29.5	508	1.67
GW D-1	D	Nov	0.85	6.30	0.00	0.28	0.77	0.34	41.0	337	72.9	2.16	23.6	31.5	515	2.79
GW D-2	D	Aug	0.29	6.85	0.02	0.07	0.04	0.07	61.6	370	91.3	2.48	25.3	21.7	580	0.57
GW D-2	D	Sept	1.30	4.96	0.14	0.22	0.42	0.14	40.3	314	70.1	2.02	19.1	32.6	483	2.59
GW D-2	D	Nov	0.45	5.11	0.26	0.41	0.77	0.48	62.7	311	77.1	2.20	21.9	33.8	513	4.21
SW F-1	F	Aug	0.50	4.76	0.12	0.04	0.31	0.12	13.0	130	30.1	4.36	7.83	14.5	205	5.86
SW F-1	F	Sept	0.94	5.56	0.16	0.28	0.42	0.18	28.7	311	60.6	2.03	25.0	25.6	458	2.79
SW F-1	F	Nov	0.83	5.43	0.00	0.22	0.69	0.33	27.9	304	58.5	2.23	24.8	34.2	457	5.79
GW F-1	F	Aug	0.31	3.99	0.09	0.10	0.05	0.09	13.9	142	31.0	4.13	7.96	14.6	217	3.48
GW F-1	F	Sept	1.12	5.45	0.13	0.21	0.45	0.22	25.9	300	55.6	2.28	25.1	27.0	441	3.39
GW F-1	F	Nov	0.74	5.47	0.00	0.19	0.69	0.34	26.9	304	58.9	2.18	25.4	31.2	455	5.60
GW F-2	F	Aug	0.38	4.96	0.05	0.03	0.07	0.06	24.3	287	57.6	2.28	21.8	19.3	417	1.82
GW F-2	F	Sept	1.10	5.16	0.27	0.24	0.81	0.12	26.7	287	53.0	2.10	20.3	28.5	423	1.16
GW F-2	F	Nov	0.35	5.83	0.26	0.41	0.77	0.44	25.2	287	53.0	2.25	20.3	32.0	425	2.90
SW I-1	I	Aug	0.39	4.53	0.11	0.09	0.18	0.10	15.3	138	33.0	4.21	8.87	14.3	218	6.45
SW I-1	I	Sept	1.05	5.71	0.24	0.23	0.41	0.13	26.0	320	60.0	2.09	24.9	28.6	468	2.58
SW I-1	I	Nov	0.27	5.71	0.28	0.41	0.79	0.48	26.2	312	56.6	2.42	23.6	33.0	460	3.14
GW I-1	I	Aug	0.20	6.10	0.37	0.12	0.73	0.10	3.85	310	54.9	2.05	22.3	18.7	418	0.73
GW I-1	I	Sept	1.00	5.35	0.14	0.25	0.42	0.12	4.48	337	59.1	2.19	24.8	28.0	461	3.44
GW I-1	I	Nov	0.17	5.86	0.26	0.41	0.77	0.46	11.2	312	56.1	2.24	24.4	31.1	443	5.58
GW I-2	I	Aug	0.34	7.11	0.02	0.08	0.03	0.08	10.0	326	62.3	1.96	24.5	17.0	449	1.14
GW I-2	I	Sept	0.97	5.48	0.17	0.22	0.48	0.17	7.47	351	65.0	1.84	25.0	27.0	483	3.04
GW I-2	I	Nov	0.17	5.59	0.26	0.42	0.77	0.50	6.95	359	67.1	2.01	26.8	31.1	498	5.55
SW K-1	K	Aug	0.45	5.76	0.02	0.11	0.22	0.12	6.52	314	62.3	3.29	19.5	17.6	429	0.86
SW K-1	K	Sept	1.15	5.24	0.24	0.23	4.52	0.13	11.9	388	81.6	2.27	21.9	25.5	536	1.03
SW K-1	K	Nov	0.11	1.79	0.27	0.42	0.78	0.46	3.78	396	86.0	2.49	24.4	33.4	548	7.99
GW K-1	K	Aug	0.53	4.81	0.02	0.05	0.12	0.10	14.3	442	100	1.61	23.4	17.7	604	0.23
GW K-1	K	Sept	1.19	4.84	0.15	0.22	0.42	0.11	11.7	403	89.1	1.32	21.7	28.6	560	3.06
GW K-1	K	Nov	0.34	3.89	0.55	0.11	0.45	0.04	12.6	389	81.3	1.60	21.0	31.4	541	2.90
GW K-3	K	Aug	0.49	4.42	0.04	0.06	0.05	0.07	9.0	290	217	2.34	19.0	16.2	557	44.2
GW K-3	K	Sept	1.21	4.42	0.14	0.25	0.47	0.12	17.0	340	70.2	1.81	19.9	26.3	479	1.64
GW K-3	K	Nov	0.47	4.27	0.26	0.44	0.76	0.49	14.0	351	70.6	2.07	20.3	31.3	493	3.01

* TDS = computed from sum of major ions (ppm)
SW = surface water
GW = groundwater

Table 10: Site Wide Minimum and Maximum Concentrations for 2007 (mg/l)

Surface Water				
Analyte	**Min**	**Location (Month)**	**Max**	**Location (Month)**
Fluoride	0.11	Nest K (Nov)	3.11	Nest A (Nov)
Chloride	1.54	Nest A (Aug)	11.7	Nest A (Nov)
Nitrite	0.00	Nest F (Nov)	0.38	Nest D (Nov)
Bromide	0.03	Nest A (Nov)	0.58	Nest D (Nov)
Nitrate	0.18	Nest I (Aug)	4.52	Nest K Sept)
Phosphate	0.06	Nest D (Aug)	0.56	Nest D (Nov)
Sulfate	3.78	Nest K (Nov)	63.4	Nest D (Nov)
Bicarbonate	80.5	Nest A (Aug)	396	Nest K (Nov)
Calcium	17.2	Nest A (Aug)	86.0	Nest K (Nov)
Potassium	2.03	Nest F (Sept)	4.36	Nest F (Aug)
Magnesium	4.22	Nest A (Aug)	25.0	Nest F (Sept)
Sodium	3.61	Nest A (Aug)	50.4	Nest A (Nov)
Total Dissolved Solids	115	Nest A (Aug)	548	Nest K (Nov)
Groundwater				
Analyte	**Min**	**Location (Month)**	**Max**	**Location (Month)**
Fluoride	0.17	I-1, I-2 (Nov)	2.39	A-1 (Sept)
Chloride	3.89	K-1 (Nov)	11.4	A-1 (Nov)
Nitrite	0.00	A-2,D-1,F-1 (Nov)	0.72	A-1 (Nov)
Bromide	0.03	F-2 (Aug)	1.00	A-1 (Sept)
Nitrate	0.03	I-2 (Aug)	1.00	A-1 (Aug)
Phosphate	0.04	K-1 (Nov)	0.50	I-2 (Nov)
Sulfate	3.85	I-1 (Aug)	67.1	D-1 (Aug)
Bicarbonate	142	F-1 (Aug)	442	K-1(Aug)
Calcium	31.0	F-1 (Aug)	217	K-3 (Aug)
Potassium	0.00	A-2 (Nov)	4.13	F-1 (Aug)
Magnesium	7.96	F-1 (Aug)	26.8	I-2 (Nov)
Sodium	14.6	F-1 (Aug)	49.7	A-1 (Nov)
Total Dissolved Solids	217	F-1 (Aug)	604	K-1 (Aug)

Trace Elements

Trace element results are presented in Table 11a, 11b and 11c. There were no trace elements that exceeded NM surface water quality standards.

7.2 Groundwater Chemistry

Field Parameters

Groundwater (GW) field parameter results for each sample collection event are shown in Table 8a, 8b and 8c. A summary is presented below for each nest area where sample collection occurred.

Nest A

Groundwater temperature at Nest A ranged from 6.43 - 13.01 ^{0}C. Conductivity values ranged from 448 - 1000 µs/cm and pH was from 6.43 - 7.82. Dissolved oxygen ranged from 1.7 - 4.2 mg/l. And total dissolved solid concentrations ranged from 338 - 478 mg/l.

Nest D

Groundwater temperature at Nest D ranged from 9.81 - 16.0 ^{0}C. Conductivity values ranged from 451 - 1414 µs/cm and pH was from 6.61 - 7.84. Dissolved oxygen ranged from 2.0 – 4.5 mg/l. Total dissolved solid concentrations ranged from 483 - 580 mg/l.

Nest F

Groundwater temperature at Nest F ranged from 7.50 – 16.7 ^{0}C. Conductivity values ranged from 373 - 904 µs/cm and pH was from 7.17 - 8.02. Dissolved oxygen, ranged from 1.8 – 9.7 mg/l. And total dissolved solids values were found to range from 217 - 455 mg/l.

Nest I

Groundwater temperature at Nest I ranged from 9.44 -17.0 ^{0}C. Conductivity values ranged from 436 -1184 µs/cm and pH was from 7.06 -7.64. Dissolved oxygen ranged from 2.1 – 2.8 mg/l. Total dissolved solids ranged from 418-498 mg/l.

Nest K

Groundwater temperature at Nest K ranged from 7.79 -16.53 ^{0}C. Conductivity values ranged from 497 - 562 µs/cm and pH was from 7.28 - 7.70. Dissolved oxygen ranged from 2.0 – 3.0 mg/l. And total dissolved solids values were found to range from 479 - 604 mg/l.

Overall, groundwater collected from piezometer GW F-1 at Nest F had both the highest pH and dissolved oxygen value of 8.02 and 9.7 mg/l, respectively. Groundwater from piezometer GW D-1 (Nest D) had the highest value for conductivity or 1414 µs/cm.

The maximum total dissolved solid concentration was detected in GW K-1 (Nest K) at 604 mg/l. The maximum groundwater temperature was measured in piezometer GW I-1 (Nest I) at 17.0 ^{0}C.

Major Cations and Anions

There was little fluctuation found in the groundwater chemistry at the study site. However, seasonal and spatial differences in groundwater quality were detected. Chemistry results are presented below for each piezometer nest area. This section summarizes by location whether a cation and/or anion was identified as the overall site wide minimum and/or maximum concentration based on three sample events and at what period of time (Aug, Sept or Nov) the peak concentration was in the shallow alluvial groundwater.

Contrary to the surface water results, high concentrations (TDS < 604 mg/l) of cations and anions were observed in groundwater during August, 2007.

Table 9 is the complete summary of the Major Chemistry Analytical Results for surface water (SW) and groundwater (GW). It is arranged in order from the up gradient site or Nest A to the down gradient site (Nest K).

Groundwater chemistry graphs for each of the major cation and anions are displayed alongside the surface chemistry graphs for comparison purposes and are shown in Figures 13a through 25b.

With exception to an exceedingly high charge balance error of 44.19% for groundwater sample GW K-3 (August), 80% of the charge balance errors were less than 5% and 17% of the charge balance errors were between 5% and 6.45%.

Nest A

The range of concentrations found in the groundwater at Nest A is presented in Table 9.

Fluoride, chloride, nitrite, bromide, nitrate, and sodium were all detected in piezometer GW A-1 and are considered the overall site wide maximum groundwater concentration value for the entire study area. Nitrate was detected in August at 1.00 mg/l. Fluoride and bromide were detected in September at concentrations of 2.39 mg/l and 1.00 mg/l, respectively. And chloride (11.4 mg/l), nitrite (0.72 mg/l), and sodium (49.7 mg/l) were found at maximum concentration levels in November.

Nitrite and potassium were not detected in GW A-2 during November and by default represent the overall site wide minimum concentration for these two analytes. This overall minimum concentration value of 0 mg/l for nitrite is also shared with piezometers from Nest D (GW D-1) and Nest F (GW F-1) during the November timeframe.

Fluoride concentrations in the groundwater at Nest A exceeded the NM human health standard of 1.6 mg/l. Those locations include GW A-1 during August (1.97 mg/l) and September (2.39 mg/l) and location GW A-2 during September at a concentration of 1.64 mg/l.

Nest D

The range of concentrations that were found in the groundwater at Nest D is presented in Table 9.

Nitrite was not detected in GW D-1 during November and by default represents along with groundwater from GW A-2 and GW F-1 the overall site wide minimum concentration of 0 mg/l.

Sulfate was found during August in piezometer GW D-1 at 67.1 mg/l to represent the overall site wide maximum concentration for the entire study area.

Nest F

The range of concentrations that were found in the groundwater at Nest F is presented in Table 9.

Nitrite was not detected in GW F-1 during November and by default represents along with groundwater from GW A-2 and GW D-1 the overall site wide minimum concentration of 0 mg/l.

Bromide, bicarbonate, calcium, magnesium, sodium and TDS were all detected in the groundwater during August and represent the overall minimum concentration value for the entire study area. Bromide was detected in piezometer GW F-2 at 0.03 mg/l. Bicarbonate (142 mg/l), calcium (31.0 mg/l), magnesium (7.96 mg/l), sodium (14.6 mg/l), and TDS (217 mg/l) were all detected in the groundwater from piezometer GW F-1.

Nest I

The range of concentrations found in the groundwater at Nest I are presented in Table 9.

Fluoride, nitrate and sulfate represent an overall site wide minimum concentration value for the study area. Fluoride was detected in two piezometers (GW I-

1 and GW I-2) at a concentration of 0.17 mg/l during November. Nitrate (0.03 mg/l) and sulfate (3.85 mg/l) were both detected in the groundwater during August in piezometers GW I-2 and GW I-1, respectively.

Phosphate (0.50 mg/l) and magnesium (26.8 mg/l) were detected during November at piezometer GW I-2 and represent the overall maximum concentration of these analytes for the study area.

Nest K

The range of concentrations found in groundwater at Nest K is presented in Table 9.

Chloride and phosphate were both detected at minimum concentrations of 3.89 mg/l and 0.04 mg/l, respectively, at piezometer GW K-1 during November.

Bicarbonate (442 mg/l) is the maximum concentration level found in the groundwater during August in piezometer GW K-1.

Calcium (217 mg/l) was detected in piezometer GW K-3 during August and is considered the maximum concentration found in the groundwater site wide. However, this concentration is suspect because of an unusually high charge balance error of 44.19%.

The maximum site wide concentration for TDS was found at piezometer GW K-1 during August at a value of 604 mg/l.

In summary, Table 10 presents each major cation and anion expressed as the overall site wide minimum and maximum concentration based on three sample events for a given location.

