CHAPTER 6-- GROUNDWATER HYDROLOGY

HydroGeo, Inc. (HydroGeo) was commissioned by CBMR to complete an updated groundwater hydrology study on Snodgrass Mountain. The main purpose of the study is to characterize the shallow groundwater system in the Snodgrass Mountain landslide deposits and its effect on slope stability and to collect baseline hydrologic data from 3 existing piezometers installed in 1995 and from 16 strategically placed piezometers installed in 2006 and 2007. A piezometer is a small diameter water well that is used to measure the hydraulic head of groundwater in a water-bearing zone. A corresponding goal of this study is to develop and compile a database of the water level monitoring data collected from all of the piezometers through time which will be used to assess the current and future slope stability of the landslide deposits on Snodgrass Mountain.

HydroGeo implemented the first phase of the groundwater hydrology study in November 2006. As part of this study, HydroGeo personnel supervised the drilling program and installed and tested 16 new piezometers on Snodgrass Mountain (Table 6-1). The initial water level in the piezometers was recorded at the time of installation. Water levels will be monitored on a continuous long-term year-round basis to provide data needed to better delineate the hydrogeologic characteristics of the shallow groundwater system on the upper and lower slopes of Snodgrass Mountain and to analyze how water level fluctuations relate to natural seasonal variations and to future snow-making and ski area expansion operations.

This report discusses the methodology and details of the groundwater hydrology study and includes specific details on the piezometer locations and installation data, hydraulic testing data, baseline groundwater level data collected to date, and information on the long-term monitoring program.

The only known historical study of the groundwater hydrology on Snodgrass Mountain was completed by Resource Consultants and Engineers in 1995 (RCE, 1995). As part of this original study, five test boreholes were drilled (SG-1, SG-2, SG-3, SG-4, and SG-5) on the “East Slide” area of Snodgrass (Figure 6-1) and piezometers were installed in three of the test boreholes (SG-3, SG-4, and SG-5).

6.1 Piezometer Installation and Testing

6.1.1 Piezometers Installed in 1994

As part of the original geologic hazards evaluation for the Environmental Impact Study (EIS) of the Snodgrass Mountain ski area expansion, RCE drilled 5 boreholes (SG-1 – SG-5) on the East Slide area of Snodgrass Mountain in the fall of 1994 (Fig. 6-1) (RCE, 1995). The boreholes were drilled in order to assess the subsurface foundation conditions along the proposed gondola route. The boreholes were logged and standard penetration testing was performed about every 5 feet in depth.

Two of these boreholes, SG-1 and SG-2, were completed in the “Chicken Bone” area on Snodgrass Mountain (Geologic Hazard Unit (GHU) 6) and were relatively shallow (25-30 ft), because the drillers encountered hard Tertiary porphyry bedrock. Since neither of these boreholes encountered groundwater, no piezometers were installed, and the borehole locations are not shown on Fig. 6-1, Piezometer Location Map.

The remaining three boreholes, SG-3, SG-4, and SG-5, were drilled at the head, center, and toe, respectively, of the East Slide area (GHU 5). Groundwater was encountered at SG-3, SG-4 and SG-5 and these boreholes penetrated through the entire body of the East Slide and into the underlying Mancos Shale bedrock. Piezometers were installed in these three boreholes by RCE in 1994 (Tables 6-1 and 6-2 and Appendix 6-2) (RCE, 1995). However, since permeability tests were not completed in these piezometers and the piezometers were not capped or protected with proper well heads, they fell into disrepair until the fall of 2006.

In November 2006, as part of the current groundwater hydrology study (this report), HydroGeo located and repaired the previously installed piezometers at SG-3, SG-4, and SG-5. HydroGeo attached three-foot lengths of 2-inch Schedule 40 PVC pipe to the top of each piezometer and fitted each piezometer with a locking well cap. HydroGeo installed and calibrated water level probes and dataloggers (Global Water WL16) in all three piezometers and set them to record water level data every hour. HydroGeo also installed a steel well head at SG-5 and set up “PVC snow poles” to help locate the piezometers for monitoring in the winter months.

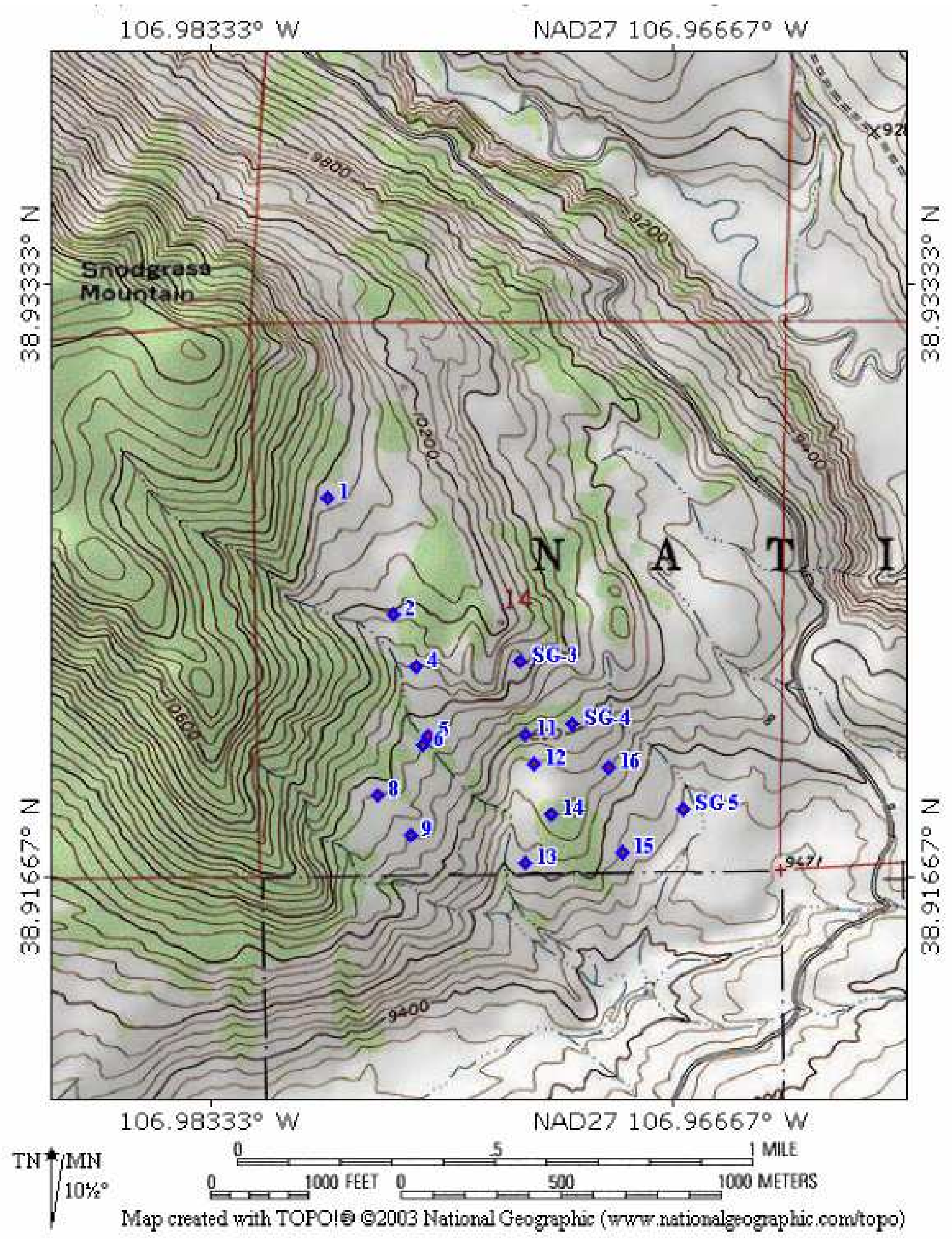

Figure 6-1. Piezometer Location Map

6.1.1.1 Piezometer SG-3

Piezometer SG-3 was completed on October 11, 1994 by RCE and is located in the upper part of GHU-5A below the "Steep Slope Band" (Figure 6-1) (RCE, 1995). The borehole was drilled to depth of 63.5 feet below ground surface (bgs). Unconsolidated landslide materials were encountered from the surface to a depth of about 63 feet bgs. RCE (1995) does not specify on the geologic log whether Mancos Shale was encountered at the bottom of the borehole. Piezometer SG-3 was completed to a depth of 63.5 feet (bgs). RCE (1995) does not specify whether the piezometer was screened or if it was simply left open. The only water-bearing interval intercepted at this location was detected at about 42 feet bgs. Since the dataloggers were installed in November 2006, the water level in piezometer SG-3 has shown typical seasonal changes over the period of record with the highest water levels recorded in May 2007 during spring snowmelt and the lowest level recorded in March 2007. The current (11/16/07) water level is 46.74 feet below top of casing (btoc). Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-2. The geologic log for piezometer SG-3 is presented in Appendix 6-2.

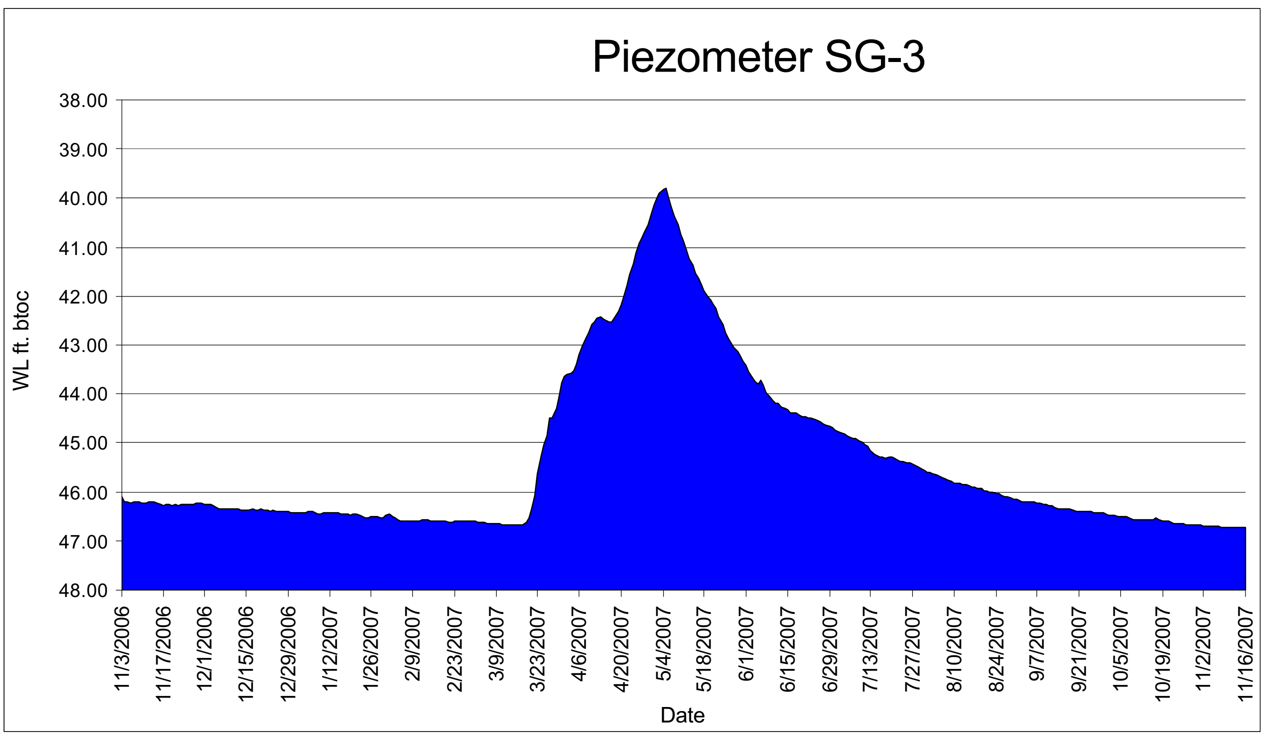

Figure 6-2. Piezometer SG-3 Water Levels

6.1.1.2 Piezometer SG-4

Piezometer SG-4 was completed on October 12, 1994 by RCE and is located in the upper part of GHU-5B below the “Steep Slope Band” (Figure 6-1) (RCE, 1995). The borehole was drilled to depth of 100.5 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of about 45 feet bgs. Mancos Shale was encountered from 45 feet bgs to the bottom of the borehole. Piezometer SG-3 was completed to a depth of 100.0 feet (bgs). RCE (1995) does not specify whether the piezometer was screened or if it was simply left open. The only water-bearing interval intercepted at this location was detected at about 11.5 feet bgs. Since the dataloggers were installed in November 2006, the water level in piezometer SG-4 over the period of record has shown typical seasonal changes with the highest water levels recorded in April 2007 during spring snowmelt and the lowest level recorded in September 2007. The current (11/18/07) water level is 21.13 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-3. The geologic log for SG-4 is presented in Appendix 6-2.

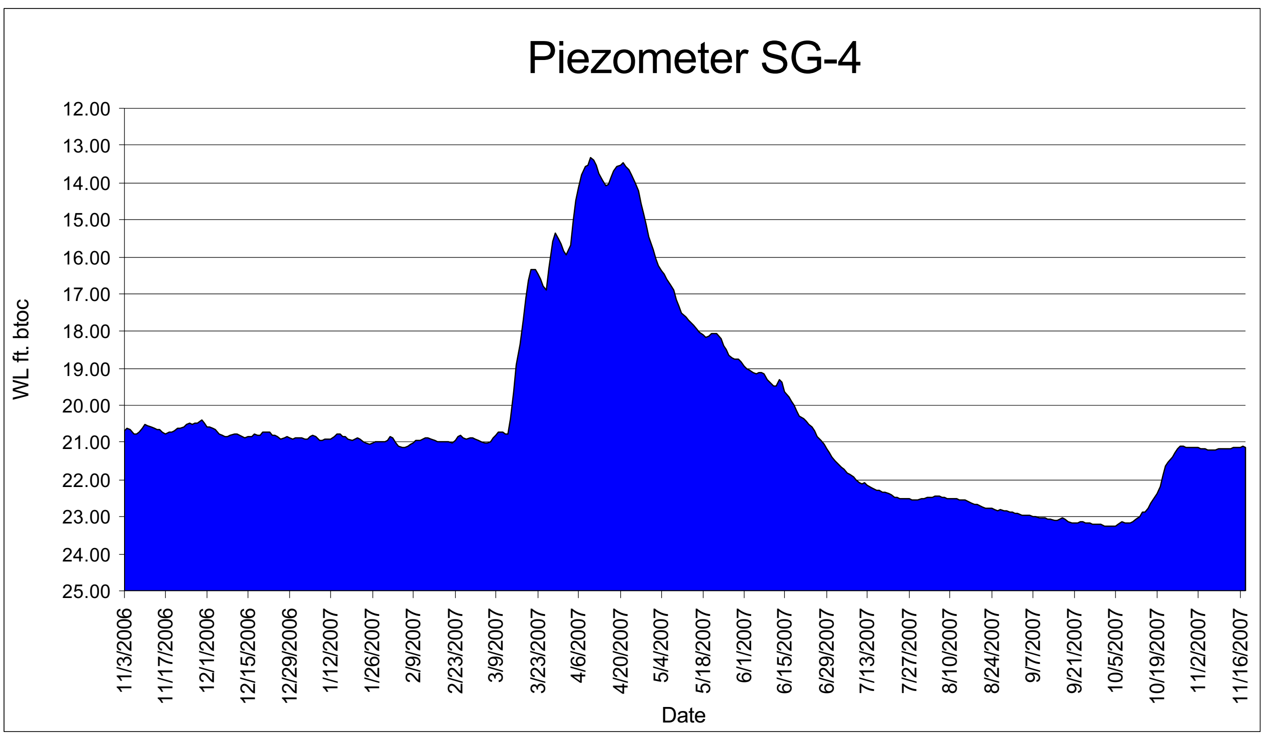

Figure 6-3. Piezometer SG-4 Water Levels

6.1.1.3 Piezometer SG-5

Piezometer SG-5 was completed on October 13, 1994 by RCE and is located in the lower part of GHU-5B below the "Steep Slope Band" (Figure 6-1) (RCE, 1995). The borehole was drilled to depth of 80.5 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of about 76 feet bgs. Mancos Shale was encountered from 76 feet bgs to the bottom of the borehole. Piezometer SG-5 was completed to a depth of 80.0 feet (bgs). RCE (1995) does not specify whether the piezometer was screened or if it was simply left open. The only water-bearing interval intercepted at this location was detected at about 10 feet bgs. Since the dataloggers were installed in December 2006, the water level in piezometer SG-5 over the period of record has shown typical seasonal changes with the highest water levels recorded in April 2007 during spring snowmelt and the lowest level recorded in March 2007. The current (11/18/07) water level is 11.04 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-4. The geologic log for piezometer SG-5 is presented in Appendix 6-2.