Figure 13a

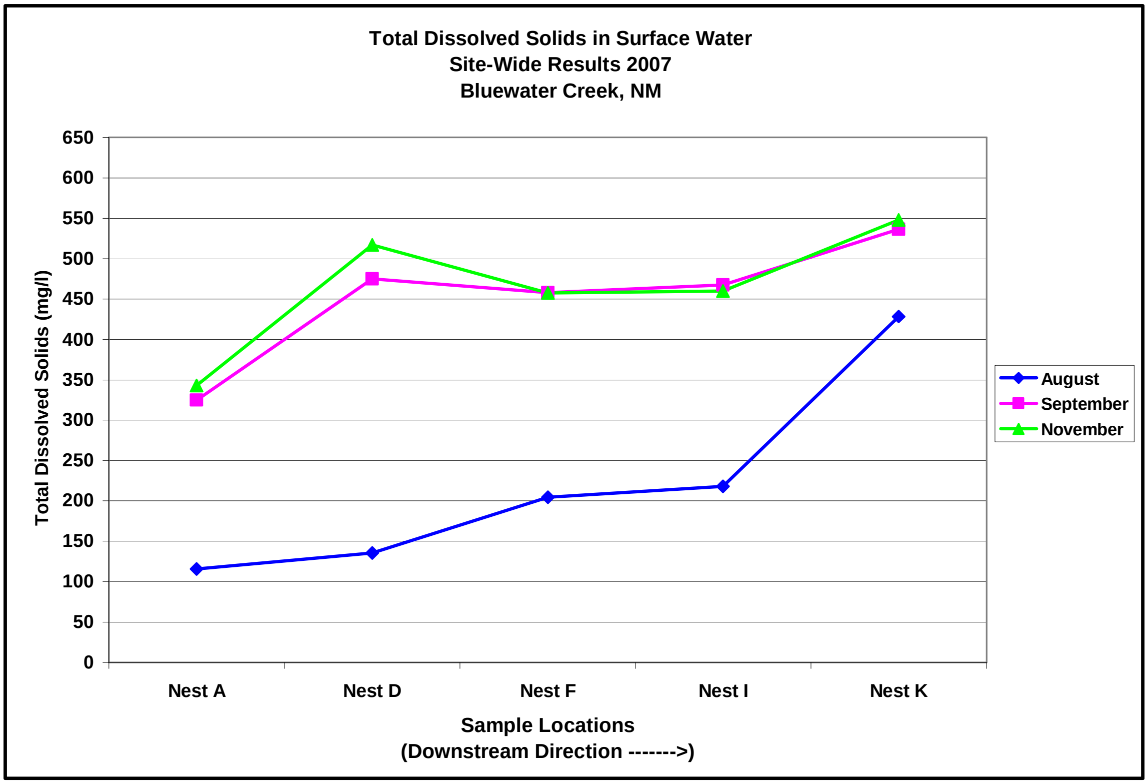


Figure 13b

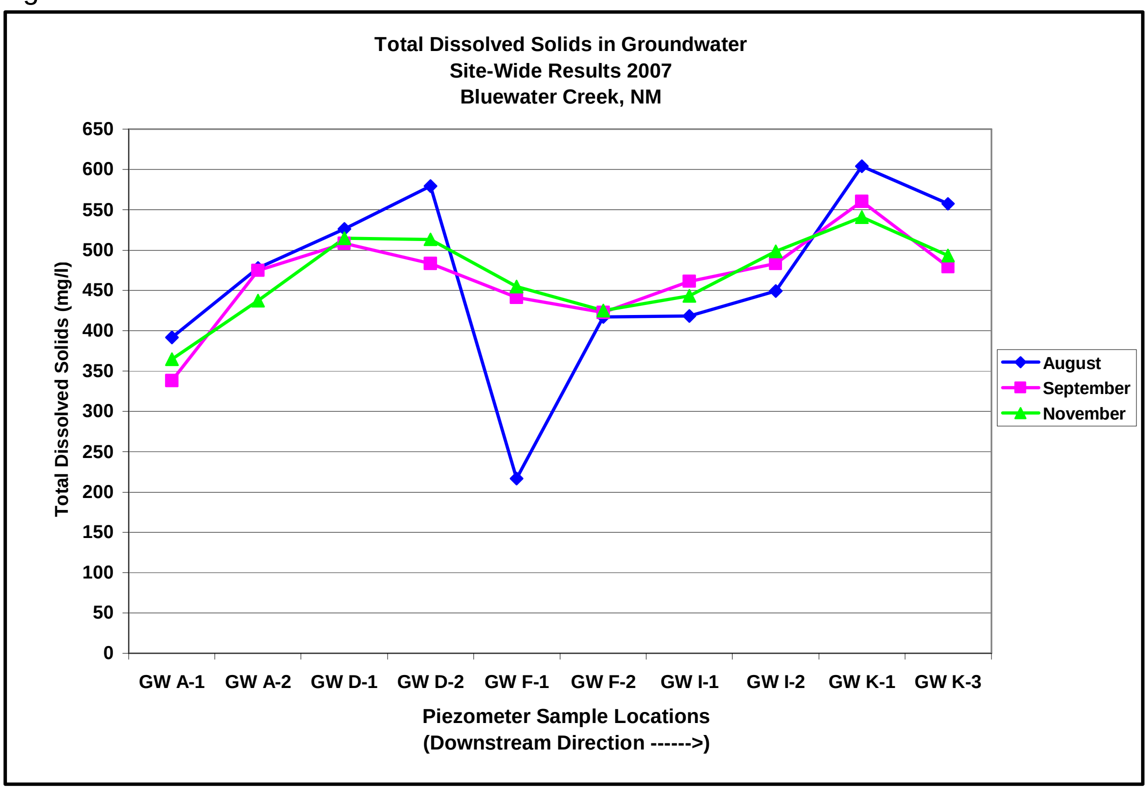


Figure 14a

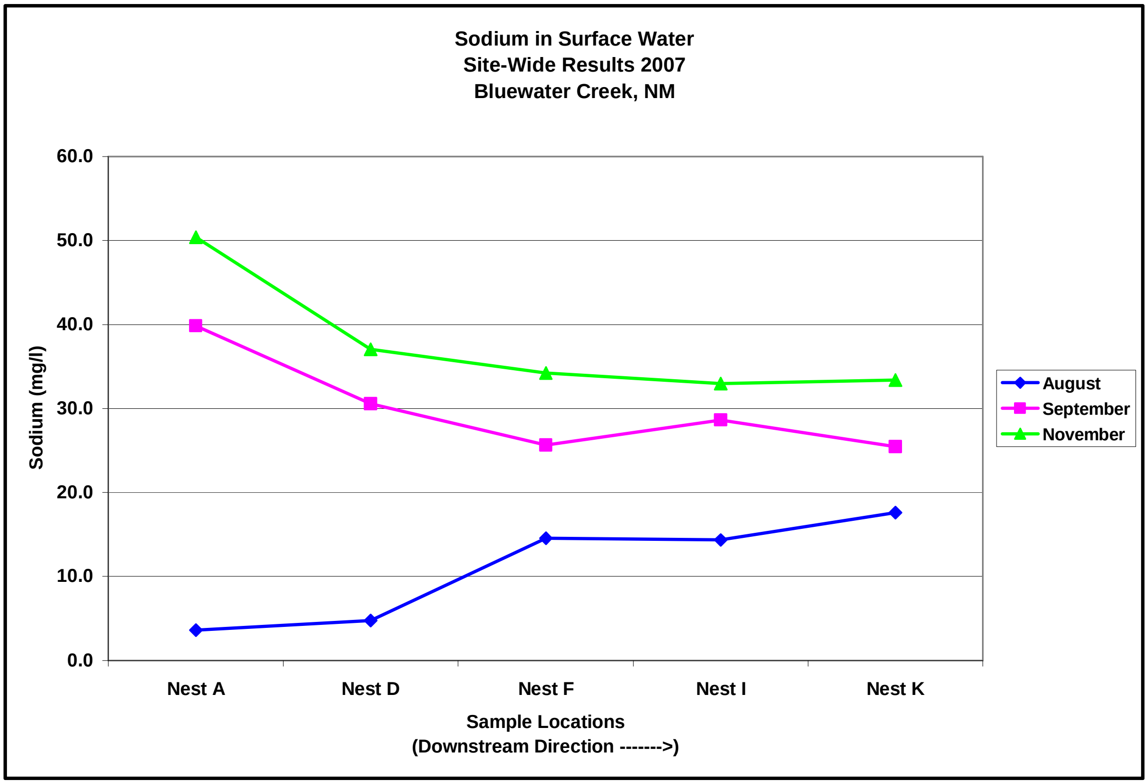


Figure 14b

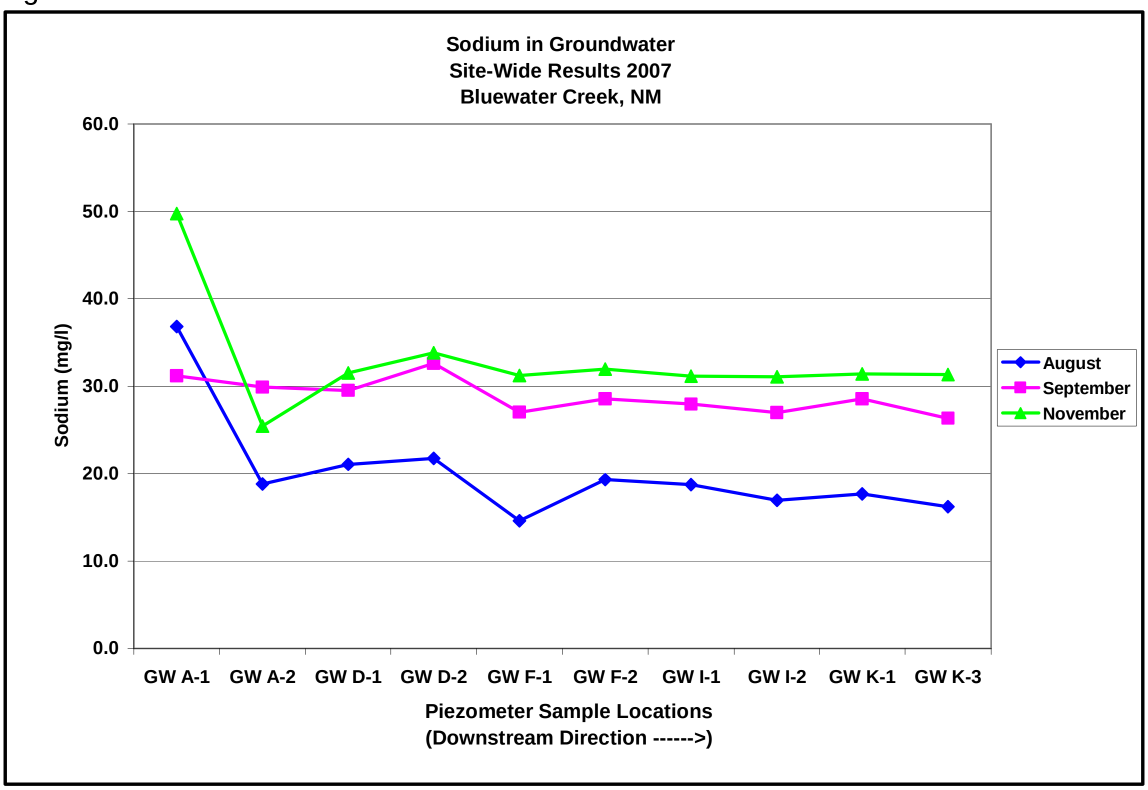


Figure 15a

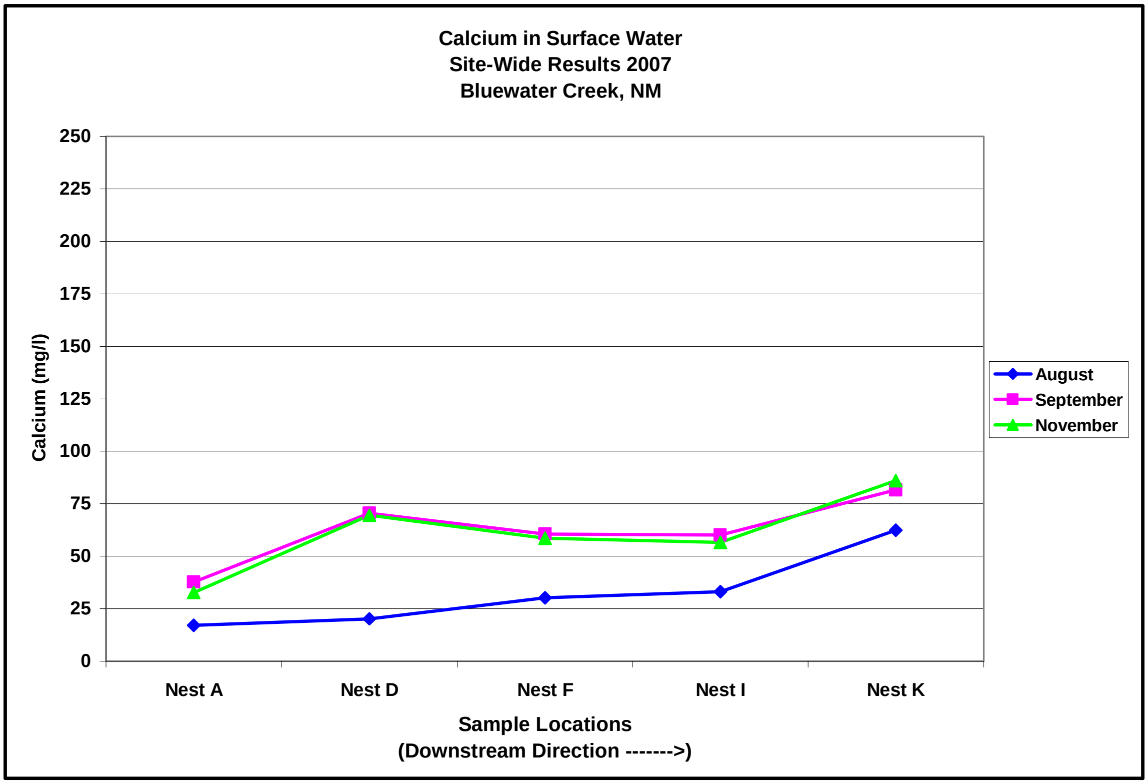


Figure 15b

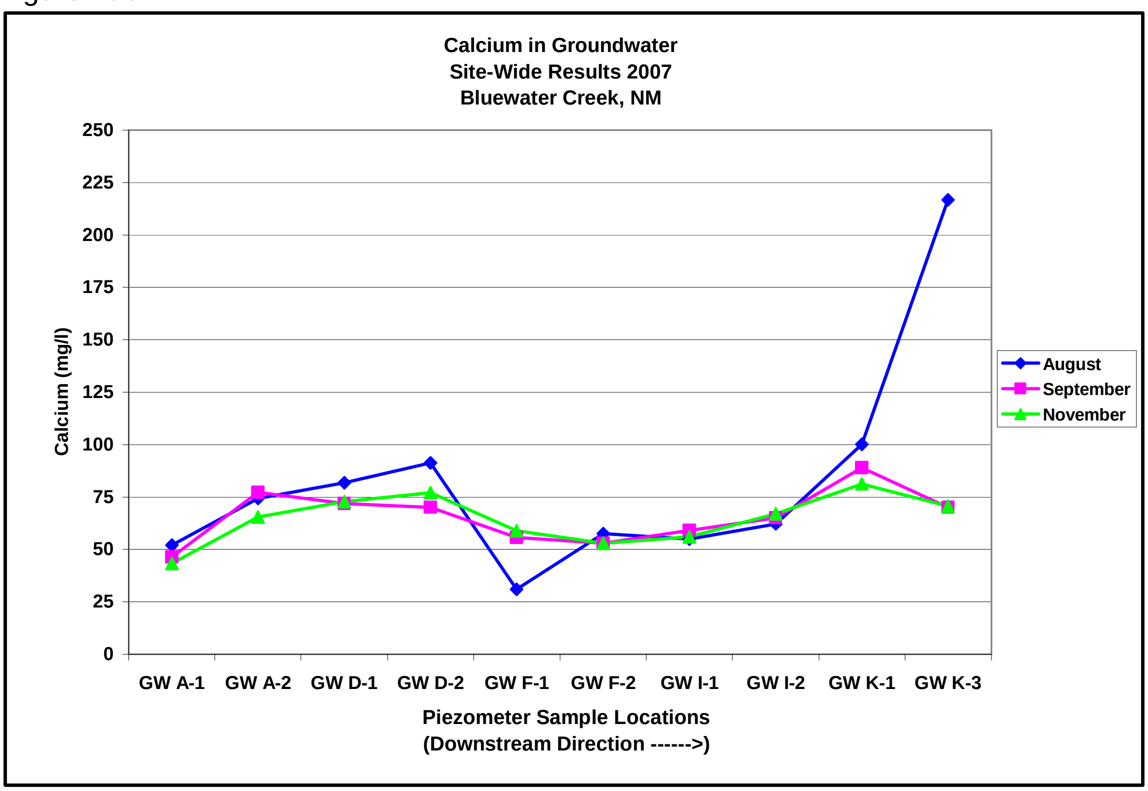


Figure 16a

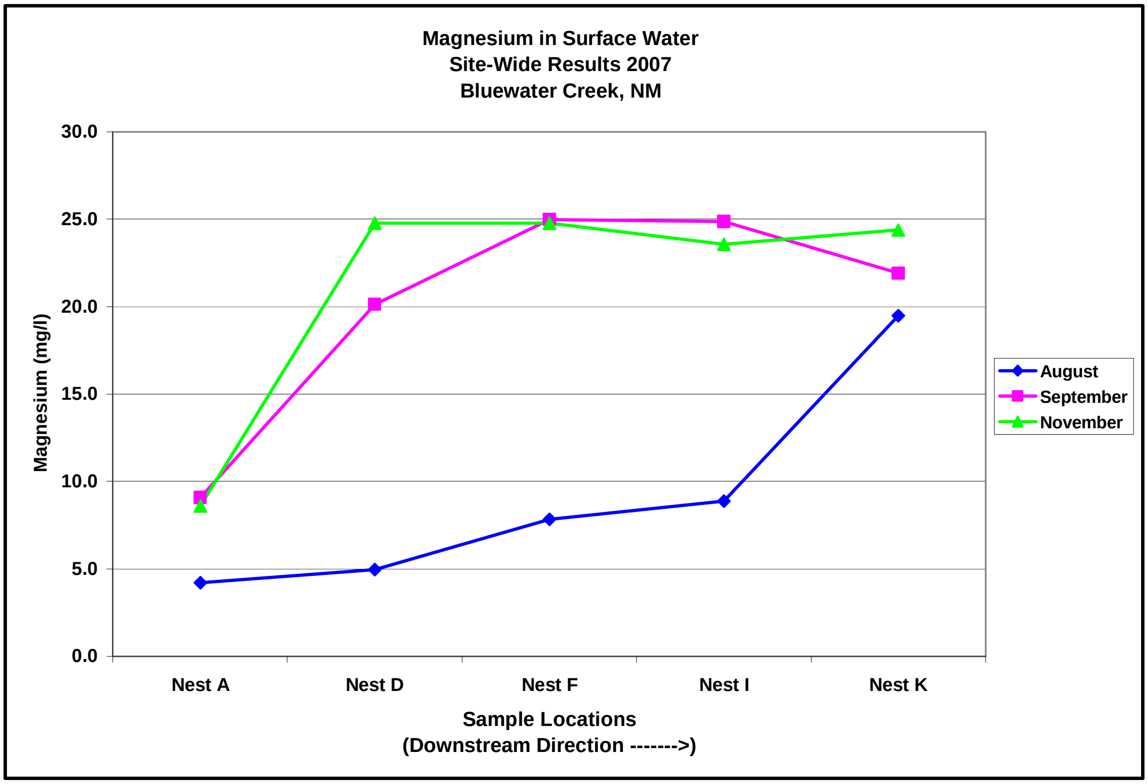


Figure 16b

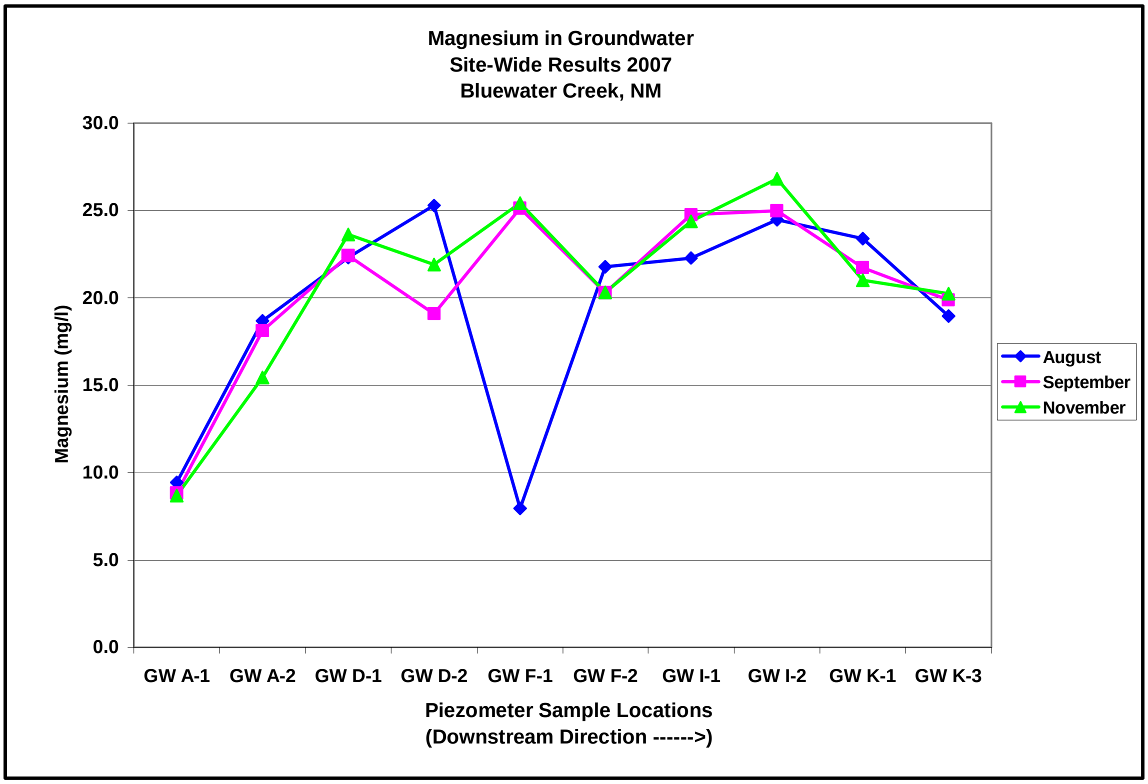


Figure 17a

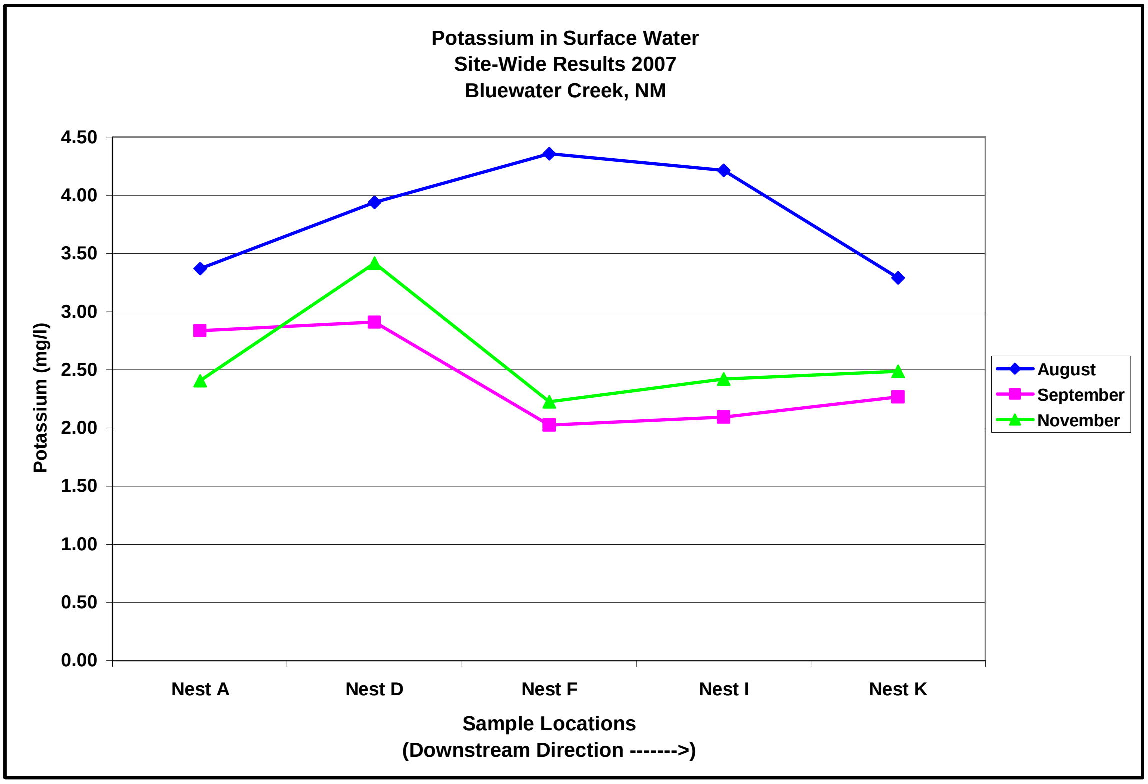


Figure 17b

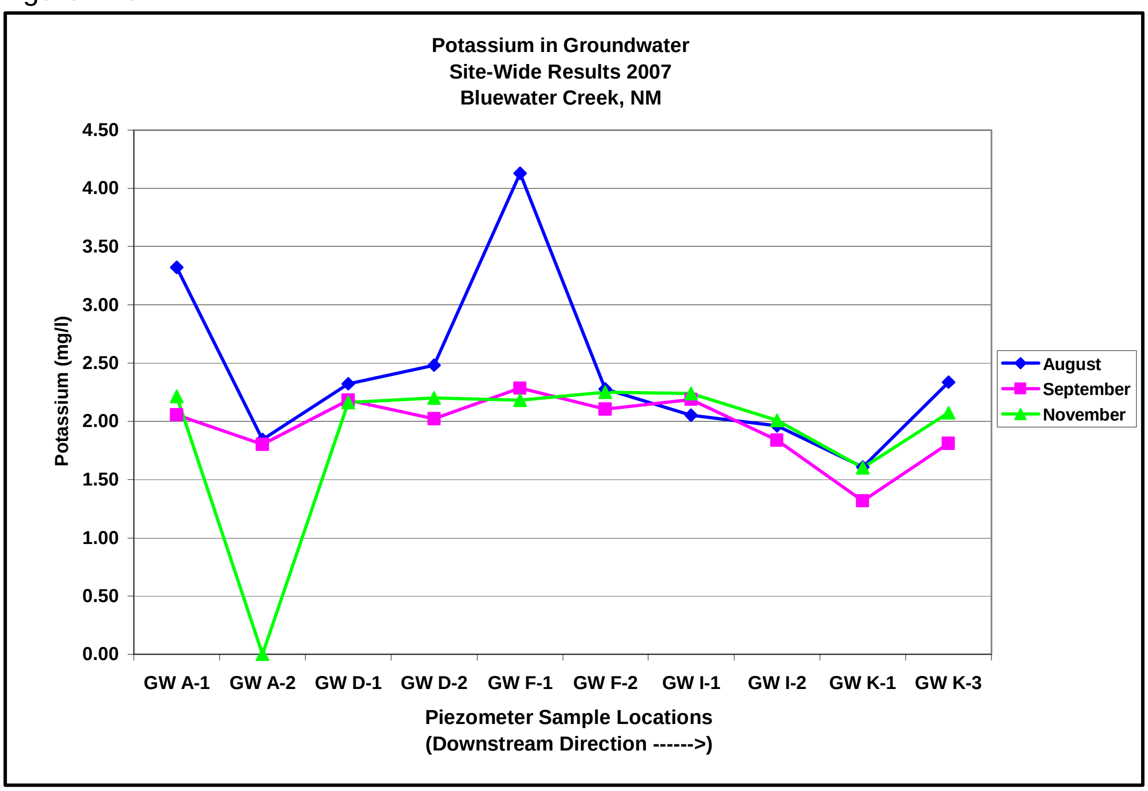


Figure 18a

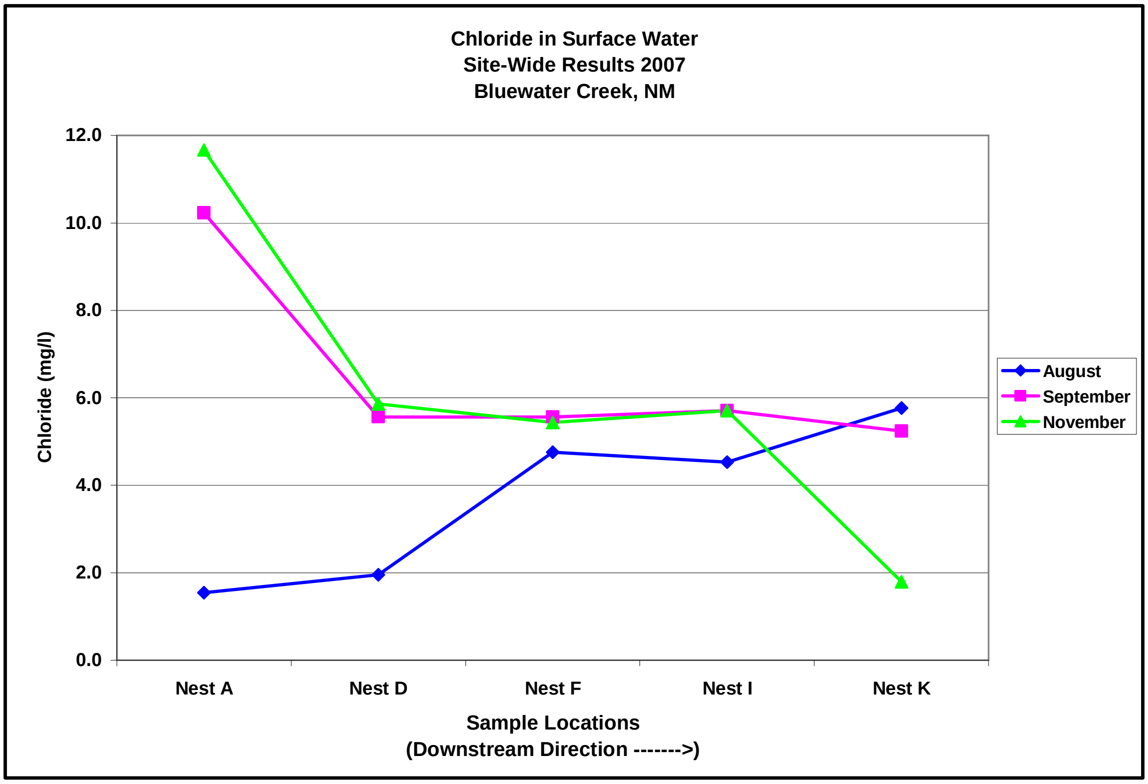


Figure 18a

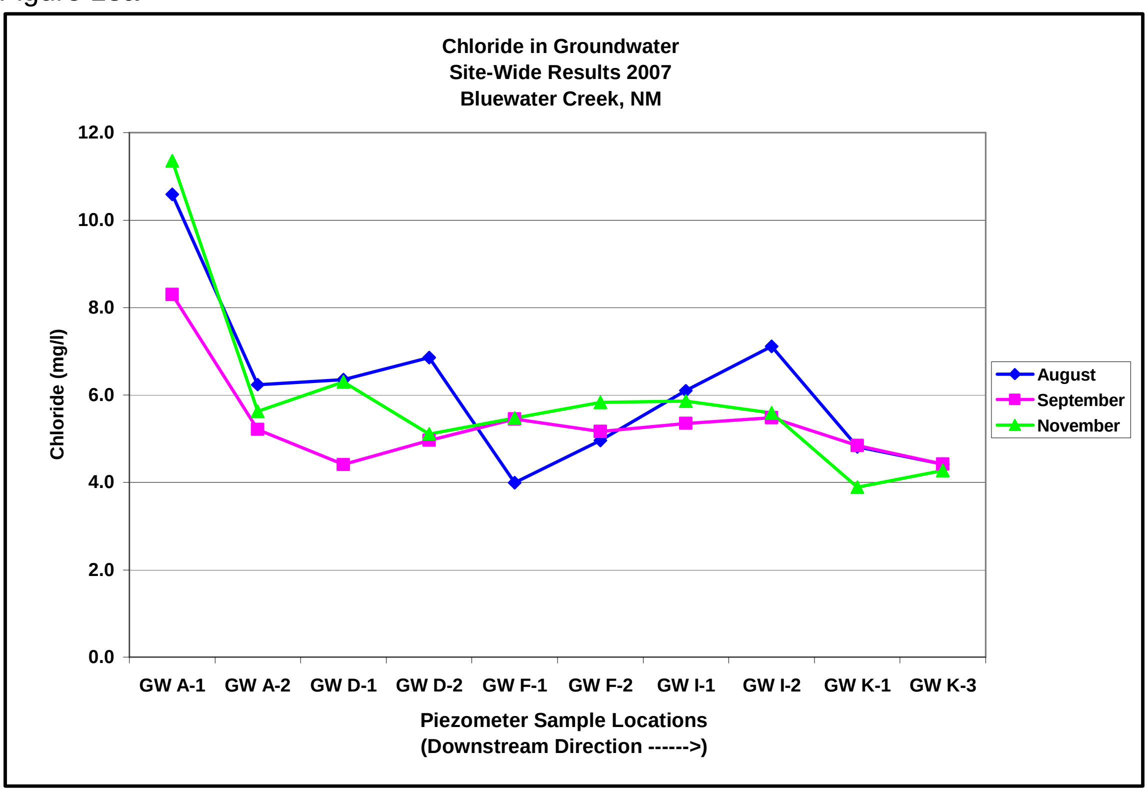


Figure 19a

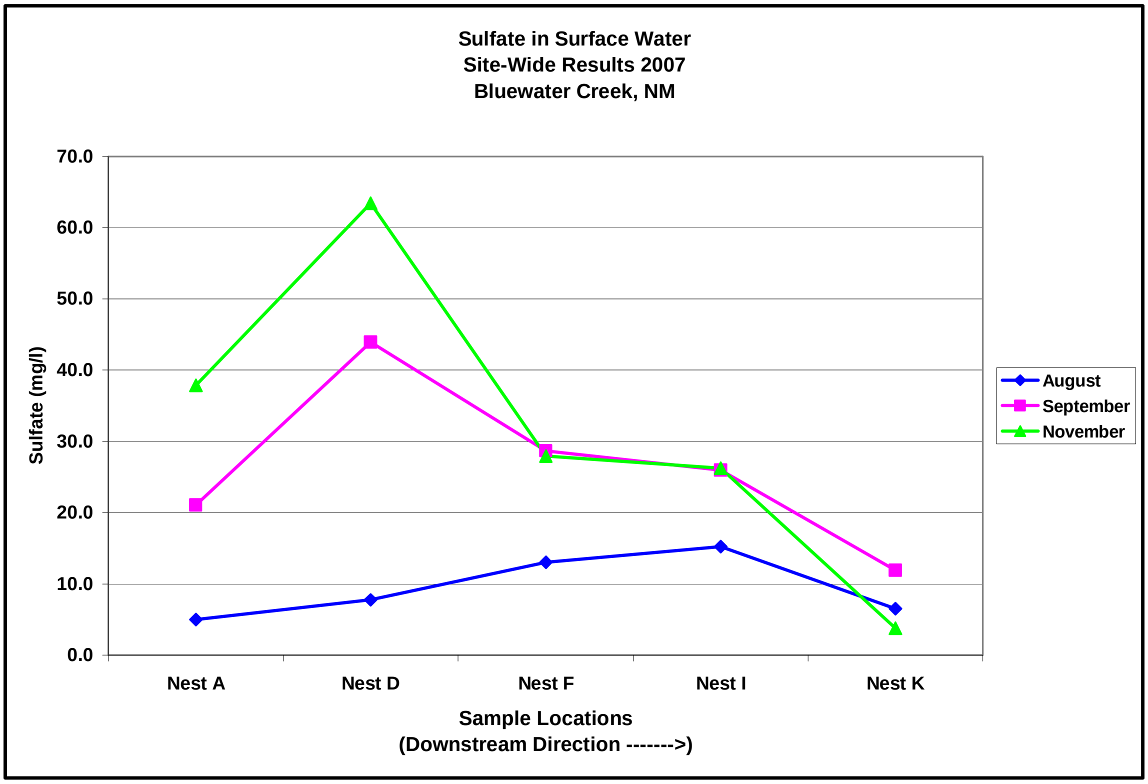


Figure 19b

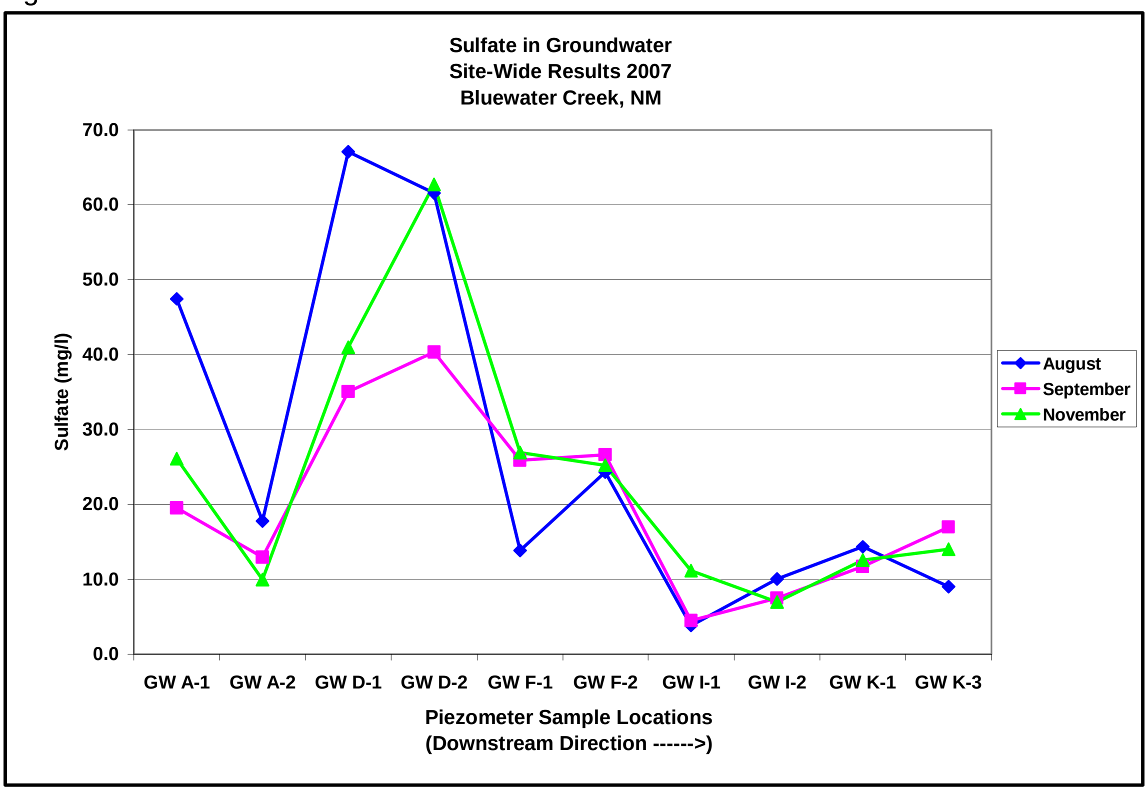


Figure 20a

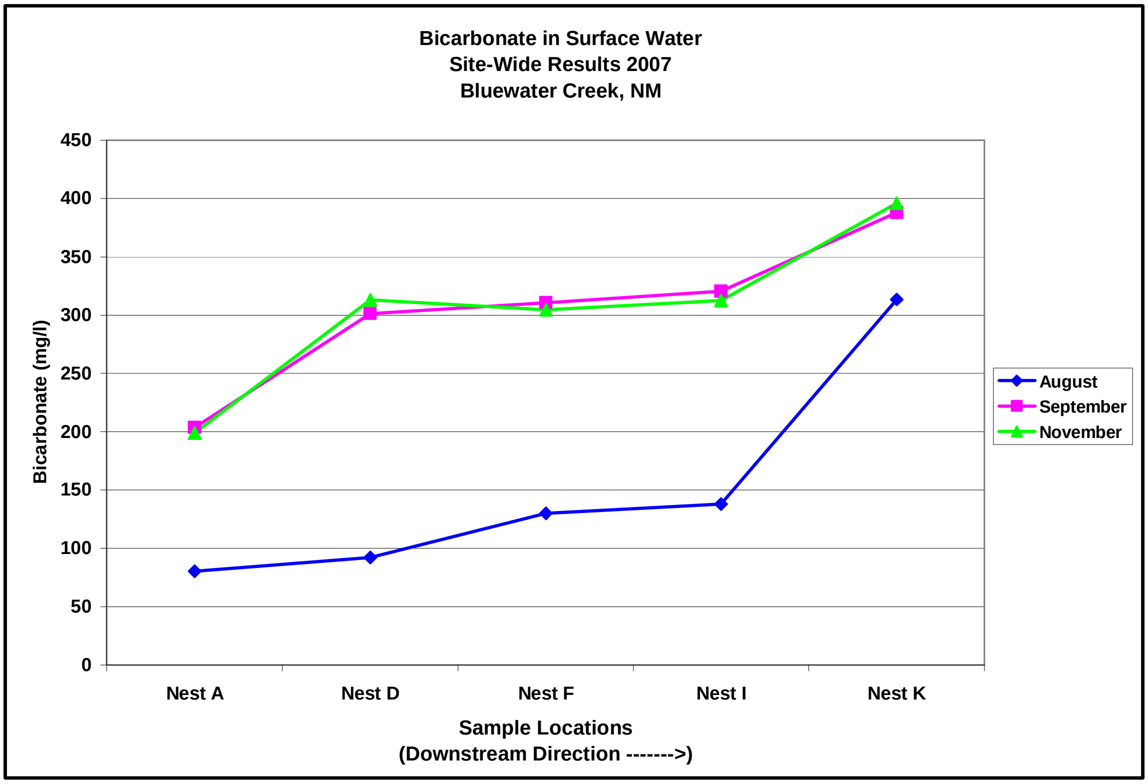


Figure 20b

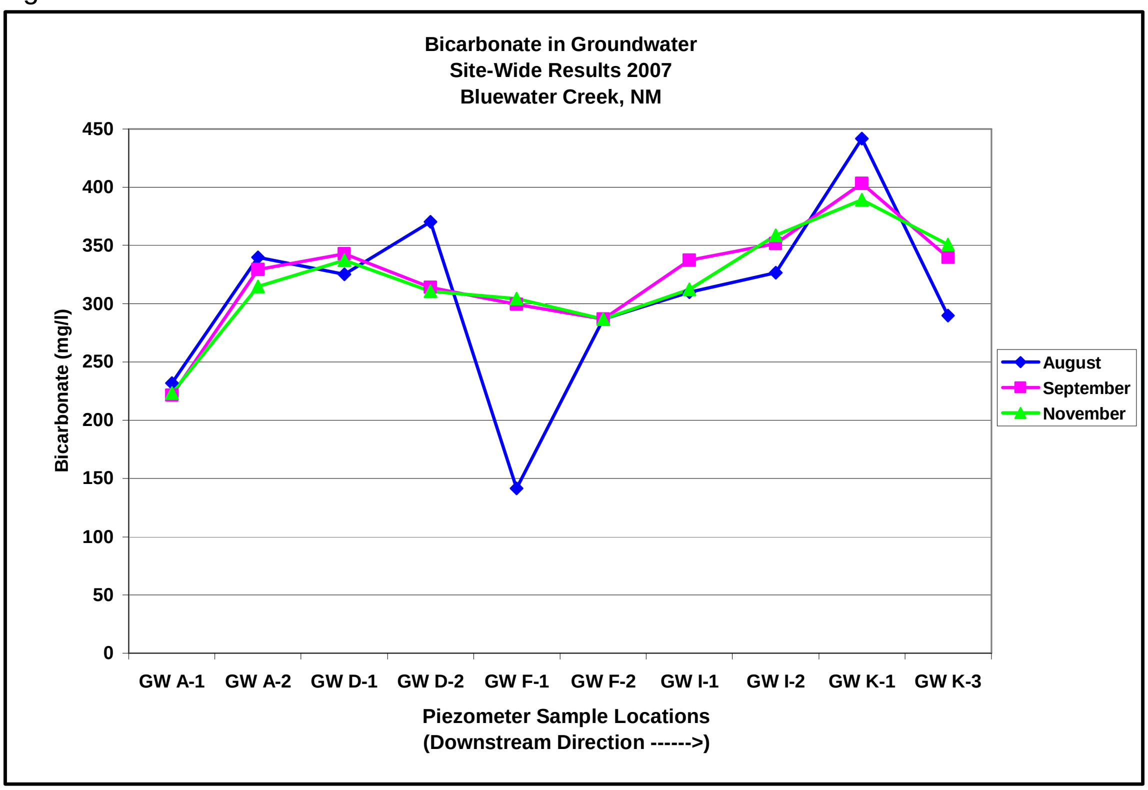


Figure 21a

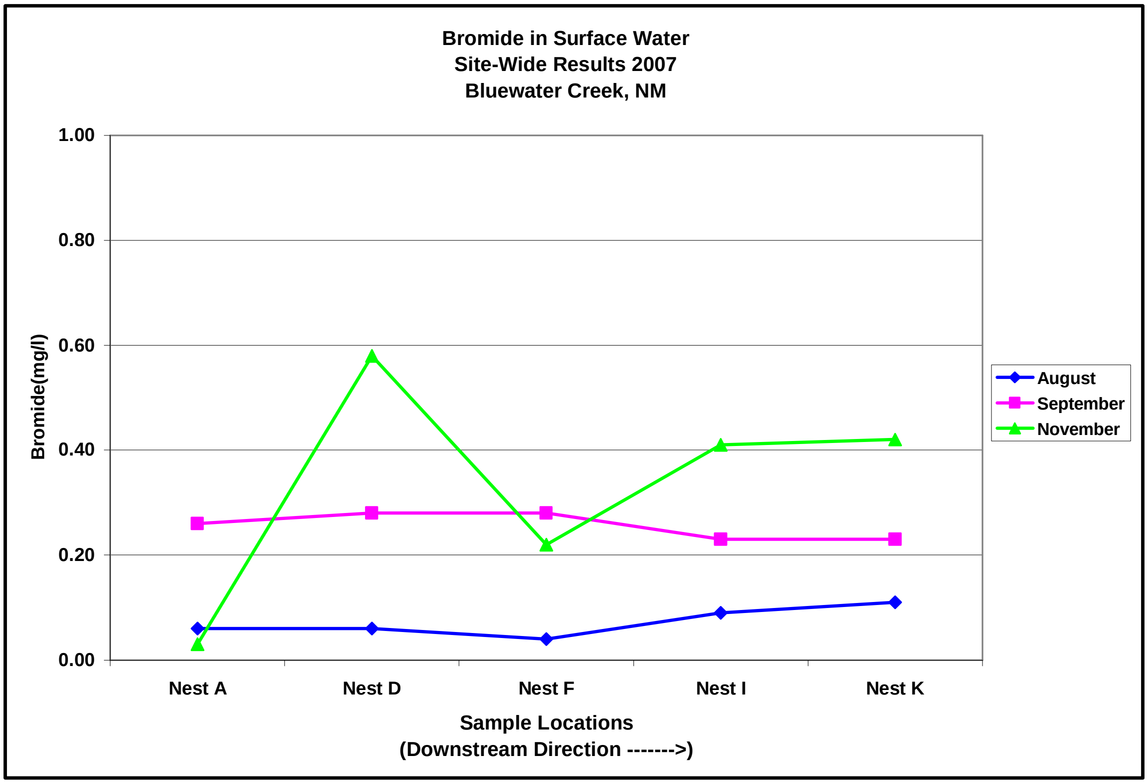


Figure 21b

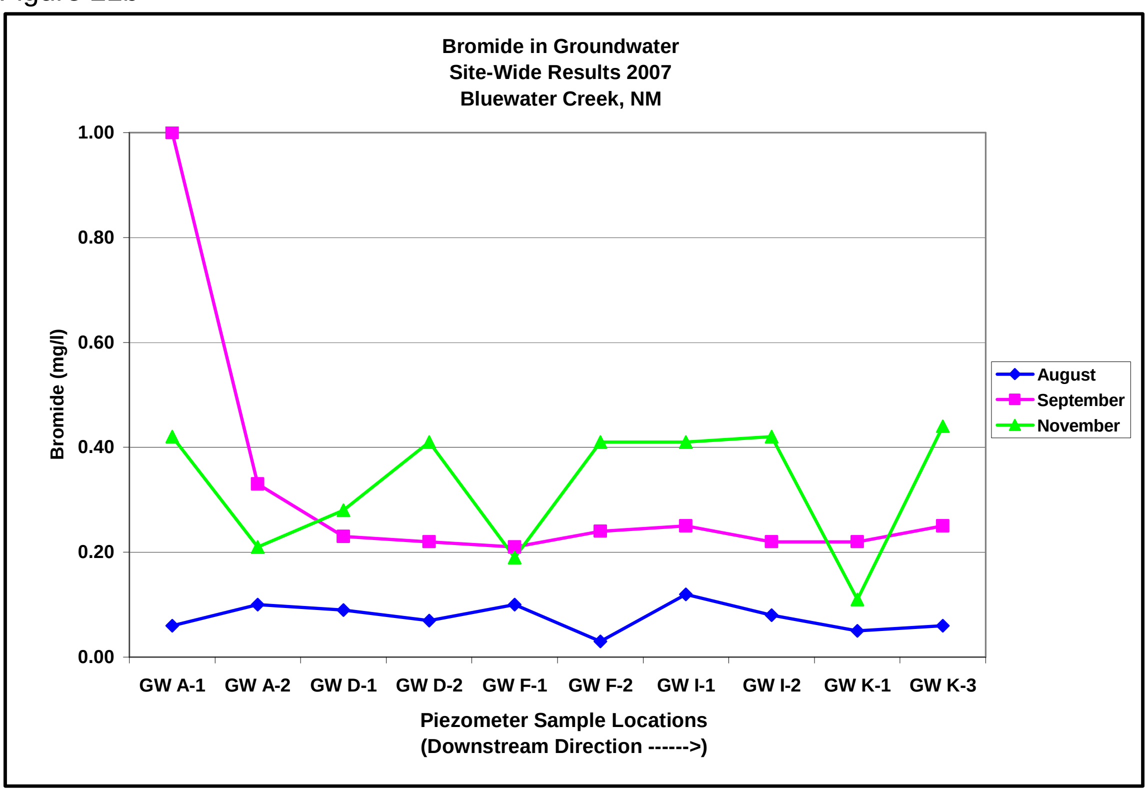


Figure 22a

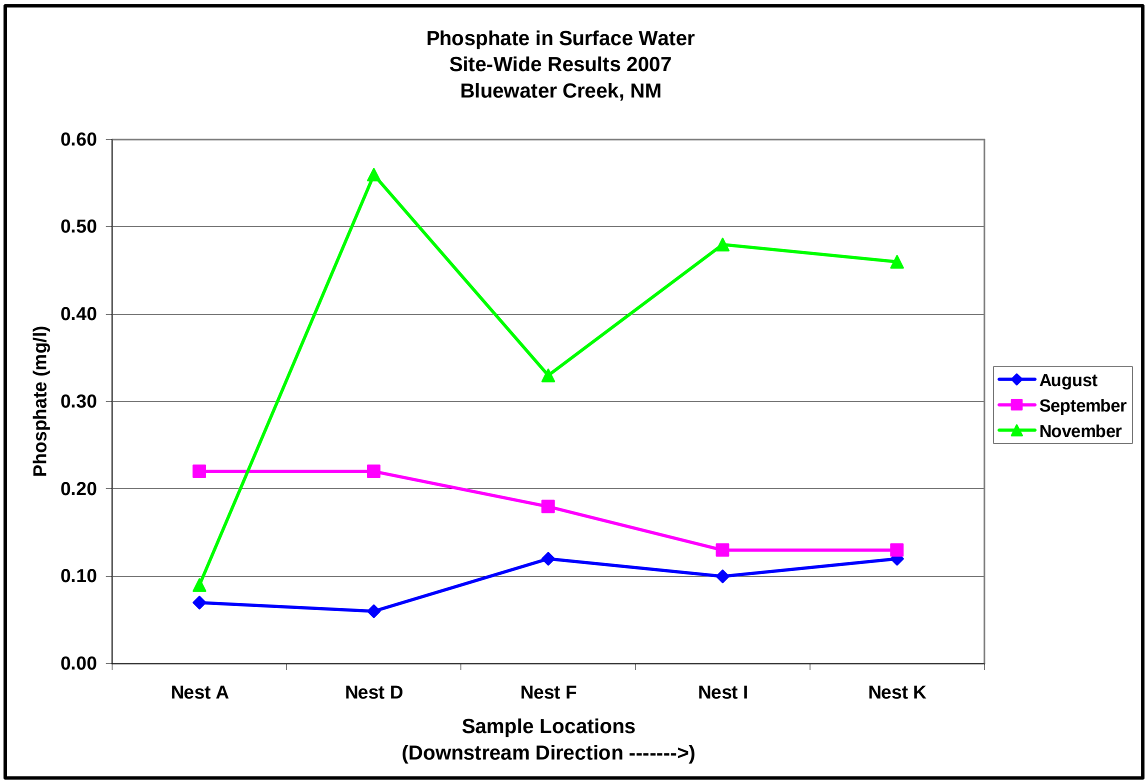


Figure 22b

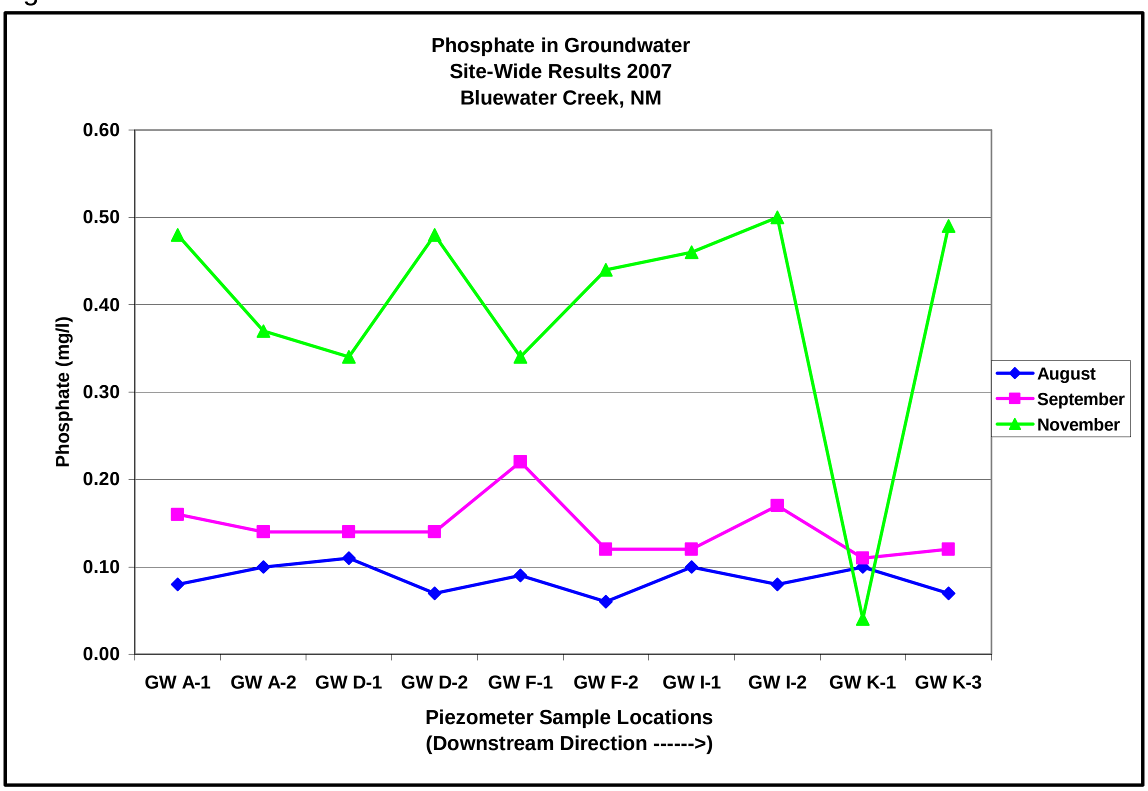


Figure 23a

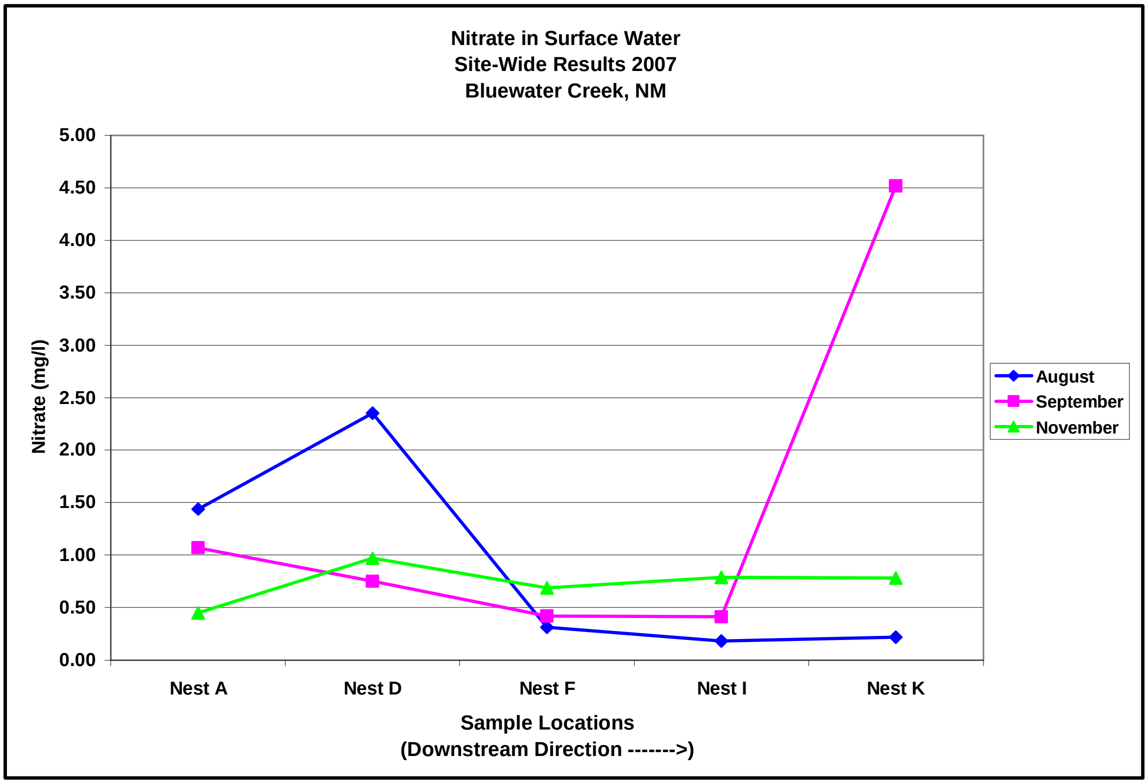


Figure 23b

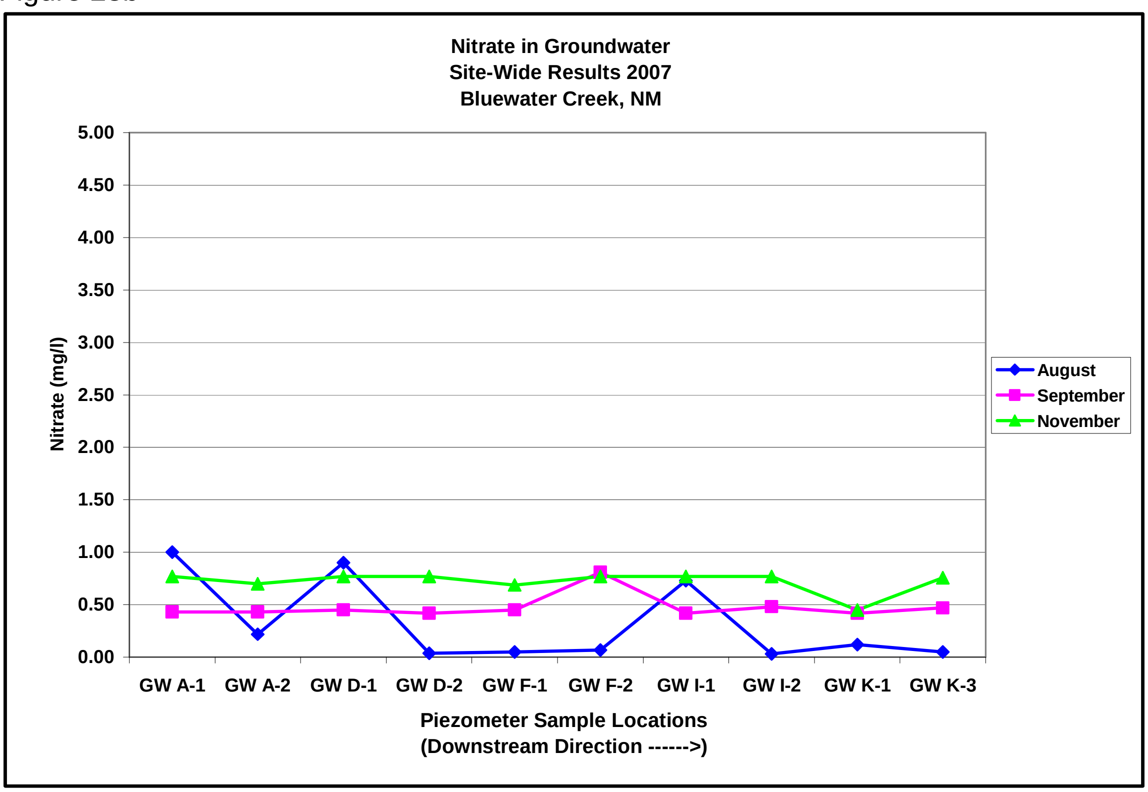


Figure 24a

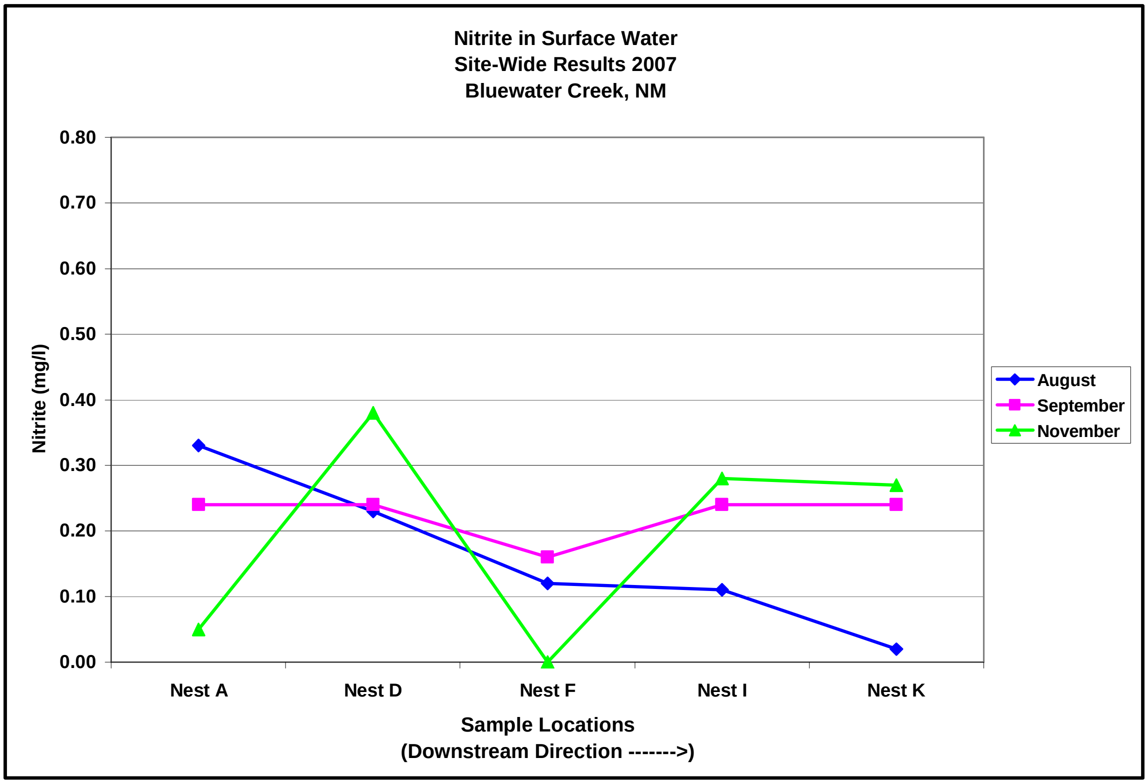


Figure 24b

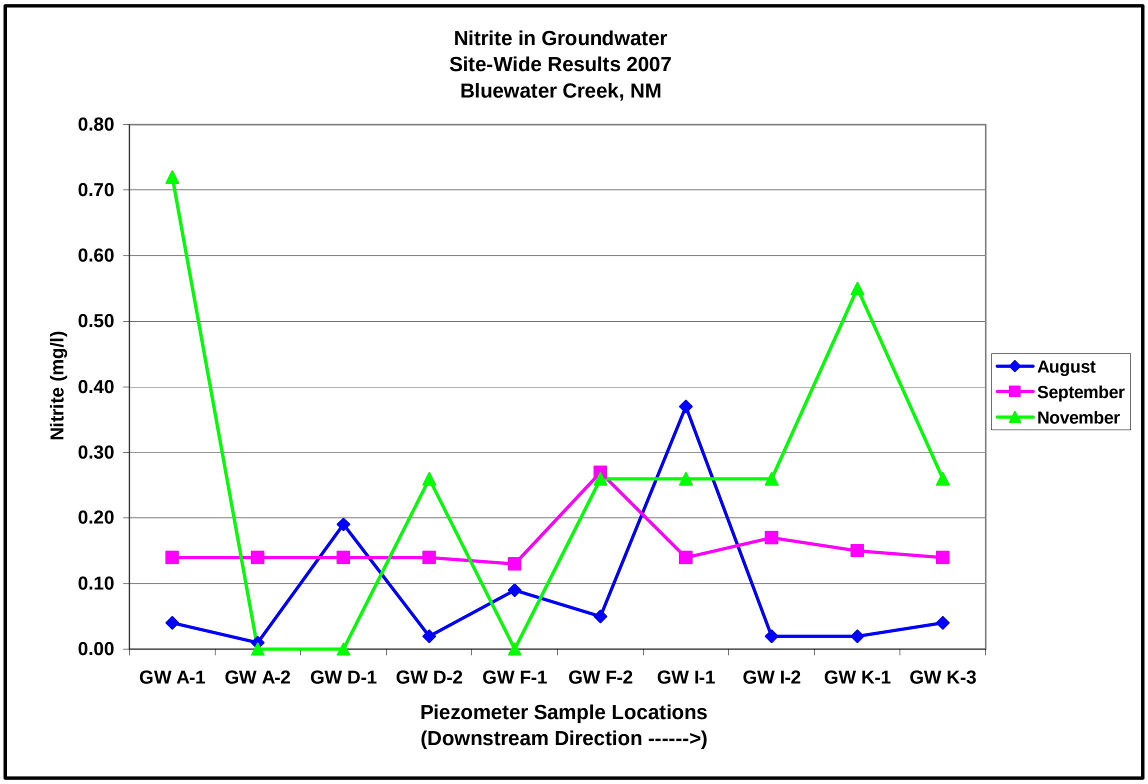


Figure 25a

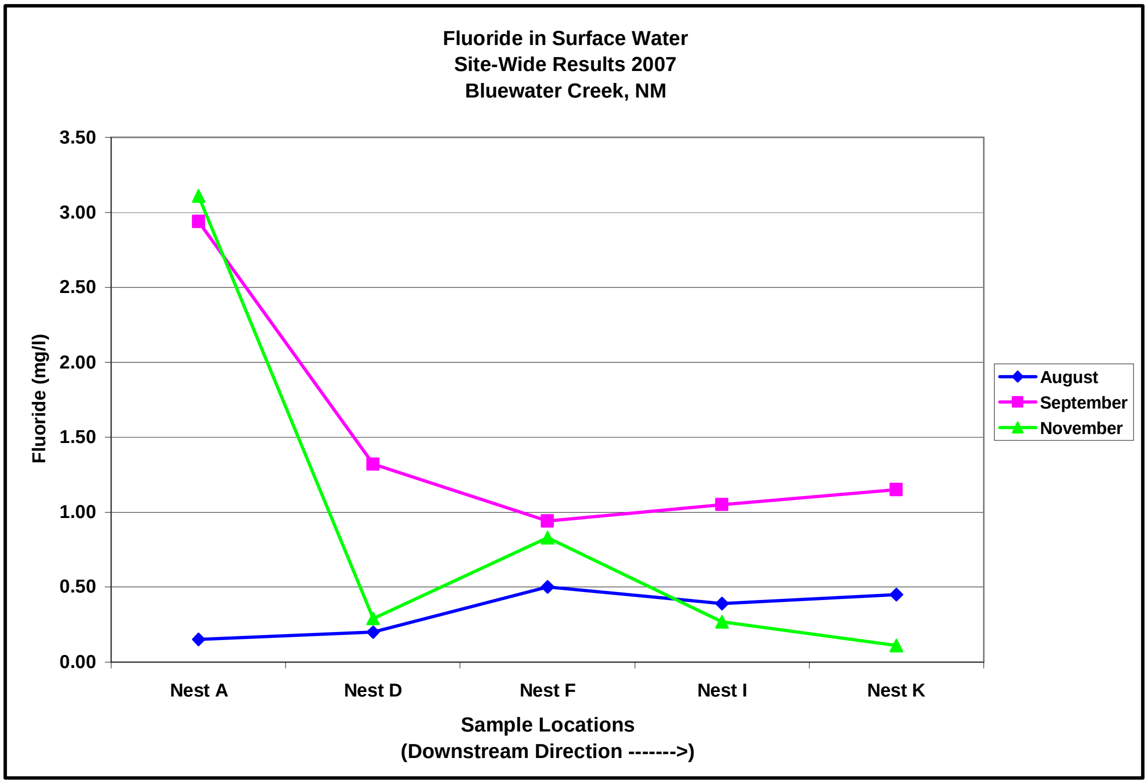


Figure 25b

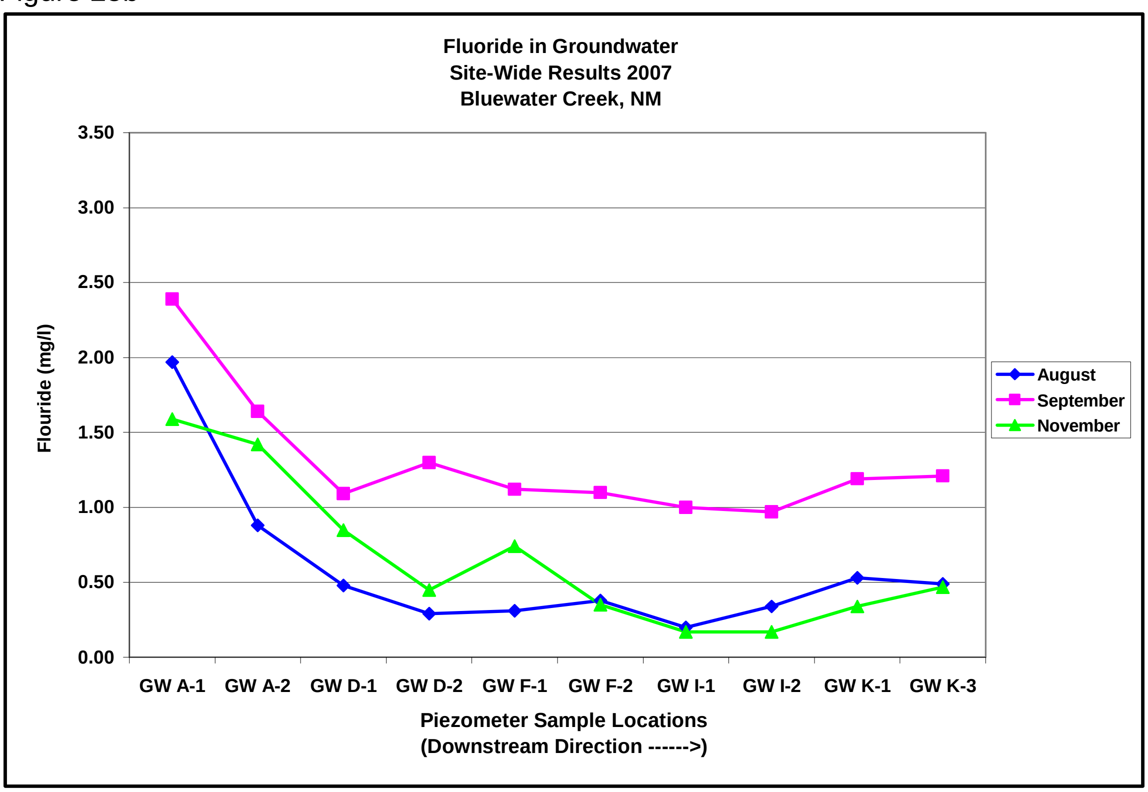


Table 11a: Trace Element Results August 2007 (mg/l)

Sample ID	Ag	Al	As	B	Ba	Be	Cd	Co	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	Sb	Se	Si	Sn	Sr	Ti	U	V	Zn
NEST A																									
SW A-1	<0.017	0.565	<0.066	0.867	0.034	<0.047	<0.049	<0.033	<0.026	0.021	0.092	<0.265	<0.029	NA	<0.031	<0.020	NA	<0.184	5.51	NA	0.080	NA	NA	0.016	0.040
GW A-1	0.074	0.333	<0.063	0.953	0.131	<0.048	<0.048	<0.032	<0.026	0.009	0.569	<0.848	1.594	NA	<0.034	<0.022	NA	<0.191	8.00	NA	0.205	NA	NA	0.066	<0.066
GW A-2	0.174	0.255	<0.061	0.720	0.266	<0.047	<0.048	<0.033	<0.025	0.018	0.010	<1.239	3.030	NA	<0.033	<0.027	NA	<0.188	9.03	NA	0.361	NA	NA	0.051	0.111
NEST D																									
SW D-1	<0.022	0.305	<0.060	1.003	0.031	<0.047	<0.049	<0.032	<0.026	0.015	<0.024	<0.305	<0.048	NA	<0.033	<0.020	NA	<0.181	6.59	NA	0.087	NA	NA	<0.012	<0.070
GW D-1	0.071	0.305	<0.059	0.891	0.199	<0.048	<0.049	<0.033	<0.025	0.006	0.670	<1.398	1.492	NA	<0.036	<0.017	NA	<0.186	11.46	NA	0.273	NA	NA	0.030	1.500
GW D-2	0.026	0.275	<0.066	0.792	0.129	<0.048	<0.049	<0.035	<0.024	0.008	<0.044	<1.558	0.833	NA	<0.036	<0.020	NA	<0.189	10.80	NA	0.373	NA	NA	0.039	0.031
NEST F																									
SW F-1	<0.006	0.763	<0.059	0.777	0.093	<0.047	<0.049	<0.033	<0.026	0.023	0.150	<0.469	<0.015	NA	<0.033	<0.014	NA	<0.188	11.01	NA	0.132	NA	NA	0.017	0.889
GW F-1	<0.027	0.263	<0.057	0.728	0.074	<0.047	<0.049	<0.033	<0.026	0.012	<0.015	<0.447	<0.044	NA	<0.033	<0.020	NA	<0.180	8.81	NA	0.127	NA	NA	0.000	<0.078
GW F-2	<0.030	0.270	<0.061	0.794	0.237	<0.047	<0.049	<0.034	<0.024	0.007	<0.005	<0.965	<0.029	NA	<0.035	<0.019	NA	<0.186	10.64	NA	0.322	NA	NA	0.042	<0.075
NEST I																									
SW I-1	<0.020	0.297	<0.054	0.794	0.081	<0.047	<0.049	<0.034	<0.026	0.012	<0.027	<0.465	<0.045	NA	<0.034	<0.021	NA	<0.182	8.72	NA	0.136	NA	NA	0.022	<0.084
GW I-1	0.015	0.255	<0.056	0.761	0.278	<0.048	<0.049	<0.034	<0.024	0.008	0.356	<0.914	0.684	NA	<0.035	<0.023	NA	<0.188	15.84	NA	0.189	NA	NA	0.055	<0.075
GW I-2	0.049	0.239	<0.058	0.663	0.343	<0.048	<0.049	<0.035	<0.025	0.007	0.294	<1.042	1.174	NA	<0.036	<0.024	NA	<0.181	12.20	NA	0.220	NA	NA	0.031	<0.077
NEST K																									
SW K-1	0.029	0.315	<0.058	0.906	0.243	<0.047	<0.048	<0.034	<0.024	0.018	<0.040	<1.070	0.920	NA	<0.036	<0.023	NA	<0.182	13.41	NA	0.267	NA	NA	0.019	<0.082
GW K-1	0.148	0.287	<0.053	0.806	0.409	<0.048	<0.049	<0.031	<0.024	0.009	<0.041	<1.760	2.715	NA	<0.033	<0.018	NA	<0.187	13.41	NA	0.356	NA	NA	0.041	<0.077
GW K-3	0.009	0.067	0.057	0.594	0.251	<0.046	<0.047	<0.033	<0.024	0.029	<0.051	<4.070	0.389	NA	<0.033	<0.022	NA	<0.177	12.18	NA	0.415	NA	NA	<0.033	<0.060

NA = Not Applicable

Table 11b: Trace Element Results September 2007 (mg/l)