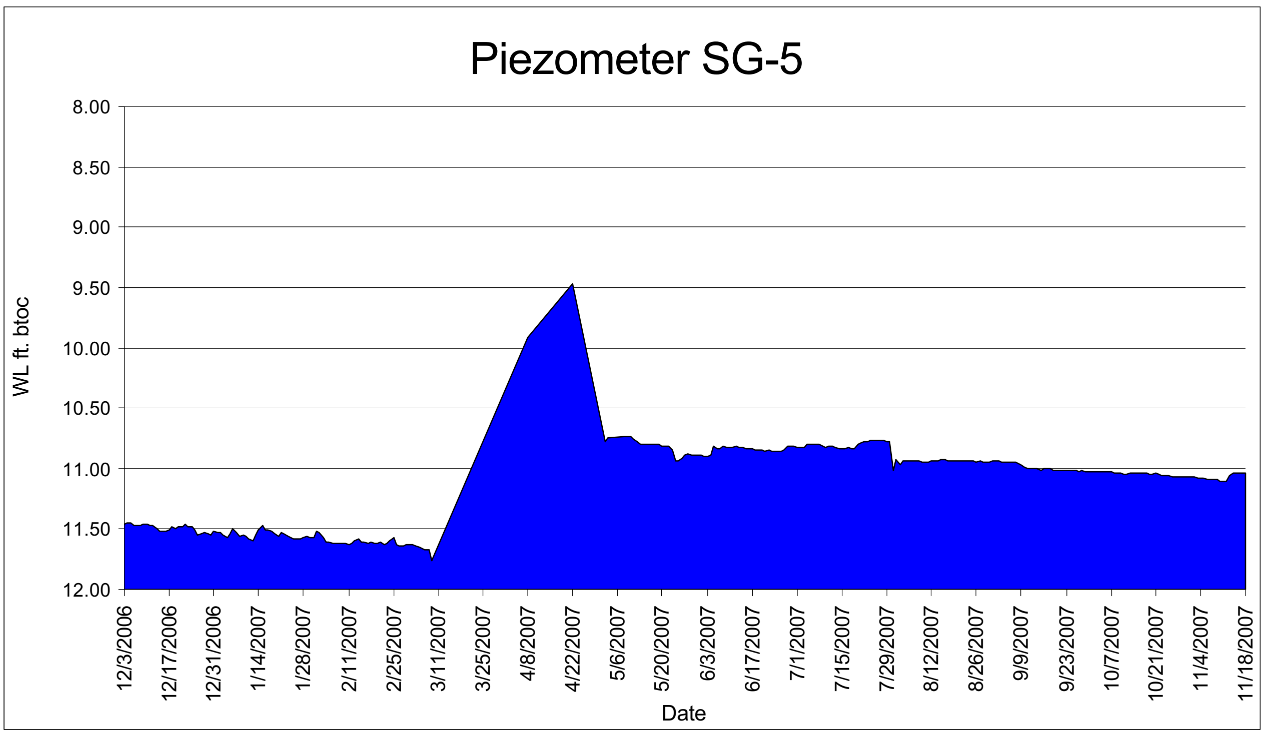

Figure 6-4. Piezometer SG-5 Water Levels

Table 6-1. Summary of Snodgrass Mountain Piezometer Completion Data
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Piezometer	Completion Date	SGM Surveyed Top of Well Head Elevation (ft) [1,2]	Piezometer Depth (feet bgs)	Borehole Diameter/ Casing Diameter (inches)	Casing\ Screen Material	Screened Intervals (ft. bgs)
Piezometers Above Steep Slope Band						
PZ-1[1]	7/10/2007	10,374[1]	27.0	6.0 / 2.0	Sch. 40 PVC \ 0.020 PVC	17.0-27.0
PZ-2	7/11/2007	10,153.97	19.0	6.0 / 2.0	Sch. 40 PVC \ 0.020 PVC	9.0-19.0
PZ-4	7/12/2007	10,072.92	40.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	30.0-40.0
PZ-5	7/16/2007	9,962.32	23.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	13.0-23.0
PZ-6A (deep)	7/16/2007	9,957.77	66.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	56.0-66.0
PZ-6B (shallow)	7/17/2007	9,957.78	25.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	15.0-25.0
PZ-8A (deep)	7/18/2007	9,954.96	56.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	46.0-56.0
PZ-8B (shallow)	7/18/2007	9,954.73	25.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	15.0-25.0
PZ-9	7/17/2007	9,891.71	37.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	27.0-37.0
Piezometers Below Steep Slope Band						
PZ-11	7/29/2007	9,790.12	56.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	46.0-56.0
PZ-12	7/29/2007	9,714.56	27.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	17.0-27.0
PZ-13A (deep)	7/24/2007	9,620.66	40.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	30.0-40.0
PZ-13B (shallow)	7/26/2007	9,622.33	17.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	7.0-17.0
PZ-14	7/28/2007	9,696.99	35.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	25.0-35.0
PZ-15	11/14/2006	9,543.38	33.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	23.0-33.0
PZ-16	11/15/2006	9,681.22	40.0	6.0 / 2.0	Sch. 40 PVC\ 0.020 PVC	30.0-40.0
SG-3[1]	10/11/1994	10,009[1]	63.5[3]	6.0[3] / 1.5[3]	Sch. 40 PVC\ ?? PVC	n.a.
SG-4[1]	10/12/1994	9,799[1]	100.0[3]	6.0[3] / 1.5[3]	Sch. 40 PVC\ ?? PVC	n.a.
SG-5	10/13/1994	9,553.74	80.0[3]	6.0[3] / 1.5[3]	Sch. 40 PVC\ ?? PVC	n.a.

n.a. – data not available
(1) Site not surveyed, elevation based on topographic map
(2) Adapted from Schmueser, Gordon Meyer (2007); surveyed top of well head casing.
(3) Adapted from RCE (1995)

Table 6-2. Summary of Snodgrass Mountain Piezometer Elevation and Ground Water Level Data

Piezometer	Geologic Hazard Unit (GHU)	Surface Elevation (ft amsl)		Groundwater Level (ft)[1]			Axial Drainage
		Calculated Ground Elevation (ft amsl)	Surveyed Top of Well Head (ft amsl)[3]	Top of PVC Casing (ft amsl)	Depth to Ground-water (ft below Top of PVC Casing (btoc)	Groundwater Elevation (ft amsl)	~Elevation (ft amsl)[4]
Piezometers Above Steep Slope Band							
PZ-1[2]	GHU-6	10,370.83[2]	10,374[2]	10,373.61[2]	28.90	10,344.71[2]	
PZ-2	GHU-6	10,150.70	10,153.97	10,153.64	8.25	10,145.39	
PZ-4	GHU-3	10,069.87	10,072.92	10,072.52	14.97	10,057.95	10,055[4]
PZ-5	GHU-3	9,959.11	9,962.32	9,962.01	14.99	9,947.02	9,935[4]
PZ-6A (deep)	GHU-1B	9,954.71	9,957.77	9,957.48	Artesian	Artesian (~9,960 ft)	9,935[4]
PZ-6B (shallow)	GHU-1B	9,954.53	9,957.78	9,957.41	19.28	9,938.13	9,935[4]
PZ-8A (deep)	GHU-1B	9,951.83	9,954.96	9,954.66	8.95	9,945.71	
PZ-8B (shallow)	GHU-1B	9,951.23	9,954.73	9,954.48	16.58	9,937.90	
PZ-9	GHU-1B	9,888.80	9,891.71	9,891.50	22.71	9,868.79	
Piezometers Below Steep Slope Band							
PZ-11	GHU-3	9,786.66	9,790.12	9,789.67	44.09	9,745.58	
PZ-12	GHU-4	9,711.02	9,714.56	9,714.25	9.91	9,704.34	
PZ-13A (deep)	GHU-4	9,617.31	9,620.66	9,620.29	20.65	9,599.64	9,595[4]
PZ-13B (shallow)	GHU-4	9,619.04	9,622.33	9,621.99	15.19	9,606.80	9,595[4]
PZ-14	GHU-2	9,694.31	9,696.99	9,696.69	27.97	9,668.72	
PZ-15	GHU-4	9,540.34	9,543.38	9,542.93	34.32	9,508.61	
PZ-16	GHU-5B	9,677.93	9,681.22	9,680.79	18.27	9,662.52	
SG-3[2]	GHU-5A	10,005.16[2]	10,009[2]	10,009[2]	46.46	9,962.54	
SG-4[2]	GHU-5B	9,795.67[2]	9,799[2,]	9,799[2]	23.22	9,775.78	
SG-5	GHU-5B	9,549.38	9,553.74	9,553.01	11.02	9,541.99	

(1) September 29, 2007
(2) Site not surveyed, elevation based on topographic map. PVC stick up height not provided in RCE (1995); measured in field.
(3) Adapted from Schmueser, Gordon, Meyer (2007); surveyed top of well head.
(4) Estimated elevation, not surveyed

6.1.2 Piezometers Installed in 2006 and 2007

The piezometers installed in 2006 and 2007 by HydroGeo are located on both private and US Forest Service (USFS) property (Figure 6-1). Prior to initiating the drilling program, CBMR notified affected landowners of the proposed drilling program and numerous permits were applied for and acquired. Since the proposed Snodgrass Mountain expansion is located within the Special Use Permit Area boundary for CBMR, the USFS requires that a Categorical Exclusion and Decision Memo be issued prior to the installation of piezometers on USFS property. In order to provide the USFS with the necessary information to grant a Categorical Exclusion and Decision Memo, two on-site visits to the proposed drilling locations were conducted on October 30, 2006 and June 1, 2007. The field trip participants, John Norton and Roark Kiklevich (CBMR), Gay Austin and Kai Allen (USFS), Joe Frank and Paul Holder (HydroGeo), and Jim McCalpin (Geo-Haz Consulting), previewed the proposed drilling site locations and access routes affecting USFS property. Subsequent to the field trip(s) and scoping process, public comments and concerns were incorporated into the original proposal and minor revisions were made. CBMR submitted a “Notice of Intent to Construct Monitoring Holes” (NOI) for 5 monitoring wells (PZ-12 – PZ-14 on USFS lands and PZ-15 and PZ-16 on private property) to the Colorado Division of Water Resources (CDWR) on November 7, 2006 and permits were approved on November 9, 2006. Subsequent NOIs for an additional 14 monitoring wells were submitted to the CDWR on June 1 and June 7, 2007 and approved on June 7 and June 12, 2007, respectively. A Categorical Exclusion and Decision Memo to drill and install the piezometers on USFS land was granted by the Gunnison Ranger District of the USFS on November 13, 2007 (USFS, 2007).

Upon approval and receipt of the required permits, HydroGeo began implementing the first phase of the drilling program in November 2006. D.A. Smith Drilling Company of Western Colorado. (D.A. Smith) located in Loma, Colorado, a MSHA and OSHA certified drilling contractor (License #1324), was retained to drill and install the piezometers.

The USFS Decision Memo (USFS, 2007) stipulations mandated that the Snodgrass Mountain drilling program must adhere to practices that incur minimal surface disturbance impacts. A hazardous material spill contingency plan was submitted and approved to the USFS prior to drilling operations. In addition, before mobilizing the drilling equipment to Snodgrass Mountain, D.A. Smith pre-cleaned all equipment according to USFS protocols to minimize the potential for inadvertently introducing of noxious weeds. In addition, in order to minimize drilling-related impacts, D.A. Smith used a Dietrich D-50 track-mounted auger drill rig and several ATV’s to assist in transporting supplies and personnel to the drill sites on Snodgrass Mountain. HydroGeo personnel also used an ATV and/or hiked to the drill sites. Furthermore, in compliance with the Decision Memo (USFS, 2007), all stream crossings on the designated drilling equipment access routes were armored with temporary bridge “swamp mats” to prevent erosion and to minimize adverse impacts to vegetation caused by the drilling equipment. The swamp mats were removed upon project completion and no roads were constructed for this project. The first phase of the drilling program began in November 2006 and was intentionally halted for several months until July 2007, due to site inaccessibility and winter snow accumulation and to avoid adverse surface impacts on wet spring soils.

HydroGeo personnel supervised the drilling operations, completed the permeability (slug) tests, and installed water level probes and data loggers in each piezometer following completion. Upon cessation of drilling operations, HydroGeo promptly reclaimed and reseeded the drill sites according to USFS protocol and the Decision Memo (USFS, 2007) requirements. After the piezometers were installed in August 2007, monitoring well permit applications were filed with the CDWR and well permits were issued in November 2007.

The following discussion provides details on the drilling, installation, and testing of the piezometers in relationship to the “Steep Slope Band” feature located on the lower slopes of Snodgrass Mountain. This Steep Slope Band runs NE-SW across the lower face of the mountain between elevations 9,750-9,900 ft (at its NE end) and 9,600-9,750 ft (at its SW end). The 150 ft-high slope band averages a 21° slope to the SE, exposes Mancos Shale on its face, and hydraulically separates the landslide deposits. Several springs also occur along this feature.

6.1.2.1 Drilling Methodology

All of the boreholes drilled in 2007 were drilled with a 6-inch diameter solid stem auger system. The boreholes were logged and standard penetration testing (SPT) was performed at approximate 5 foot intervals. A split spoon sampler was used to collect in-situ soil\rock samples for geotechnical testing and geologic description. Particular attention was made to collect samples from the failure plane at the base of the landslide deposits. It should be noted that in the November 2006 drilling period, the use of a hollow stem auger system was implemented, but this was deemed unsuitable, because of the frequency of encountering large impenetrable boulders in the Snodgrass Mountain landslide deposits. The split spoon samples and selected drill cutting samples are archived at GeoHaz Consulting.

The piezometers installed in 2006 and 2007 were completed with 2-inch Schedule 40 PVC screw jointed casing and 0.020 inch factory slotted screen. The screened intervals were 10 feet in length at the bottom of the piezometers within the water-bearing zones identified during the drilling operations. End caps were installed on the bottom of each piezometer. The annulus of the screened intervals and several feet above the screen were filled with 10/20 silica sand filter pack, followed by a 1 to 2 foot seal of hydrated 3/8 inch bentonite chips. The remainder of the annulus was filled with native drill cuttings and the top 2 feet was filled with cement seal in which a locking steel well head was placed. In compliance with the Decision Memo (USFS, 2007), the cuttings from the drilling activities were placed back in the borehole and/or contoured around the vicinity of the borehole. In addition, all abandoned boreholes were backfilled and restored to natural contours.

Piezometer construction and geologic log diagrams are presented in Appendix 6-1 and a summary of the piezometer construction details, elevations, and groundwater level data are in Tables 6-1 and 6-2.

After the completion of the slug tests (Section 6.3), Global Water Model WL-16 water level probes and dataloggers were installed in each piezometer in August 2007, except at piezometers PZ-15 and PZ-16 where probes and dataloggers were installed in

January 2007. The dataloggers were calibrated to the water level at the time of installation and set to continuously record water levels every hour. There is minimal water level data available at this time (November 2007) since the majority of the dataloggers were not installed until August 2007. However, water level data has been collected since January 2007 at piezometers PZ-15 and PZ-16and since December 2006 at piezometer SG-5. Two to three months of baseline data are inadequate to make inferences about climatological or seasonal variations. However, the longer term initial baseline data collected since January 2007 from piezometers PZ-15 and PZ-16 and since December 2006 from piezometer SG-5 indicate distinct seasonal hydrographs. The continuous water level data recorded by the dataloggers will be useful for comparison to baseline conditions (pre-ski area expansion) to determine if groundwater level changes are due to seasonal changes, climatological events, or ski area activities in the future.