Sample ID	Ag	Al	As	B	Ba	Be	Cd	Co	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	Sb	Se	Si	Sn	Sr	Ti	U	V	Zn
NEST A																									
SW A-1	0.004	0.263	0.002	0.772	0.089	<0.042	<0.039	<0.025	<0.021	0.030	<0.009	0.043	<0.027	NA	<0.032	<0.011	NA	<0.133	9.070	NA	0.225	NA	NA	0.300	<0.079
GW A-1	0.109	0.260	<0.006	0.825	0.178	<0.041	<0.039	<0.025	<0.020	0.033	0.186	0.009	2.078	NA	<0.032	<0.008	NA	<0.130	6.773	NA	0.197	NA	NA	0.346	<0.074
GW A-2	0.177	0.278	<0.009	0.809	0.256	<0.041	<0.039	<0.025	<0.019	0.032	0.134	<0.032	2.964	NA	<0.029	<0.004	NA	<0.124	7.003	NA	0.342	NA	NA	0.346	<0.003
NEST D																									
SW D-1	<0.004	0.303	<0.007	0.875	0.151	<0.042	<0.039	<0.025	<0.020	0.036	0.028	<0.035	<0.004	NA	<0.033	<0.006	NA	<0.124	7.547	NA	0.281	NA	NA	0.318	<0.075
GW D-1	0.058	0.246	<0.002	0.957	0.214	<0.044	<0.039	<0.025	<0.018	0.063	0.405	<0.046	1.046	NA	<0.031	<0.006	NA	<0.112	9.334	NA	0.254	NA	NA	0.245	<0.058
GW D-2	0.155	0.266	<0.005	0.767	0.071	<0.041	<0.039	<0.025	<0.018	0.031	0.005	<0.034	2.549	NA	<0.030	<0.010	NA	<0.115	9.186	NA	0.298	NA	NA	0.342	<0.066
NEST F																									
SW F-1	0.014	0.272	<0.009	0.733	0.213	<0.042	<0.039	<0.025	<0.019	0.032	0.003	<0.022	0.008	NA	<0.032	<0.009	NA	<0.130	9.118	NA	0.237	NA	NA	0.289	<0.076
GW F-1	<0.009	0.235	0.001	1.321	0.207	<0.042	<0.037	<0.022	<0.016	0.210	0.069	<0.025	<0.023	NA	<0.028	<0.007	NA	<0.118	9.070	NA	0.237	NA	NA	0.238	<0.045
GW F-2	<0.001	0.259	<0.006	0.701	0.225	<0.043	<0.039	<0.025	<0.019	0.026	<0.023	<0.008	<0.008	NA	<0.033	<0.012	NA	<0.127	8.948	NA	0.308	NA	NA	0.259	<0.073
NEST I																									
SW I-1	<0.007	0.248	<0.008	0.710	0.209	<0.041	<0.039	<0.026	<0.020	0.030	0.002	<0.022	<0.025	NA	<0.032	<0.007	NA	<0.123	8.827	NA	0.231	NA	NA	0.328	<0.076
GW I-1	0.049	0.233	0.004	0.820	0.314	<0.044	<0.039	<0.025	<0.019	0.048	0.139	<0.029	0.729	NA	<0.031	0.010	NA	<0.121	13.67	NA	0.216	NA	NA	0.252	<0.062
GW I-2	0.047	0.234	<0.001	0.645	0.360	<0.042	<0.039	<0.024	<0.019	0.036	0.259	<0.027	0.555	NA	<0.031	<0.007	NA	<0.116	10.92	NA	0.221	NA	NA	0.288	<0.069
NEST K																									
SW K-1	0.019	0.292	<0.004	0.686	0.247	<0.043	<0.039	<0.026	<0.019	0.027	0.010	<0.043	0.410	NA	<0.031	<0.009	NA	<0.118	11.72	NA	0.308	NA	NA	0.240	<0.074
GW K-1	0.129	0.273	0.000	0.699	0.321	<0.042	<0.039	<0.024	<0.019	0.028	0.068	<0.054	2.195	NA	<0.033	<0.009	NA	<0.110	11.56	NA	0.304	NA	NA	0.270	0.117
GW K-3	<0.001	0.265	<0.003	0.850	0.223	<0.043	<0.039	<0.026	<0.018	0.039	0.019	<0.048	0.036	NA	<0.031	<0.007	NA	<0.116	10.44	NA	0.290	NA	NA	0.292	<0.056

NA = Not Applicable

Table 11c: Trace Element Results November 2007 (mg/l)

Sample ID	Ag	Al	As	B	Ba	Be	Cd	Co	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	Sb	Se	Si	Sn	Sr	Ti	U	V	Zn
NEST A																									
SW A-1	<0.001	0.331	<0.034	0.657	0.064	<0.072	<0.037	<0.028	<0.026	0.028	<0.038	0.050	<0.040	NA	<0.026	<0.020	NA	<0.178	15.875	NA	0.217	NA	NA	0.028	<0.082
GW A-1	0.166	0.330	<0.053	0.827	0.151	<0.064	<0.037	<0.030	<0.028	0.026	0.193	0.020	1.923	NA	<0.028	<0.018	NA	<0.183	14.875	NA	0.182	NA	NA	0.266	<0.080
GW A-2	0.251	0.313	<0.039	0.753	0.236	<0.062	<0.036	<0.029	<0.026	0.028	0.317	<0.037	3.073	NA	<0.029	<0.019	NA	<0.164	12.7	NA	0.346	NA	NA	0.293	<0.056
NEST D																									
SW D-1	0.028	0.340	<0.051	0.786	0.150	<0.065	<0.037	<0.028	<0.028	0.030	<0.044	<0.050	<0.031	NA	<0.028	<0.017	NA	<0.176	12.85	NA	0.322	NA	NA	0.254	<0.077
GW D-1	0.108	0.312	<0.038	0.765	0.214	<0.064	<0.036	<0.029	<0.029	0.030	0.353	<0.060	0.916	NA	<0.028	<0.011	NA	<0.177	14.00	NA	0.262	NA	NA	0.271	<0.065
GW D-2	0.242	0.320	<0.045	0.734	0.074	<0.063	<0.036	<0.028	<0.028	0.025	0.029	<0.054	3.056	NA	<0.027	<0.019	NA	<0.178	14.15	NA	0.332	NA	NA	0.305	<0.036
NEST F																									
SW F-1	0.016	0.299	<0.048	0.774	0.211	<0.064	<0.036	<0.029	<0.026	0.033	<0.040	<0.039	0.014	NA	<0.026	<0.012	NA	<0.179	15.175	NA	0.239	NA	NA	0.252	<0.079
GW F-1	0.018	0.287	<0.049	0.756	0.211	<0.065	<0.036	<0.028	<0.026	0.034	0.623	<0.036	<0.035	NA	<0.029	<0.020	NA	<0.190	14.75	NA	0.240	NA	NA	0.253	<0.056
GW F-2	0.053	0.297	<0.053	0.708	0.212	<0.063	<0.037	<0.030	<0.028	0.025	0.059	<0.021	<0.019	NA	<0.031	<0.010	NA	<0.186	14.75	NA	0.316	NA	NA	0.299	<0.074
NEST I																									
SW I-1	0.022	0.309	<0.041	0.745	0.224	<0.064	<0.036	<0.029	<0.027	0.026	<0.042	<0.031	<0.005	NA	<0.029	<0.016	NA	<0.187	13.125	NA	0.240	NA	NA	0.293	<0.079
GW I-1	0.100	0.299	<0.040	0.735	0.276	<0.066	<0.037	<0.029	<0.027	0.024	0.287	<0.025	0.801	NA	<0.030	<0.019	NA	<0.182	17.325	NA	0.202	NA	NA	0.234	<0.079
GW I-2	0.084	0.271	<0.031	0.650	0.371	<0.062	<0.035	<0.028	<0.028	0.027	1.596	<0.040	0.724	NA	<0.030	<0.021	NA	<0.175	16.975	NA	0.237	NA	NA	0.355	<0.069
NEST K																									
SW K-1	0.052	0.307	<0.034	0.738	0.252	<0.066	<0.036	<0.030	<0.029	0.028	0.312	<0.074	0.170	NA	<0.027	<0.018	NA	<0.169	17.1	NA	0.333	NA	NA	0.240	0.000
GW K-1	0.241	0.306	<0.042	0.733	0.300	<0.065	<0.036	<0.027	<0.025	0.045	0.998	<0.078	2.973	NA	<0.024	<0.019	NA	<0.183	16.325	NA	0.298	NA	NA	0.241	<0.061
GW K-3	0.083	0.329	<0.043	0.812	0.226	<0.063	<0.035	<0.029	<0.027	0.026	0.064	<0.055	1.019	NA	<0.031	<0.019	NA	<0.168	15.875	NA	0.292	NA	NA	0.305	<0.071

NA = Not Applicable

Trace Elements

Trace element results in groundwater are presented in Table 11a, 11b and 11c. Trace elements iron and boron exceeded NM standards. Iron was detected in GW I-2 at a concentration of 1.6 mg/l; exceeding the NM standard for domestic water supply of 1.0 mg/l. Boron was detected at several locations and include the following: GW A-1 (Aug, Sept, Nov), GW A-2 (Sept), GW D-1 (Aug, Sept, Nov), GW D-2 (Aug and Sept), GW F-1 (Sept and Nov), GW F-2 (Aug), GW I-1 (Aug and Sept), GW K-1 (Aug), and GW K-3 (Sept and Nov). These locations exceeded the boron NM standard for irrigation use (groundwater) of 0.75 mg/l. The range of boron concentrations at the above locations were from 0.76 mg/l to 1.32 mg/l.

7.3 Surface Water Hydrology

Precipitation

The average daily rain event for the study period is 0.05 inches (0.13 cm). For this study, a daily precipitation event greater than 0.46 inches (or 1.17 cm) is defined as a significant rain event. There were 6 significant rain events during the course of this study which ranged from 1.17 cm recorded on July 19 and September 4, 2007 to the largest rain event that occurred on December 1 with a measured 1.85 cm of rain.

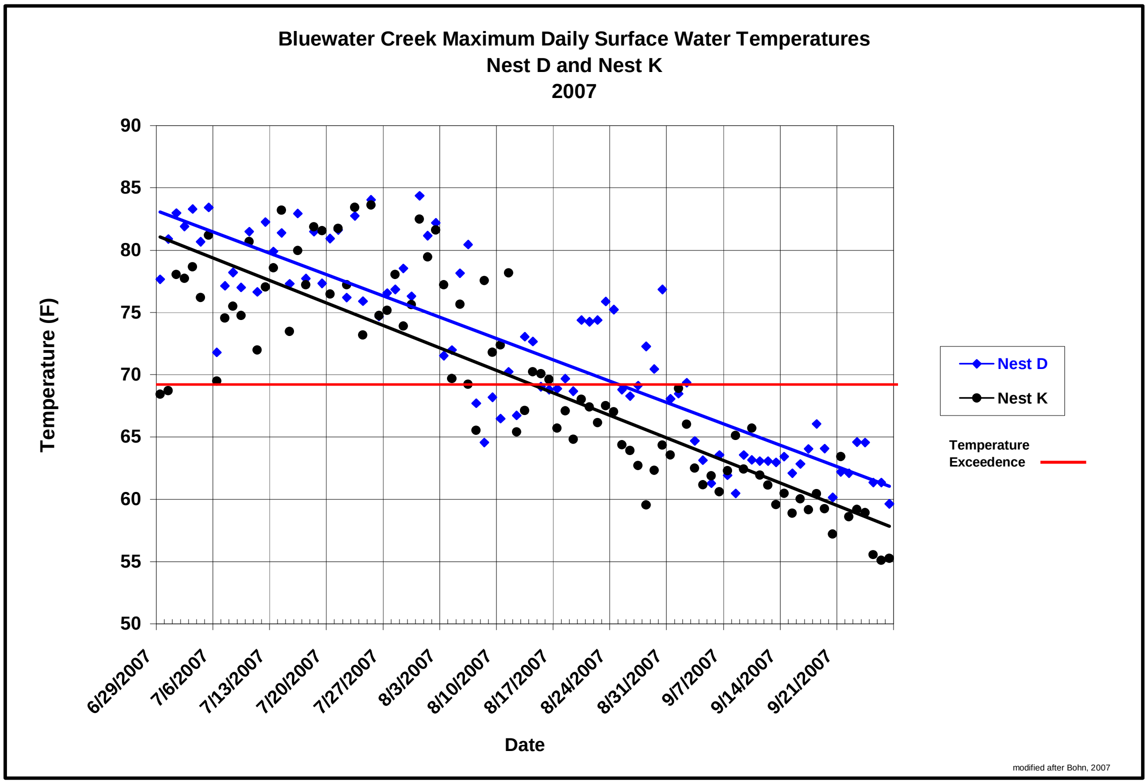
In summary, these significant rain events occurred on July 19 (1.17 cm), August 12 (1.42 cm), September 4 (1.17 cm), September 11 (1.80 cm), November 30 (1.47 cm) and December 1 (1.85 cm). These rain events were recorded at the study site near Piezometer Nest H. However, similar rain events in magnitude were also recorded at the Bluewater Ridge Remote Area Weather Station (headwaters) on July 19 (2.18 cm), November 30 (1.47 cm) and December 1 (1.17 cm).

Daily precipitation is shown on the Depth-to-Water and Groundwater Elevation graphs located in Figure 26a through Figure 36b.

Surface Water Temperature

Surface water temperature was collected at two stream locations adjacent to Piezometer Nest D and Nest K from June 29 through September 27, 2007. For this 3 month period, surface water temperature at Nest D ranged from 8.8 ^{0}C on September 27 to 29.1 ^{0}C on July 31 with an overall average of 18.5 ^{0}C. Surface water temperature collected at Nest K ranged from 9.4 ^{0}C on September 27 to 28.7 ^{0}C on July 25 with an overall average of 17.1 ^{0}C. The maximum daily water temperature is shown in Figure 37 and indicates that Bluewater Creek exceeds the New Mexico Standards for Interstate and Intrastate Surface Waters (NM Administrative Code 20.6.4) for temperature (> 20 ^{0}C or 68 ^{0}F) for surface water temperature through August. A designated use for Bluewater Creek includes coldwater aquatic life.

Figure 37: Bluewater Creek Maximum Daily Surface Water Temperature



Surface Water Flow

Flow was measured at Nest F and Nest I during the November Sample collection event to be 0.07 cfs and 0.16 cfs, respectively.

7.4 Groundwater Hydrology

Groundwater Temperature

Groundwater temperature was collected at each nest inside the piezometer closest to the stream edge (A-1, D-1, F-1, I-1 and K-1). Only the temperature data associated with the five piezometers nests where groundwater samples were collected from are presented here. Displayed below is the maximum, minimum and mean groundwater temperature for the duration of the study period (June – December, 2007).

The minimum groundwater temperature was found to have been recorded in December (during 12/1 – 12/7).The maximum groundwater temperature was recorded in August from 8/3 – 8/25.

GW Temperature ^{O}C			
Piezometer	**Min**	**Max**	**Mean**
GW A-1	5.2	16.3	11.7
GW D-1	6.6	16.7	12.9
GW F-1	5.6	17.8	12.8
GW I-1	7.1	17.1	12.2
GW K-1	3.8	17.6	12.5

One week of groundwater temperature data for every month of data collected was selected to review the average daily fluctuation in groundwater temperature across the study period and to show seasonal and spatial variations (Table 12). The highest average daily fluctuation in groundwater temperature was observed in November.

Table 12: Average Daily Fluctuation in Groundwater Temperature (^{0}C)

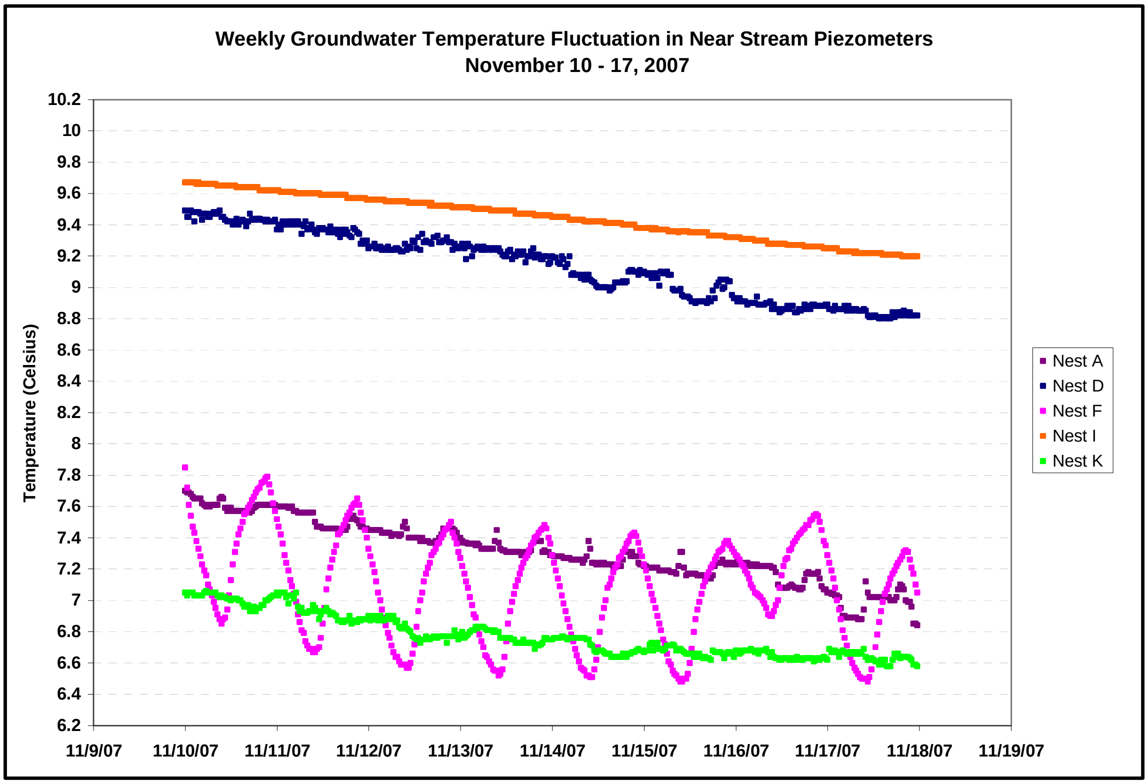
2007	**Piezometer GW A-1**	**Piezometer GW D-1**	**Piezometer GW F-1**	**Piezometer GW I-1**	**Piezometer GW K-1**
June 12-19	0.07	0.09	0.34	0.07	0.19
July 5 -12	0.05	0.13	0.32	0.15	0.10
August 20-27	0.03	0.02	0.20	No data	0.16
September 8 -13	0.06	0.09	0.27	0.10	0.22
October 6-13	0.11	0.11	0.80	0.08	0.35
November 10-17	0.17	0.14	0.90	0.06	0.31
December 1-7	0.31	0.13	0.20	0.10	0.85
Overall Daily Average	0.13	0.11	0.50	0.11	0.19

Downstream Direction →

As shown in Figure 38, during November the groundwater at Nest F, in particular, is highly connected to the surface water displaying near diurnal type fluctuation commonly seen and expected in surface water temperature (USGS, 2003).

The average overall daily change in water temperature fluctuation at Nest F is $0.50\,^{0}$ C. If daily fluctuation is >0.5 ^{0}C then it can reasonably be said with confidence that there is connection to the surface water (personal communication with Dr. Cliff Dahm, October 2008) through hyporheic flow.

Figure 38



Additionally, the entire data set (from June 2007 – Dec 2007) was reviewed at each nest for daily change in groundwater temperature. The data revealed daily fluctuations varying in magnitude indicating a connection to the surface water at certain time periods with exception to Nest I. The daily change in groundwater temperature for each nest is shown on Figures 39 through 43.

Groundwater temperature at Nest A, D, and K shows several days where the fluctuation was near or exceeded 0.5 ^{0}C per day. These days were mostly associated with rain events; which shows connection to the surface water. Nest F illustrates the strongest connection to the surface water displaying diurnal type fluctuation commonly seen in surface water temperature changes.

Figure 39

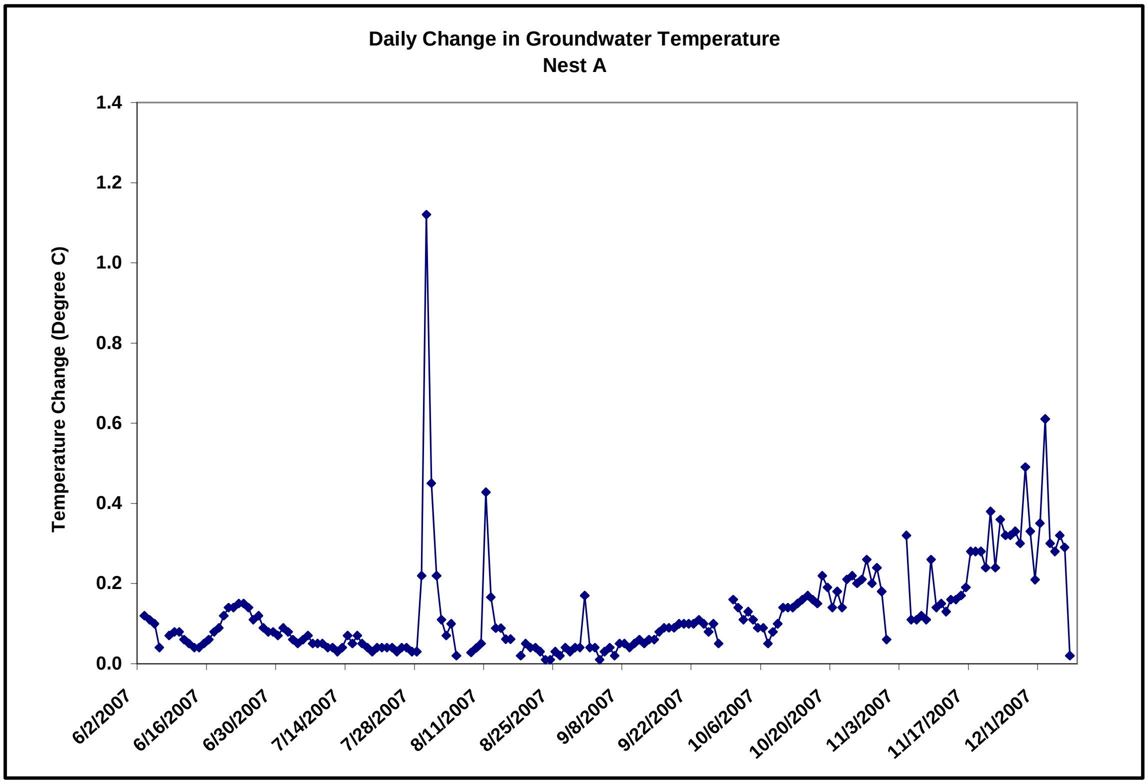


Figure 40

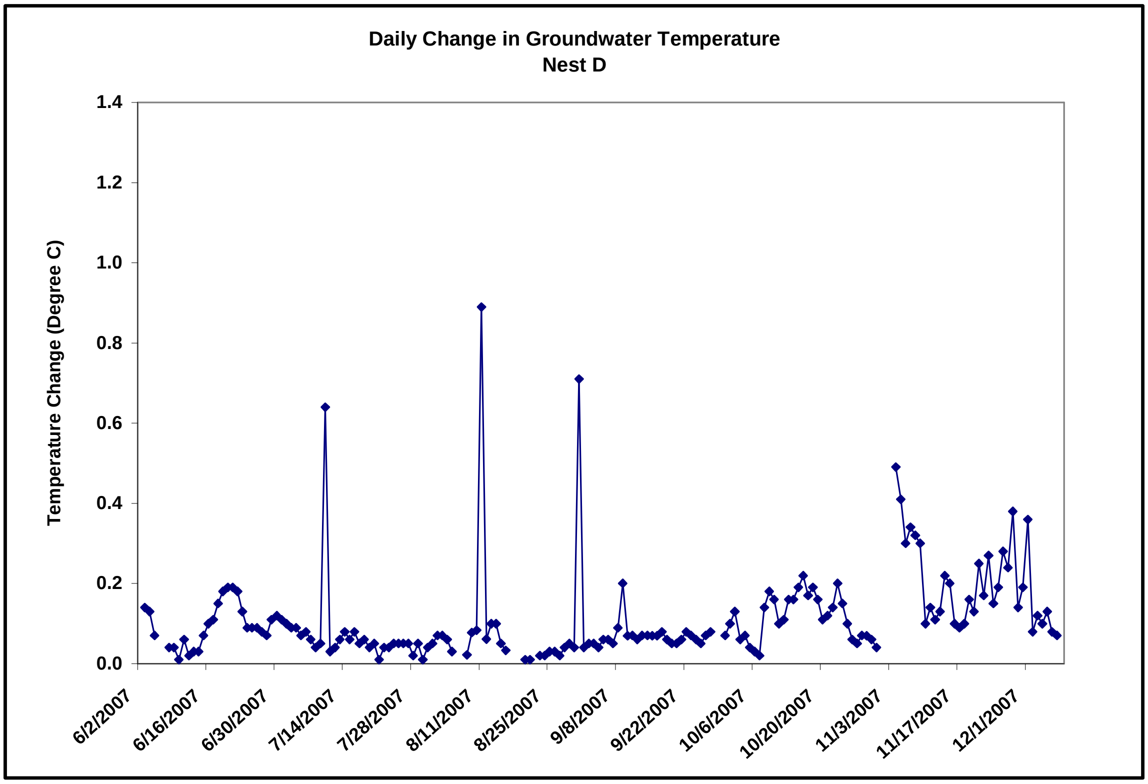


Figure 41

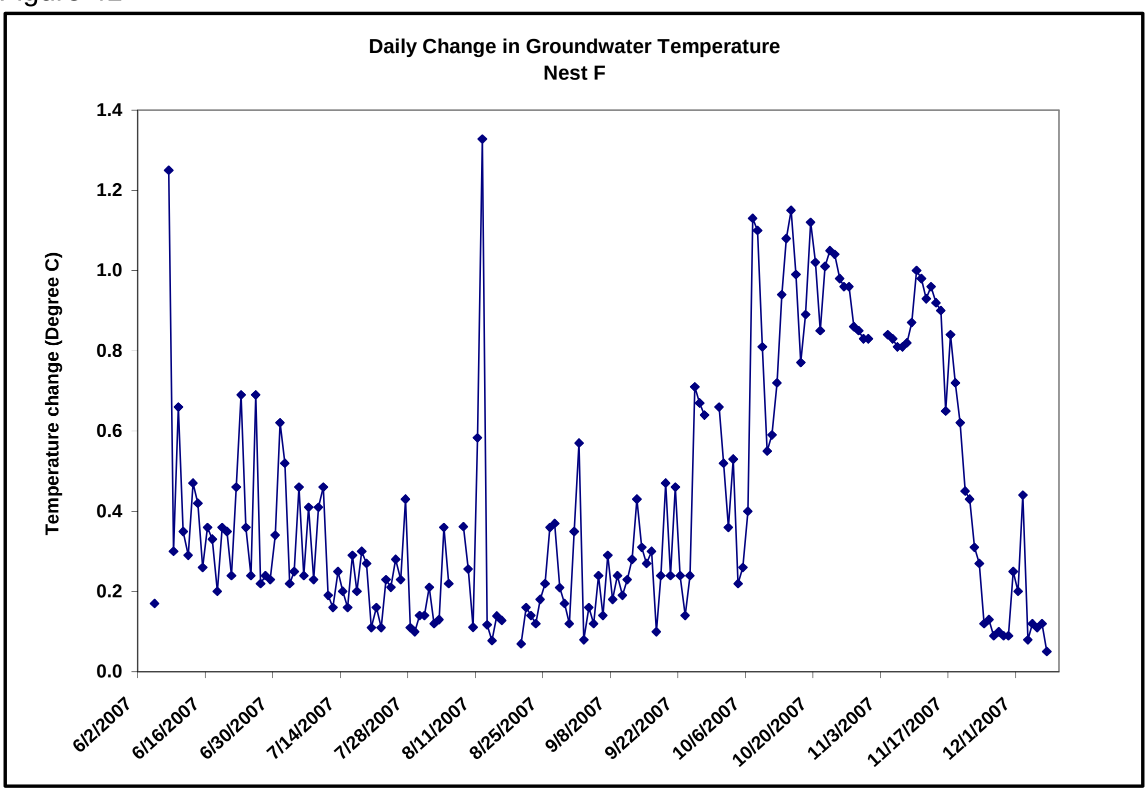


Figure 42

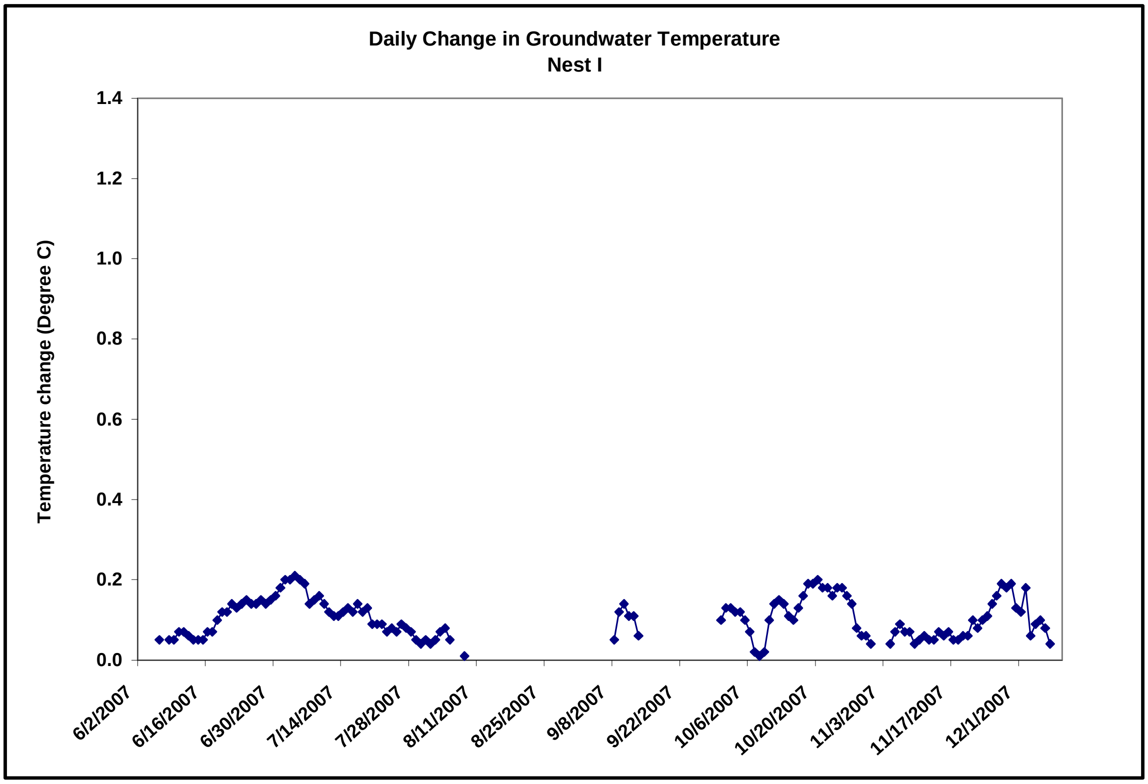
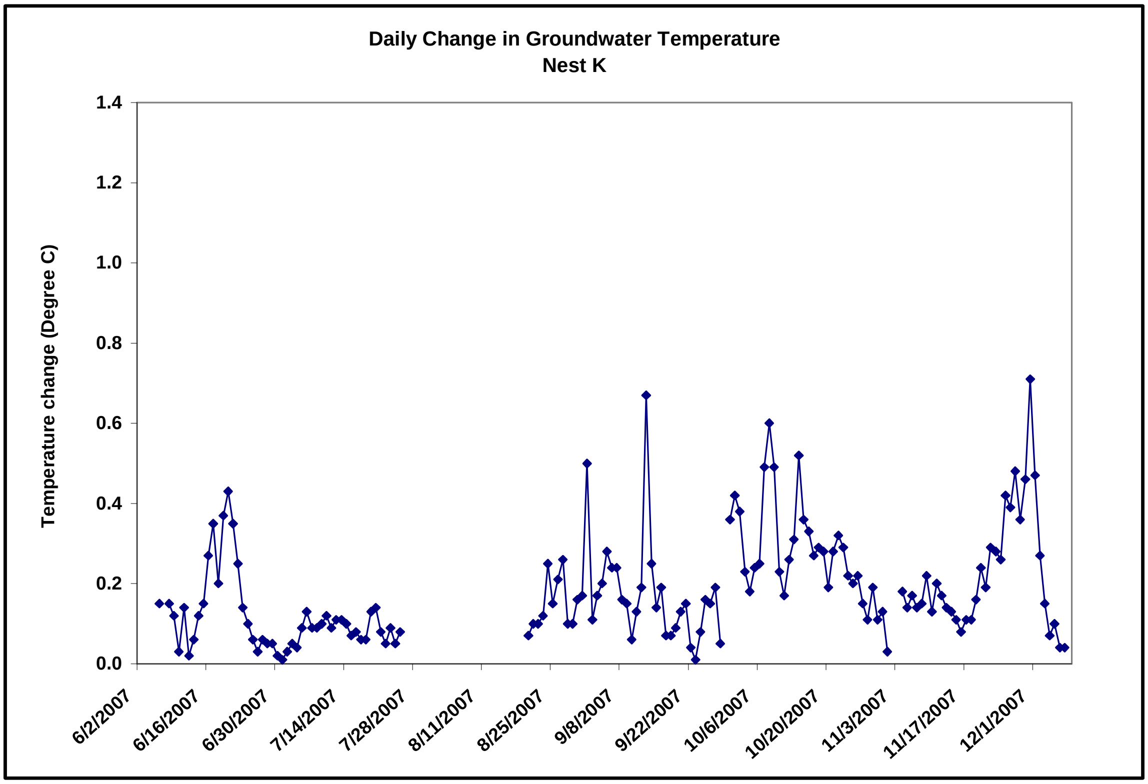


Figure 43



Ground Water Levels

Historical (April 2004 – December 2007)

Groundwater hydrographs have been prepared for water levels measured from April 1, 2004 through approximately mid-to-late 2006 (data collection ended at various times in 2006). Hydrographs have been placed in Appendix 11.2. For comparison purposes, groundwater elevation collected from this study (June 1 through December 10, 2007) are also included in these hydrographs.

During the 2 year monitoring period that first began in 2004, four significant rain events occurred on July 24, 2004 (3.61 cm), August 10, 2005 (3.18 cm), August 14, 2006 (5.08 cm) and October 8, 2006 (2.62). All the hydrographs show a response (rise) to these events but vary in magnitude. Also, it appears there is not a direct correlation between the size or amount of a rain event and the magnitude of the rise in water levels thereafter. Some hydrographs show a lag in response and some show quick response from the onset of a rain event. A possible explanation is because the center of the storm may not have been at the rain gauge or entirely in the watershed. Temporal variations or low water levels during the summer and higher water levels during the fall/winter are shown to be mostly present.

According to NOAA, 2005 was the driest period in New Mexico since record keeping began and is evident on the hydrographs. Overall, waters levels on average have decreased along Bluewater Creek since groundwater monitoring began in 2004.

Based on average groundwater elevations obtained from the 2004-2006 data and from the data collected during this study in 2007 (June-December), all the piezometers except for 4 show a drop in water levels. The greatest drop in water levels was at Nest B at 1.112 meters or about 3.67 feet. On the other hand, Nest K shows an average rise in water levels in two piezometer locations. The least amount of groundwater change was seen at Nest H. The magnitude of the average change in water levels varies at each Nest location is summarized below in Table 13.

Table 13: Change in Groundwater Levels since 2004

Nest A	(-) Drop in Water Level (m)	(+) Rise in Water Level (m)
GW A-1	-0.387	
GW A-2	-0.391	
GW A-3	-0.436	
Nest B		
GW B-1	-1.112	
GW B-3	-1.095	
Nest C		
GW C-1	-0.656	
GW C-2	-0.705	
GW C-3	-0.772	
Nest D		
GW D-1	-0.219	
GW D-2	-0.212	
GW D-3	-0.278	
Nest E		
GW E-1	-0.061	
GW E-3	-0.335	
Nest F		
GW F-1	-0.108	
GW F-2	-0.370	
Nest G		
GW G-1	-0.214	
GW G-2	-0.547	
GW G-3		+0.381
Nest H		
GW H-1	-0.096	
GW H-2	-0.054	
GW H-3	-0.067	
Nest I		
GW I-1	-0.181	
GW I-2	-0.29	
Nest J		
GW J-2		+0.148
GW J-3	-1.037	
Nest K		
GW K-1		+0.086
GW K-2	-1.00	
GW K-3		+0.301

Study Period (6/1/07 – 12/10/2007)

Well hydrographs have been prepared for each of the piezometer nests (11 in total) and can be found in Figures 26a through 36b. These hydrographs are referenced to below ground surface (bgs). All the hydrographs show a lag response to precipitation events.

Ground water elevation hydrographs were also prepared for each piezometer nest and are shown alongside the depth-to-water hydrographs in Figures 25b through 35b. Groundwater elevation hydrographs show similar water table connection and similar response to rain events as also shown in the depth-to-water hydrographs.

Nest A

All three piezometers at Nest A showed similar response to precipitation events but varied in magnitude. The piezometer closest to stream bed or GW A-1 showed the greatest change in water levels due to precipitation events in comparison to the other two piezometers. During the study period, the depth-to-water fluctuated 1.84 m at GW A-3 and 1.90 m at GW A-1. The depth-to-water at GW A-2 fluctuated the least or approximately 0.52 m (Figure 26a).

A high water table level was consistent and expected throughout the duration of the study at the piezometer closest to the stream's edge. At Nest A, GW A-1 (closest to the stream's edge) reported an average recorded depth-to water of 0.9 m bgs followed by GW A-3 and GW A-2 with an average depth-to-water measurement of 1.32 m and 2.27 m bgs, respectively. Furthermore, the second (behind GW B-3) deepest depth-to-water measurement across the entire study site was recorded in piezometer GW A-2 at 2.57 m bgs on July 28, 2007.

Patterns of seasonal variation (low in the summer) and high in the fall/winter are present.

At the start of the study period, depth-to-water levels show a decline from June 1 to July 29, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. Water levels did start to rise after July 29 but it wasn't until the August 11, 2007 minor rain event of 0.66 cm that the most dramatic rise in water level was seen in GW A-1 and GW A-3. This sudden maximum change in water level was 1.90 m and 1.65 m. respectively. The water level in piezometer GW A-1 rose the highest at -0.58 m (above ground surface) 3.5 hours after this rain event on August 11, 2007.

A rain event of 1.42 cm, more than twice the amount seen on August 11, occurred less than 24 hours hours later on August 12 but water levels continued to decline. It was not until 20 days later or August 31 that a response or rise in water level occurred in GW A-1 but significantly less in GW A-2 and GW A-3. A small rise in water levels was seen in GW A-1 on September 6 or two days after a significant rain event of 1.17 cm (September 4).

For all three piezometers at Nest A, from September 6 until December 2, water levels remained fairly constant despite three rain events that occurred on September 11 (1.80 cm), November 30 (1.47 cm) and December 1(1.85 cm).

Nest B

The two piezometers at Nest B showed similar response to precipitation events but varied in magnitude. The piezometer closest to stream bed or GW B-1 showed the greatest magnitude in change in water levels due to precipitation events in comparison to GW B-3. During the study the depth-to-water fluctuated 0.81 m at GW B-3 and 1.00 m at GW B-1 (Figure 27a).

A high water table level was consistent and expected throughout the duration of the study at GW B-1 (closest to the stream's edge) with an average recorded depth-to-water of 1.04 m bgs. Piezometer location GW B-3 had an average depth-to-water measurement of 2.15 m bgs. The deepest depth-to-water measurement across the entire study site was recorded in piezometer GW B-3 at 2.67 m bgs on August 3, 2007.

Patterns of temporal variation (low in the summer) and high in the fall/winter are present.

At the start of the study period, depth-to-water levels at both piezometers (GW B-1 and GW B-3) show a gradual decline from June 1 to August 3, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. Water levels did begin to rise significantly after August 3, 2007.

Ground water level in GW B-1 peaked on August 7, or 4 days prior to the peak that was seen at Nest A on August 11. The change (rise) in water level seen at GW B-1 was 0.89 m. Thereafter, water level declined for about 2 weeks until another rise in water level at GW B-1 occurred on August 31. This also coincides to a rise in water levels seen at the Nest A piezometers. After August 31, water levels mostly leveled out with just a small rise in water level after a rain event on September 4 (1.17 cm). A rain event occurred on September 11 (1.80 cm) with no rise in water level. Instead, water levels dropped slightly.

Ground water level in GW B-3 peaked on August 12 during a rain event (1.42 cm) unlike that at Nest A where water levels continued to drop after the August 12 rain event. This change in water level seen at GW B-3 was 0.81 m. The water level in piezometer GW B-3 peaked at 1.85 m (bgs); 8.5 hours after the start of the August 12 rain event (1.42 cm).

From September 1 until December 3, water levels remained fairly constant at GW B-3 despite four rain events that occurred on September 4 (1.17cm), September 11 (1.80 cm), November 30 (1.47 cm) and December 1(1.85 cm).

Nest C

All three piezometers showed similar response to precipitation events but varied in magnitude. The piezometer closest to stream bed or GW C-1 showed the greatest magnitude in change in water levels due to precipitation events in comparison to the other two piezometers. During the study period, depth-to-water fluctuated 0.40 m at GW C-3 and 1.95 m at GW C-1. The fluctuation of 1.95 m seen in piezometer GW C-1 is the maximum water level change seen in any piezometer during the duration of the study. The depth-to-water at GW C-2 fluctuated approximately 1.1 m during the study period (Figure 28a).

A high water table level was consistent and expected throughout the duration of the study at GW C-1 (closest to the stream's edge) with an average recorded depth-to water of 1.06 m bgs. Piezometers GW C-2 and GW C-3 each had an average depth-to-water measurement of 1.34 m and 1.45 m bgs, respectively.

Water levels in piezometers GW C-2 and GW C-3 did not show significant patterns of temporal variation (low in the summer) and high in the fall/winter. Instead, there was an average consistency throughout the seasons with exception to rainfall response where there is a sudden rise in the water table. And depth-to-water at GW C-1 was on average higher in the summer and lower in the fall/winter or contrary to what is expected.

At the start of the study period, depth-to-water levels show a gradual decline from June 1 to August 6, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. Water levels did start to rise after August 6 but it wasn't until the August 11, 2007 rain event of 0.66 cm that the most dramatic rise in water level was seen in GW C-1 and GW C-2. This sudden maximum change in water level was 1.64 m and 1.10 m. respectively. The depth-to-water level in piezometer GW C-1 peaked on August 11, 2007 at -0.46 m (above ground surface), 3.5 hours after the onset of this rain event.

A rain event of 1.42 cm, more that twice the amount seen on August 11, occurred less than 24 hours later on August 12 but water levels continued to decline. It was not until 20 days later or August 31 that a response or rise in water level occurred in GW A-1 but significantly less in GW C-2 and GW C-3. A small rise in water levels was seen in GW C-1 on September 6 and in GW C-2 on September 7 after a rain event of 1.17 cm on September 4; a lag time of 2 -3 days.

A rain event on December 1, 2007 delivered 1.85 cm of precipitation. Unlike all the other piezometer nests throughout the study it was at Nest C that the maximum change or rise in water levels occurred for this particular rain event. Within 12 hours from the onset of rain event, the water level at GW C-1 rose 0.86 cm.

Nest D

All three piezometers at Nest D showed similar response to precipitation events but varied in magnitude. From the data collected, the piezometer closest to stream bed or GW D-1 showed the greatest magnitude in change in water levels due to precipitation events in comparison to the other two piezometers. During the study period, the depth-to-water fluctuated 0.49 m at both GW D-2 and GW D-3. The depth-to-water at GW D-1 fluctuated the most at approximately 1.07 m (Figure 29a).

A high water table level was consistent and expected throughout the duration of the study at the piezometer closest to the stream's edge. At Nest D piezometer GW D-1 (closest to the stream's edge) had an average depth-to water of 0.50 m bgs followed by GW D-3 and GW D-2 with an average depth-to-water measurement of 0.89 m and 1.14 m bgs, respectively.

There is slight temporal variation (low in the summer) and high in the fall/winter but it is not as strong as what is seen at Nest A, Nest B, Nest K and Nest J.

At the start of the study period, depth-to-water levels show an decreasing trend from June 1 to August 6, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. Water levels did start to rise after August 6 but it wasn't until the August 11, 2007 rain event of 0.66 cm that the most dramatic rise in water level was seen in GW D-1. Unfortunately, there was no data at this time (August 11) for GW D-2 and GW D-3 but highly likely a similar response to that seen in GW D-1 would also have been seen at GW D-2 and GW D-3. The sudden maximum change in water level in GW D-1 from the August 11 rain event was 1.0 m. The water level in piezometer GW D-1 rose to -0.41 m (above ground surface) in 3.5 hours after the onset of August 11, 2007 rain event.

A rain event of 1.42 cm, more than twice the amount seen on August 11, occurred less than 24 hours later on August 12 but water levels continued to decline. It was not until 20 days later or August 31 that a rise in water level occurred in GW D-1 but significantly less response was seen in GW D-2 and GW D-3. On the contrary, a small rise in water level was seen in GW D-1, GW D-2 and GW D-3 on September 6 or just two days after a significant rain event of 1.17 cm that occurred on September 4. Water levels also rose slightly in response to another rain event that occurred on September 11 (1.80 cm). GW D-1 responded on September 11 but water levels in GW D-2 and GW D-3 responded a day later on September 12.

Following the September 11 rain event, water levels began to slowly decline until a significant rain event of 1.85 cm occurred on December 1, 2007. In this instance, it was GW D-3 that showed the showed the greatest change or rise in water level and not GW D-1 (the piezometer closest to the stream bed) as was the case for the August 11 rain event.

Nest E

The two piezometers at Nest E show similar response to precipitation events but varied slightly in magnitude. The piezometer closest to stream bed or GW E-1 did not show the greatest magnitude in change in water levels due to precipitation events in comparison to the other piezometer nests located upstream. At Nest E, GW E-3 showed the greatest magnitude in water level change.

During the study period, the depth-to-water fluctuated 0.82 m at GW E-1 and 1.04 m at GW E-2 (Figure 30a).

A high water table level was consistent and expected throughout the duration of the study at GW E-1 (closest to the stream's edge) with an average recorded depth-to water of 0.50 m bgs. Piezometer GW E-3 had an average depth-to-water measurement of 1.11 m bgs

There is not a strong temporal variation (low in the summer) and high in the fall/winter at Nest E.

At the start of the study period, depth-to-water levels showed minimal change from June 1 to August 7, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. Water levels did rise and fall briefly on August 7 from a rain event (0.86 cm) that occurred the day on

August 6, 2007 but it wasn't until the August 11, 2007 minor rain event of 0.66 cm that the most dramatic rise in water level was seen in GW E-1 and GW E-3. This sudden maximum change in water level was 0.76 m and 0.96 m. respectively. The water level in piezometer GW E-1 rose the highest to -0.244 m (above ground surface) 4 hours after this rain event on August 11, 2007.

A rain event of 1.42 cm, more than twice the amount seen on August 11, occurred less than 24 hours on August 12 but water levels continued to decline. It was not until 20 days later or August 31 that a response or rise in water level occurred in GW E-1 and to a lesser extent in GW E-3. A small rise in water level was seen in GW E-1 and GW E-3 on September 7 or three days after a rain event of 1.17 cm (September 4).

From September 7 until December 1, water levels remained fairly constant and slowly increased in December at GW E-1. No data were collected from GW E-3 after September 13. Water level in GW E-1 rose slightly on December 2; one day after a rain event of 1.85 cm occurred on December 1.

Nest F

The two piezometers at Nest F show similar response to precipitation events but varied in magnitude.

During the study period, the depth-to-water fluctuated 1.28 m at GW F-1 and 0.16 m at GW F-2 (Figure 31a).

A high water table level was consistent and expected throughout the duration of the study at GW F-1 (closest to the stream's edge) with an average recorded depth-to water of 0.34 m bgs which is also considered the shallowest average recorded water level found throughout the entire study area. Piezometer GW F-2 had an average depth-to-water measurement of 1.27 m bgs.

There is not a strong temporal variation (low in the summer) and high in the fall/winter at Nest F.

At the start of the study period, depth-to-water levels showed minimal change from June 1 to August 11, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. It wasn't until the August 11, 2007 minor rain event of 0.66 cm that the most dramatic rise in water level was seen in GW F-1. Data were missing from GW F-2. This maximum change in water level at GW F-1 from this rain event was 1.25 m. The water level in piezometer GW F-1 rose to the maximum highest level site wide to -0.851 m (above ground surface) 4.5 hours after this rain event on August 11, 2007.

A rain event of 1.42 cm, more than twice the amount seen on August 11, occurred less than 24 hours on August 12 but water levels continued to decline. It was not until 20 days later or August 31 that a response or rise in water level occurred in GW F-1 and to a lesser extent in GW F-2. A small rise in water level was seen in GW F-1 and GW F-2 on September 6 and 7 or 2-3 days after a rain event of 1.17 cm (September 4).