6.1.2.2 Piezometer PZ-1

Piezometer PZ-1 was drilled and completed on July 10, 2007 and is located on the upper part of GHU-6 above the “Steep Slope Band” (Figure 6-1). The borehole was drilled to a depth of 67 feet below ground surface (bgs). During drilling, unconsolidated landslide materials were encountered from the surface to a depth of 51 feet bgs and Mancos Shale was encountered from a depth of 51 feet to 67 feet. Piezometer PZ-1 was completed to a depth of 27 feet (bgs) because the hole collapsed to that depth when the drill string was removed, and it contains 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 22.5 feet bgs. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-1 has been rising slowly and is currently (11/16/07) at about 28.90 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-5. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

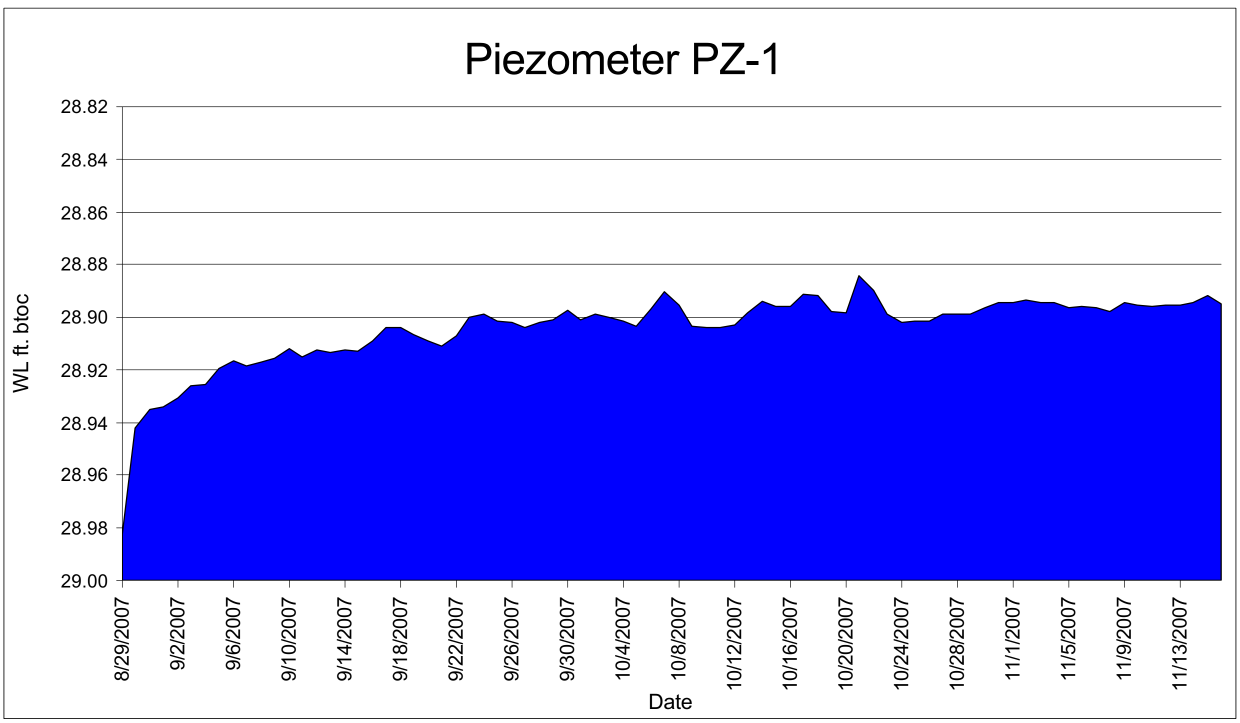

Figure 6-5. Piezometer PZ-1 Water Levels

6.1.2.3 Piezometer PZ-2

Piezometer PZ-2 was drilled and completed on July 11, 2007 and is located on the lower part of GHU-6 above the "Steep Slope Band" (Figure 6-1). The borehole was drilled to a depth of 20 feet below ground surface (bgs). Unconsolidated landslide materials were encountered from the surface to a depth of 16.75 feet bgs and Mancos Shale was encountered from a depth of 16.75 feet to 20 feet. Piezometer PZ-2 was completed to a depth of 19 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 10.5 feet bgs. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-2 has been relatively steady and is currently (11/16/07) at about 9.18 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-6. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

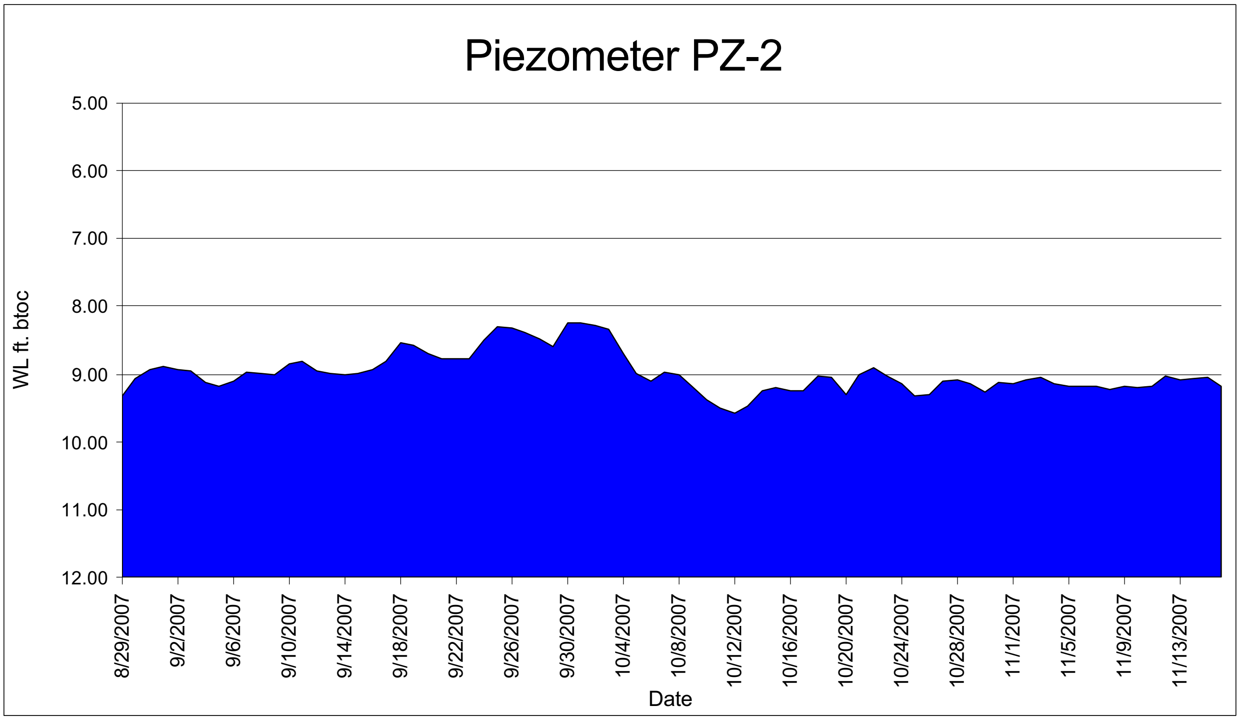

Figure 6-6. Piezometer PZ-2 Water Levels

6.1.2.4 Piezometer PZ-3

The proposed piezometer PZ-3 was not drilled, due to access concerns and problems.

6.1.2.5 Piezometer PZ-4

Piezometer PZ-4 was drilled and completed on July 12, 2007 and is located on the upper south side of GHU-3 above the “Steep Slope Band” and north of the “Axial Drainage” (Figure 6-1). The borehole was drilled to depth of 44 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 41 feet bgs and Mancos Shale was encountered from a depth of 41 feet to 44 feet. Piezometer PZ-4 was completed to a depth of 40 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 38 feet bgs. Between July 12 and August 29 (when the datalogger was installed) the water table rose from 38 ft below surface to 14.7 ft below the surface, a rise of nearly 24 ft. This indicates strongly confined conditions. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-4 has been lowering slowly and is currently (11/16/07) at about 15.61 feet btoc. The water level in this piezometer is approximately 3 feet above the water level in the adjacent “Axial Drainage”. The water level data collected to date cover a very short time period and are considered preliminary, but indicate that the drainage is gaining in this area. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-7. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

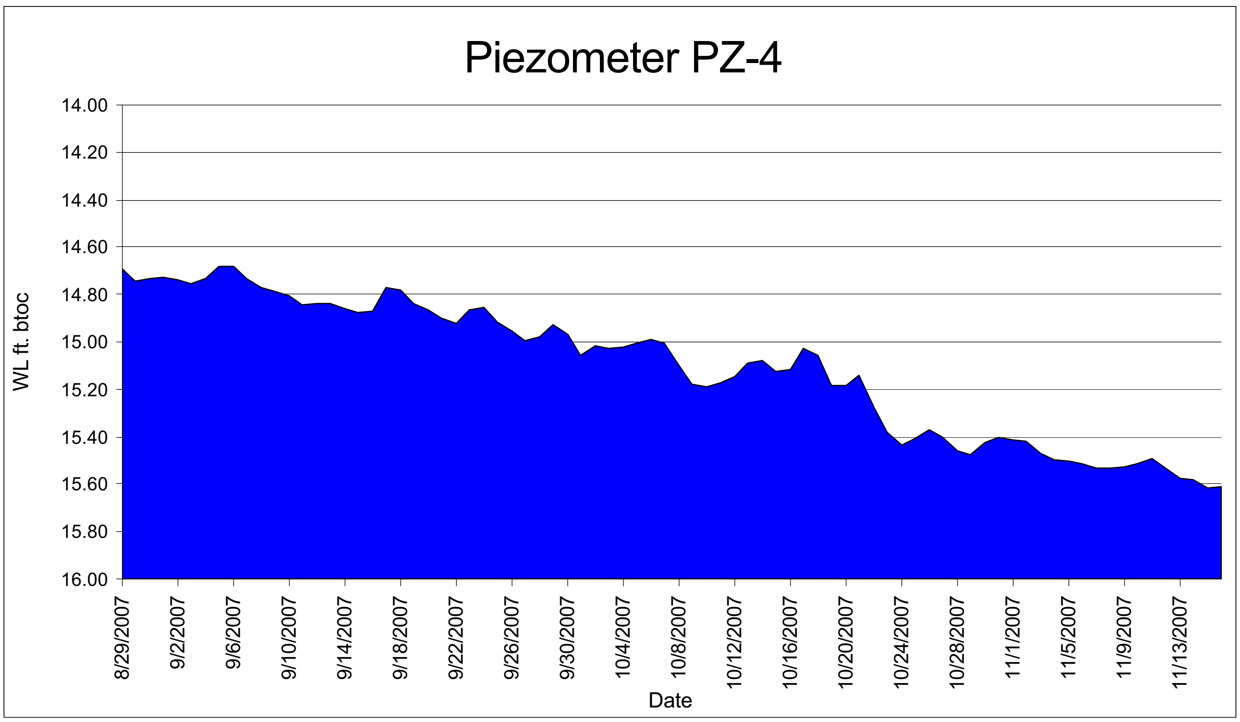

Figure 6-7. Piezometer PZ-4 Water Levels

6.1.2.6 Piezometer PZ-5

Piezometer PZ-5 was drilled and completed on July 13-16, 2007 and is located on the middle south side of GHU-3 above the “Steep Slope Band” and north of the “Axial Drainage” (Figure 6-1). The borehole was drilled to depth of 89 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 85 feet bgs and Mancos Shale was encountered from a depth of 85 to 89 feet. Piezometer PZ-5 was completed to a depth of 23 feet (bgs) because the hole collapsed to that depth when the drill string was removed, and it contains 10 feet of screen at the bottom. The piezometer was screened in the upper water-bearing interval intercepted at this location, which was detected at about 21 feet bgs. A lower water-bearing interval was also encountered at a depth of about 64 feet bgs above the Mancos Shale. However, a deep piezometer could not be installed at this interval because of severe caving borehole conditions. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-5 has been rising slowly and is currently (11/16/07) at about 14.76 feet btoc. The water level in this piezometer is approximately 12 feet above the water level in the adjacent “Axial Drainage”. The water level data collected to date cover a very short time period and are considered preliminary, but indicate that the drainage is gaining in this area. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-8. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

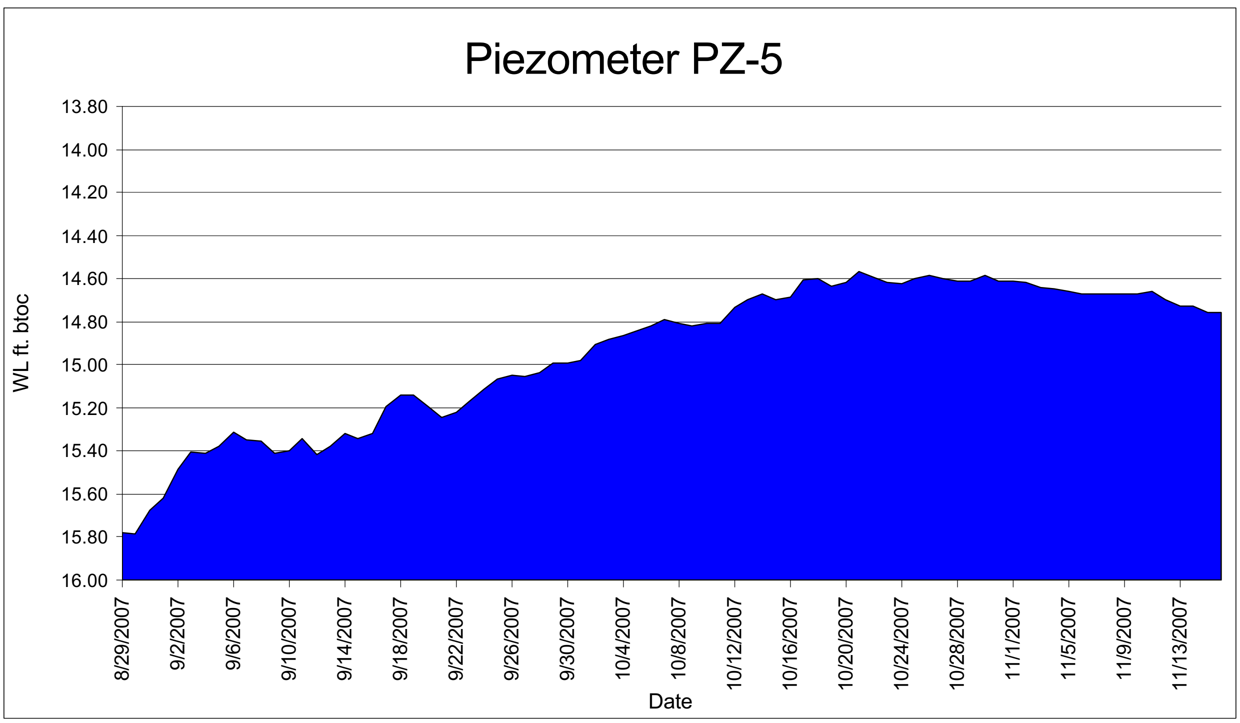

Figure 6-8. Piezometer PZ-5 Water Levels

6.1.2.7 Piezometer PZ-6

Two piezometers were installed at the PZ-6 location: a deep piezometer, PZ-6A, and a shallow piezometer, PZ-6B. Piezometer PZ-6A was completed on July 16, 2007 and piezometer PZ-6B was completed on July 17, 2007. Both of these piezometers are located on the upper north side of GHU-1B above the "Steep Slope Band" and south of the "Axial Drainage" (Figure 6-1).

6.1.2.7.1 PIEZOMETER PZ-6A

The borehole for piezometer PZ-6A was drilled to depth of 86 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 81 feet bgs and Mancos Shale was encountered from a depth of 81 to 86 feet. Piezometer PZ-6A was completed to a depth of 66 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the lower water-bearing interval intercepted at this location, which was detected at about 60 feet bgs. Since completion, piezometer PZ-6A has had artesian flow of about 0.5 gpm, with an estimated hydraulic head elevation of 9,960 ft amsl. The hydraulic head in this piezometer is approximately 25 feet above the water level in the adjacent "Axial Drainage". The water level data collected to date cover a very short time period and are considered preliminary, but indicate that the drainage is gaining in this area, if this lower water-bearing zone is hydraulically connected to the surface stream. Summaries of the piezometer completion details are presented on Tables 6-1 and 6-2. Piezometer logs and construction diagrams are in Appendix 6-1.

6.1.2.7.2 Piezometer PZ-6B

The borehole for PZ-6B was drilled to depth of 25 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 25 feet bgs. Piezometer PZ-6B was completed to a depth of 25 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the upper water-bearing interval intercepted at this location, which was detected at about 21 feet bgs. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-6B has been rising and is currently (11/16/07) about 17.57 feet btoc. The water level in this piezometer is approximately 3.5 feet above the water level in the adjacent "Axial Drainage". The water level data collected to date cover a very short time period and are considered preliminary, but indicate that the drainage is gaining in this area. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-9. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