From September 7 until December 8, water levels remained on average fairly steady with a slight gradual increase but with no real significant response to three rain events that occurred on September 11 (1.80 cm), November 30 (1.47 cm) and December 1 (1.85 cm).

Nest G

All three piezometers at Nest G show similar response to precipitation events but varied in magnitude. From the data collected, the piezometer closest to stream bed or GW G-1 showed the greatest magnitude in change in water levels due to precipitation events in comparison to the other two piezometers. During the study period, the depth-to-water fluctuated nearly the same magnitude at GW G-1 and GW G-2 or at 0.89 m and 0.84 m, respectively. The depth-to-water at GW G-3 fluctuated the least or approximately 0.46 m (Figure 32a).

A high water table level was consistent and expected through the duration of the study at the piezometer closest to the stream's edge. At Nest G, GW G-1 (closest to the stream's edge) had an average recorded depth-to water of 0.59 m bgs followed by GW G-2 and GW G-3 with an average depth-to-water measurement of 1.17 m bgs and 1.23 m bgs, respectively.

There is not a strong temporal variation (low in the summer) and high in the fall/winter at Nest G.

At the start of the study period, depth-to-water levels showed a slight decrease in water levels from June 1 to August 11, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. It wasn't until the August 11, 2007 minor rain event of 0.66 cm that the most dramatic rise in water level was seen in GW G-1 followed by GW G-2 and GW G-3 with a sudden maximum change in water level (rise) of 0.83 m, 0.78 m and 0.39 m, respectively. The water level in piezometer GW G-1 rose to the highest water level seen at Nest G of -0.215 m (above ground surface) 6 hours after this rain event on August 11, 2007.

A rain event of 1.42 cm, more than twice the amount seen on August 11, occurred less than 24 hours on August 12 but water levels continued to decline. It was not until 20 days later or August 31 that a response or rise in water level occurred in GW G-1 and to a lesser extent in GW G-2 and GW G-3 on September 1, 2007. A small rise in water level was seen in all three piezometers on September 7 or 3 days after a significant rain event of 1.17 cm (September 4). Another rain event occurred on September 11 of 1.80 cm in which all three piezometers showed a response on September 11 (GW G-1) and on September 12 (GW G-2 and GW G-3).

From September 12 until December 2, water levels remained on average steady with only a slight response to a later rain event that occurred on December 1 (1.85 cm).

Nest H

All three piezometers at Nest H show similar response to precipitation events but varied in magnitude. From the data collected, the piezometer closest to the stream bed or GW H-1 showed the greatest magnitude in change in water levels due to precipitation events in comparison to the other two piezometers. Of all the piezometer nests in this study, Nest H displays the site-wide minimum for depth-to-water fluctuation during the entire study period. Depth-to-water only fluctuated 0.24 m at GW H-3 and 0.27 m at GW H-1. And the most fluctuation was seen at GW H-2 at 0.32 m (Figure 33a).

A high water table level was consistent and expected throughout the duration of the study at those piezometers closest to the stream's edge. However, at Nest H, this was not the case. Instead, the average recorded depth-to-water at GW H-1 (closest to the stream's edge) had the lowest water level of 1.37 m bgs. The highest average depth-to-water was seen in GW H-3 at 1.25 m bgs.

There is not a strong temporal variation (low in the summer) and high in the fall/winter at Nest H.

At the start of the study period, depth-to-water levels showed a slight decrease in water levels from June 1 to August 11, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. It wasn't until the August 11, 2007 minor rain event of 0.66 cm that the most dramatic rise in water level was seen in GW H-1 and in GW H-3 where there was a sudden maximum change in water level (rise) of 0.19 m and 0.15 m, respectively. The water level in piezometer GW H-1 rose to the highest water level seen at Nest H of 1.168 m bgs 7 hours after this rain event on August 11, 2007.

A rain event of 1.42 cm, more than twice the amount seen on August 11, occurred less than 24 hours on August 12 but water levels continued to decline. It was not until 21 days later or September 1 that a response or rise in water level occurred in all three piezometers. A smaller rise in water level was seen again in all three piezometers on September 12 or 1 day after a rain event of 1.80 cm on September 11.

From September 12 until December 7, water levels increased slightly with no real response to rain events that occurred on November 30 (1.47 cm) and December 1 (1.85 cm).

Nest I

The piezometers at Nest I show similar response to precipitation events but varied in magnitude. Nest I, like Nest H, displayed minimum depth-to-water fluctuation during the study period. The depth-to-water fluctuated only 0.31 m at GW I-4 and 0.33 m at GW I-2 with the most fluctuation seen at GW I-1 at 0.56 m (Figure 34a)

A high water table level was consistent and expected throughout the duration of the study at those piezometers closest to the stream's edge. However, at Nest I, this was not the case. Instead, the average recorded depth-to-water at GW I-1 (closest to the stream's edge) had the lowest water level of 1.08 m bgs. The highest average depth-to-water was seen in GW I-2 at 0.95 m bgs followed by GW I-4 at 0.97 m bgs.

There is not a strong temporal variation (low in the summer) and high in the fall/winter at Nest I. Furthermore, water levels at GW I-1 were opposite than expected or higher in the summer and lower in the fall/winter.

At the start of the study period, depth-to-water levels showed a slight decrease in water levels from June 1 to August 10, 2007 even while several minor rain events and one major rain event on July 19, 2007 (1.17 cm) occurred during this same period. It wasn't until the August 11, 2007 minor rain event of 0.66 cm that the most dramatic rise in water level was seen in GW I-4 where there was a 0.14 m change in water level (rise).

A rain event of 1.42 cm, more than twice the amount seen on August 11, occurred less than 24 hours on August 12 but water levels continued to decline. Small responses (rise) were seen in GW I-2 and GW I-1 between the September 4 and September 11 rain events of 1.17 cm and 1.80 cm, respectively. After the September 11 rain event, water levels began to decrease at GW I-1 while water levels at GW I-1 and GW I-2 remained relatively steady in comparison. Water levels at GW I-1 and GW I-2 increased slightly in response to a rain event that occurred on December 1 (1.85 cm).

Nest J

The two piezometers at Nest J show similar response to precipitation events but varied in magnitude. Results from the other piezometer nests have shown the piezometer closest to the stream bed to have the greatest magnitude in change in water levels due to precipitation events (Figure 35a). However, at Nest J, Piezometer J-3 had the greatest change in water level during the September 1 rain event but not during the December 1, 2007 rain event. Throughout the study period at Nest J, depth-to-water fluctuated 1.16 m at GW J-2 and 1.22 m at GW J-3.

It has already been shown from the earlier nests that a high water table level has shown to be consistent and expected throughout the duration of the study at the piezometer closest to the stream's edge. This is not the case at Nest J (or at Nest H and Nest I). Instead, the piezometer located the farthest from the stream or GW J-2 shows a shallow water table with an average recorded depth-to-water of 0.43 m bgs. Piezometer GW J-3 (the piezometer closest to the stream's edge) has an average depth-to-water of 0.57 m bgs. Of the 11 piezometer nests in this study, Nest J has the third shallowest ground water levels (behind Nest F and Nest K). Nest J and Nest K are located in riparian areas with active beaver activity.

Patterns of temporal variation (low in the summer) and high in the fall/winter are present at Nest J.

At the start of the study period in early June depth-to-water levels at both piezometers (GW J-2 and GW J-3) were very high with depth-to-water measurement just below the ground surface. Water levels then decreased until a rain event on July 5 of 0.84 cm registered a rise in water level that same day at GW J-3 (closest to the stream's edge) and the next day (July 6) at GW J-2. This rise in water levels at Nest J on July 5 and July 6 was not seen in any of the other upstream nests as prominent as it is shown in this hydrograph for Nest J. In most of the upstream nests (A through I), there was little or no response in water levels to the July 5 rain event. After this rain event (July 5), water levels at Nest J continued to follow a decreasing trend until August 11, 2007 when water levels began to increase due to a 1.42 cm rain event. The water level peaked on August 12, or 7 hours after the onset of the rain event to a depth-to-water seen in piezometer GW J-3 of -0.15 (above ground surface).The magnitude or change in water level seen in GW J-3 in response to this rain event on August 11 was 1.20 m in GW J-3 and 1.13 m in GW J-2.

Thereafter, water levels continued to decrease until another rise in water levels occurred on September 1. Rain events occurred on September 4 (1.17 cm) and again on September 11 (1.80 cm) with minimum response. Water levels continued to decline, but remained at a higher level than from the summer. A large response in water level (rise) was then seen on December 1 due to a rain event that same day of 1.85 cm. This response at Nest J on December 1, 2007 was also seen at Nest C and at Nest D of similar magnitude (and much less at other nests).

Nest K

The piezometers at Nest K show similar response to precipitation events but varied in magnitude. The piezometer GW K-2 showed the greatest magnitude in change in water levels due to precipitation events. Throughout the study period at Nest K, depth-to-water fluctuated 0.575 m at GW K-1 and 1.024 m at GW K-2 (Figure 36a)

A high water table level was consistent and expected through the duration of the study at the piezometer closest to the stream's edge. At Nest K, GW K-1 (closest to the stream's edge) has an average depth-to water of 0.391 m bgs and piezometer GW K-2 has an average depth-to-water measurement of 0.524 m bgs. Additionally, the average depth-to-water (0.391 m bgs) seen at GW K-1 is the second shallowest (behind GW F-1) average depth-to-water recorded across the study area. Patterns of temporal variation (low in the summer) and high in the fall/winter occur at Nest K.

Similar to Nest J, in early June depth-to-water levels at both piezometers (GW K-1 and GW K-2) were very high (< 0.5 m bgs). Water levels then slightly decreased until a rain event on July 5 of 0.84 cm registered a small rise in water level that same day at GW J-3 (closest to the stream's edge) and the next day (July 6) at GW J-2. This rise in water levels at Nest J on July 5 and July 6 was not seen in any of the other upstream nests except in Nest J. In most of the upstream nests (A through I), there was little or no response in water levels to this July 5 rain event. But at Nest K, following this rain event (July 5), water levels continued to follow a decreasing trend until August 11, 2007 when water levels began to increase due to a 1.42 cm rain event. The magnitude or change in water level seen in GW K-2 in response to this rain event on August 11 was approximately 0.95m

Thereafter, water levels continued to decrease until another rise in water levels occurred on September 1. Rain events occurred on September 4 (1.17 cm) and again on September 11 (1.80 cm) with minimum response. Water levels continued to decline, but remained at a mostly higher level than from the summer. A response in water level (rise) was seen on December 1 due to a rain event that same day of 1.85 cm. This response was also seen at Nest C and Nest J of greater magnitude and less at Nest D.

Figure 26a

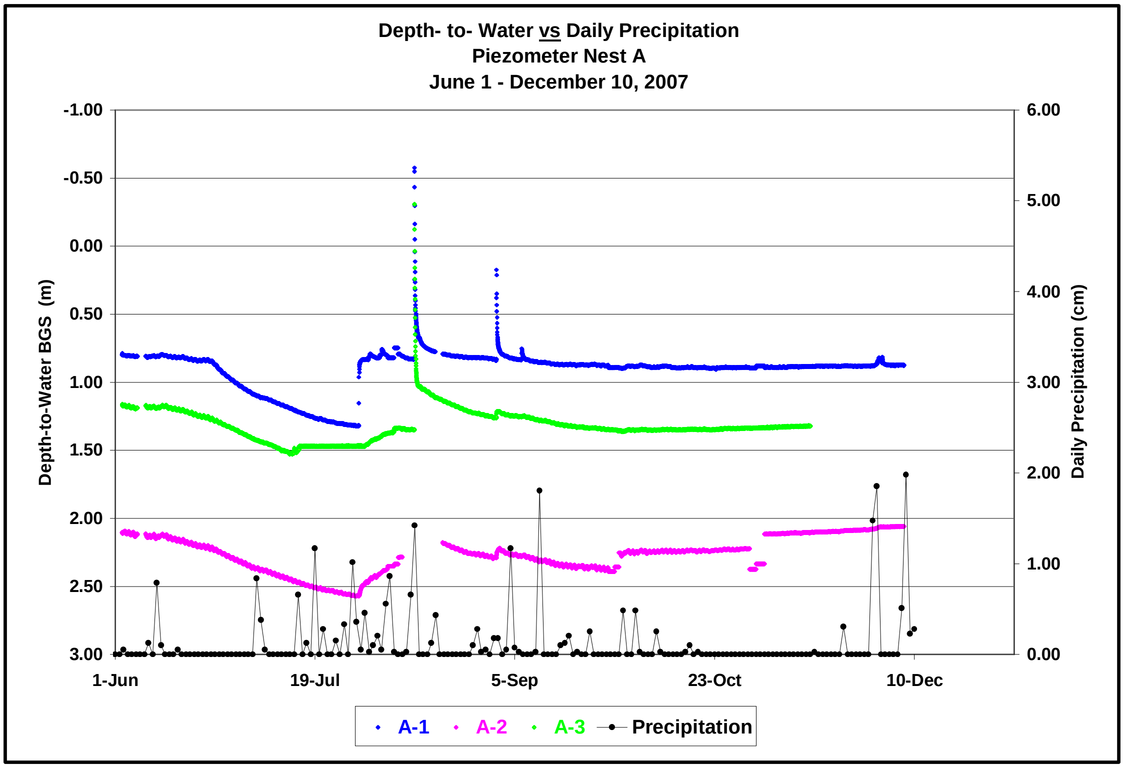


Figure 26b

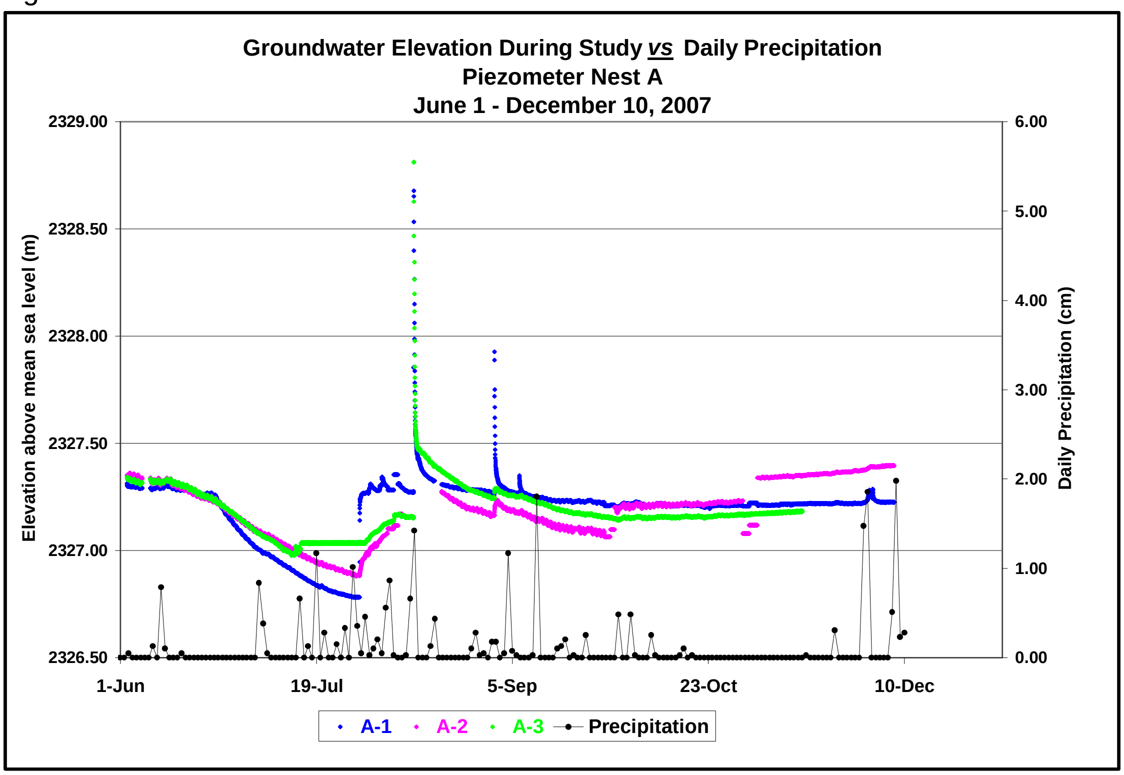


Figure 27a

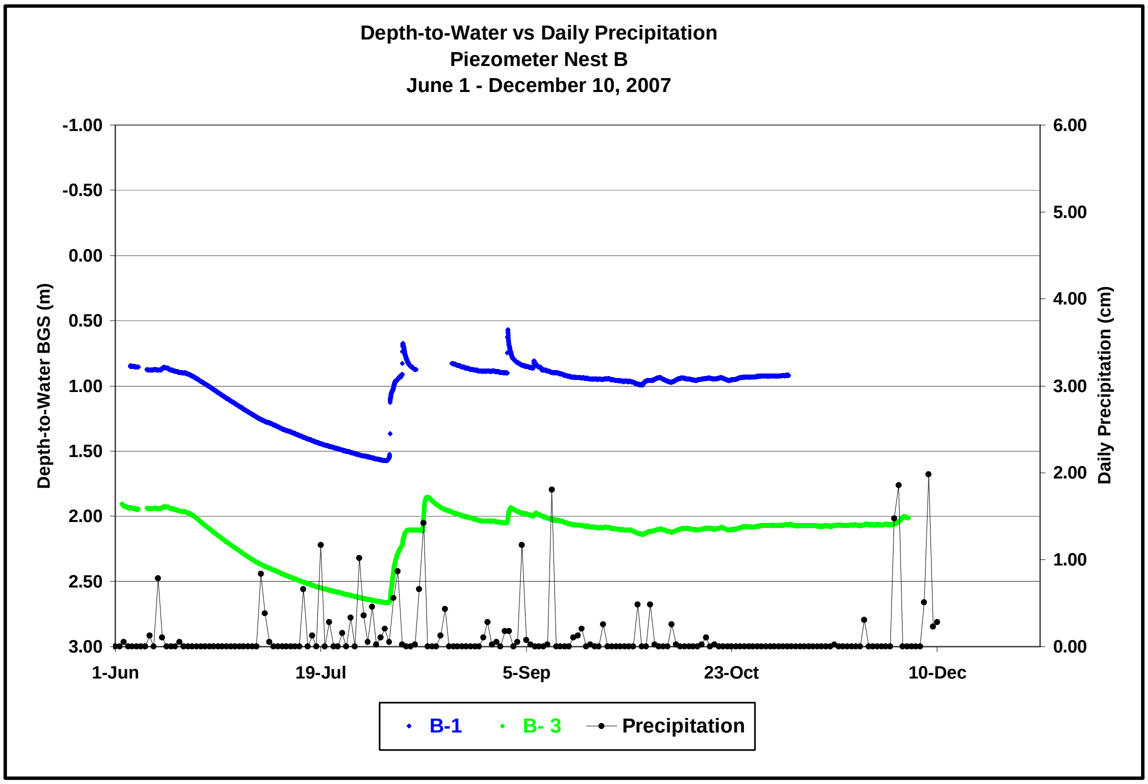


Figure 27b

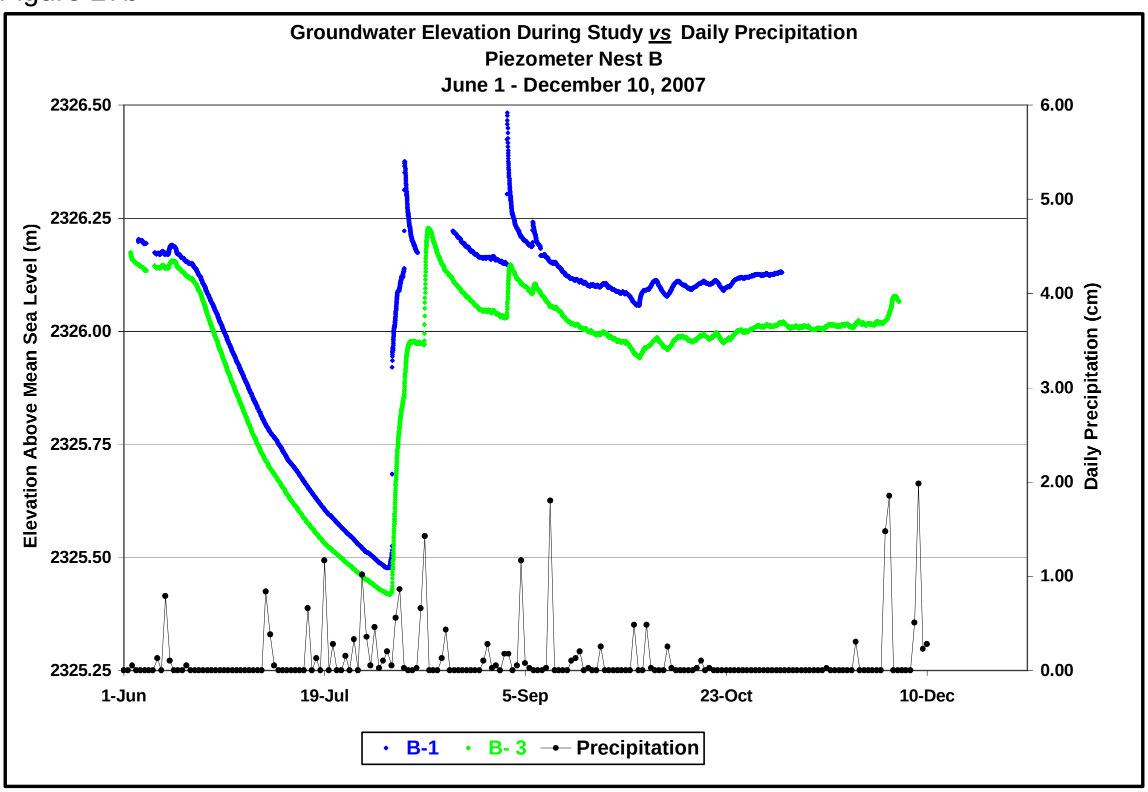


Figure 28a

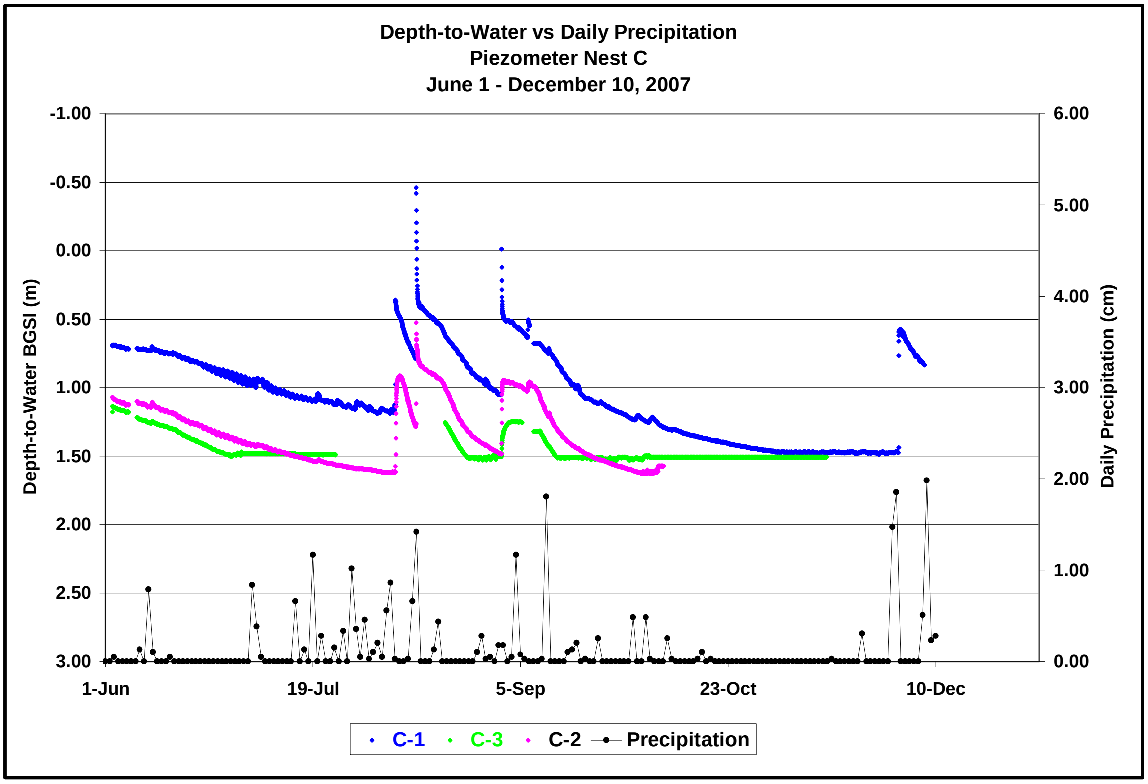


Figure 28b

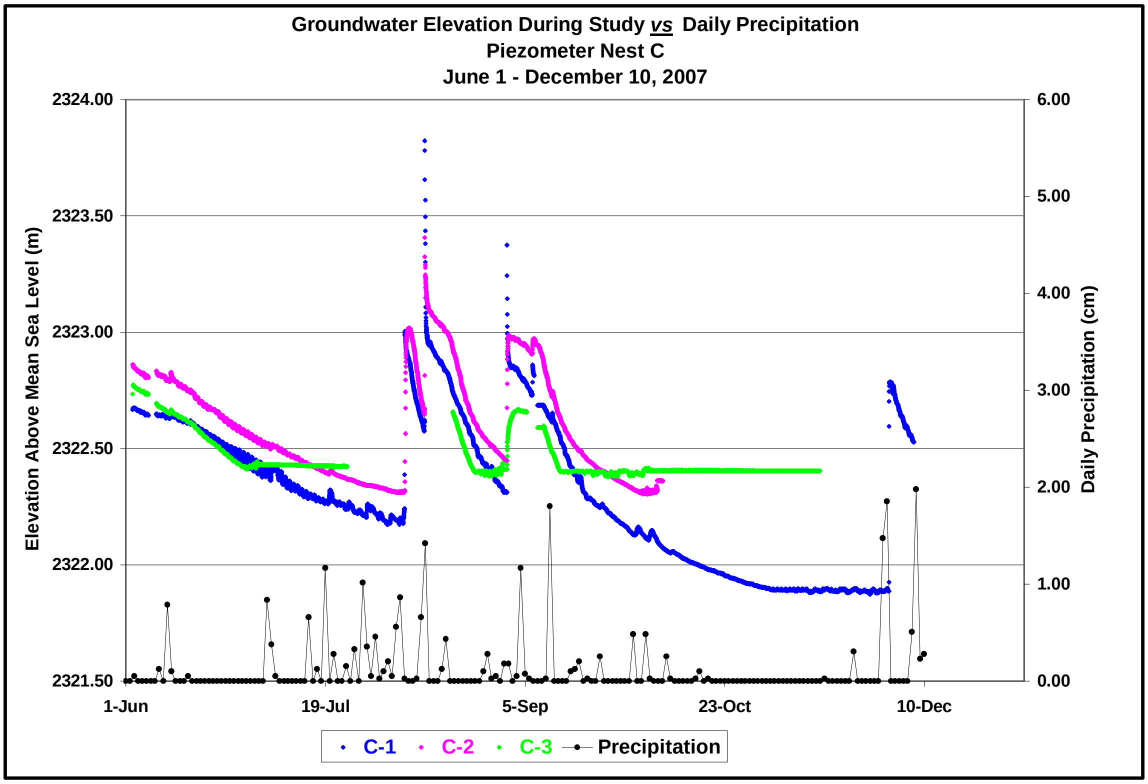


Figure 29a

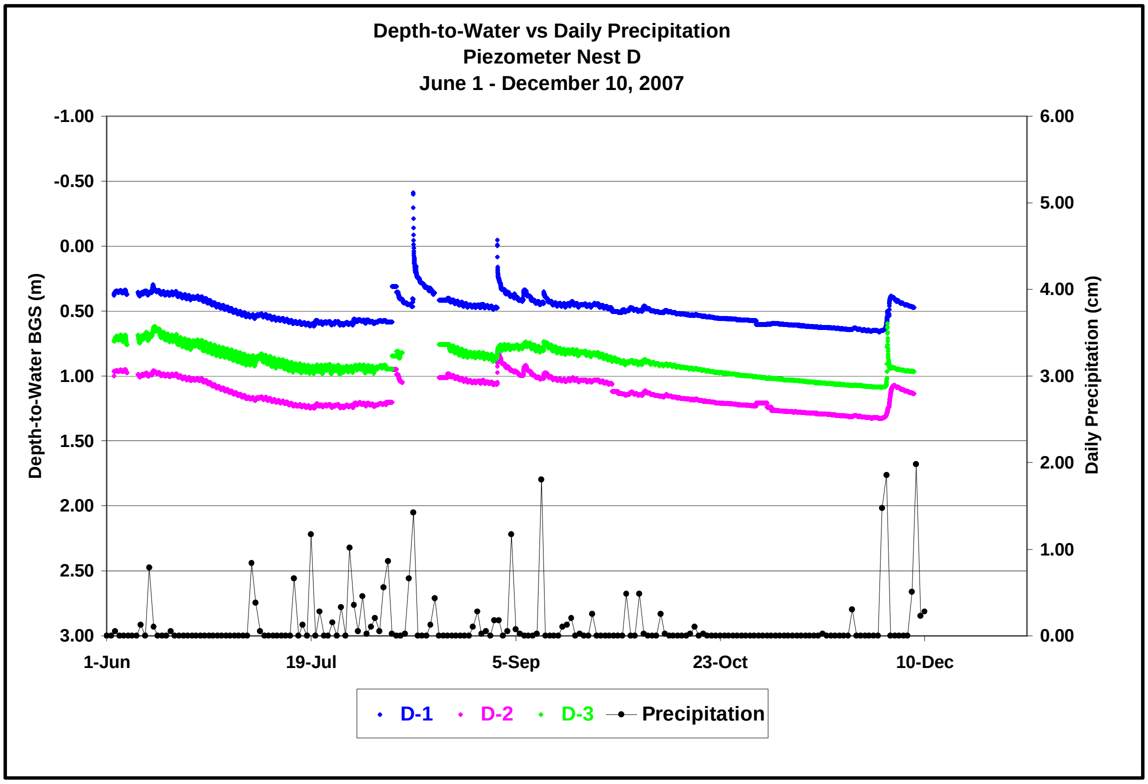


Figure 29b

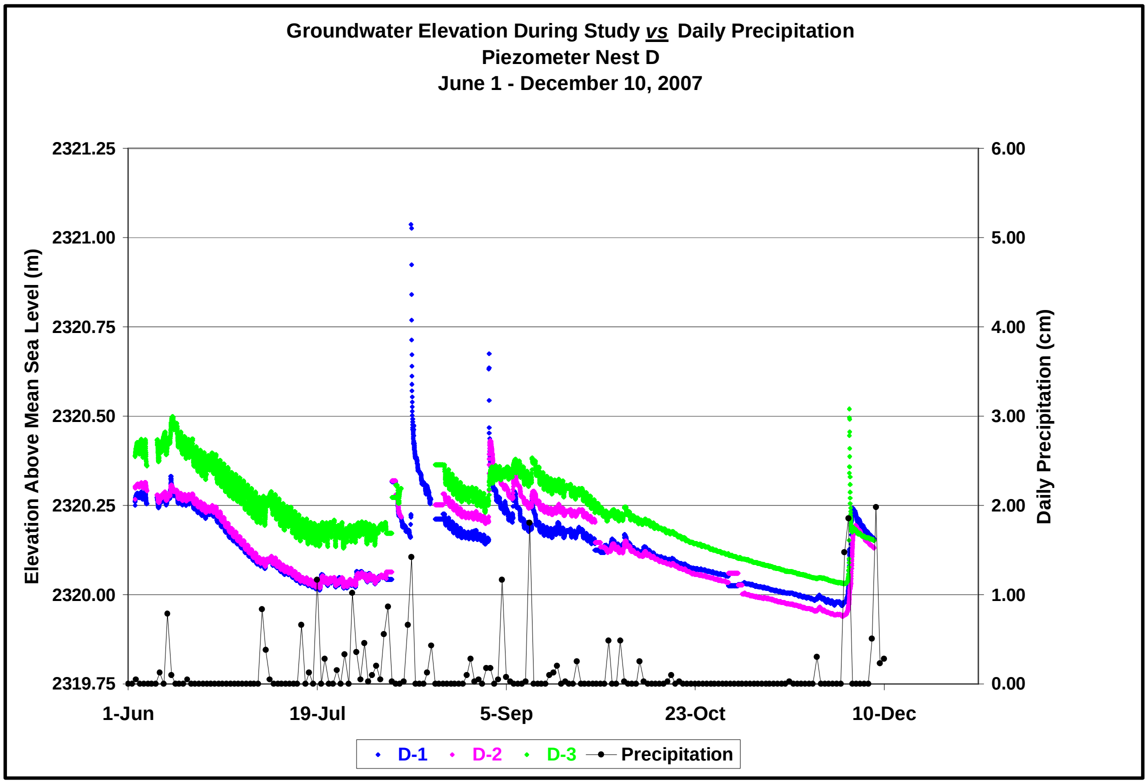


Figure 30a

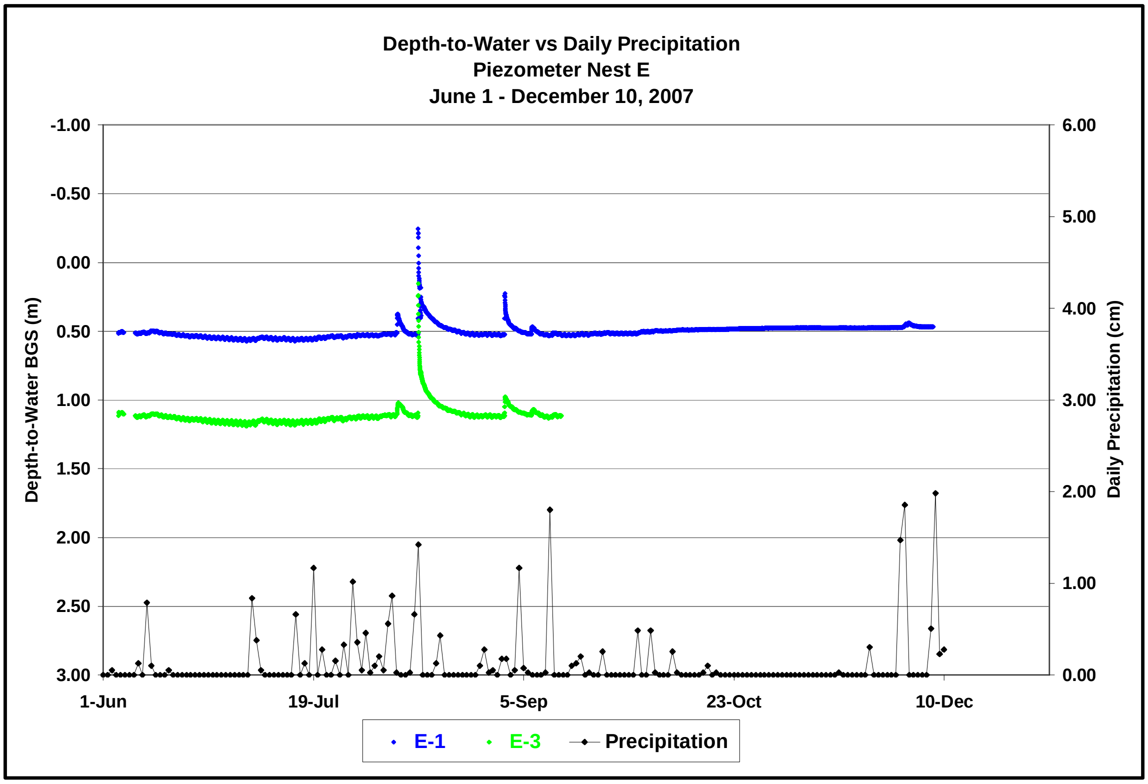


Figure 30b

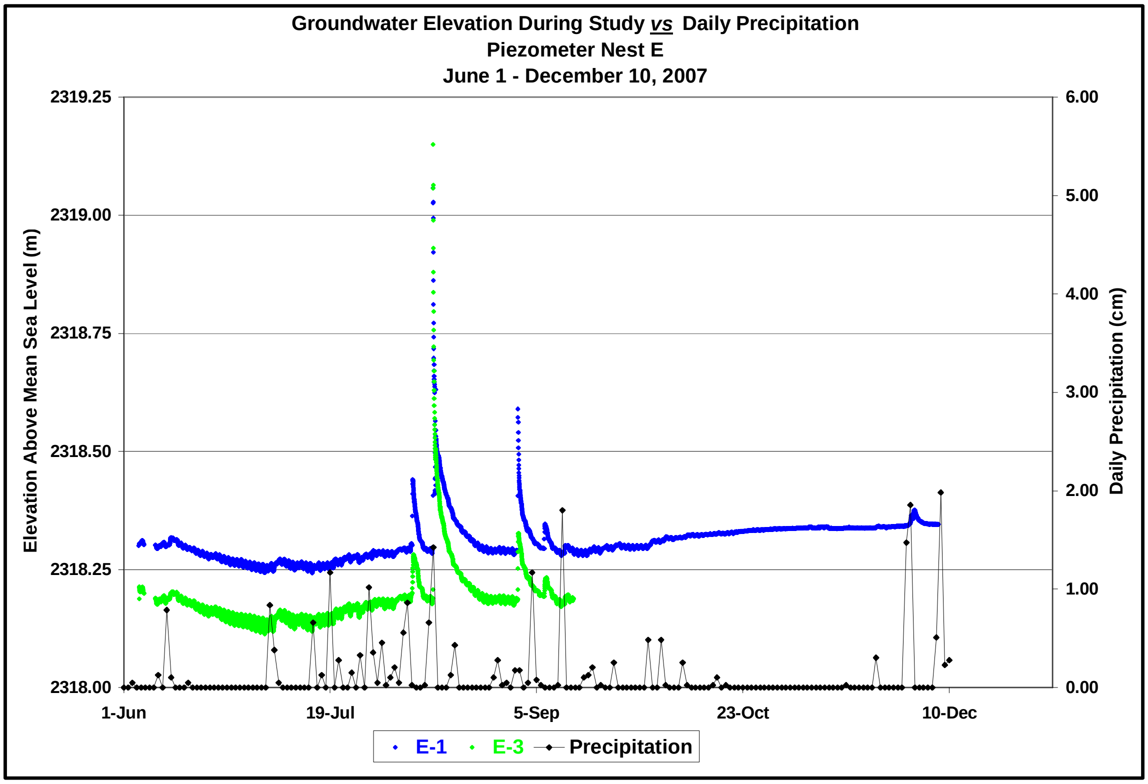


Figure 31a

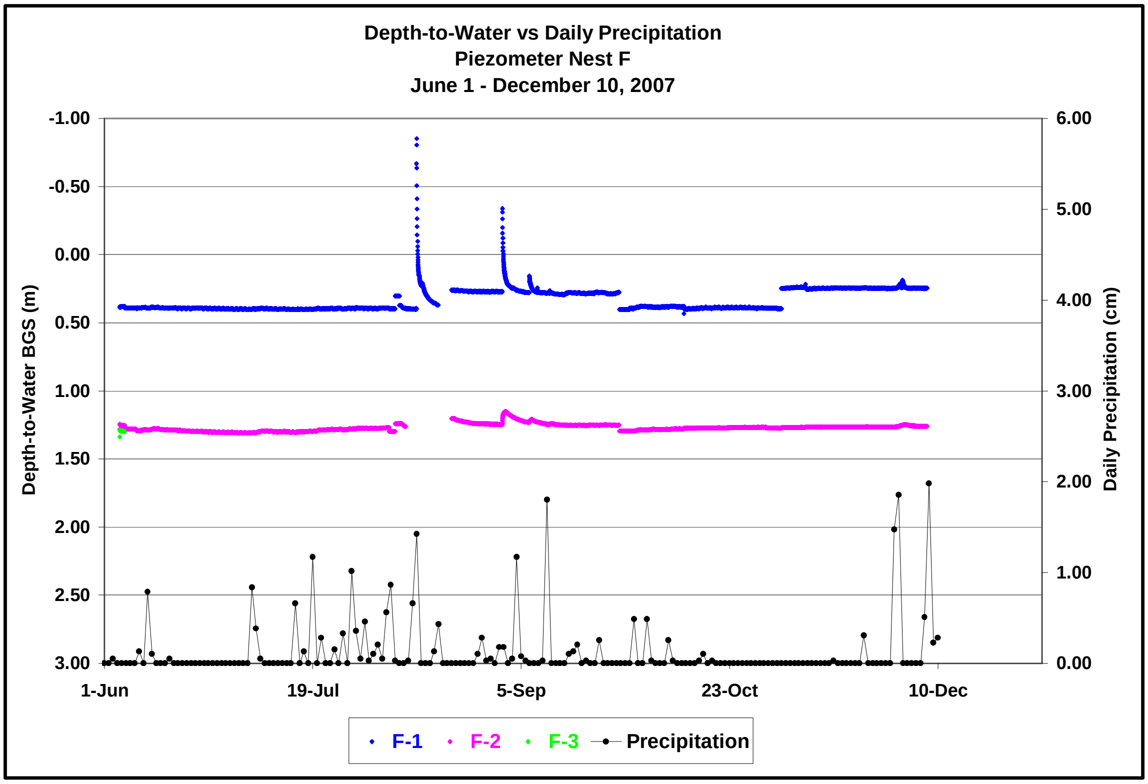


Figure 31b

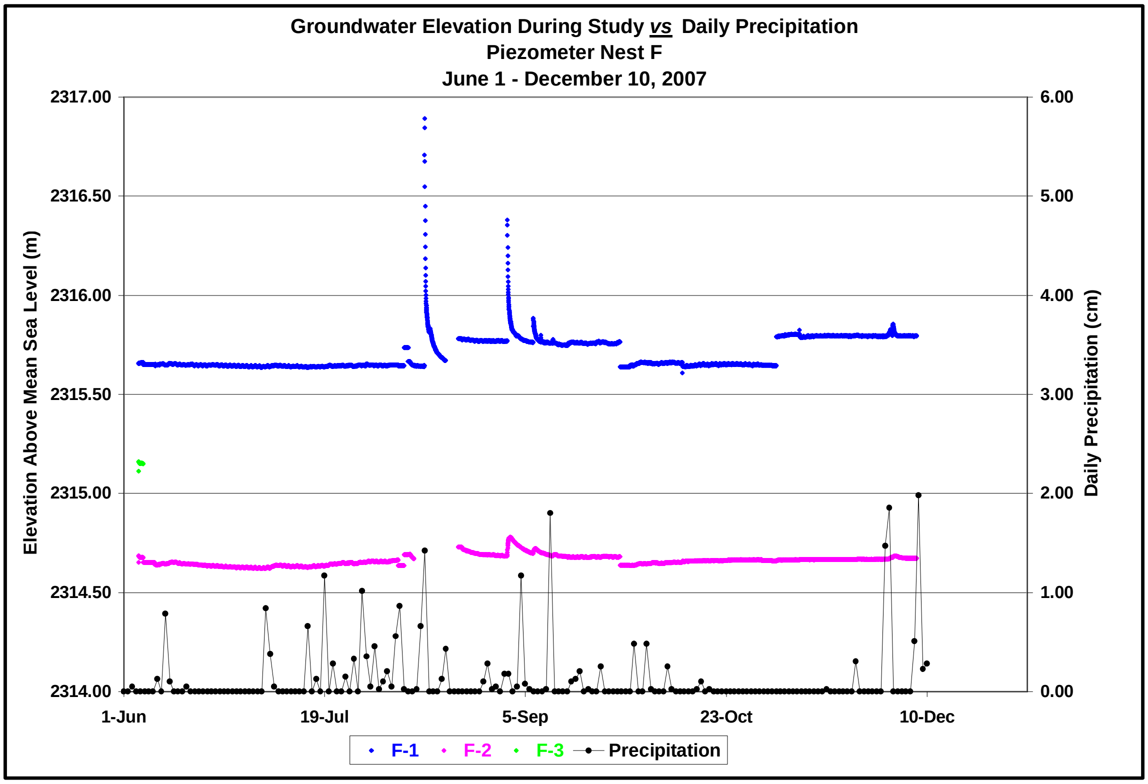


Figure 32a

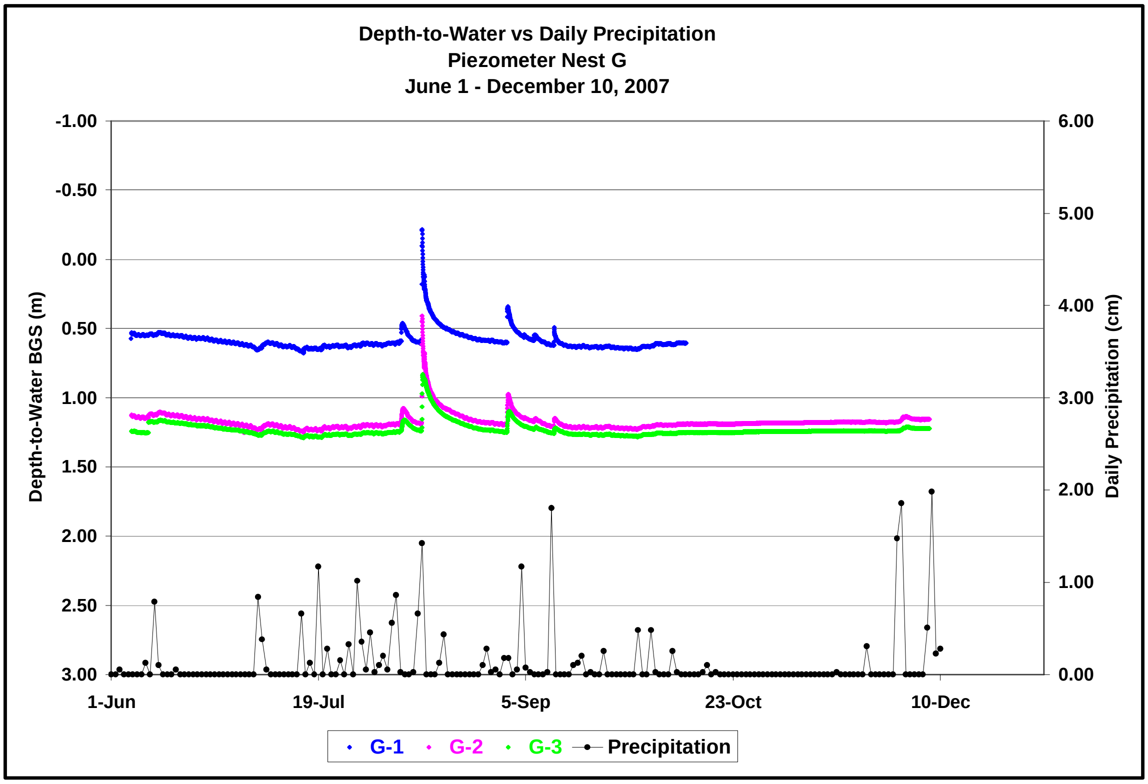


Figure 32b

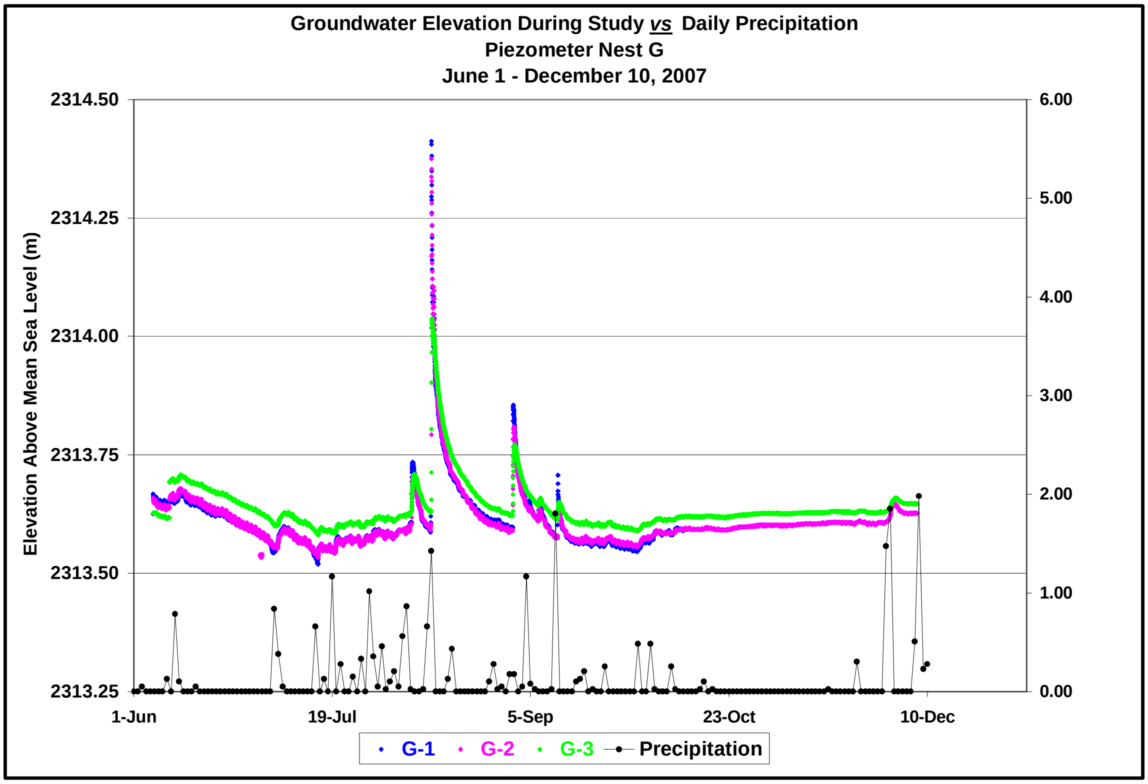


Figure 33a

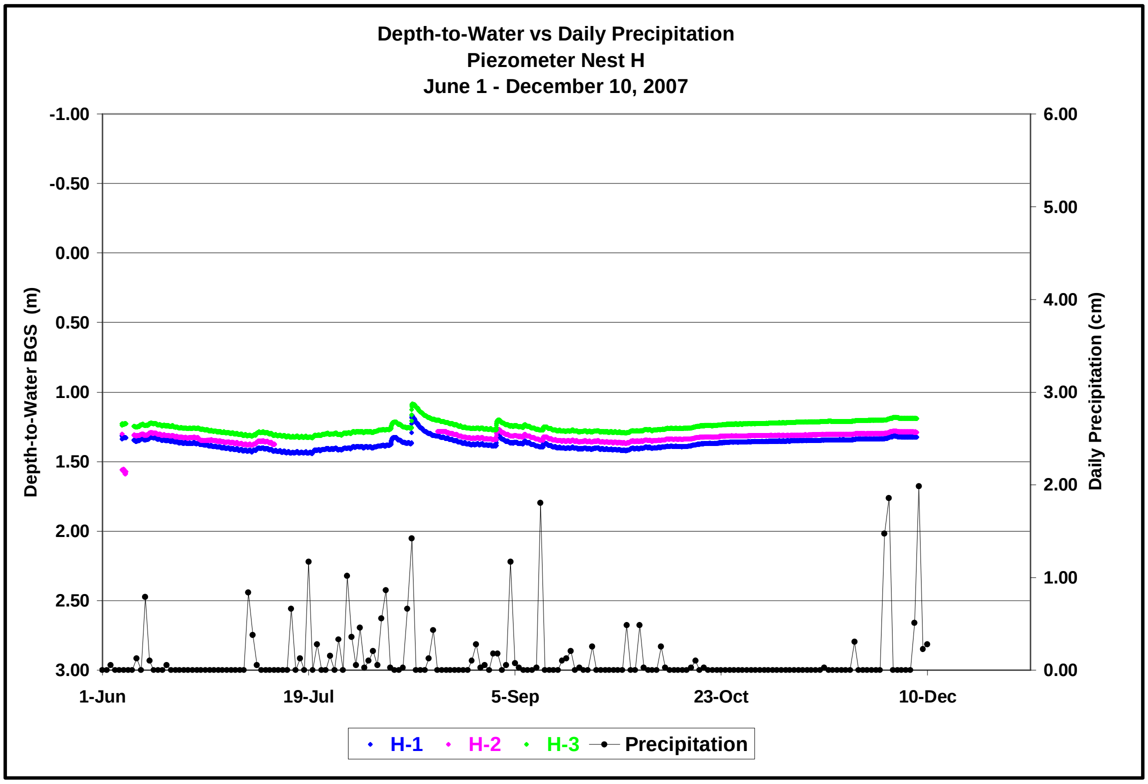


Figure 33b

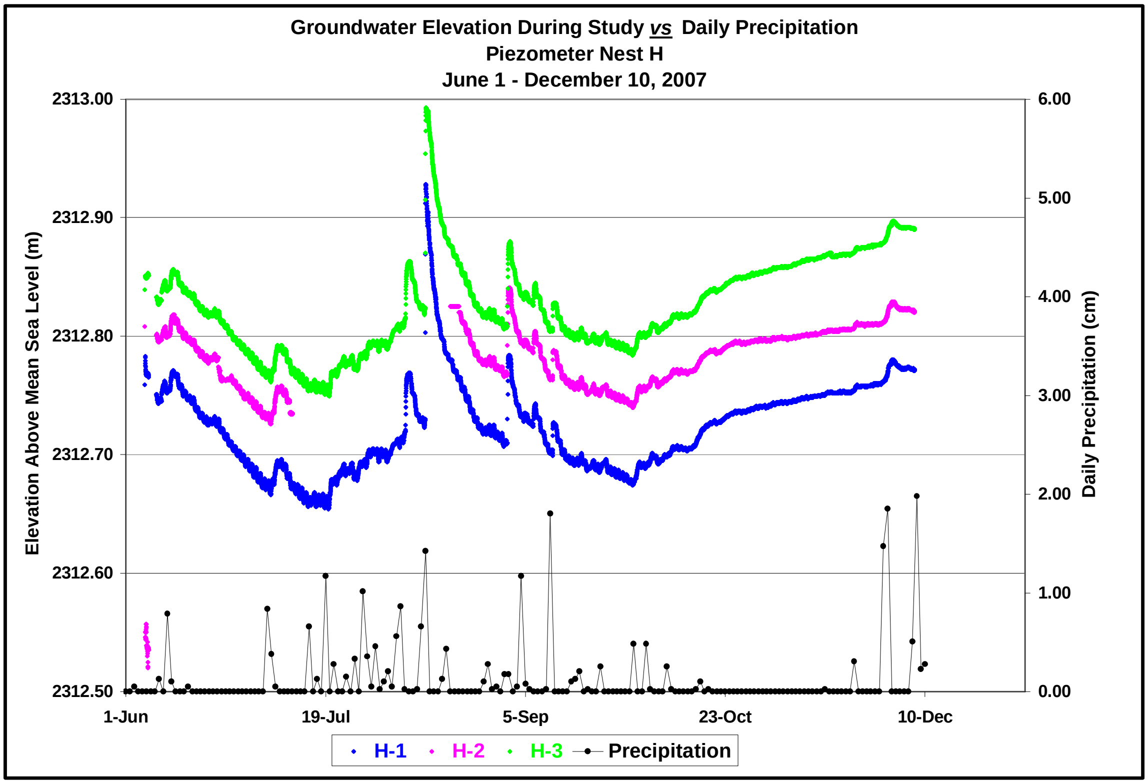


Figure 34a

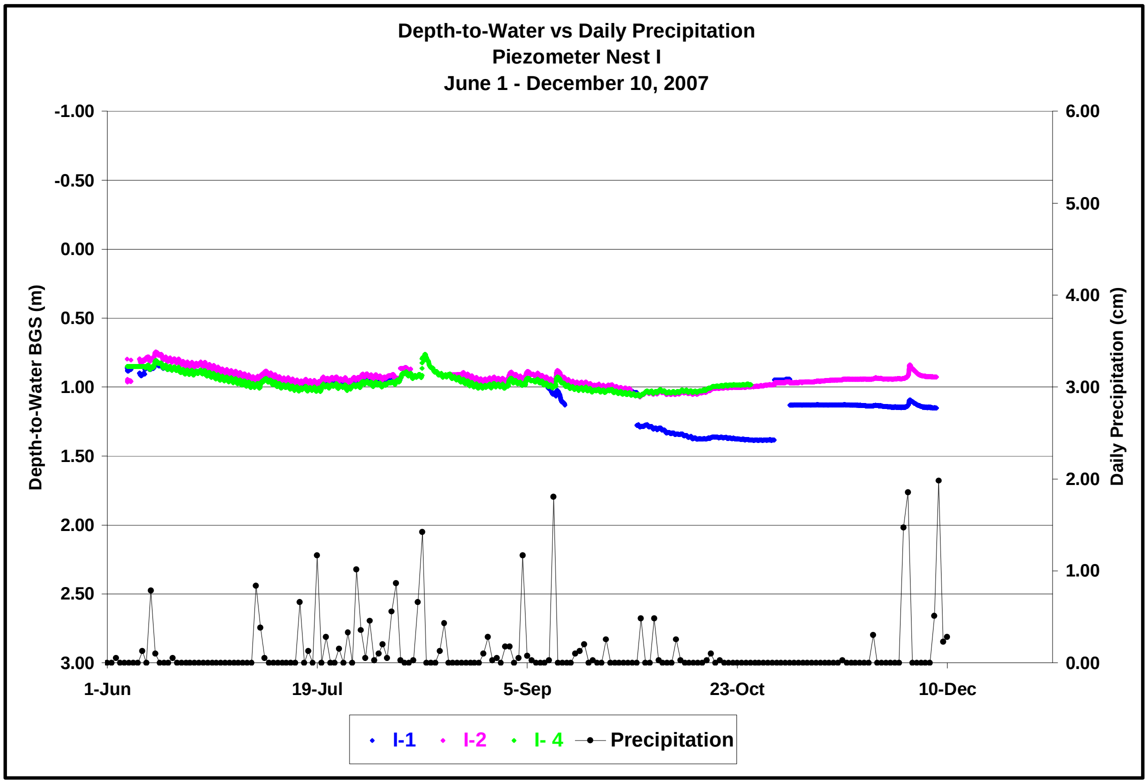


Figure 34b

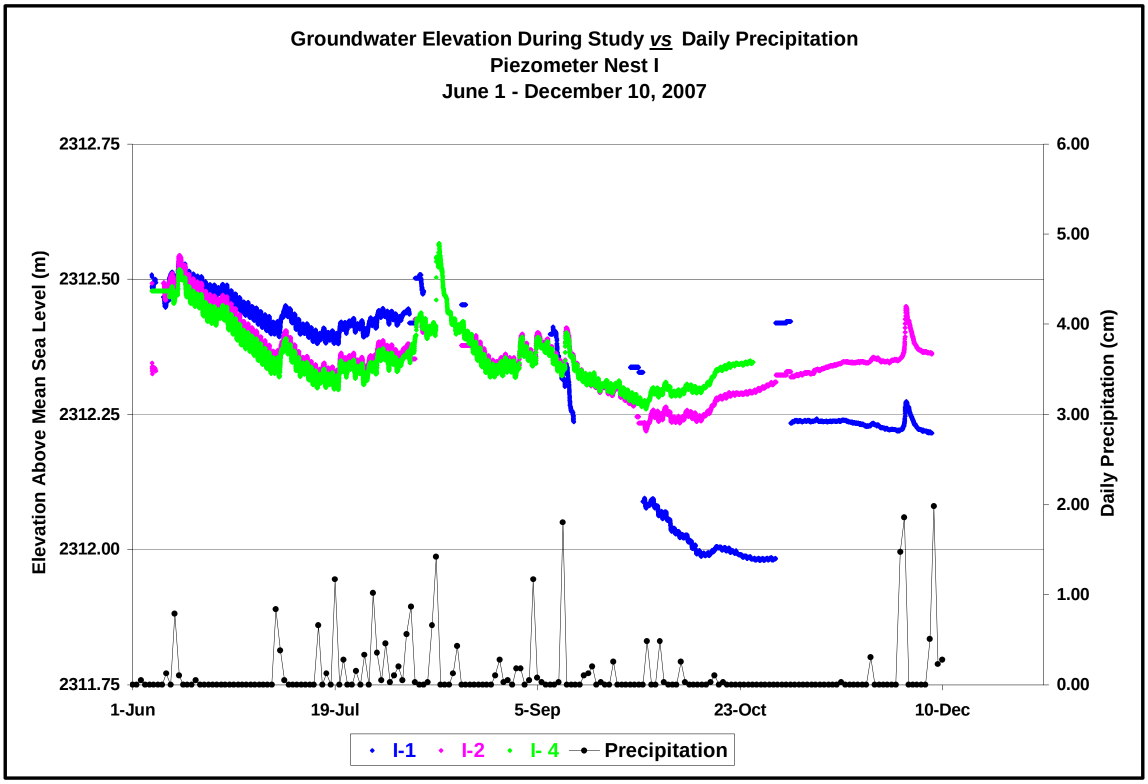


Figure 35a

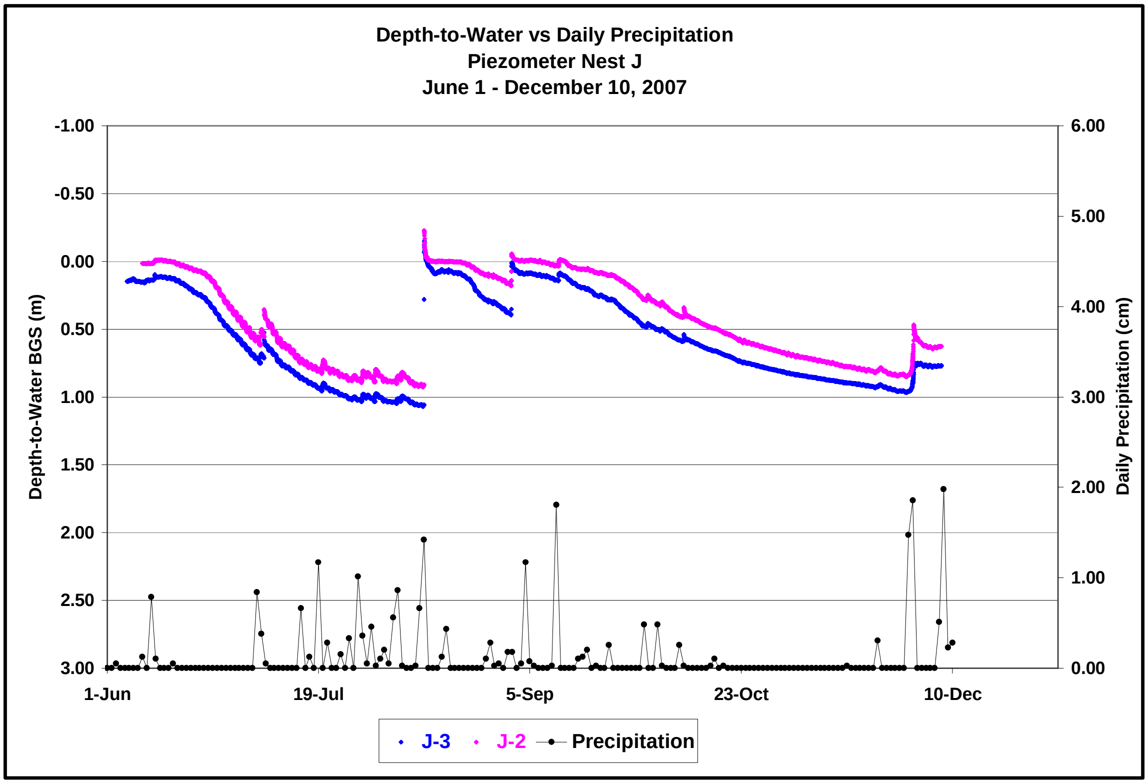


Figure 35b

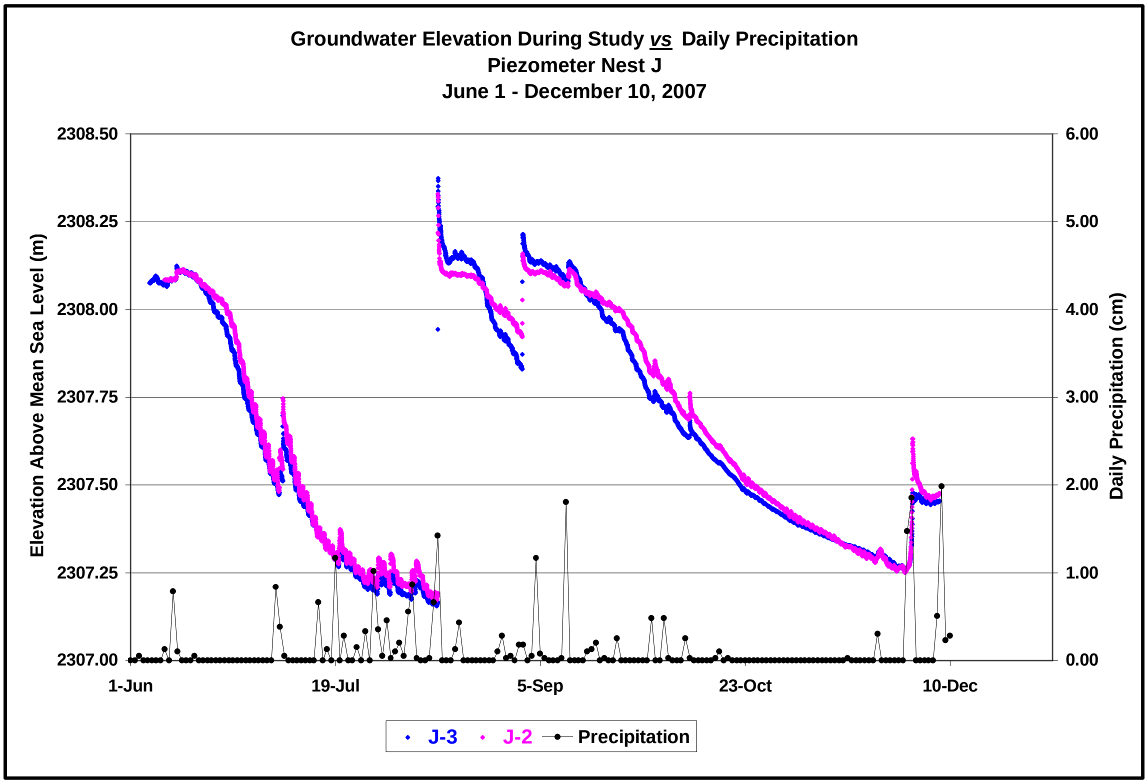


Figure 36a

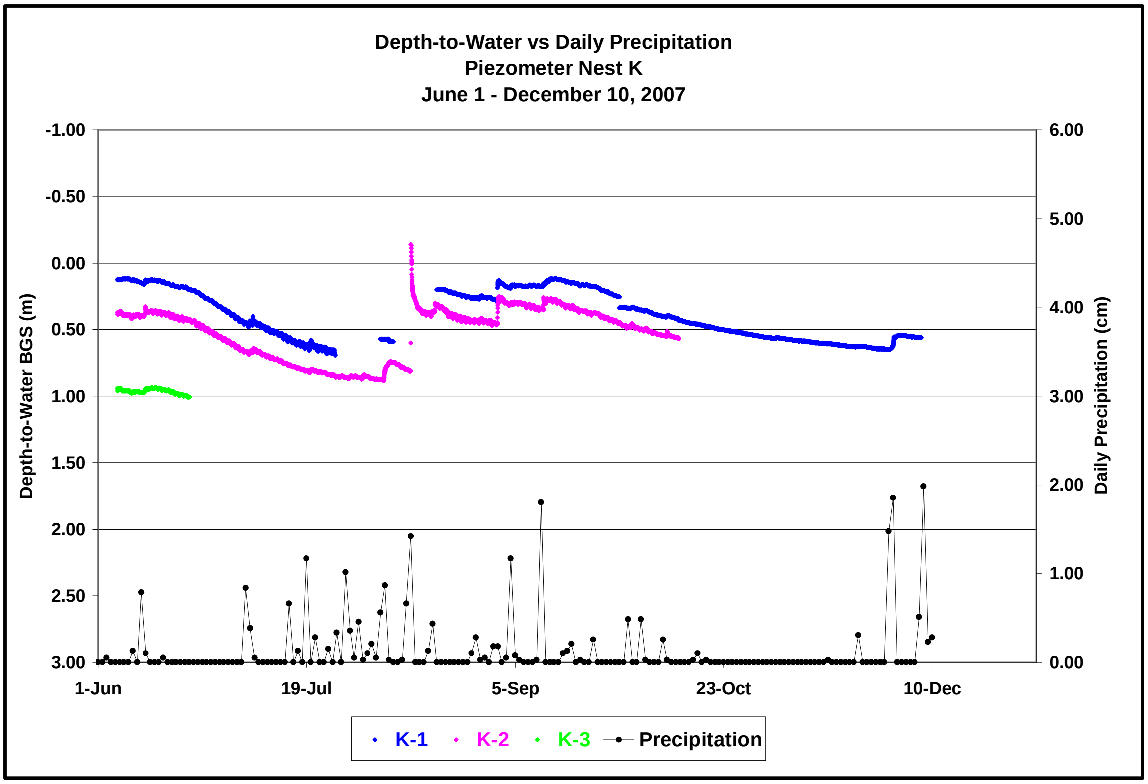
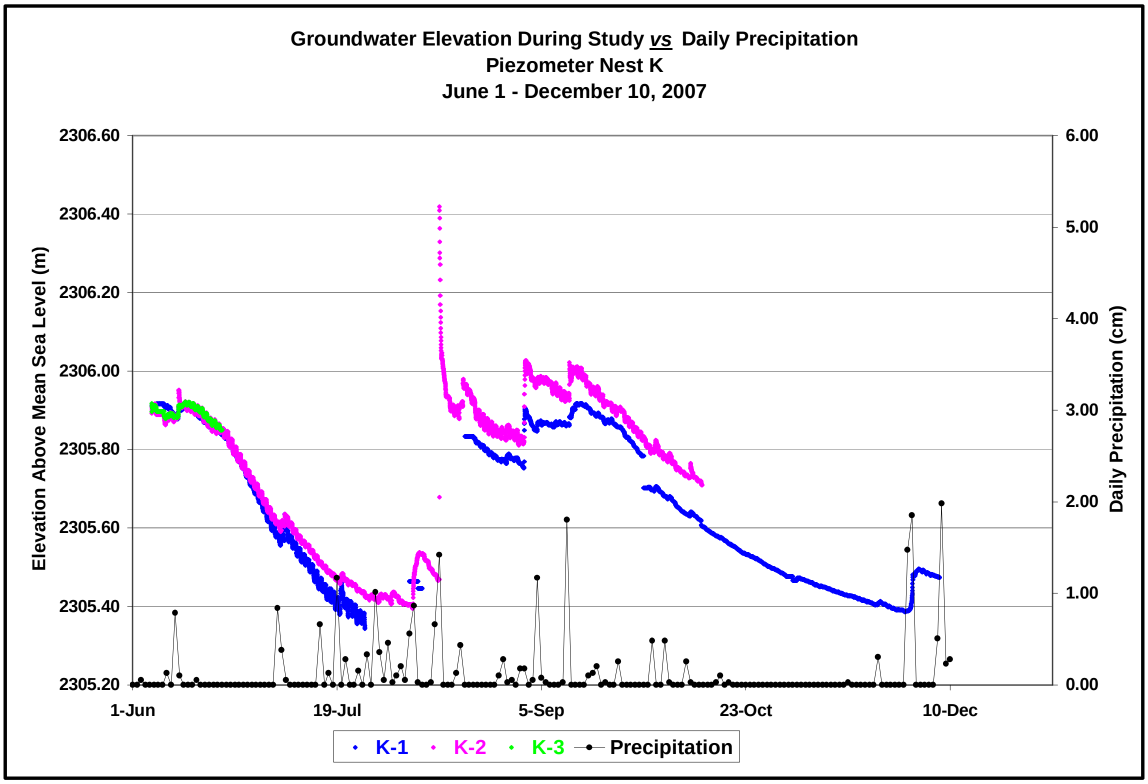


Figure 36b



8.0 DISCUSSION

This study has shown that Bluewater Creek exhibits variable spatial and temporal patterns in its losing and gaining reaches across the study area.

Spatially, it has been shown that those piezometers monitored within a particular nest exhibit a similar behavior in the rise and fall of the water table differing only in magnitude. On average for any given nest, ground water levels fluctuated less in piezometers furthest away from the stream and varied most in those closest to the stream.

Across the study area, the average depth-to-water differs by 1.88 m; from the upstream location at Nest A (2.27 m bgs) to 0.39 m bgs at the downstream location or Nest K.

Historically, water levels have dropped on average since monitoring began in 2004. All the piezometers show a drop in water levels (on average ~1.3 feet) except at Nest G, J and K (see Table 13). Water level monitoring began in 2004 when precipitation was below normal during 2003-2005. (http://www.srh.noaa). Precipitation started to recover in 2005 and since then it would be expected to see recovery in the groundwater levels. An explanation to this overall decrease in water levels will need to be further investigated due to the fact annual precipitation on average for the study area has been near normal since 2006 (http://www.srh.noaa). A rise in water levels seen at piezometers GW G-3 (+0.381 m), GW J-2 (+ 0.148 m), GW K-1 (+ 0.086 m) and GW K-3 (+ 0.301 m) can be partially explained by the fact that Nest J and K are rich riparian areas with beaver activity. Evidently any precipitation that has been received has been more than enough to sustain surface saturation in these areas. Nest G has seen the most significant rise in water levels since 2004. An explanation might suggest the rise in water level is due to difference in heterogeneities in the soil and geology and/or smaller effective porosity at this location.

Across the study site, the magnitude of water table fluctuation on average for upstream sites (Nest A, Nest C) was greater than downstream sites (Nest F, Nest H, Nest I). A possible explanation for this is a change in soil texture and topography. Infiltration may be less at Nest H and Nest I due to finer-grained soils. These nests are also located in a topographic low in comparison to Nest A and so recharge may simply be limited at Nest H and I.

Temporal differences were expected and this study has shown that the water levels on average are mostly low during the summer and high during the fall/winter. Nests A, B, J and K showed stronger temporal variations in comparison to the other nests. In addition, within a well nest, the piezometer closest to the stream edge responded with the most significant rise in water level during precipitation events which occur in July through September.

This magnitude differs from nest to nest. This occurs because the magnitude of seasonal water-table fluctuations depends on the amount of recharge or discharge added or removed from the aquifer along Bluewater Creek (i.e., whether the reach is gaining from the aquifer or losing water to the aquifer). The magnitude of seasonal water-table fluctuation can also depend on the hydraulic conductivity of the aquifer.

Each depth-to-water hydrograph clearly shows at a minimum two instances where the water levels rose dramatically and peaked; one on August 11 and the other on August 31 (or September 1, 2007 depending on the nest). The August 11 rainfall was 0.66 cm. However, three later rain events on 9/11 (1.80 cm), 11/30 (1.47 cm) and 12/1 (1.85 cm) were of higher precipitation amounts yet resulted in a less dramatic water level peak (with exception to Nest C, D and J) as seen on 8/11 and 8/31-September 1, 2007. Therefore, it can be said that the amount of rainfall is not directly proportionate to the magnitude of the response or rise in water levels afterwards. Furthermore, the response or rise in water level that is seen in the piezometer is simply showing a *portion* of the infiltrated water from any given rain event that entered the groundwater as subsurface flow. The *remainder* of the water which doesn't get to the subsurface is what is known as stream discharge or stream runoff. Had this study collected discharge data, it would have helped to explain why we don't always see a response or rise in water levels in the piezometers after a rain event.

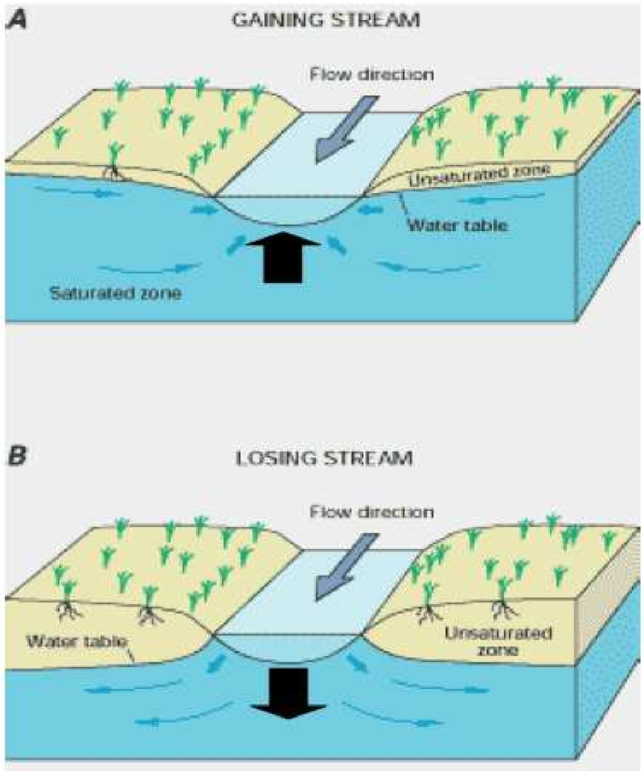
A lag is evident and varies in magnitude within any given nest and across the study area. A water level response (rise) is not instantaneous from the time of the precipitation to when there is a rise in the water level. For example, the most significant rise in water levels occurred on August 11, 2007. This event was not considered a significant event. However, earlier smaller rain events (i.e, July 19, August 5) in combination with the August 11 rain event seems to have triggered a threshold for the dramatic response seen in the hydrographs on August 11. This lag is best seen in the piezometer closest to the stream bank from the upstream location (A) to the downstream location (J) in which water levels peaked at Nest A, C, and D about 3.5 hours from the start of the August 11 rain event. In the downstream direction, water levels peaked at Nest E (in 4 hours), Nest F (in 4.5 hours), Nest G (in 6 hours), Nest H in 7 hours and Nest J in 6.5 hours. Not all flow is derived strictly from the headwaters down gradient and so this lag could also be explained by the influence of some lateral inflow from the hillslopes that have been invoked from the outcome of the rain event.

Within any given nest, all the piezometers were similar in response to rain events but differed in magnitude. Those piezometers near the stream edge exhibited the largest rise in water level following a rain event. A possible explanation is bank storage effects Todd (1955) outlined the concept of bank storage. Field conditions after the August 11 rain event suggest stream levels reached past bank full. If this was the case, groundwater levels can be temporarily raised near the channel by inflow from the stream during a significant rain or flood period (Todd, 1955). This volume of water stored and released after such an event is described as bank storage. Another explanation and probably most likely is the proximity of the piezometer to the stream's edge.

Also within each nest, all of the piezometers positioned closest to the streambed on average had the shallowest depth-to-water with exception to Nest H, Nest I, and Nest J. The shallowest average depth-to-water was in piezometer GW F-1 at 0.335 m bgs followed by GW K-1 at 0.91 m bgs. The deepest average depth-to-water was found in piezometer GW B-1 at 2.664 m bgs followed by GW A-2 at 2.266 m bgs.

There are two types of surface water- groundwater interaction. A gaining stream is when groundwater contributes to the stream (Figure 44a) and a losing stream is when surface water contributes to the groundwater (Figure 44b). Streams may 1) gain groundwater in some reaches and 2) lose in others or 3) exhibit both characteristics in the same reach. All these scenarios are present at Bluewater Creek and depend on days since precipitation has occurred.

Figure 44A and 44B: Gaining Stream and Losing Stream



Modified from (USGS 2006)

Losing and gaining reaches have been determined from this study. Losing and gaining trend graphs were prepared for all the piezometer nests but only Nest A, D, F, I and K are presented here and later in this discussion in terms of chemistry variation amongst losing and gaining segments along Bluewater Creek. The losing – gaining trend graphs for the rest of the piezometer nests (Nest B, C, E, G, H, and J) are located in Appendix 11.3. Since this study does not have surface water level data, losing-gaining stream trend graphs were prepared under the assumption that the water level in the piezometer closest to the stream edge (i.e., A-1, D-1, F-1, I-1 and K-1) represents the best estimate for the stream water level. For the purpose of this discussion this piezometer can be envisioned as a stilling well. Manual water levels were obtained on the day of sample collection at those piezometers without an electronic datalogger at Nest A, D, F, I and K. This allowed for a complete determination of the losing-gaining stream characteristic on the day of sample collection at these five piezometer nests.

Losing-gaining trends were also determined and expressed as a percentage for the overall stream reach at all eleven piezometer nests for the study period.

Head difference was calculated between the head measured in the stream (or in this case, the piezometer closest to the stream edge) and the head measured in the remaining four piezometers that make up a nest with respect to the stream level. A positive head difference indicates flow is toward the stream (gaining stream) and a negative head difference indicates flow is away from the stream (losing stream).

The losing-gaining trend graph for Nest A is shown in Figure 45. Overall, 57% of the groundwater measurements collected over this period indicates a losing stream and 43% of the groundwater measurements collected indicates a gaining stream. Furthermore, at each of the three sample collection periods, the stream is entirely losing.

The losing-gaining trend graph for Nest D is shown in Figure 46. Overall, 26% of the groundwater measurements collected over this period indicates a losing stream and 74% of the groundwater measurements collected indicates a gaining stream. Specifically, during the August sample collection, the stream was dominantly losing to ground water except at GW D-2 where the stream was gaining (GW D-2 → GW D-1). During the September sample collection, the stream is losing at two locations (GW D-1 → GW D-4 and GW D-1→ GW D-5) and gaining at two locations (GW D-2→ GW D-1 and GW D-3→ GW D-1) and then during the November sample collection period, the stream is mostly losing to groundwater except at one location (GW D-3) where the stream is gaining (GW D-3→ GW D-1). This set of observations again illustrates the strong seasonality of the site hydrology.

The losing-gaining trend graph for Nest F is shown in Figure 47. Overall, 100% of the groundwater measurements collected over this period indicates a losing stream. And during all three sample collection events, the stream was losing.

The losing-gaining trend graph for Nest I is shown in Figure 48. 59% of the groundwater measurements collected over this period indicates a losing stream and 41% of the groundwater measurements collected indicates a gaining stream. At the time of sample collection the stream is losing at two locations (GW I-1→ GW F-4, and GW I-1 → GW I-2) and gaining at two locations (GW I-3 → GW I-1 and GW I-5 → GW I-1)

The losing-gaining trend graph for Nest K is shown in Figure 49. Overall, 11% of the groundwater measurements collected over this period indicates a losing stream and 89% of the groundwater measurements collected indicates a gaining stream.

Specifically, during the August sample collection, the stream was gaining. During September and November sample collection, the stream was dominantly gaining except at GW K-5 where the stream was losing (GW K-1→ GW K-5).

Figure 45
Losing and Gaining Trends at Nest A
June 2 - December 7, 2007

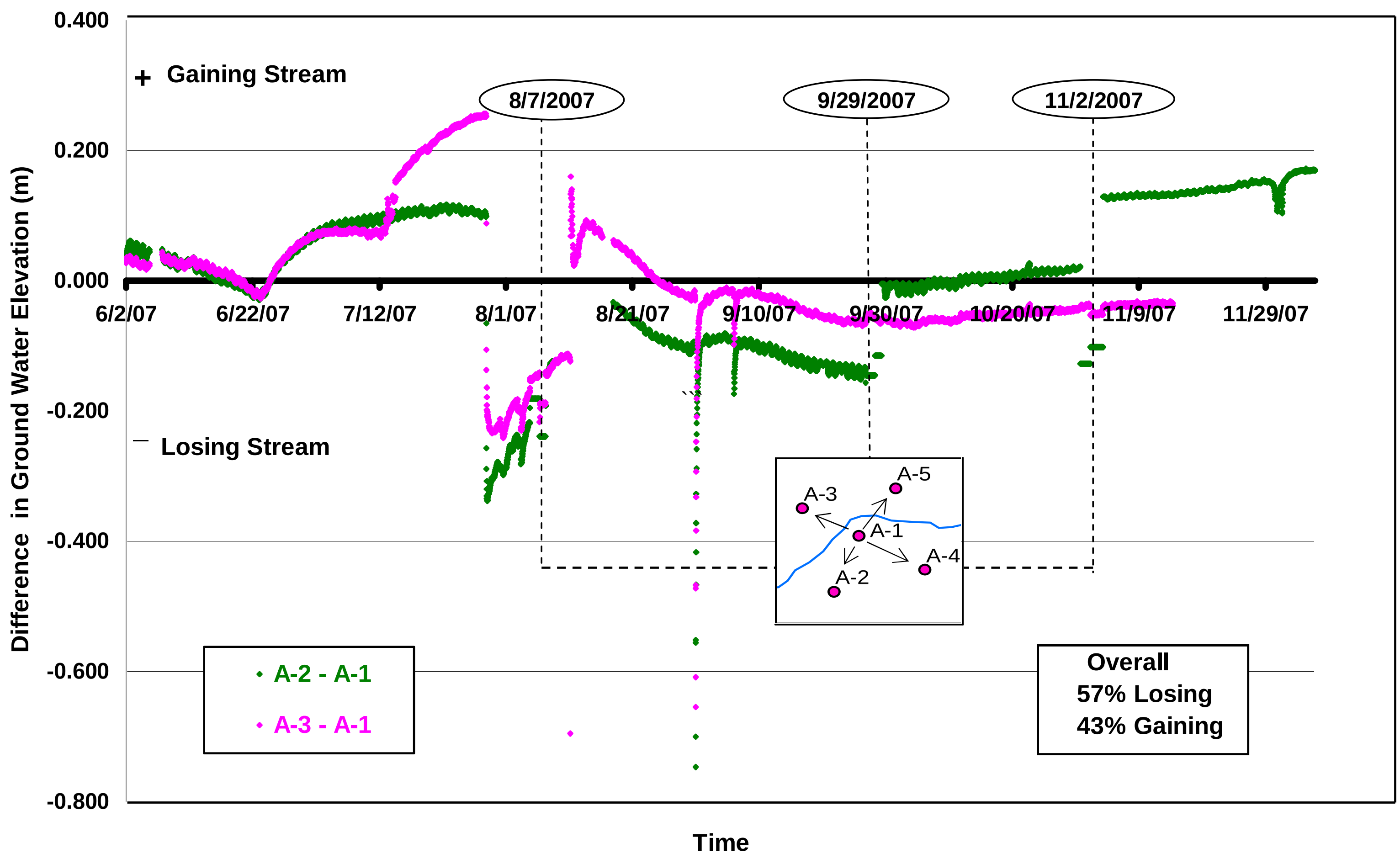
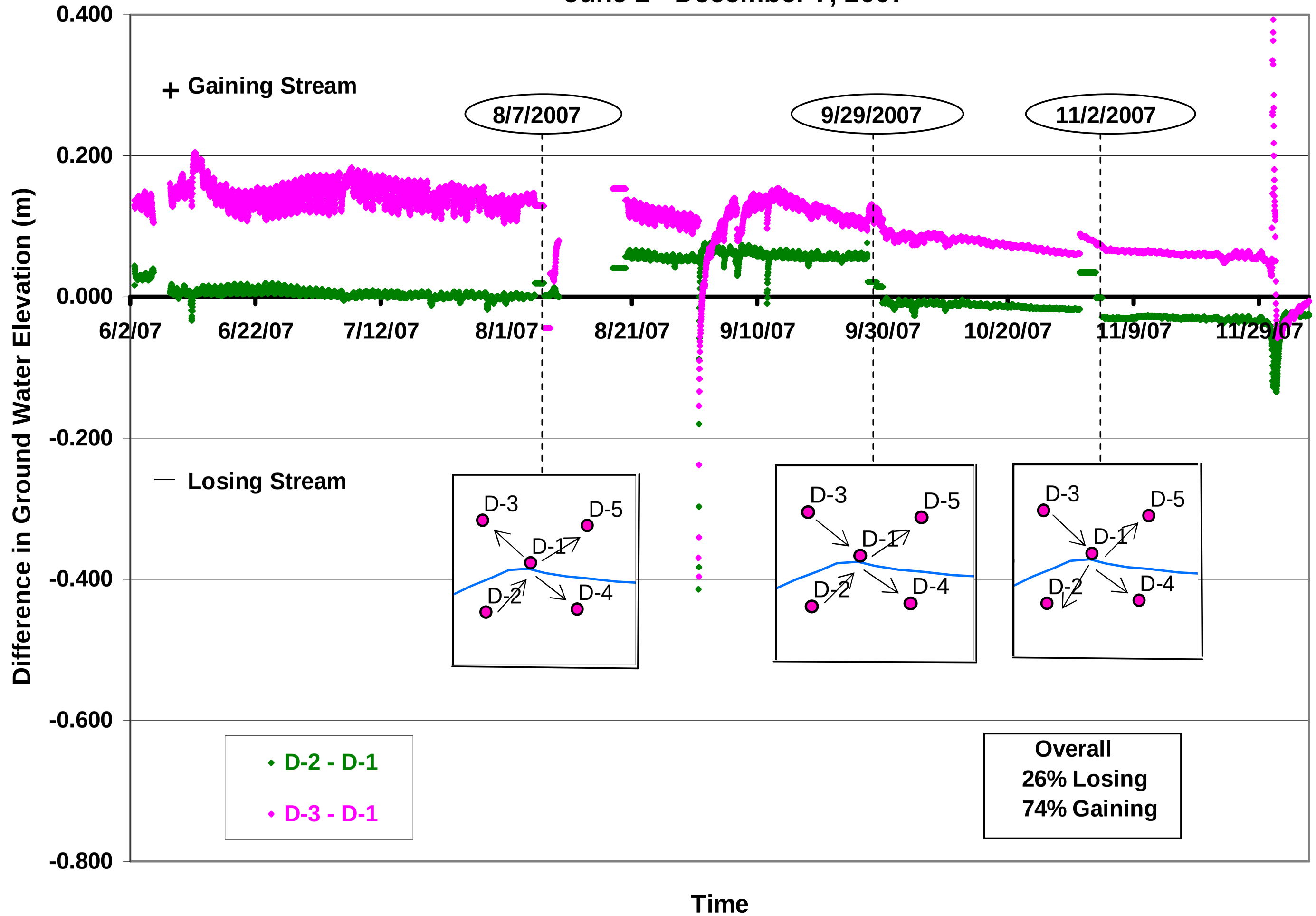


Figure 46
Losing and Gaining Trends at Nest D
June 2 - December 7, 2007



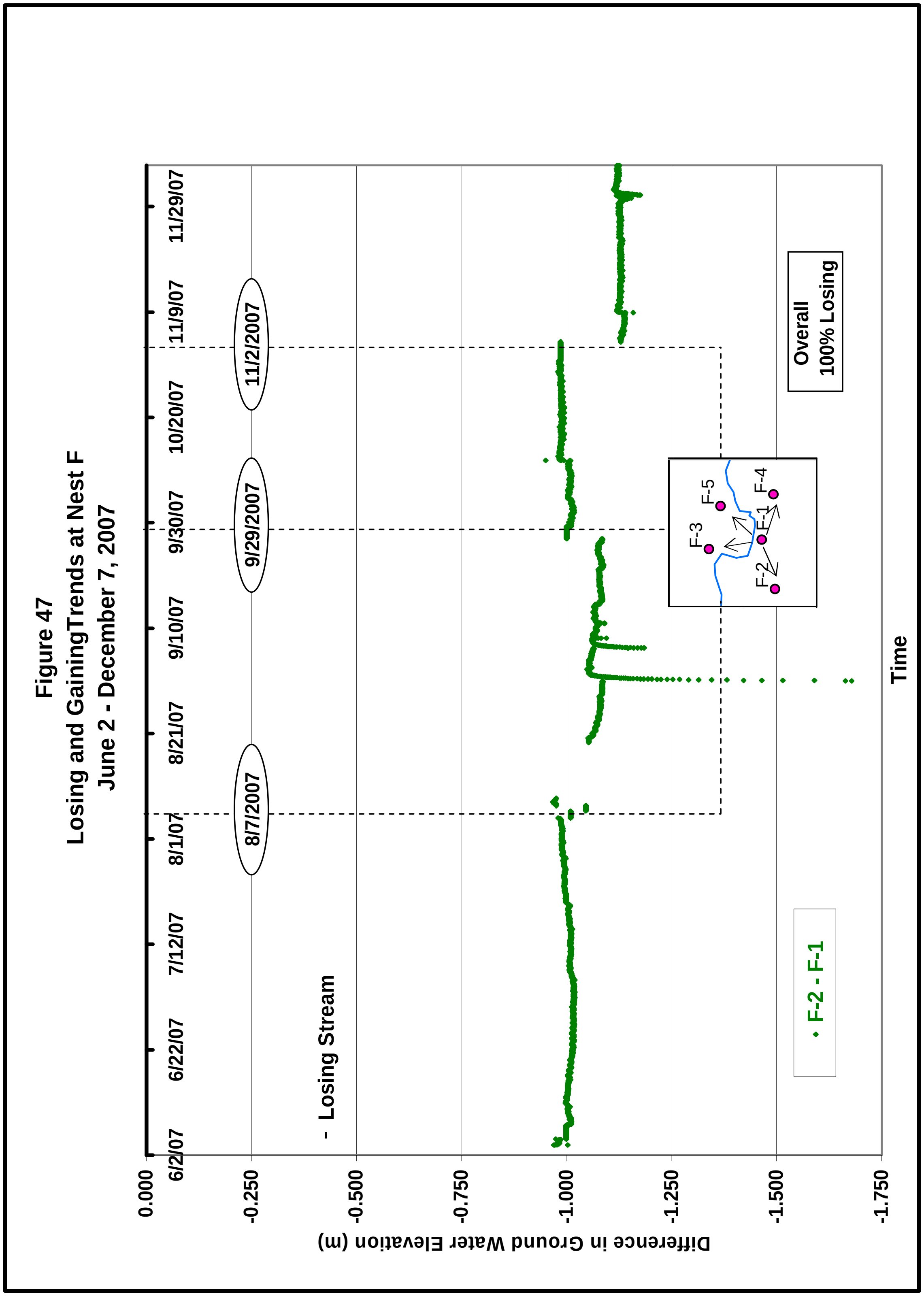
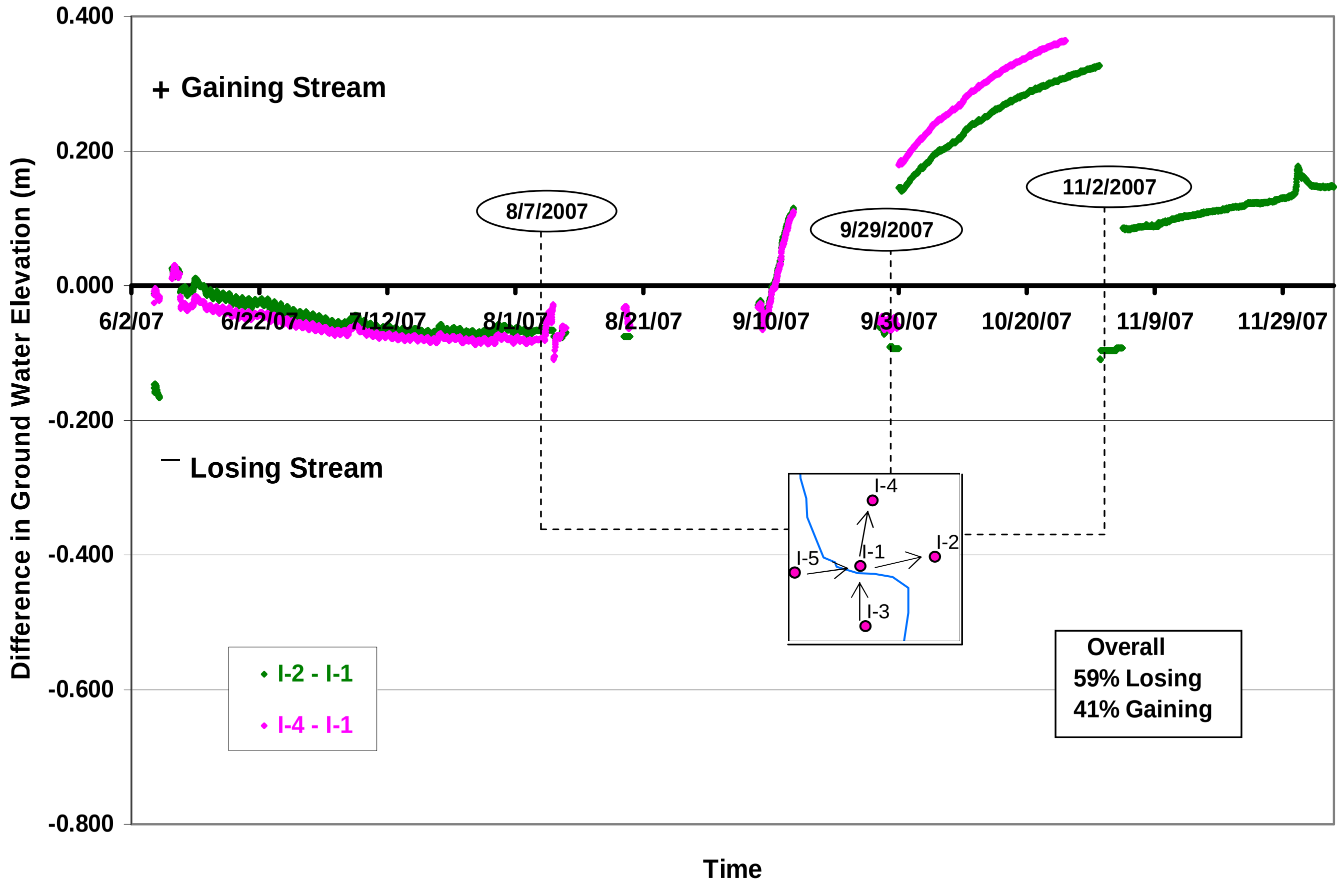