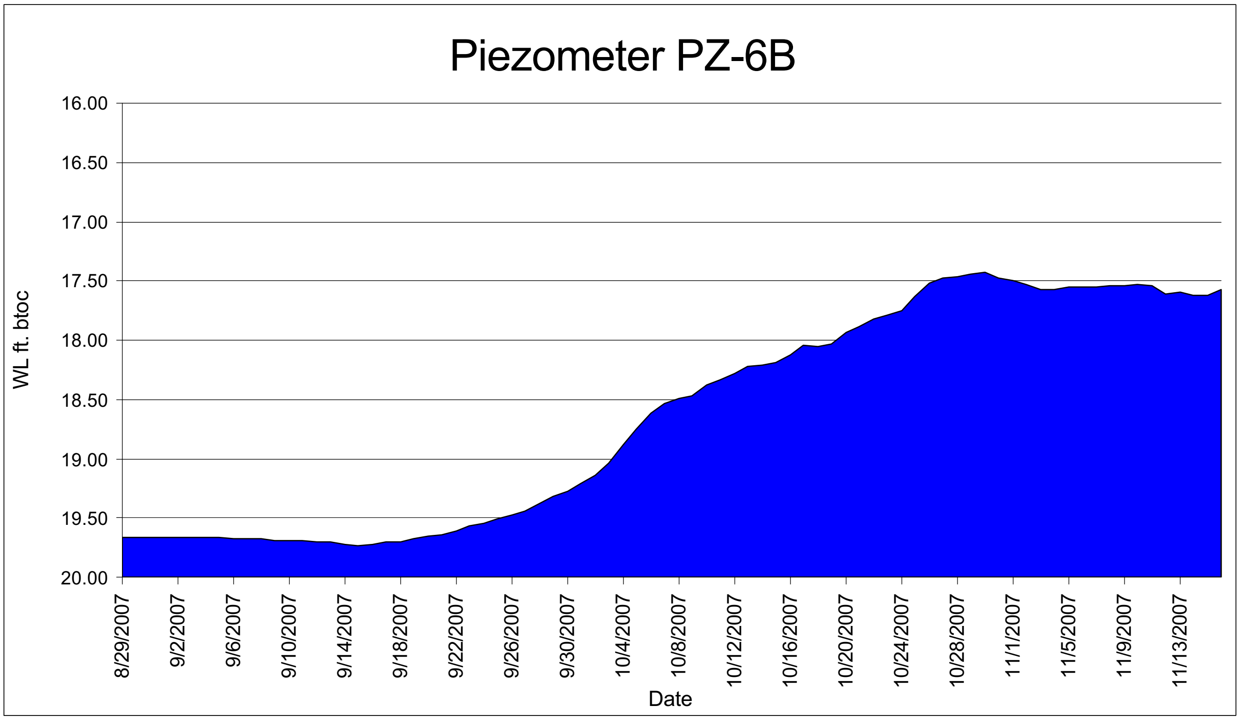

Figure 6-9. Piezometer PZ-6B Water Levels

6.1.2.8 Piezometer PZ-7

The proposed piezometer PZ-7 was not drilled, due to access concerns and problems.

6.1.2.9 Piezometer PZ-8

Two piezometers were installed at the PZ-8 location: a deep piezometer, PZ-8A, and a shallow piezometer, PZ-8B. Both piezometers were completed on July 18, 2007 and are located on the upper north side of GHU-1B above the "Steep Slope Band" (Figure 6-1).

6.1.2.9.1 PIEZOMETER PZ-8A

The borehole for PZ-8A was drilled to depth of 60 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 46 feet bgs and Mancos Shale was encountered from a depth of 46 to 60 feet. Piezometer PZ-8A was completed to a depth of 56 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the lower water-bearing interval intercepted at this location, which was detected at about 41 feet bgs. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-8A has dropped steadily and is currently (11/16/07) at 9.53 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-10. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

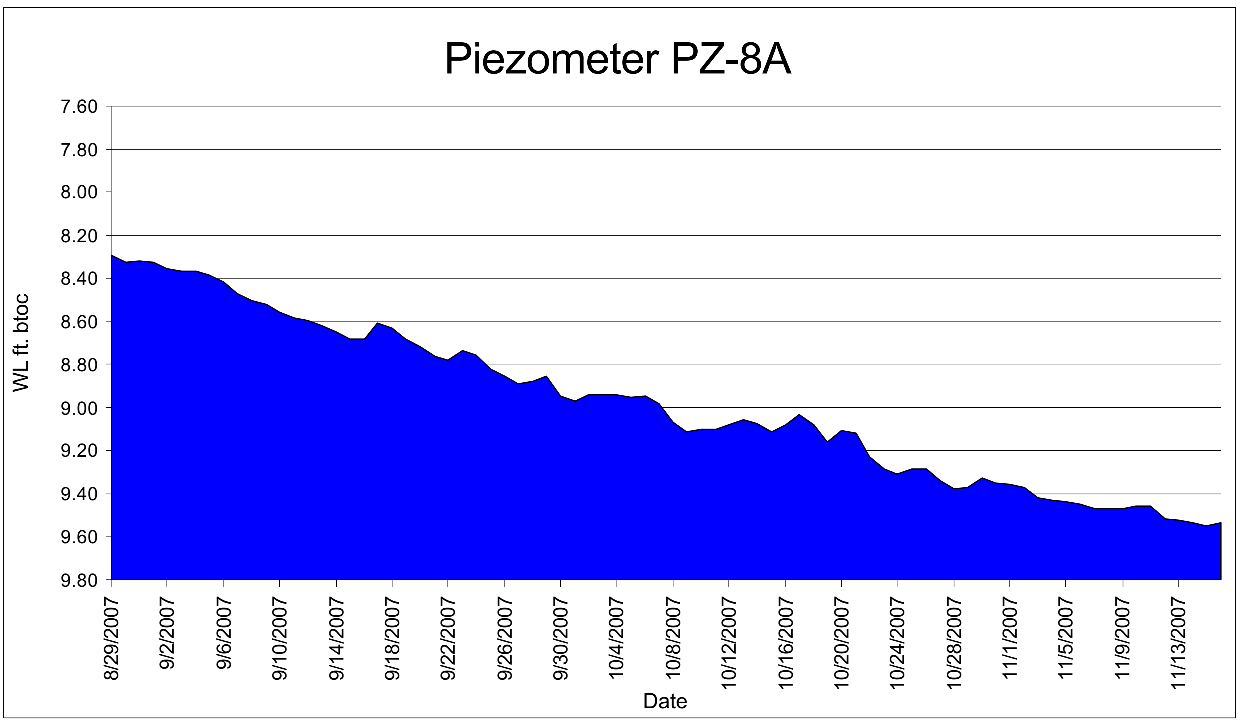

Figure 6-10. Piezometer PZ-8A Water Levels

6.1.2.9.2 PIEZOMETER PZ-8B

The borehole for piezometer PZ-8B was drilled to depth of 25 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 25 feet bgs. Piezometer PZ-8B was completed to a depth of 25 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the upper water-bearing interval intercepted at this location, which was detected at about 19 feet bgs. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-8B has lowering steadily and is currently (11/16/07) about 16.96 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-11. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

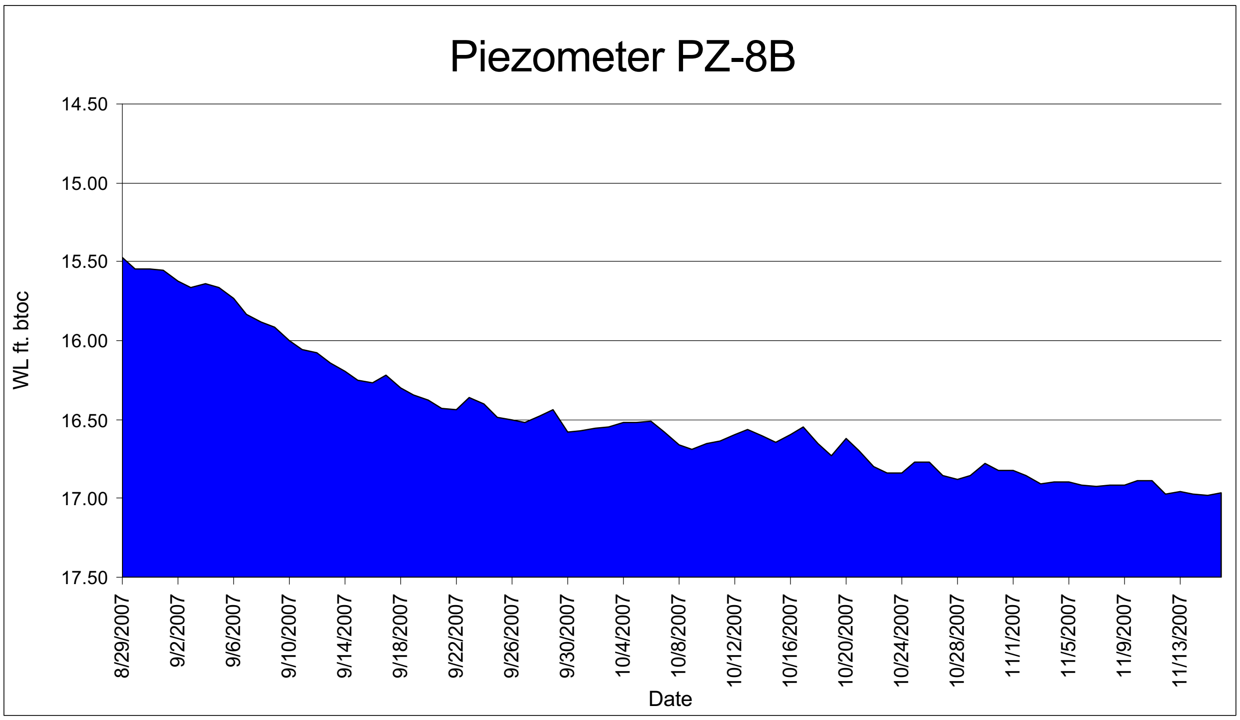

Figure 6-11. Piezometer PZ-8B Water Levels

6.1.2.10 Piezometer PZ-9

Piezometer PZ-9 was drilled and completed on July 17, 2007 and is located in the center of GHU-1B above the “Steep Slope Band” (Figure 6-1). The borehole was drilled to depth of 81 feet below ground surface (bgs). Unconsolidated landslide materials were encountered from the surface to a depth of 75 feet bgs and Mancos Shale was encountered from a depth of 75 feet to 81 feet. Piezometer PZ-9 was completed to a depth of 37 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 26 feet bgs. A lower water-bearing interval above the Mancos Shale was not detected at this site. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-9 has been relatively steady and is currently (11/16/07) at about 22.35 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-12. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