Figure 47
Losing and GainingTrends at Nest F
June 2 - December 7, 2007

Figure 48
Losing and Gaining Trends at Nest I
June 2 - December 7, 2007



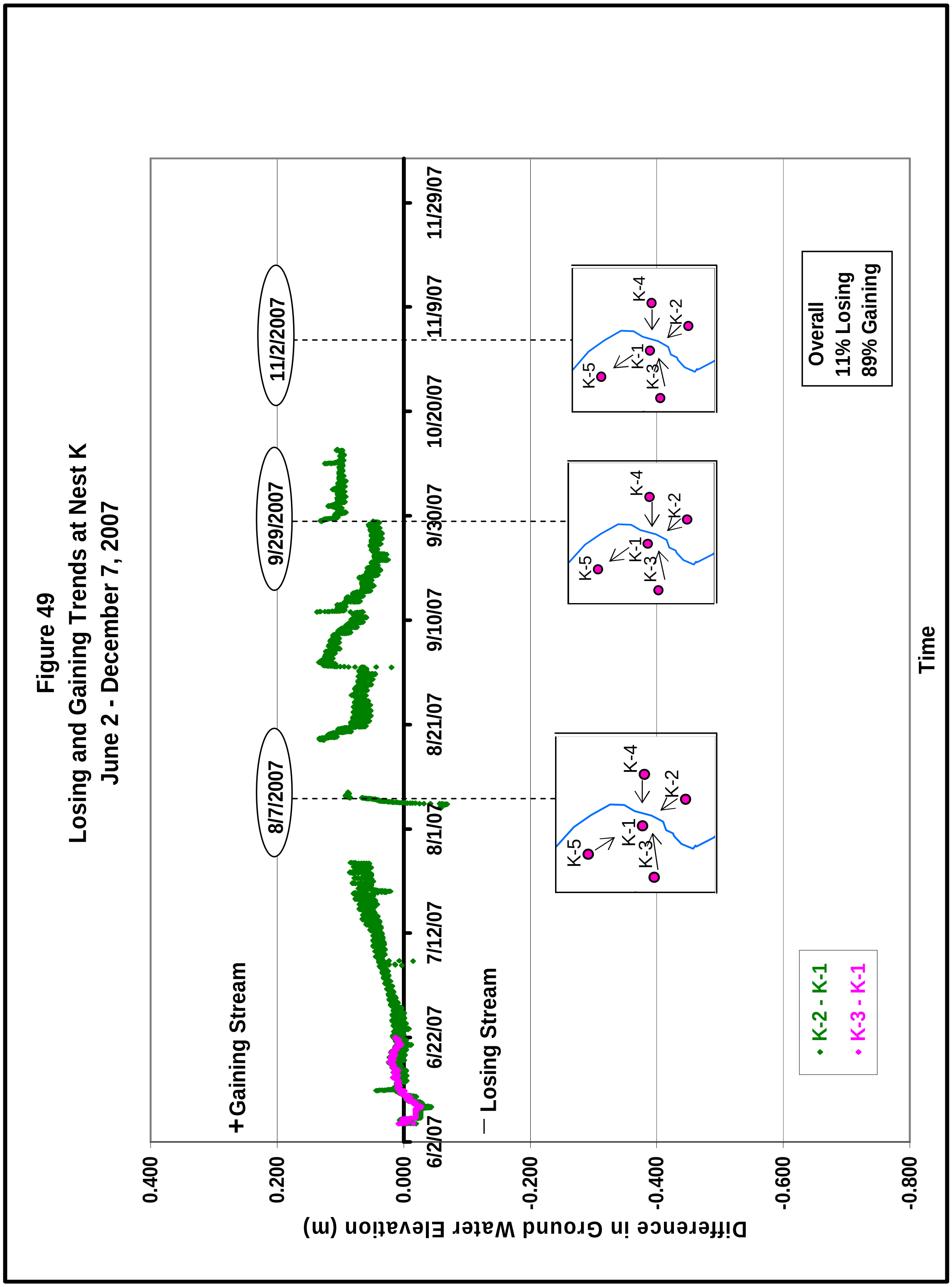


Figure 49
Losing and Gaining Trends at Nest K
June 2 - December 7, 2007
+ Gaining Stream
— Losing Stream
Difference in Ground Water Elevation (m)
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
6/2/07
6/22/07
7/12/07
8/1/07
8/21/07
9/10/07
9/30/07
10/20/07
11/9/07
11/29/07
Time
8/7/2007
9/29/2007
11/2/2007
K-5
K-1
K-3
K-4
K-2
K-2 - K-1
K-3 - K-1
Overall
11% Losing
89% Gaining

This study has identified losing-gaining reaches along Bluewater Creek. These results indicate that this stream is strongly influenced by groundwater exchange with the primary source of recharge being precipitation. The eleven piezometer nests represent an approximately 6.4 km stretch of stream. Groundwater level data show 6 of the 11 nest areas (55%) indicate a gaining stream and 5 of the 11 nest areas (45%) indicate a losing stream. Identifying where a stream is losing and gaining is particularly helpful in regards to riparian restoration. This study has also verified there has been a decrease in groundwater levels since 2004 when monitoring began.

WATER CHEMISTRY

This study has also shown that water quality parameters and biogeochemical processes found in Bluewater Creek and its alluvial aquifer reflect the temporal and spatial variations.

As mentioned above, water quality results were obtained under mostly losing stream conditions.

Spatial variation

Results show no major differences in the water quality between groundwater and surface water as shown in Piper diagram Figure 50a and 50b, respectively. Both waters are a calcium-bicarbonate type water. Piper diagram shown in Figure 50c nicely illustrates the highly connected surface water and groundwater at Nest F. There is however one location along the stream where the surface water and groundwater are distinguishable and this occurs at Nest I (Figure 50d).

Figure 50a: Piper Diagram for Groundwater

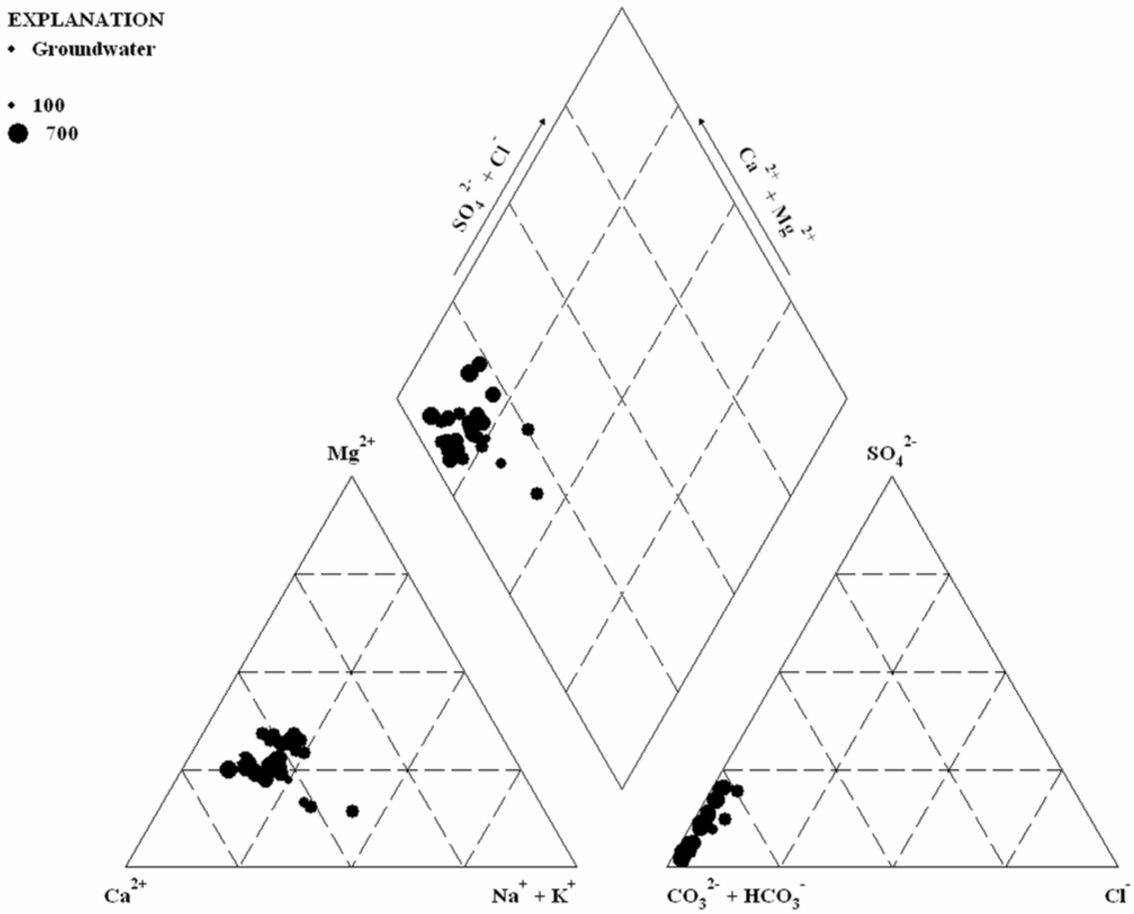


Figure 50b: Piper Diagram for Surface Water

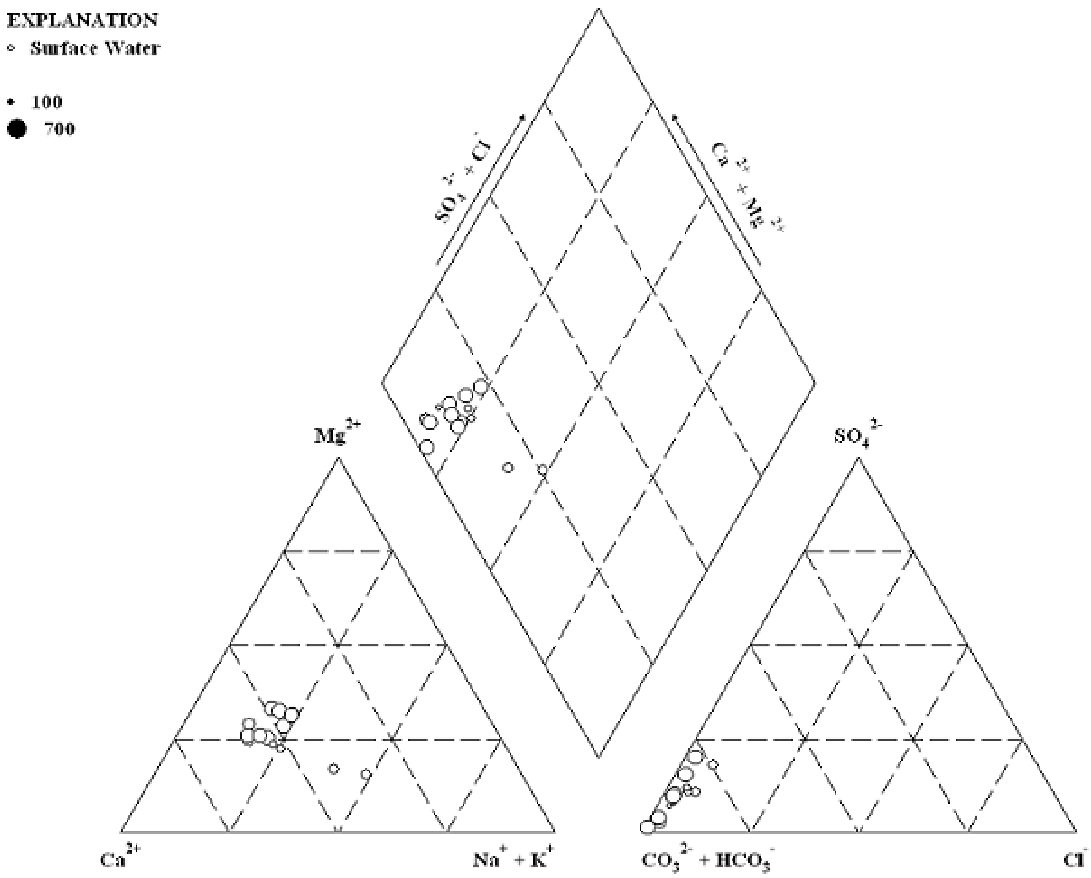


Figure 50c: Piper Diagram for Surface Water and Groundwater at Nest F

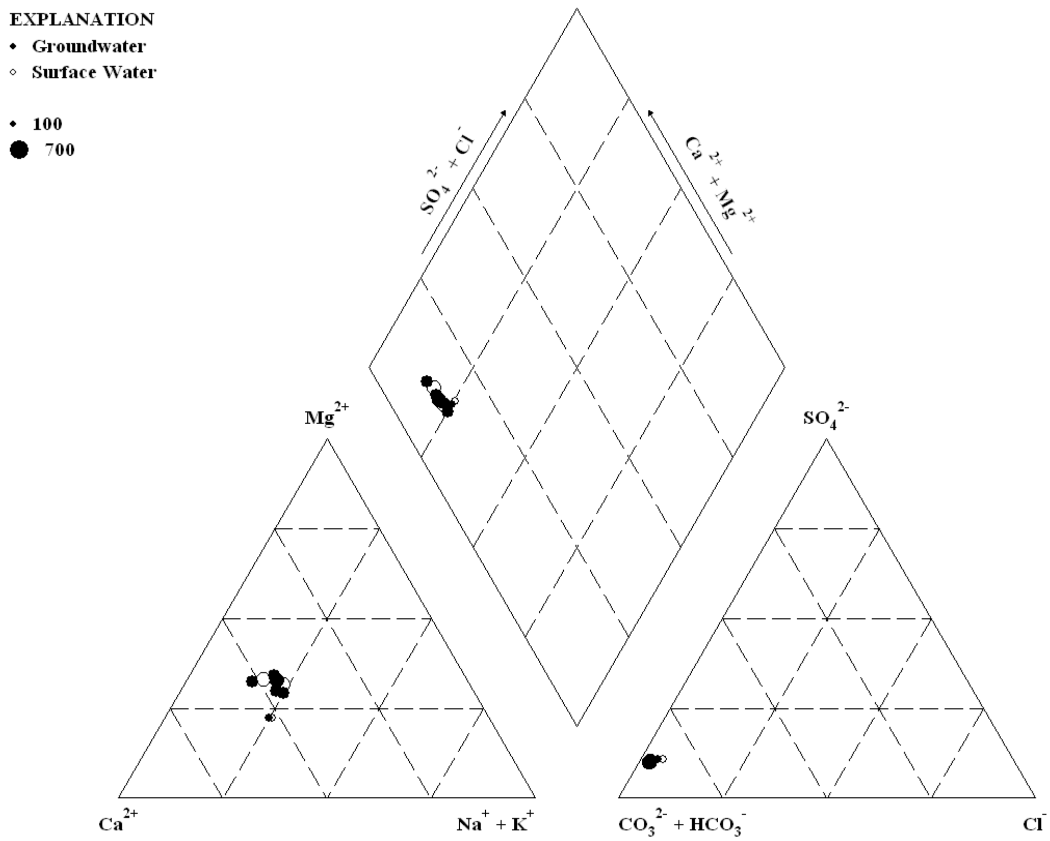
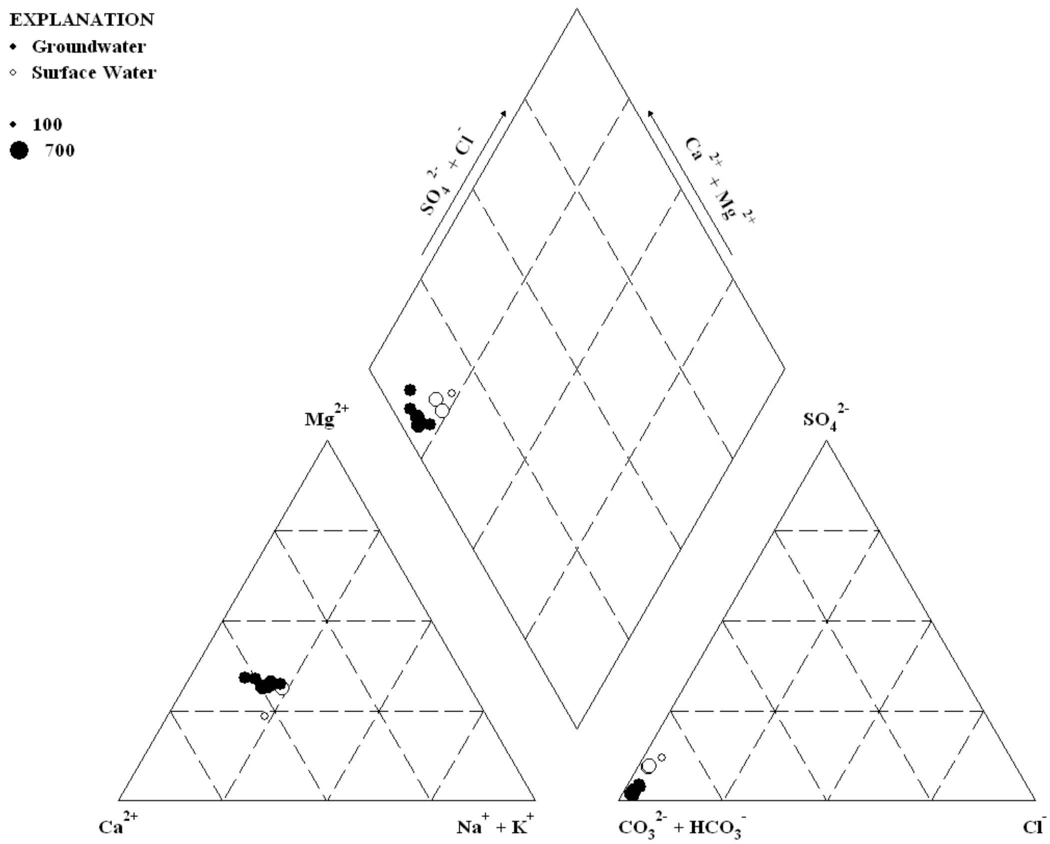


Figure 50d: Piper Diagram for Surface Water and Groundwater at Nest I



Temporal Variation

Temporal variation is evident and consists primarily of a rain event just prior to the August 7, 2007 sample collection event and differences during base flow conditions from samples collected in September and November, 2007.

Surface water results from the August 2007 sample event show low concentrations of major cations/anions (TDS < 429 mg/l) than at base flow conditions. Potassium, however, was detected at higher concentrations during August and lower concentrations during September and November. A possible explanation for this is potassium concentrations increase with an increase in stream flow that is primarily controlled by the leaching of organic matter (Drever and Miller, 1977). Contrary to surface water results, groundwater results show high concentrations (TDS <604 mg/l) of cations and anions during August 2007.

1) Precipitation Event in August 2007

Precipitation that falls on the land surface can essentially follow three routes. It can be returned to the atmosphere through evapotranspiration, it can contribute to runoff (overland flow) and/or join up with a surface water body, or it can simply infiltrate into the soils where it can eventually become a part of a groundwater aquifer (underflow).

A study by Drever and Miller, 1977 provides a detailed analysis of the water chemistry of a small alpine stream following a storm event. In this particular study, conductivity sampling was performed during and after a rain event. Results show two components of the storm runoff which are best illustrated as the rise and fall of the water in which conductivity concentrations were plotted against gauge height. The first component (rise in water) was further defined as overland flow and subsurface flow is essentially the second component.

Factor analysis was performed in the study as well, and it was concluded that the chemistry of a stream during a rain event does not simply reflect dilution by precipitation. Instead, water quality of a stream from an initial storm event shows an initial increase in salinity due to the soluble salts percolating out from the soil zone. Near the end of the storm these salts eventually become completely leached where simple dilution was the main control on overall solute concentration (Miller and Drever, 1977).

Similar generalities from the Miller and Drever study can be applied to the chemistry variability that is seen in this study. Sample collection on August 7, 2007 began 18 hours after a rain event of at least 0.56 inches which was recorded at the study site. However, it is anticipated that additional precipitation was generated from different areas within the Bluewater watershed. Sample collection was completed within 24 hours after the rain event. This study looked at the Average Total Dissolved Solids - Chloride relationship for the August precipitation (Figure 51). This figure shows the TDS range for the 2007 spring discharge for reference purposes. One would expect to see a similar TDS range for a high flow scenario such as a rain event which is the case for the August rain event with the exception of the high concentration of TDS-Chloride in the surface water at Nest K. This could be downstream effects from cattle. A high value of nitrate was also detected in the surface water at Nest K

2) Base flow conditions in September and November 2007 are shown in Figure 52.

Figure 51

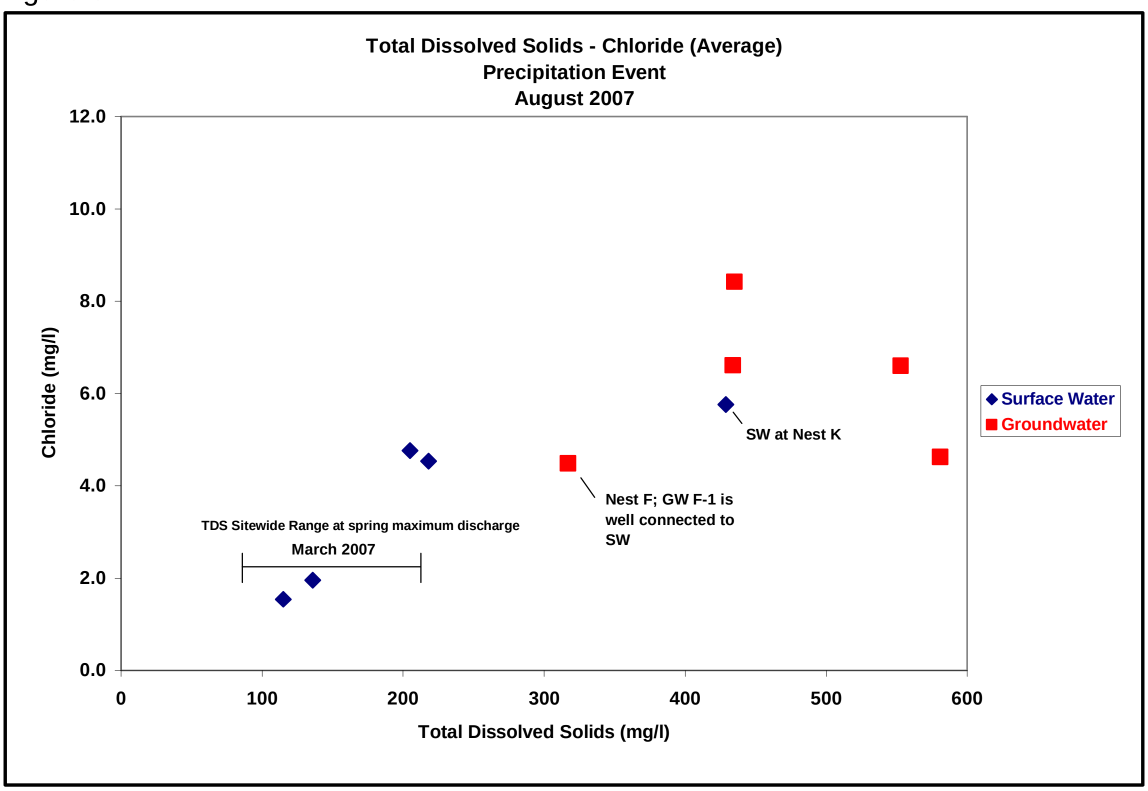
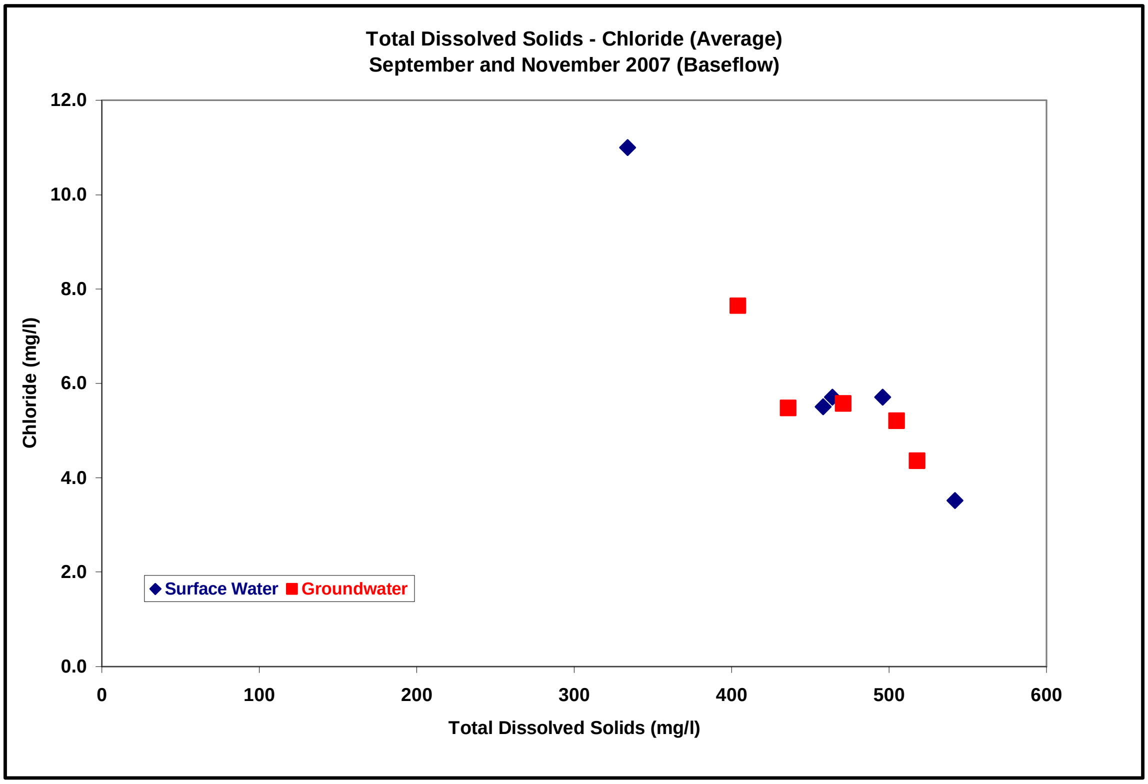


Figure 52



Results show for the Bluewater system, the salt content is reduced by at least 50%. What this tells us is that 50% of the water was rainwater (essentially requiring that the stream double after the rain event in order to dilute the solute content by 50%). The Miller and Drever study area had a much higher discharge than Bluewater, and showed only a ~10% difference in conductivity which is to be expected for a larger watershed with larger streams and higher discharge.

BIOGEOCHEMICAL PROCESSES

There are three predominant biogeochemical processes occurring at Bluewater Creek and its associated alluvial aquifer and each is influenced by redox reactions which involve the transfer of electrons from one chemical species to another.

1) Aerobic Respiration

Fish and many other aquatic organisms need oxygen to live. Water gains oxygen by turbulence, the atmosphere, and photosynthesis. Water loses oxygen when it is over-populated with algae and bacteria that break down the algae for respiration. This process is referred to as aerobic respiration and results in depletion of DO levels in groundwater.

The general equation for aerobic respiration is the following:

$$\text{Organic carbon} + O_2 \rightarrow C0_2 + H_20 + \text{Biomass}$$

Surface water is generally found to be well oxygenated in comparison to ground water. The dissolved oxygen levels in the surface water and ground water confirm this except at Nest F. The groundwater level results from this study have identified the stream segment adjacent to the Nest F piezometer as a losing stream (see Nest F Losing - Gaining Trend Figure 47). Where there is a losing stream one would therefore expect for the groundwater to be recharging and for the groundwater chemistry to look more like surface water chemistry. Nowhere else along Bluewater Creek is this more evident than at groundwater well F-1 (GW F-1); the groundwater DO concentration levels are nearly the same concentration levels seen in the surface water at Nest F for all three sample collection events (Tables 8a,8b,and 8c). Everywhere else along the stream in this study there has been enough time and organic material during infiltration for the groundwater (even for the groundwater well near the stream edge) to cause oxygen depletion by aerobic respiration processes.

2) Nitrate Reduction (Denitrification)

In nitrate reduction, bacteria will use nitrate ions as the terminal electron acceptor in order to oxidize organic carbon to $C0_2$ (Drever, 1997).This process is called nitrate reduction or denitrifcation and the end product is nitrogen (N_2).

The general equation for denitrification is the following:

$$\text{Organic Carbon} + NO_3^- \rightarrow N_2 + CO_2 + H_2O + \text{Biomass}$$

3) Sulfate Reduction-

Chemical reduction of oxidized sulfur ions (sulfate ions) to the sulfide state occurs frequently in groundwater (Todd, 1980). This reaction takes place in the presence of sulfate-reducing bacteria (SRBs) and can be accompanied by high bicarbonate and carbon dioxide contents and contain hydrogen sulfide (Todd, 1980). This process is called sulfate reduction.

The general equation for sulfate reduction is the following:

$$\text{Organic Carbon} + SO_4^{2-} \rightarrow HS^- + CO_2 + H_2O + \text{Biomass}$$

Average and standard deviation was determined for sulfate concentration at each Piezometer Nest where sample collection occurred. Box-and whisker plots are shown on Figures 53a through 53e.

It is likely that sulfate is being reduced in groundwater at GW I-1: note that the surface water sulfate concentration is elevated relative to the groundwater levels. Additional graphs were plotted with the y-axis shown as the sulfate/chloride ratio instead of just sulfate to assess potential effects of evapotranspiration in increasing solute concentrations. The same conclusion can be made: groundwater at Nest I indicates sulfate reduction. Furthermore, during purging and sample collection, there was a strong hydrogen sulfide odor.

Figure 53a: Box and Whisker Plot for sulfate at piezometer Nest A

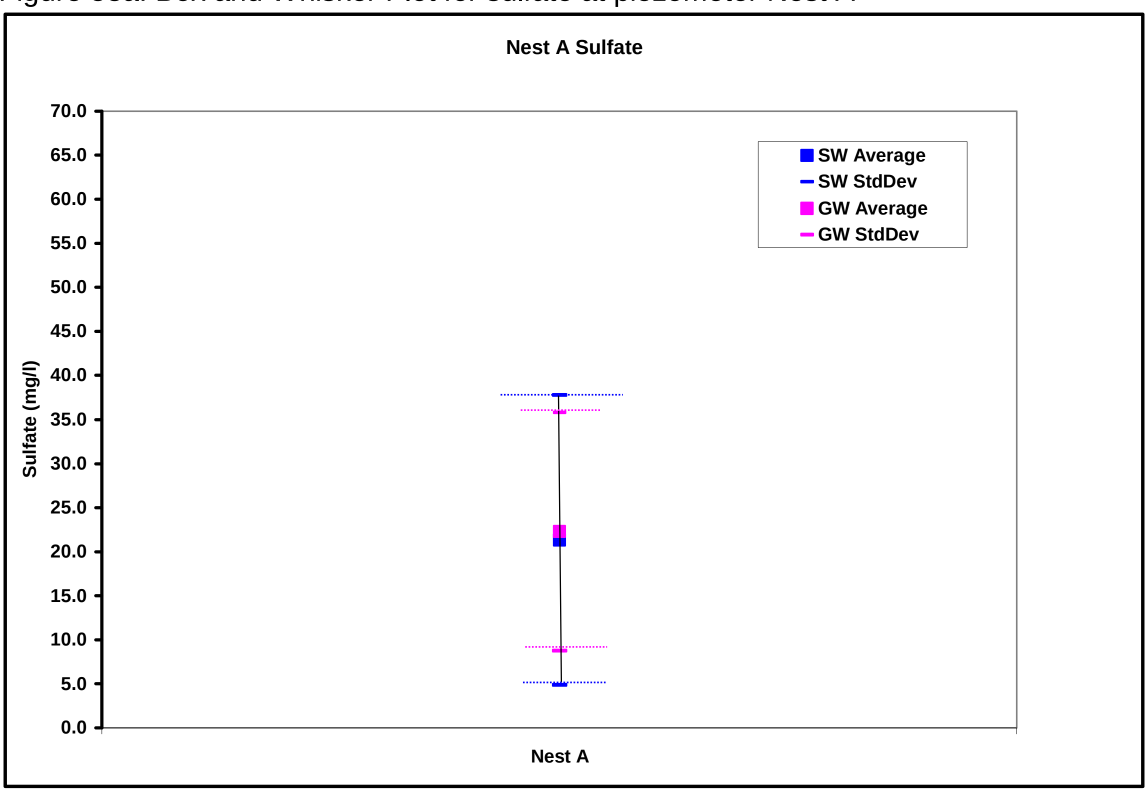


Figure 53b: Box and Whisker Plot for sulfate at piezometer Nest D

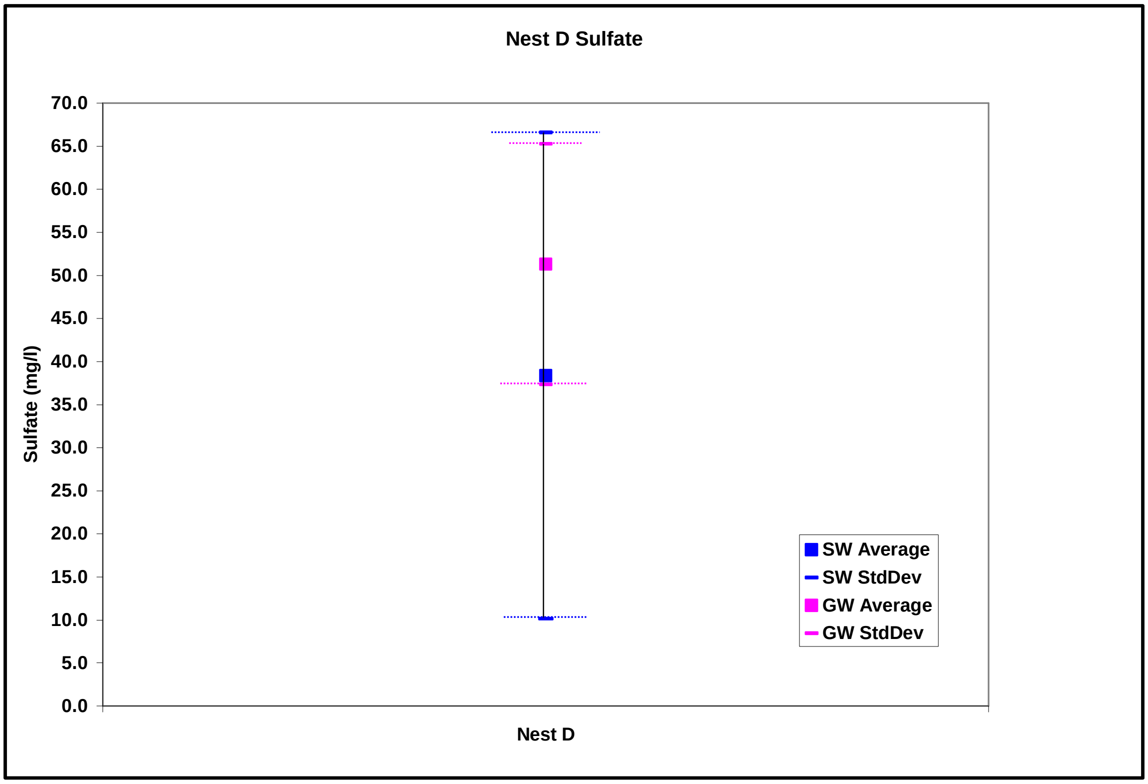


Figure 53c: Box and Whisker Plot for sulfate at piezometer Nest F

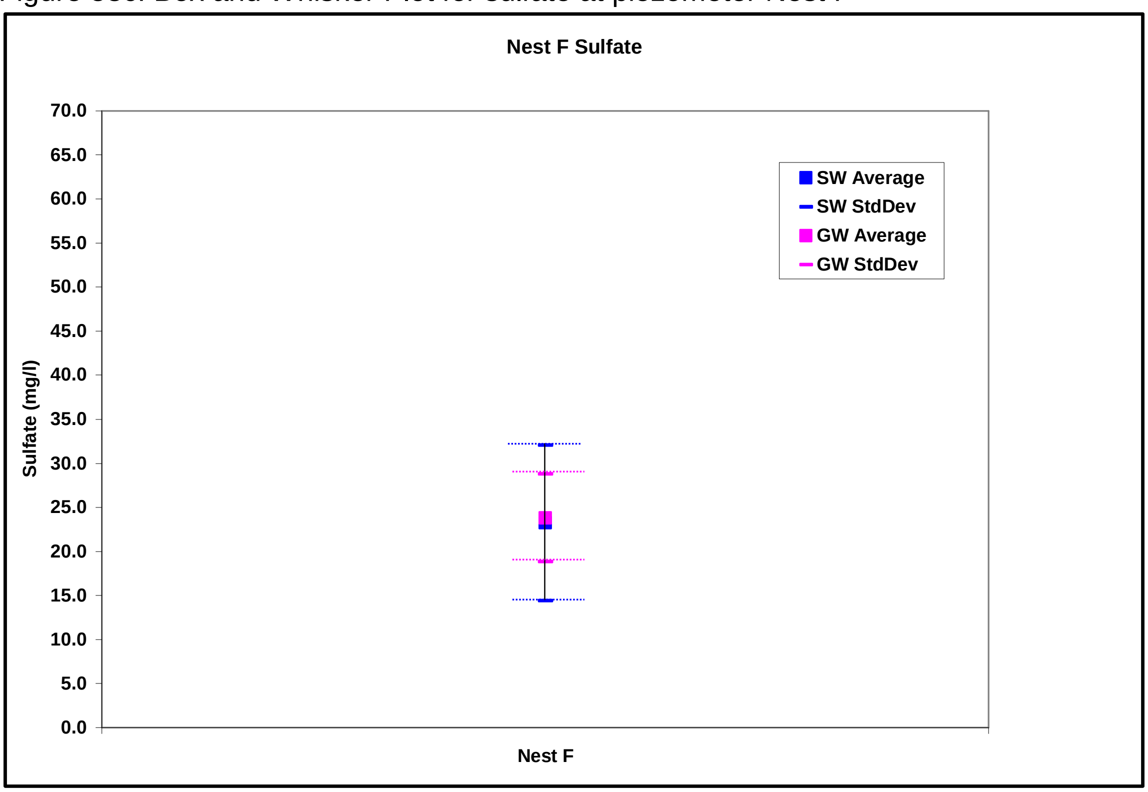


Figure 53d: Box and Whisker Plot for sulfate at piezometer Nest I

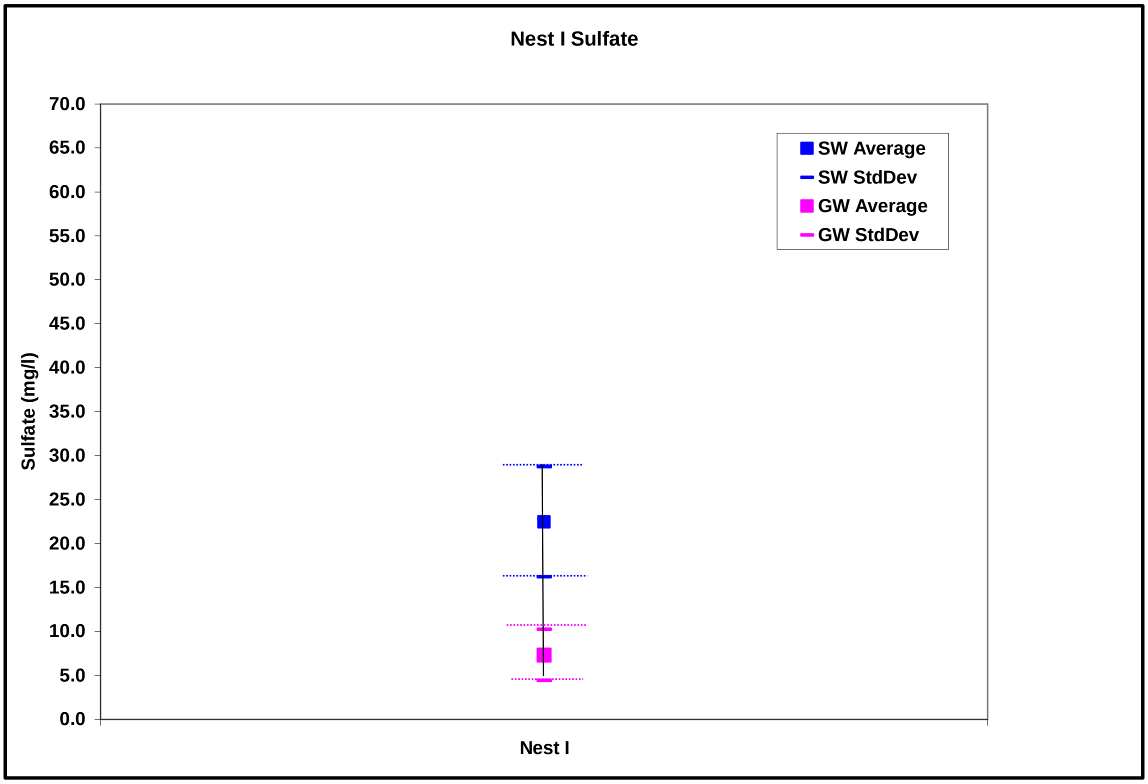
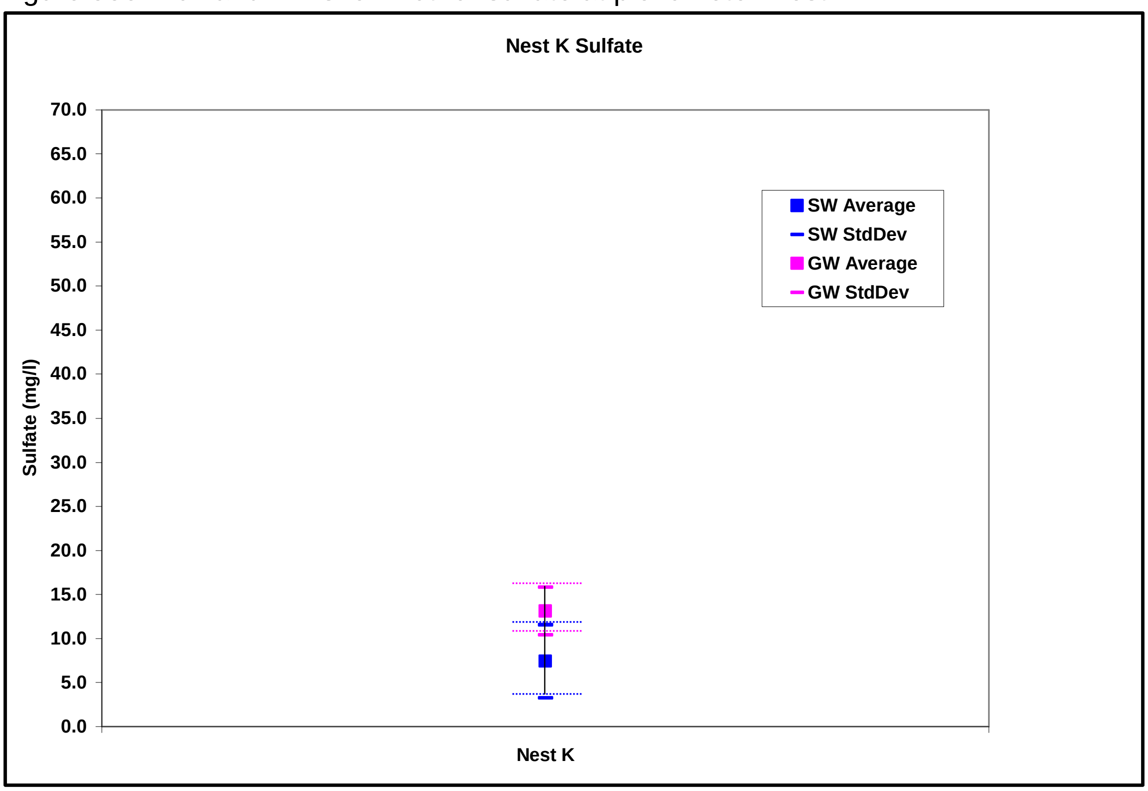


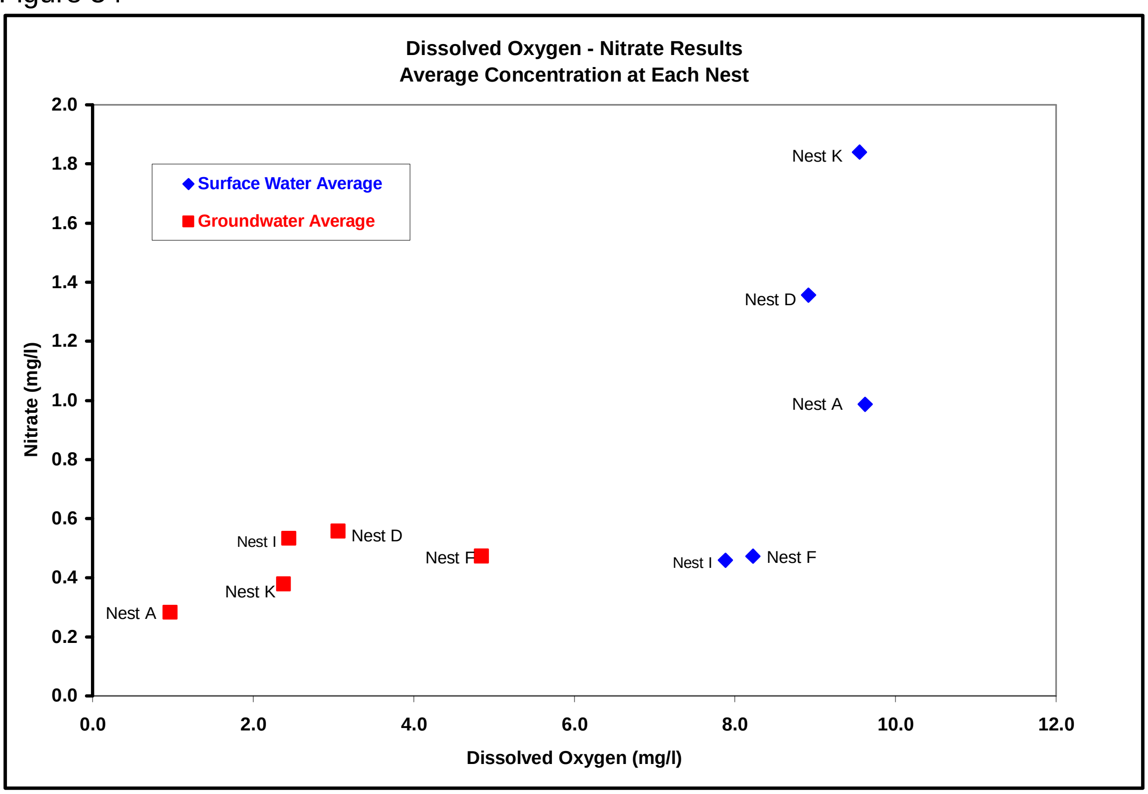
Figure 53e: Box and Whisker Plot for sulfate at piezometer Nest K



NITRATE

Nitrate (NO_3) is one of the most commonly identified contaminants found in ground water (Freeze and Cherry, 1979). Nitrate levels range from 0.03 mg/l to 4.52 mg/l in the groundwater at Bluewater Creek; well below the New Mexico Standard of 10 mg/l. In surface water, nitrate concentrations ranged from 0.18 mg/l to 2.35 mg/l. Nitrate is caused by both natural and anthropogenic courses. Natural sources of nitrates can include igneous rocks, the atmosphere and decomposition of organic material. Examples of anthropogenic sources at the study area include agricultural activities such as manure from range animals. Although there is still evidence of the effects of cattle in some reaches, shown by consistent elevated levels in most surface samples, evidently nitrate reduction maintains the nitrate concentrations within an acceptable range in the alluvial aquifer over the period studied. This is a classic example of the 'ecosystem service' provided by hyporheic exchange. Figure 54 shows an overall pattern of high concentrations of nitrate in the surface water with respect to groundwater

Figure 54

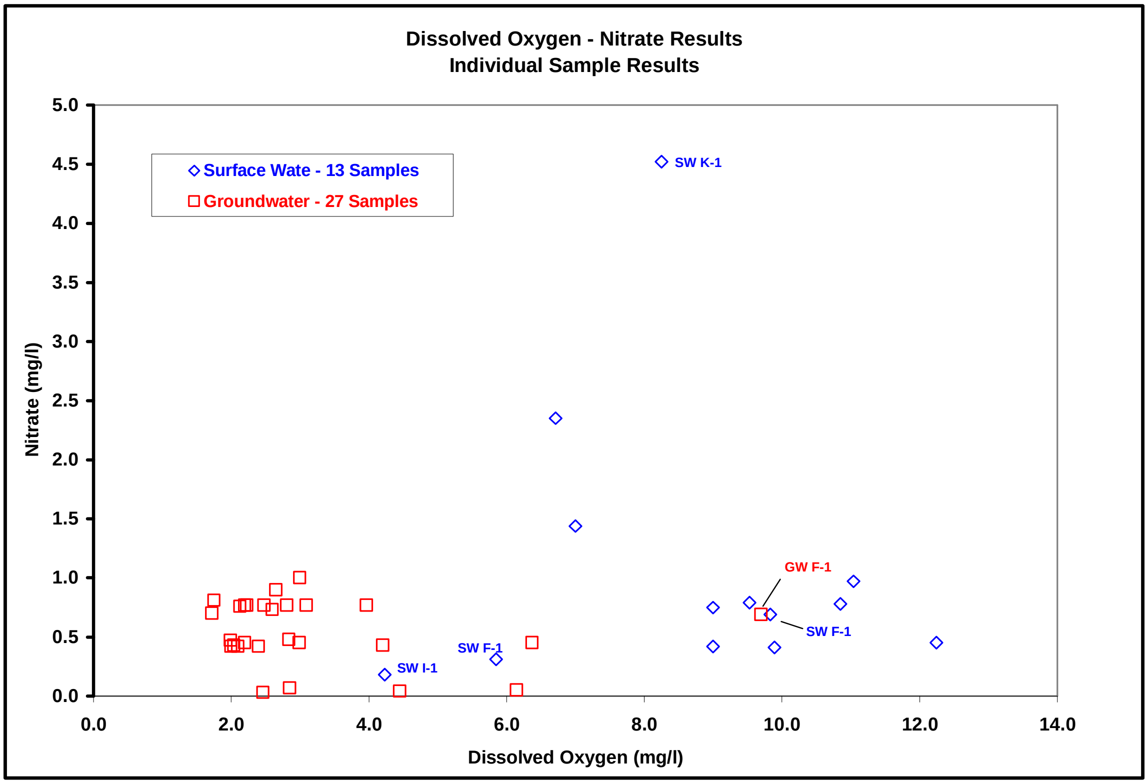


DISSOLVED OXYGEN (DO)

Oxygen solubility in water is a function of temperature. Cold water has more oxygen than warm water as is the case from the November surface water DO results but with exception to the surface water (SW I-1) collected adjacent to piezometer Nest I.

The surface water at Nest I has a lower concentration of DO in comparison to the other surface water sample results for November. A possible explanation would be if the surface water at Nest I shows gaining behavior. Figure 48 shows the losing-gaining trend at Nest I during November to be losing (I-1→ I-4 and I-1→ I-2) and gaining (I-5→ I-1 and I-3 →I-1). Since a portion of the groundwater is entering the stream, this could offer an explanation for the lower DO concentration in the stream. In addition, Figure 54 shows groundwater consistently exhibits low DO relative to surface water.

Figure 55



A couple outliers here in the surface water for dissolved oxygen include SW I-1 and SW F-1, in which both are below the standard for the streams designated use of 6 mg/l, which can be a problem during the hot summer months (little shade along the creek) and warm water does hold less DO than cooler water. These samples (outliers) shown in Figure 55 were from August.

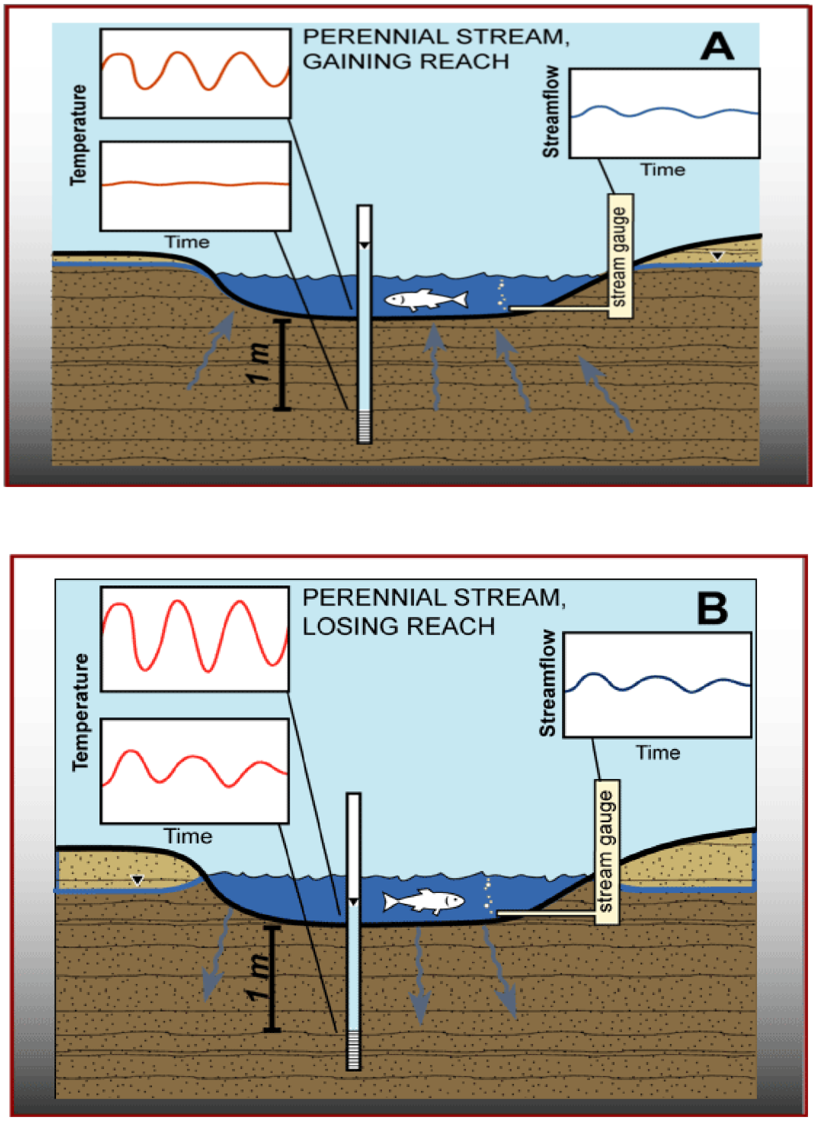
Another outlier seen at SW K-1 shows a high nitrate value of 4.52 mg/l. This could be the downstream effects of cattle grazing at Nest I. This sample (outlier) was from September. This apparently is not uncommon and therefore may not be an outlier after all. Recall from Table 3 that nitrate levels were also high (4.2 – 7.7 mg/l) in the surface water collected in the DuBey study in 2003 with the highest concentration detected near Nest F (7.7 mg/l)

The surface water at SW I-1 is gaining 50% of the time and is enough to show that at this location (Figure 55) the surface water is becoming more like the GW at I-1. Contrary to the losing-gaining trend at Nest F to be losing 100% of the time, SW F-1 is suggestive of a gaining stream.

WATER TEMPERATURE

Surface water and groundwater temperature results demonstrate connectivity between the shallow alluvial aquifer and surface water at Bluewater Creek. Stream temperature plays an important role in the health and sustainability of the aquatic life in streams. Furthermore, the interaction between surface water and groundwater is important in controlling stream temperature. Stonestrom & Constanz 2003 show typical temperature variation of groundwater and surface water under gaining and losing stream conditions (Figures 56 a-b) for a perennial stream.

Figure 56 A - B: Temperature variation of groundwater and stream under gaining (a) and losing stream (b) conditions (adopted from Stonestrom & Constanz, 2003)



In comparison to the temperature variations presented by Stonestrom & Constantz, Bluewater Creek at Nest D and Nest K both illustrate a gaining stream where the stream demonstrates diurnal temperature variation; stronger in magnitude during the summer and less during the fall/winter. This is to be expected. Since surface water is gaining water from the ground water, one would expect see little variation in ground temperature over time. This relatively constant groundwater temperature is nicely illustrated at Nest D and Nest K. This correlates well to the overall losing-gaining trend graphs for Nest D and Nest K (Figures 57a and 57b) which primarily shows a gaining stream at both these locations. In this manner, plotting surface water and groundwater temperature together when it is available can determine/verify whether a stream is losing or gaining. Rain events will cause groundwater water temperatures to increase because during a rain event the stream is essentially acting as a losing stream and so with the surface water being lost to groundwater one would expect to see groundwater temperatures to reflect surface water temperatures. This is shown at Nest D and to a lesser extent at Nest K due to the scale on the figure.

If there is an absence of surface water temperature to compare with groundwater temperature as is the case for Nests A, F and I, adequate conclusions can still be made in terms of looking at the daily change in temperature. As shown on Table 12, there is a significant daily fluctuation with the week of November 10-17 displaying the greatest temperature change.

Chemistry shows that the surface water and groundwater at Nest F is well connected. Temperature data independently confirms this conclusion. Temperature data shown in Figure 58 for the week of November 10-17, 2007 clearly illustrate diurnal fluctuations at Nest F. This is expected at a losing reach of stream which this study has shown from water level data. Surface water is being lost to the ground water at Nest F and one would expect to see groundwater temperatures to reflect surface water temperature behavior (diurnal fluctuation).

Figure 57a

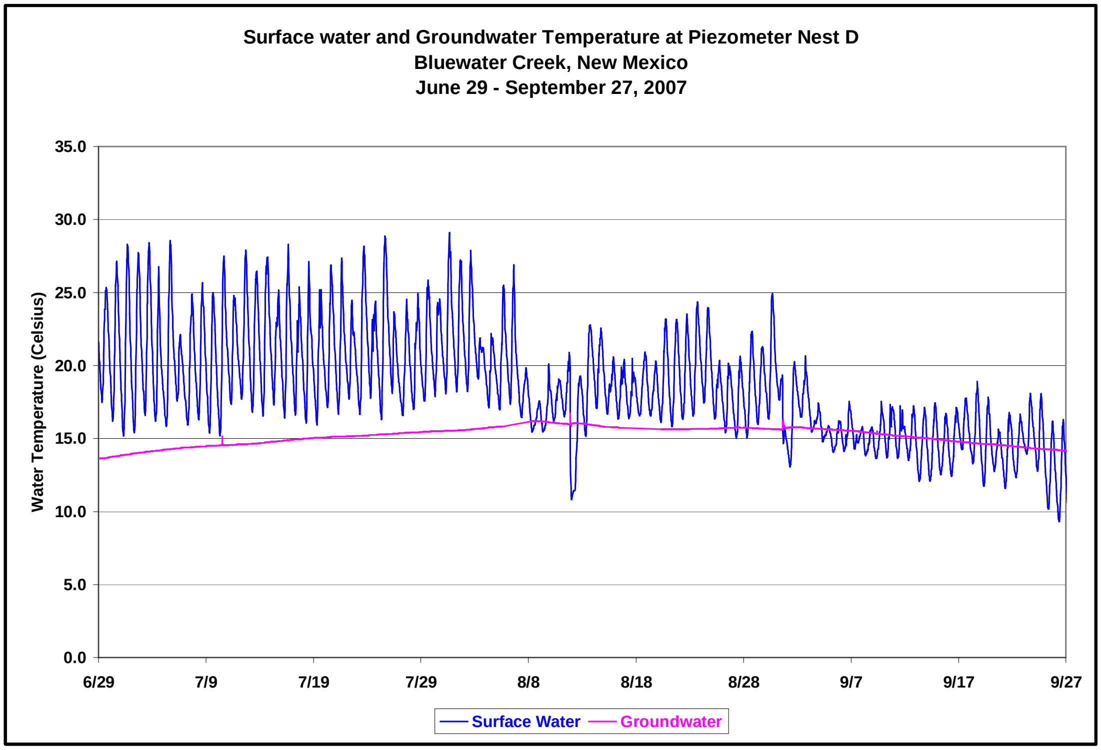
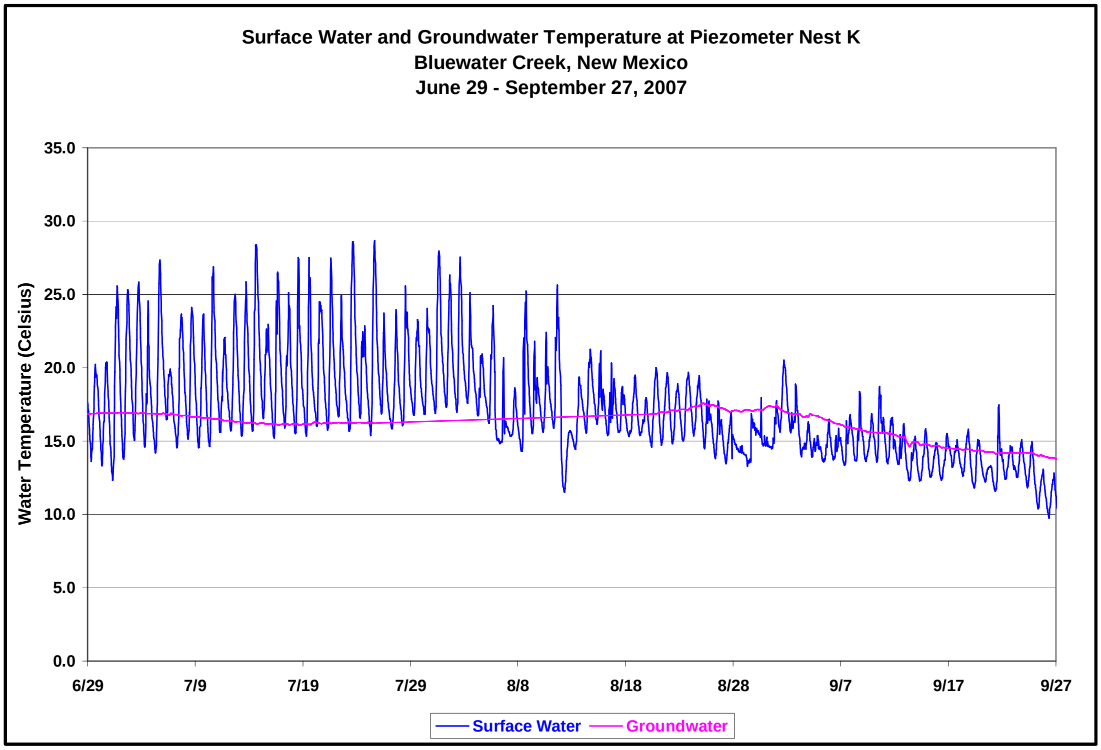
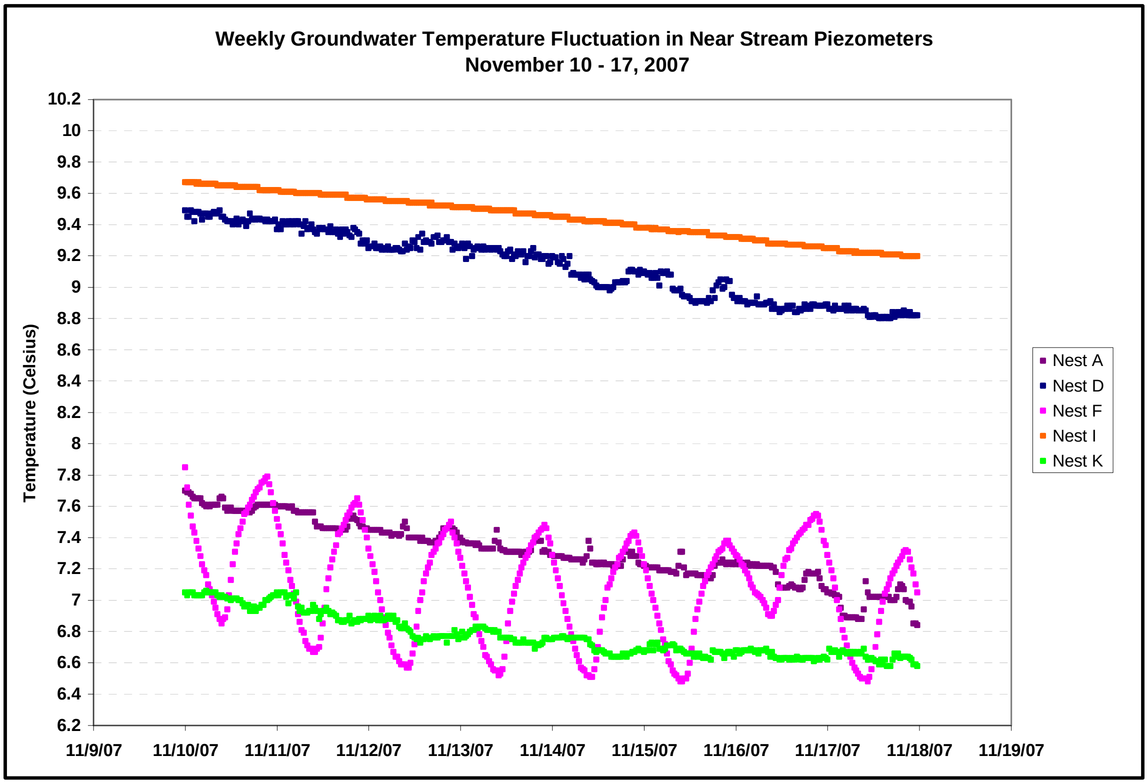


Figure 57b



`Figure 58



Weekly Groundwater Temperature Fluctuation in Near Stream Piezometers
November 10 - 17, 2007
Temperature (Celsius)
10.2
10
9.8
9.6
9.4
9.2
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
6.2
11/9/07
11/10/07
11/11/07
11/12/07
11/13/07
11/14/07
11/15/07
11/16/07
11/17/07
11/18/07
11/19/07
Nest A
Nest D
Nest F
Nest I
Nest K

9.0 CONCLUSIONS

- Water Levels have dropped since monitoring began in 2004 (except at Nest G, J and K).

- Temporal and spatial variation in GW levels

- Groundwater level response during precipitation events of differing magnitude across the study area

- 55% of the GW measurements collected indicates a gaining stream and 45% indicated a losing stream

- GW temperature fluctuations indicate a varying degree of SW-GW connection across the study area
  - GW F-1 - diurnal fluctuation; indicative of strong connection to the SW

- SW-GW Chemistry – no significant differences
  - Nitrate (higher concentrations in SW with respect to GW)
  - DO (Low concentrations in groundwater except at GW F-1)
  - GW F-1 and SW F-1 - highly connected
  - GW and SW at Nest I – less connected

- Three biogeochemical processes occurring in the SW and GW

10.0 RECOMMENDATIONS

1) Continue water level monitoring.
2) Perform additional water quality sampling for nitrate.
3) Incorporate a sonde for time-based measurement of DO, conductivity, pH (as well as Temperature). This will provide a better resolution of the site across a more inclusive time span.
4) Incorporate the water temperature data from 2004-2006 into this study.
5) Continue surface water temperature monitoring.
6) Determine gaining-losing trends from the 2004-2206 water level data and incorporate results into this study.

11.0 APPENDICES

11.1 Remote Acquisition Weather Station (RAWS) Data
(see next page)

RAWS Data

Average Monthly Precipitation for Bluewater Ridge and Bluewater Creek, NM

Month	**BW Ridge (cm)**	**BW Creek (cm)**
July 2003	1.57	2.44
Aug	11.43	10.34
Sept	5.21	6.10
Oct	1.93	1.57
Nov	2.92	2.41
Dec	1.24	0.84
Total	**24.31**	**23.70**
January 2004	2.26	1.19
Feb	2.11	1.80
Mar	1.07	0.69
Apr	4.57	4.85
May	0.00	0.00
June	0.86	0.79
July	3.71	5.16
Aug	3.43	3.02
Sept	10.90	2.44
Oct	2.11	2.01
Nov	2.29	1.68
Dec	2.67	2.24
Total	**35.97**	**25.86**
January 2005	3.61	3.30
Feb	5.44	4.45
Mar	4.27	3.45
April	3.33	3.45
May	0.74	0.91
June	1.78	1.07
July	3.71	2.57
Aug	8.92	9.04
Sept	2.13	2.41
Oct	1.93	2.36
Nov	0.66	0.36
Dec	0.33	0.25
Total	**36.83**	**33.63**

RAWS Data

Average Monthly Precipitation for Bluewater Ridge and Bluewater Creek, NM

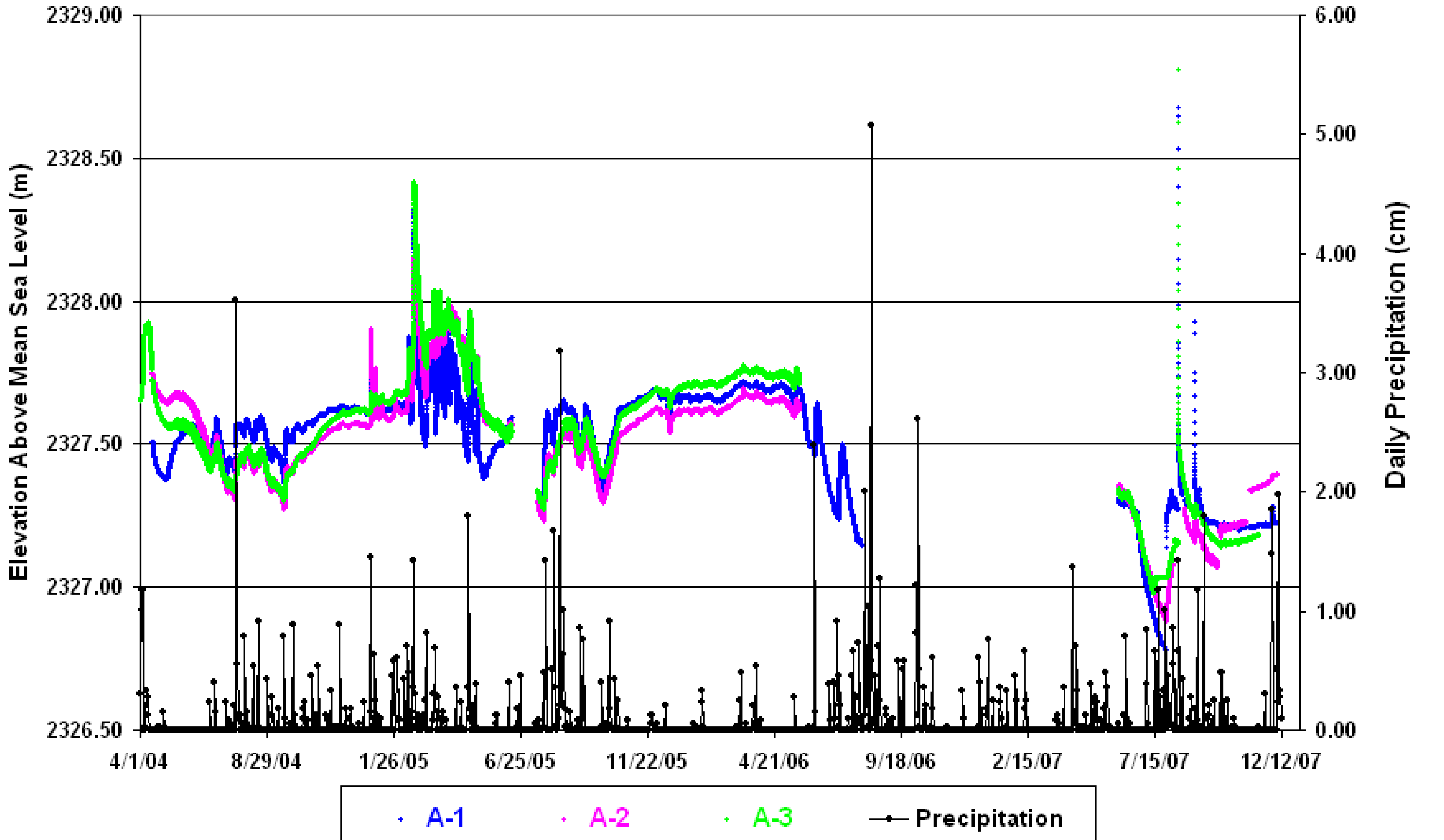
Month	BW Ridge (cm)	BW Creek (cm)
January 2006	1.02	0.66
Feb	0.03	0.00
Mar	2.24	1.63
April	0.36	0.13
May	0.53	0.28
June	3.10	3.05
July	5.97	4.95
Aug	15.24	13.08
Sept	3.00	2.08
Oct	5.33	6.73
Nov	1.07	0.36
Dec	2.74	2.21
Total	**40.61**	**35.15**
January 2007	2.21	1.75
Feb	2.36	1.35
Mar	0.81	0.69
April	2.87	2.82
May	2.34	2.36
June	1.65	1.12
July	7.90	5.87
Aug	5.13	5.13
Sept	2.41	4.04
Oct	1.30	1.42
Nov	1.47	1.57
Dec	5.44	5.59
Total	**35.89**	**33.71**
January 2008	3.76	4.17
Feb	3.45	2.57
Mar	0.41	0.23
April	0.23	0.08
May	2.26	2.39
June	1.37	1.14
July	13.21	2.29
Total	**24.69**	**12.85**

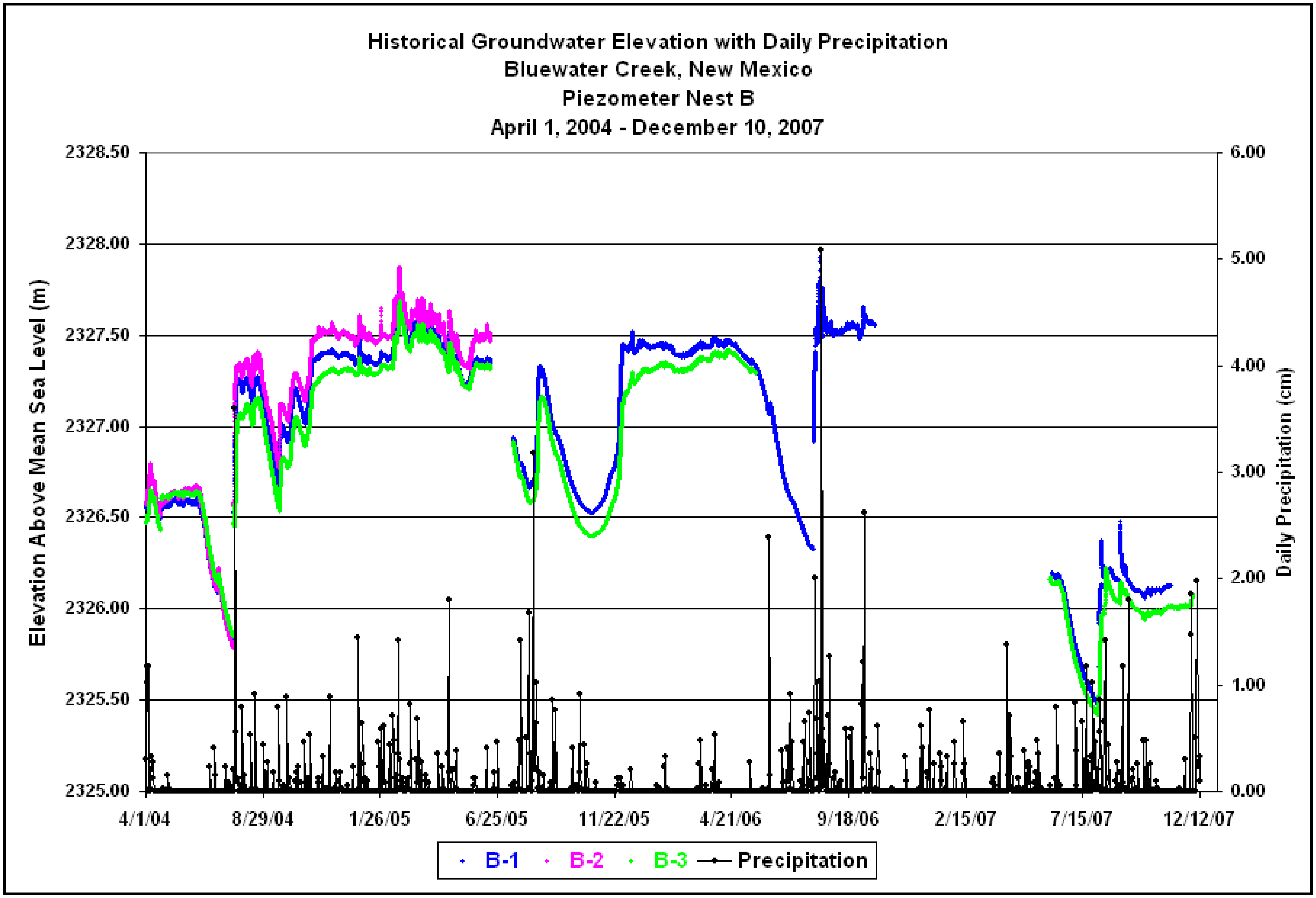
Data obtained from Western Regional Climate Center - RAWS USA Climate Archive
http://www.raws.dri.edu

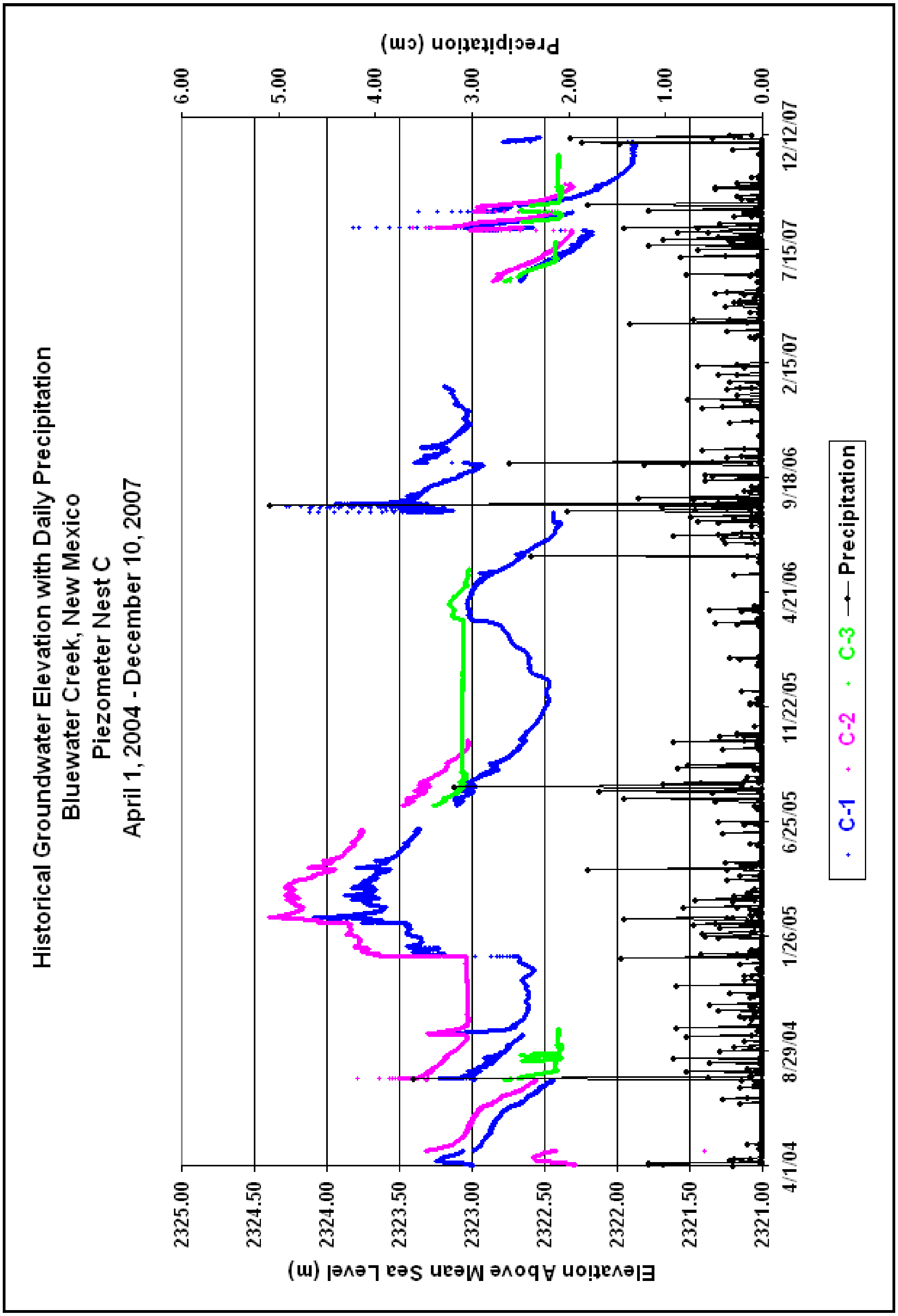
11.2 Groundwater Elevation Hydrographs for Years 2004 – 2007

(see next page)

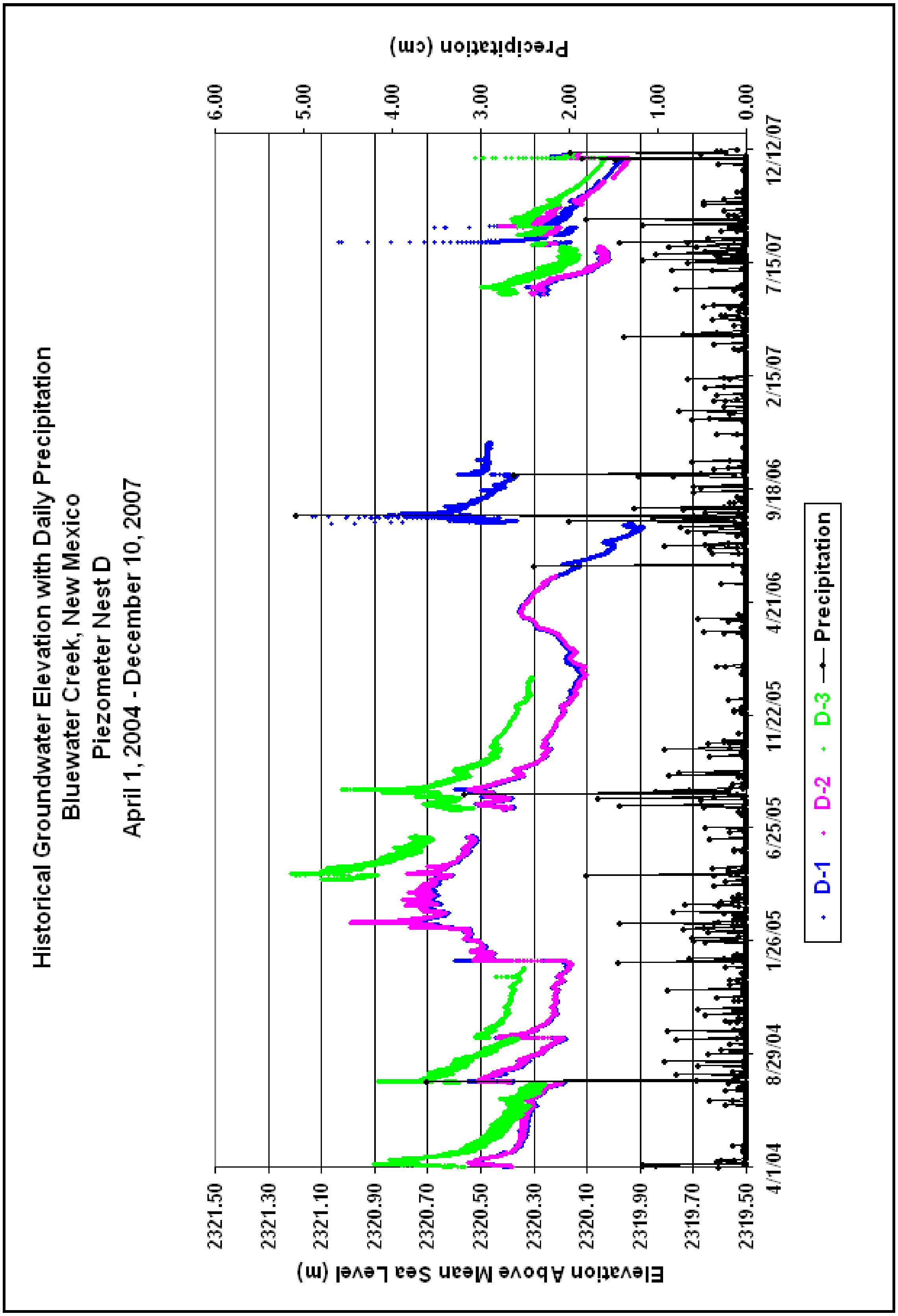
Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest A
April 1, 2004 - December 10, 2007



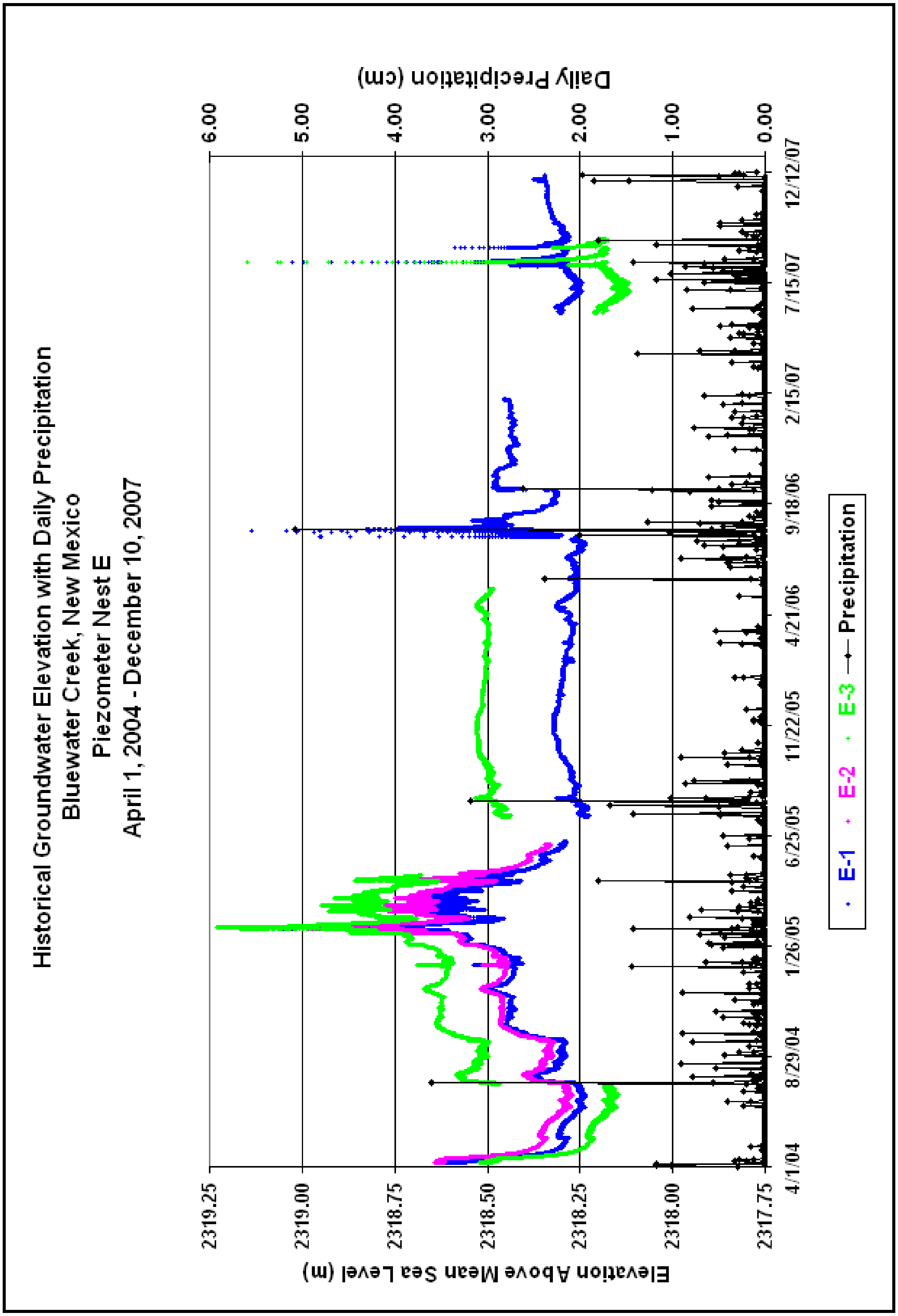

Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest B
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
Daily Precipitation (cm)
2328.50
2328.00
2327.50
2327.00
2326.50
2326.00
2325.50
2325.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
B-1
B-2
B-3
Precipitation

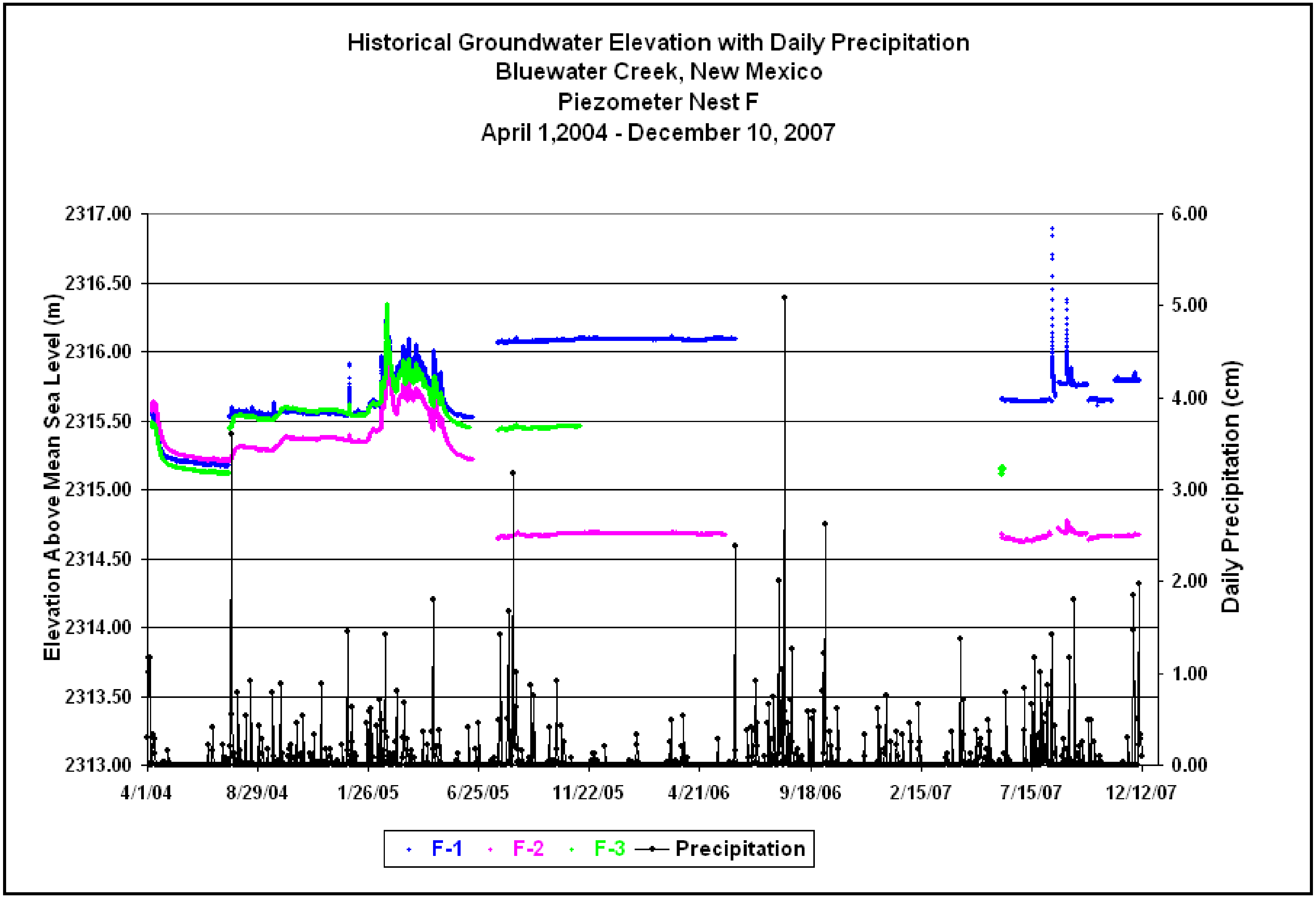


Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest C
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
Precipitation (cm)
2325.00
2324.50
2324.00
2323.50
2323.00
2322.50
2322.00
2321.50
2321.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
C-1
C-2
C-3
Precipitation

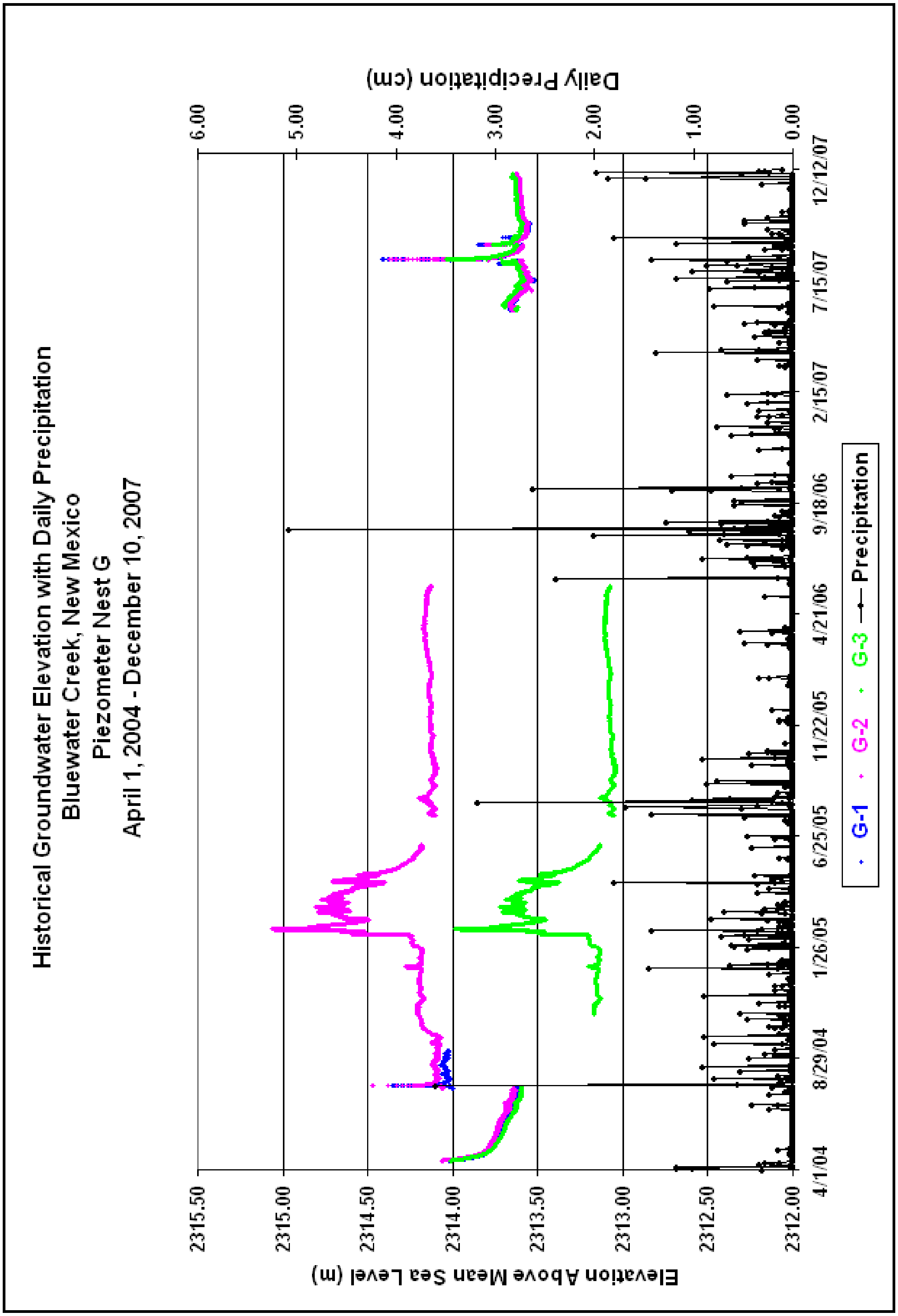


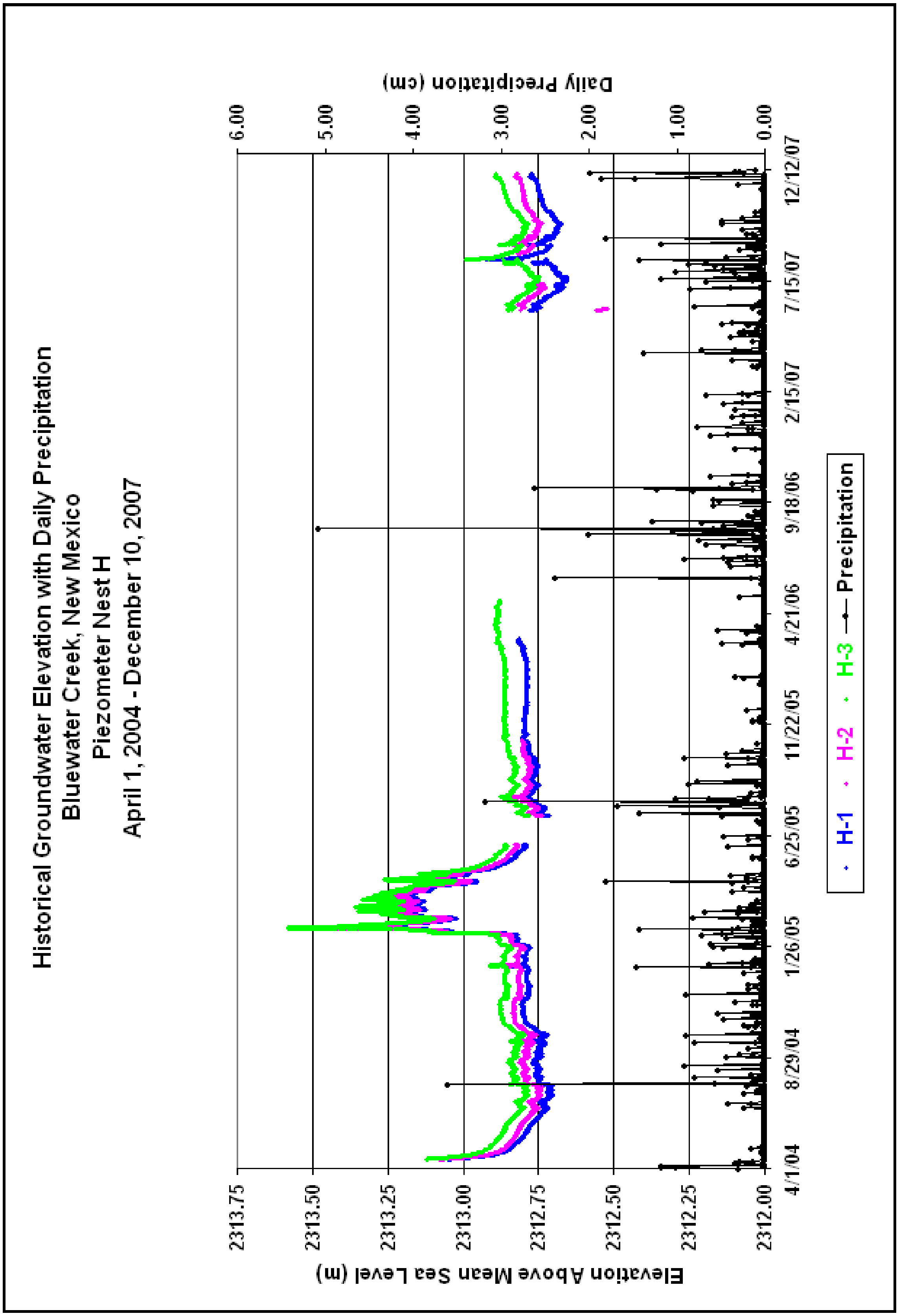
Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest D
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
Precipitation (cm)
2321.50
2321.30
2321.10
2320.90
2320.70
2320.50
2320.30
2320.10
2319.90
2319.70
2319.50
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
D-1
D-2
D-3
Precipitation

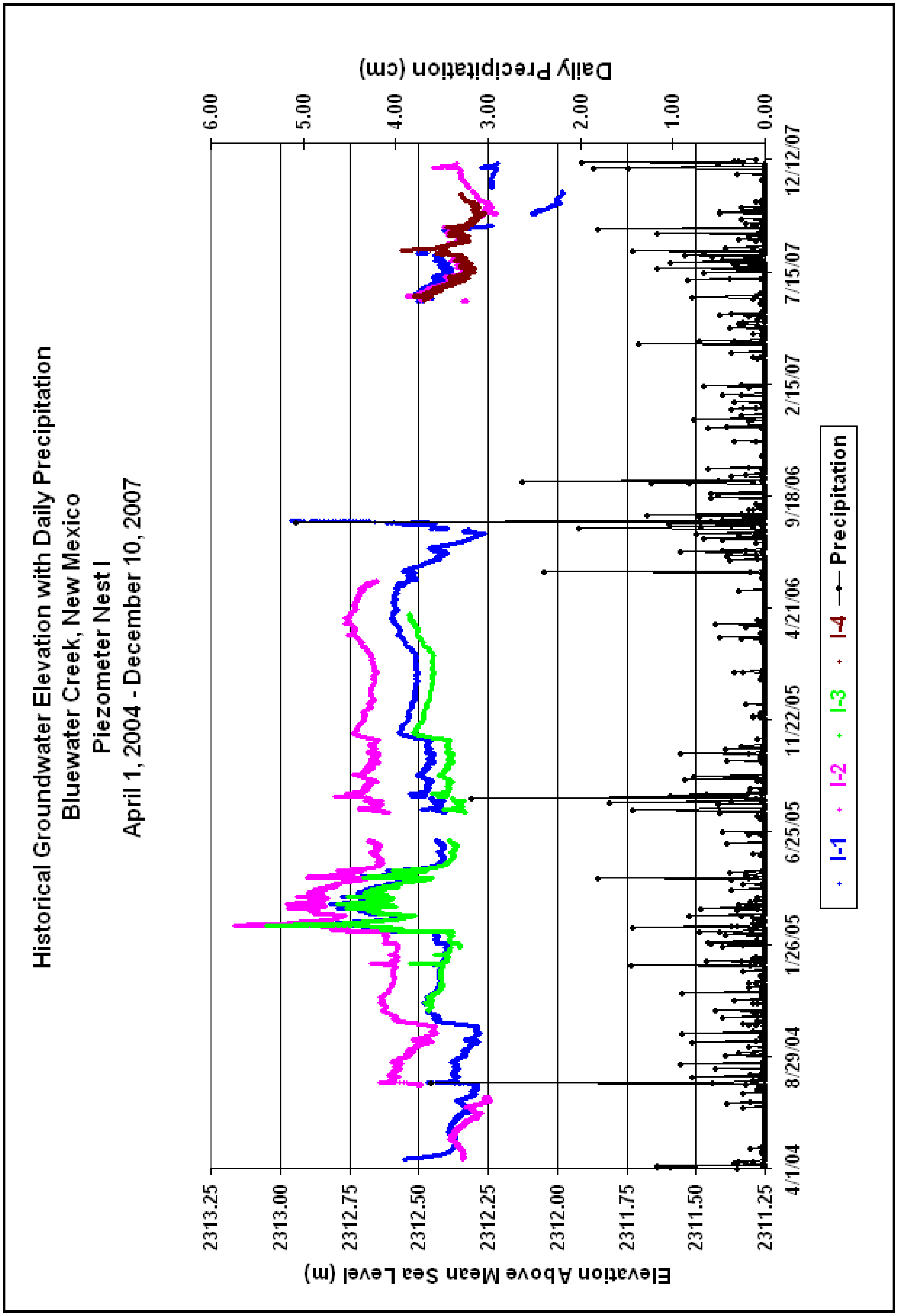

Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest E
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
Daily Precipitation (cm)
2319.25
2319.00
2318.75
2318.50
2318.25
2318.00
2317.75
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
E-1
E-2
E-3
Precipitation



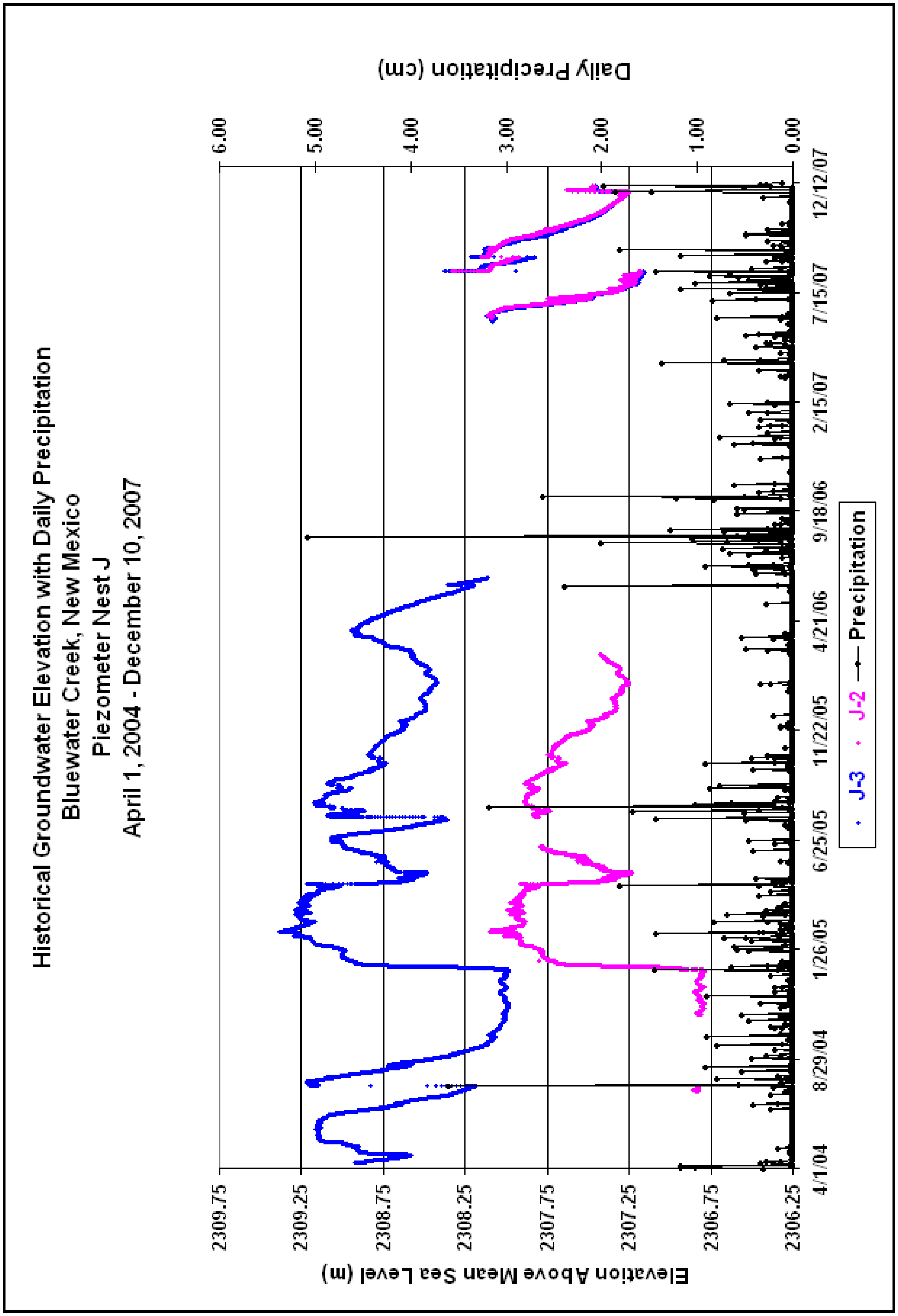
Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest F
April 1,2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
2317.00
2316.50
2316.00
2315.50
2315.00
2314.50
2314.00
2313.50
2313.00
Daily Precipitation (cm)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
F-1
F-2
F-3
Precipitation


Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest G
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
Daily Precipitation (cm)
2315.50
2315.00
2314.50
2314.00
2313.50
2313.00
2312.50
2312.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
G-1
G-2
G-3
Precipitation

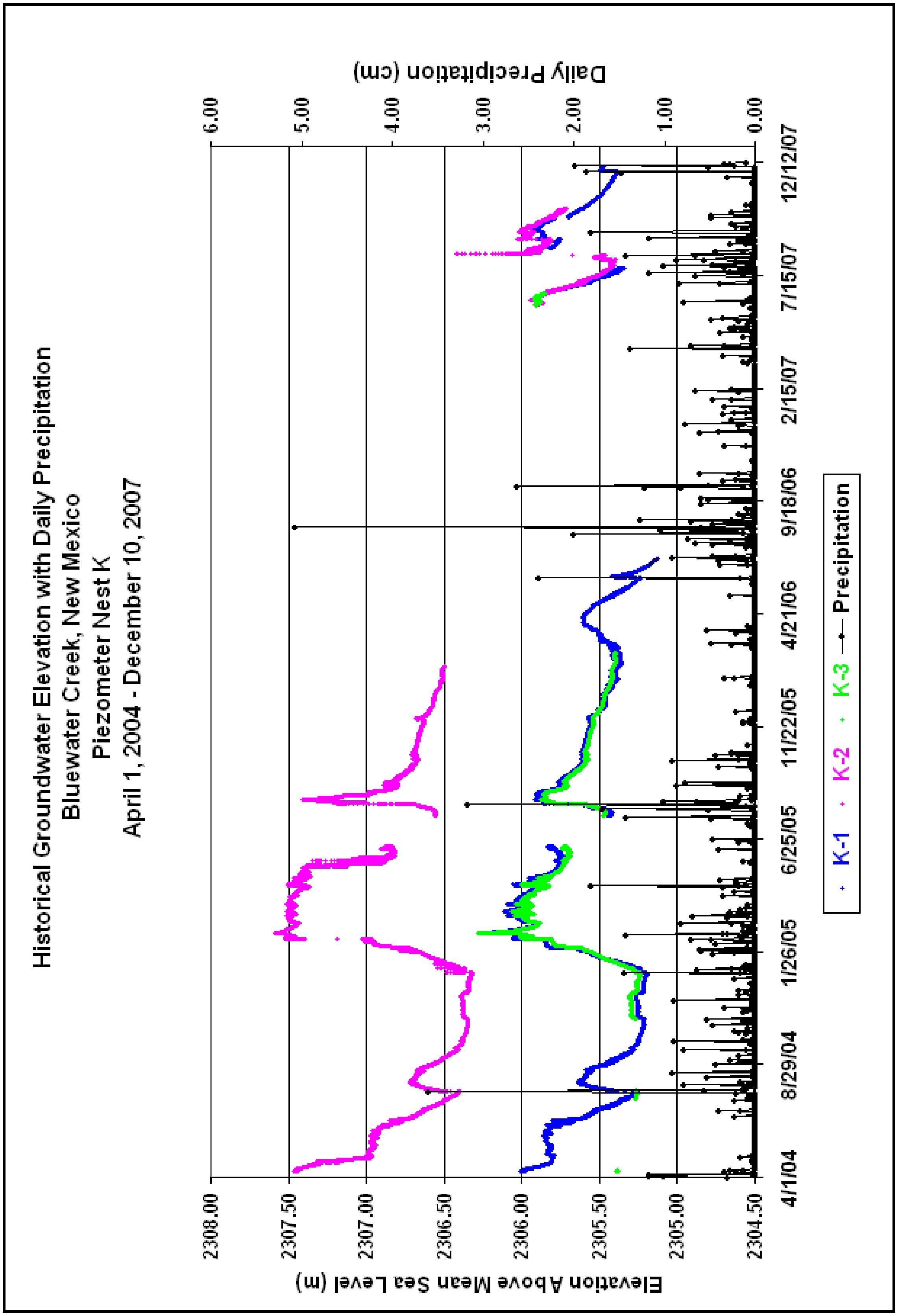

Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest H
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
Daily Precipitation (cm)
2313.75
2313.50
2313.25
2313.00
2312.75
2312.50
2312.25
2312.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
H-1
H-2
H-3
Precipitation



Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest I
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
2313.25
2313.00
2312.75
2312.50
2312.25
2312.00
2311.75
2311.50
2311.25
Daily Precipitation (cm)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
I-1
I-2
I-3
I-4
Precipitation



Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest J
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
Daily Precipitation (cm)
2309.75
2309.25
2308.75
2308.25
2307.75
2307.25
2306.75
2306.25
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
J-3
J-2
Precipitation

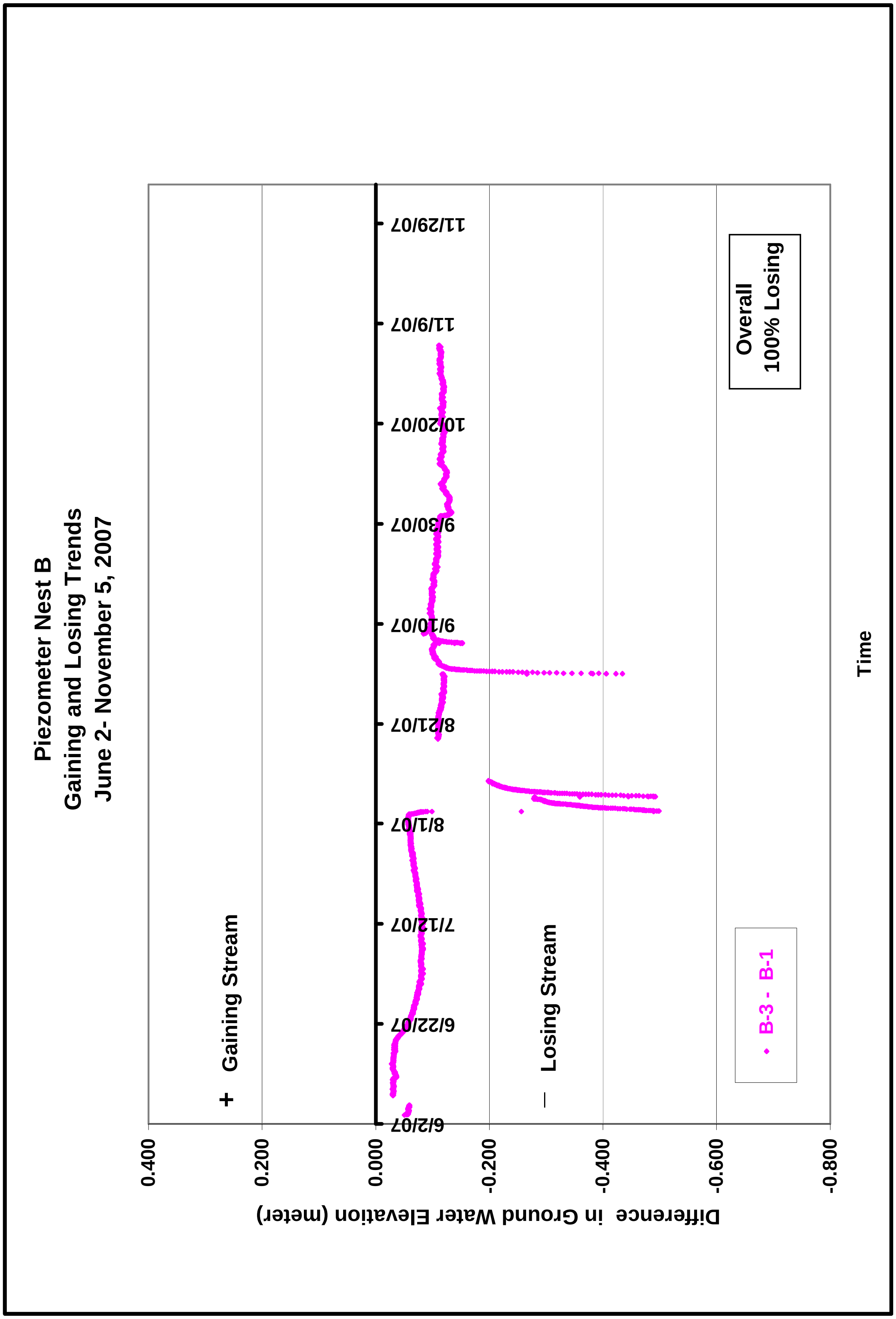


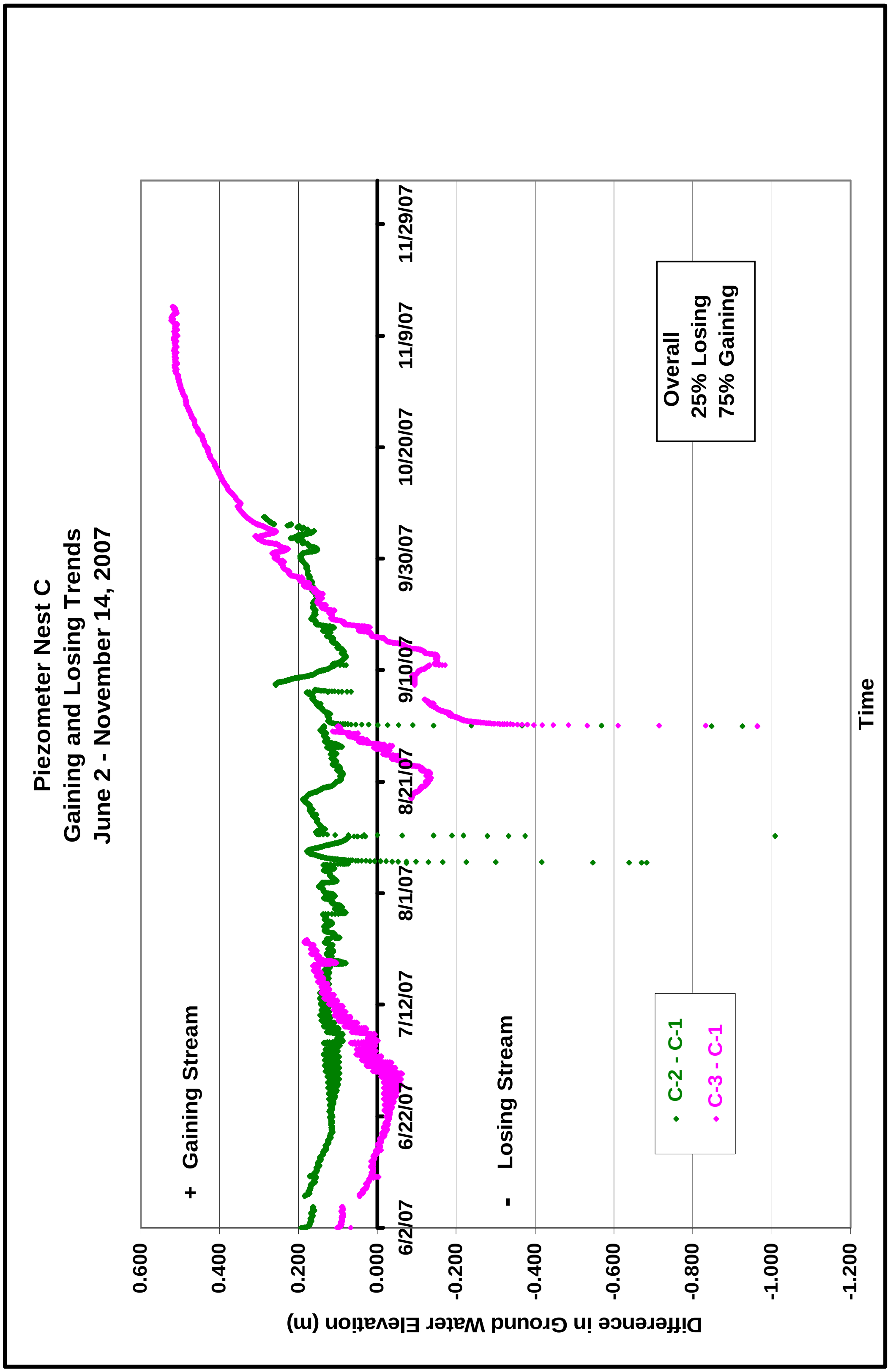
Historical Groundwater Elevation with Daily Precipitation
Bluewater Creek, New Mexico
Piezometer Nest K
April 1, 2004 - December 10, 2007
Elevation Above Mean Sea Level (m)
2308.00
2307.50
2307.00
2306.50
2306.00
2305.50
2305.00
2304.50
Daily Precipitation (cm)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
4/1/04
8/29/04
1/26/05
6/25/05
11/22/05
4/21/06
9/18/06
2/15/07
7/15/07
12/12/07
K-1
K-2
K-3
Precipitation

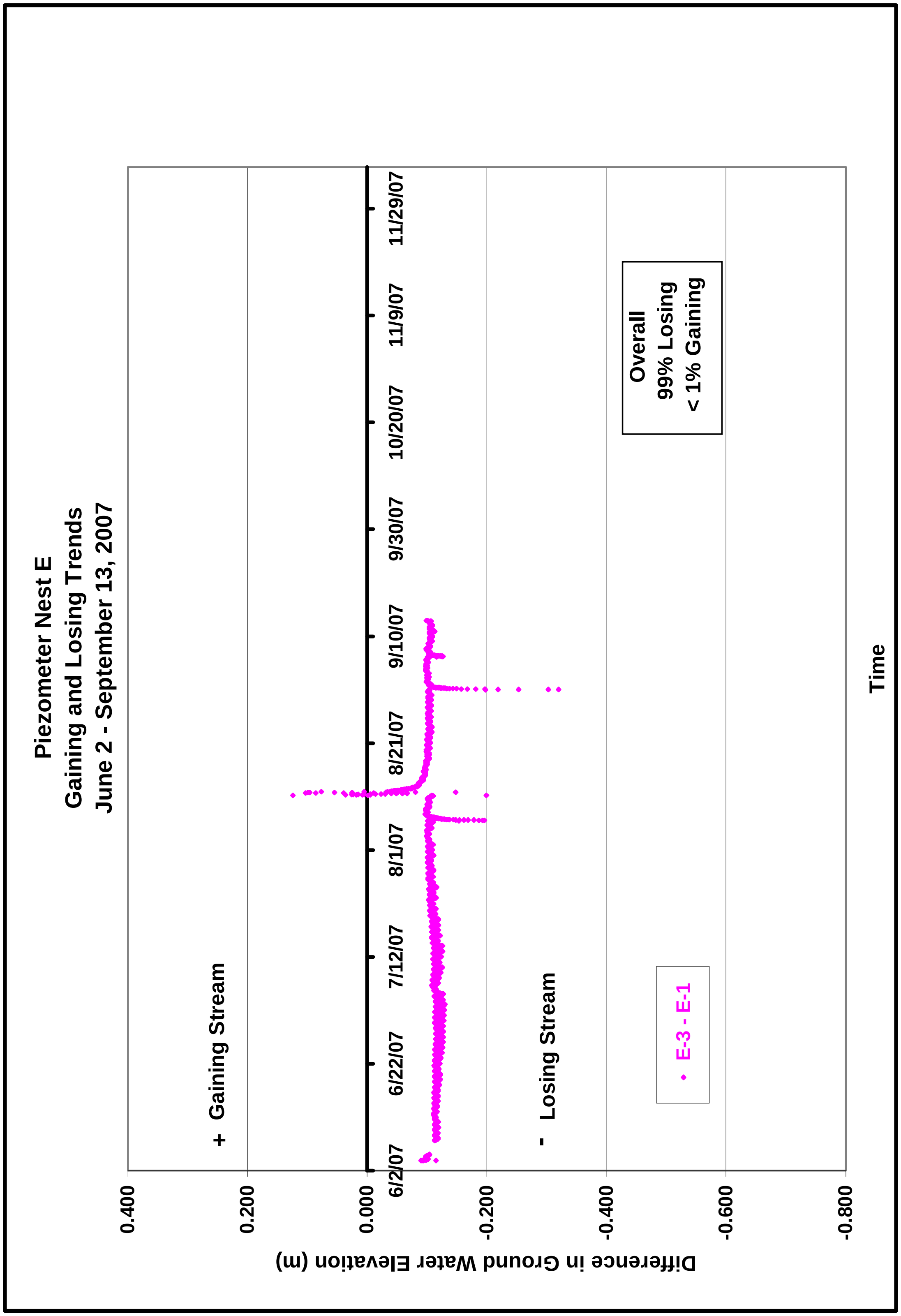
11.3 Losing – Gaining Trend Graphs

(see next page)

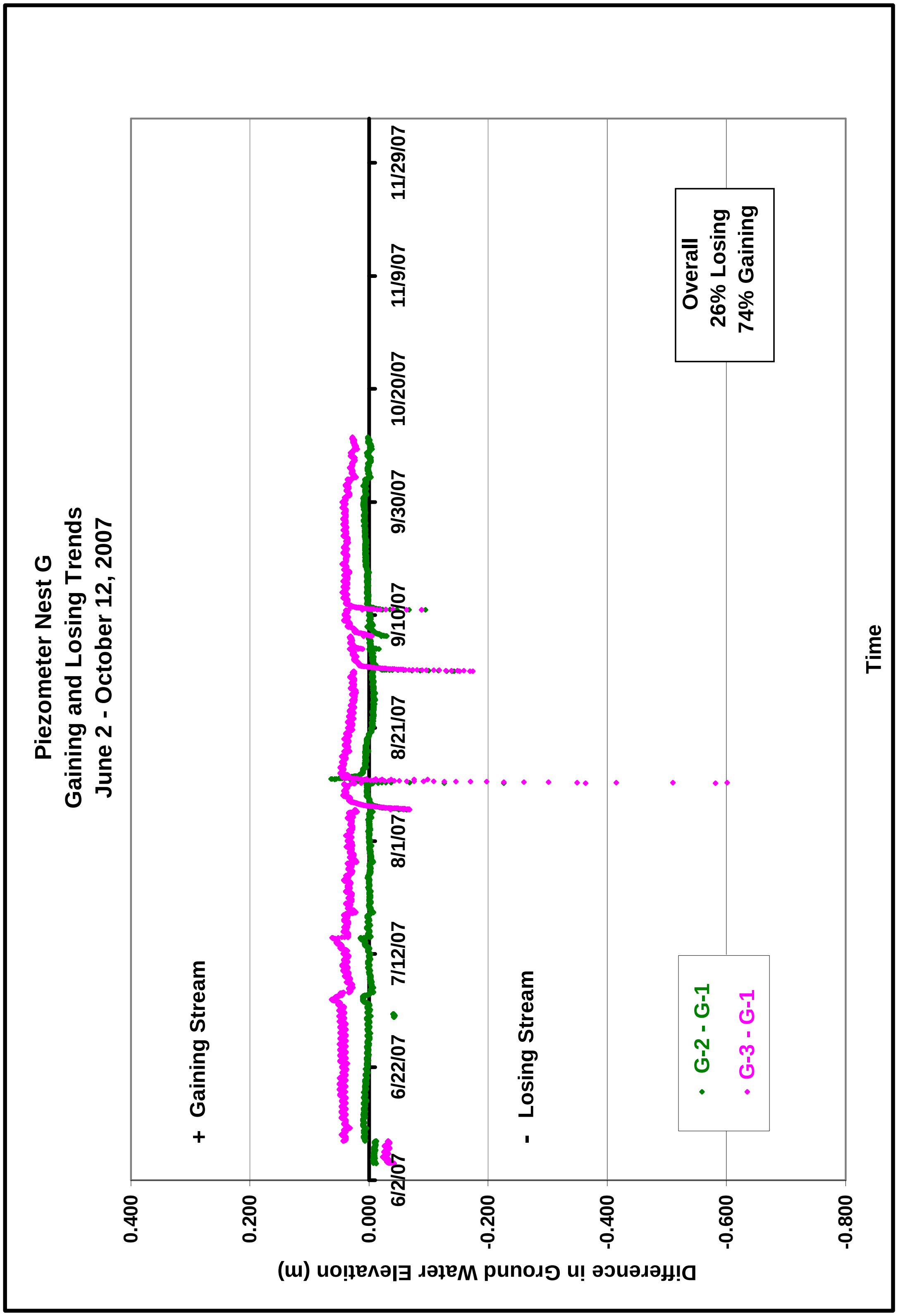
Included here are Piezometer Nests B, C, E, G, H, and J
(Piezometer Nests A, D, F, I and K are provided in the text)

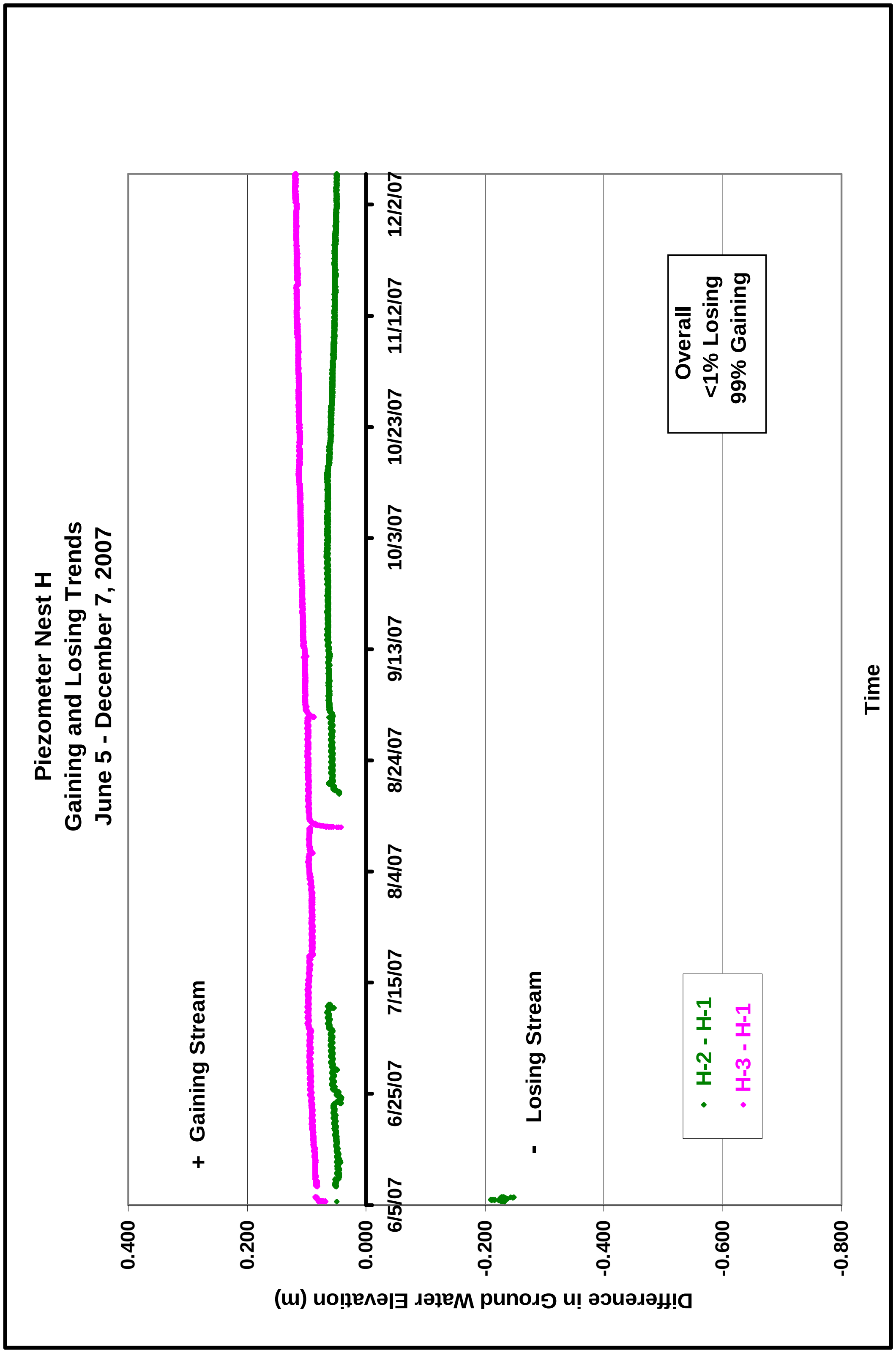

Piezometer Nest B
Gaining and Losing Trends
June 2- November 5, 2007
+ Gaining Stream
— Losing Stream
B-3 - B-1
Overall
100% Losing
Difference in Ground Water Elevation (meter)
Time
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
6/2/07
6/22/07
7/12/07
8/1/07
8/21/07
9/10/07
9/30/07
10/20/07
11/9/07
11/29/07


Piezometer Nest C
Gaining and Losing Trends
June 2 - November 14, 2007
+ Gaining Stream
- Losing Stream
C-2 - C-1
C-3 - C-1
Overall
25% Losing
75% Gaining
Difference in Ground Water Elevation (m)
0.600
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
-1.000
-1.200
6/2/07
6/22/07
7/12/07
8/1/07
8/21/07
9/10/07
9/30/07
10/20/07
11/9/07
11/29/07
Time

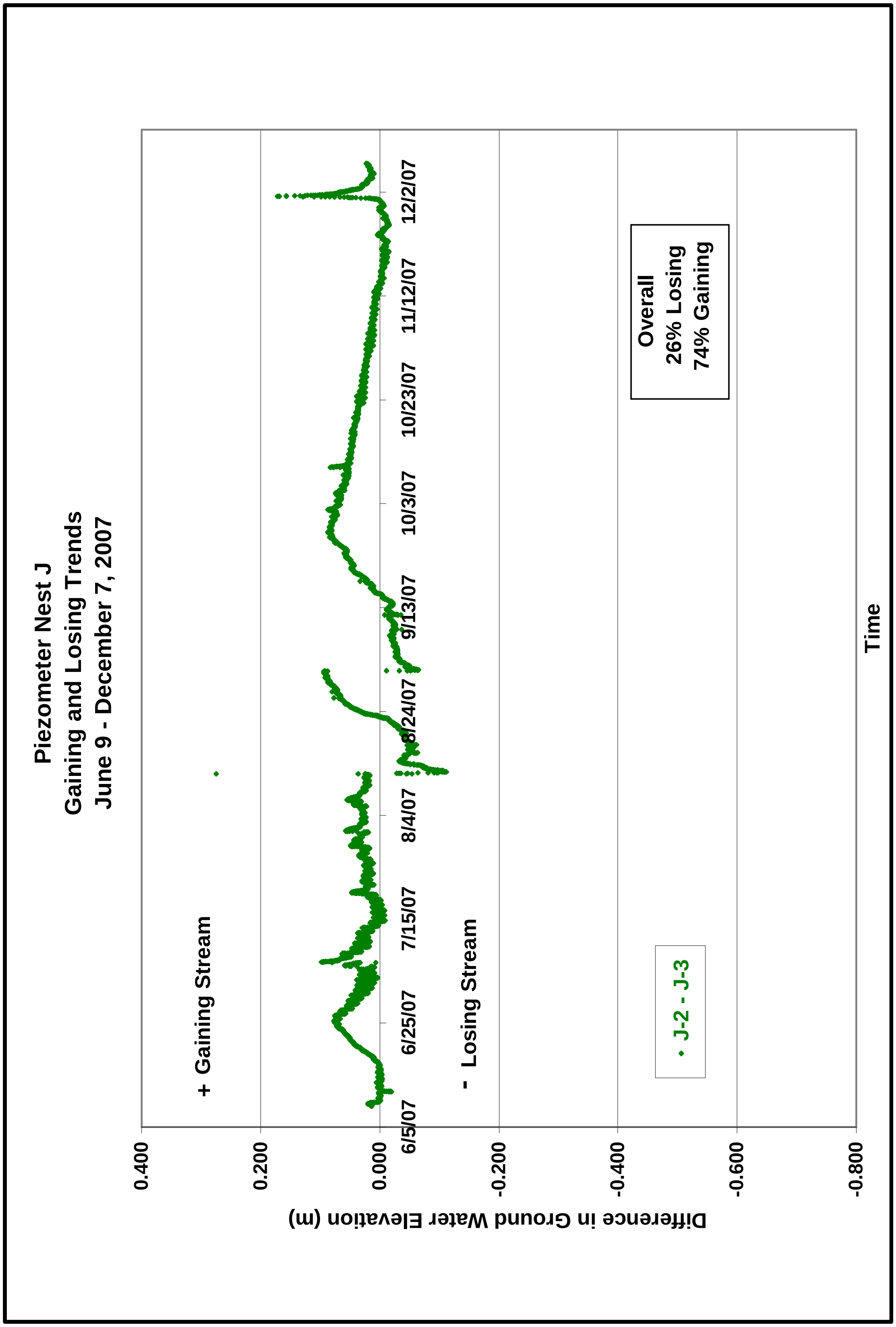


Piezometer Nest E
Gaining and Losing Trends
June 2 - September 13, 2007
+ Gaining Stream
- Losing Stream
E-3 - E-1
Overall
99% Losing
< 1% Gaining
Difference in Ground Water Elevation (m)
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
6/2/07
6/22/07
7/12/07
8/1/07
8/21/07
9/10/07
9/30/07
10/20/07
11/9/07
11/29/07
Time


Piezometer Nest G
Gaining and Losing Trends
June 2 - October 12, 2007
+ Gaining Stream
- Losing Stream
G-2 - G-1
G-3 - G-1
Overall
26% Losing
74% Gaining
Difference in Ground Water Elevation (m)
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
6/2/07
6/22/07
7/12/07
8/1/07
8/21/07
9/10/07
9/30/07
10/20/07
11/9/07
11/29/07
Time



Piezometer Nest H
Gaining and Losing Trends
June 5 - December 7, 2007
+ Gaining Stream
- Losing Stream
Difference in Ground Water Elevation (m)
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
6/5/07
6/25/07
7/15/07
8/4/07
8/24/07
9/13/07
10/3/07
10/23/07
11/12/07
12/2/07
Time
H-2 - H-1
H-3 - H-1
Overall
<1% Losing
99% Gaining



Piezometer Nest J
Gaining and Losing Trends
June 9 - December 7, 2007
+ Gaining Stream
- Losing Stream
J-2 - J-3
Overall
26% Losing
74% Gaining
Difference in Ground Water Elevation (m)
Time
0.400
0.200
0.000
-0.200
-0.400
-0.600
-0.800
6/5/07
6/25/07
7/15/07
8/4/07
8/24/07
9/13/07
10/3/07
10/23/07
11/12/07
12/2/07

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