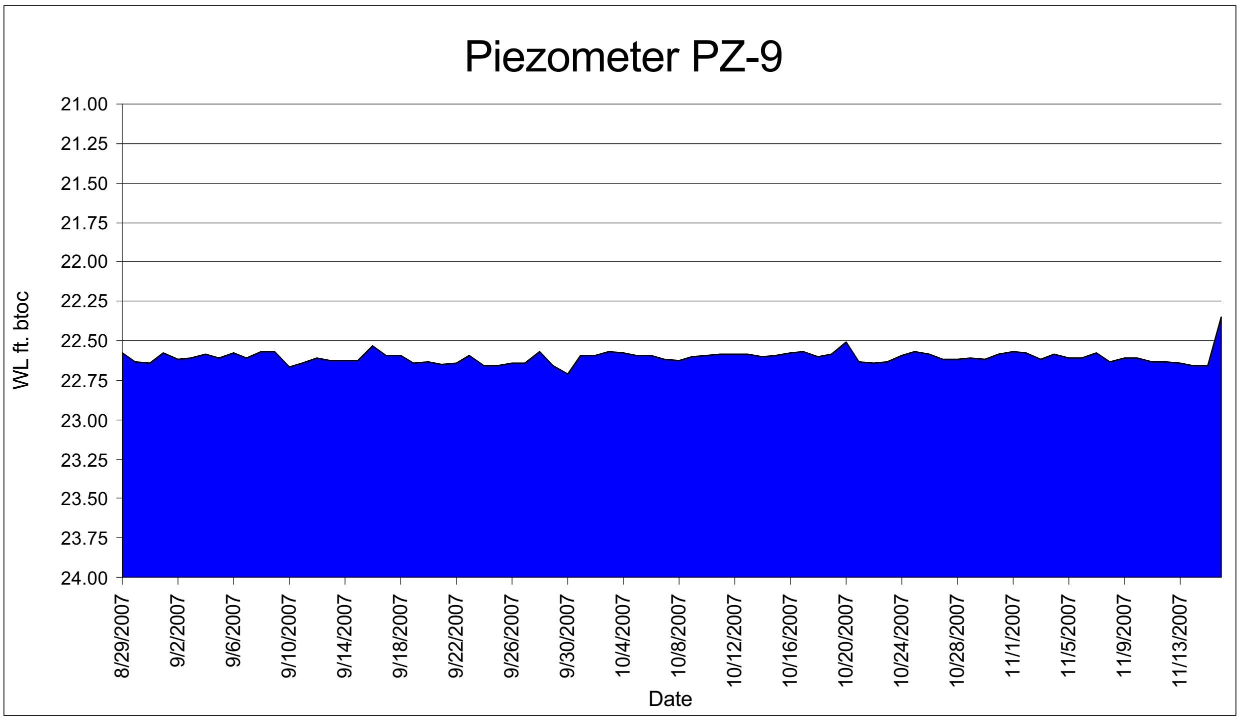

Figure 6-12. Piezometer PZ-9 Water Levels

6.1.2.11 Piezometer PZ-10

The proposed piezometer PZ-10 was not drilled, due to access concerns and problems.

6.1.1.12 Piezometer PZ-11

Piezometer PZ-11 was drilled and completed on July 29, 2007 and is located on the lower part of GHU-3 below the "Steep Slope Band" (Figure 6-1). The borehole was drilled to depth of 57 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 42 feet bgs and Mancos Shale was encountered from a depth of 42 feet to 57 feet. Piezometer PZ-11 was completed to a depth of 56 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 52 feet bgs. Since the datalogger was installed in August 2007, the water level in piezometer PZ-11 has been rising and is currently (11/18/07) at about 40.98 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-13. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

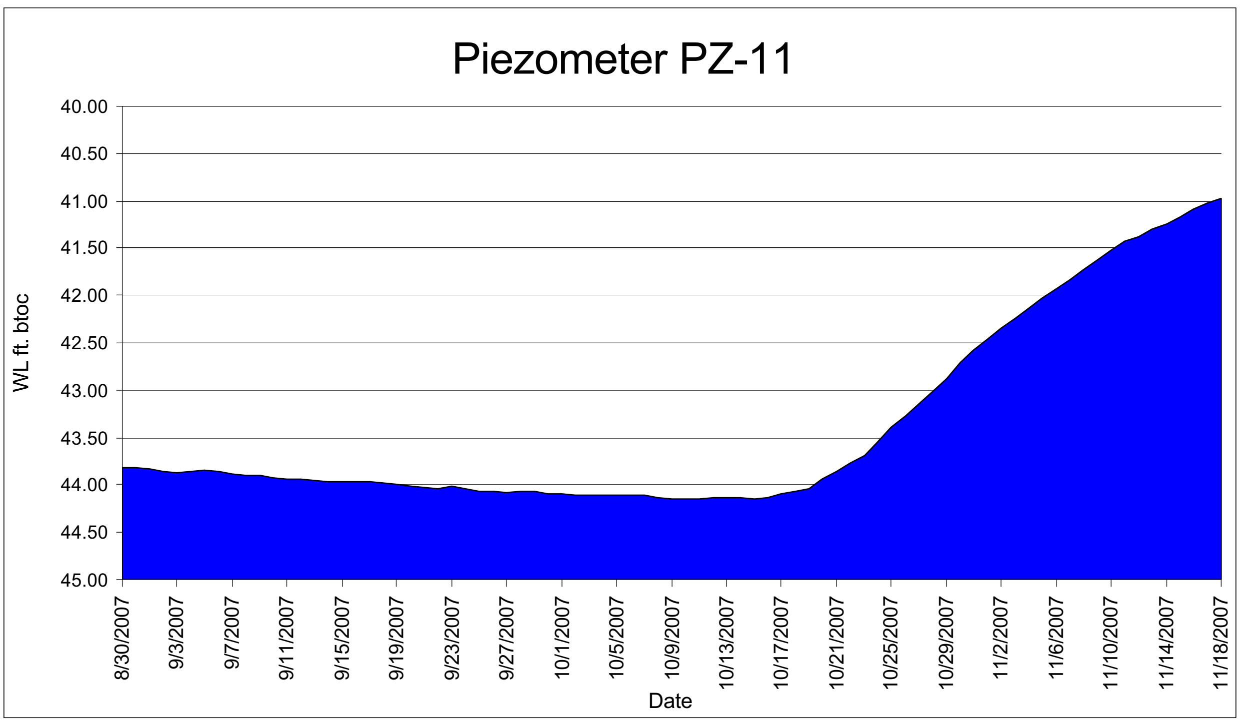

Figure 6-13. Piezometer PZ-11 Water Levels

6.1.2.13 Piezometer PZ-12

Piezometer PZ-12 was drilled and completed on July 29, 2007 and is located on the upper part of GHU-4 below the “Steep Slope Band” (Figure 6-1). The borehole was drilled to depth of 90 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 68 feet bgs and Mancos Shale was encountered from a depth of 68 feet to 90 feet. Piezometer PZ-12 was completed to a depth of 27 feet (bgs) because the hole collapsed to that depth when the drill string was removed, and contains 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 10 feet bgs. Since the datalogger was installed in August 2007, the water level in piezometer PZ-12 has been rising slowly and is currently (11/18/07) at about 8.13 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-14. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

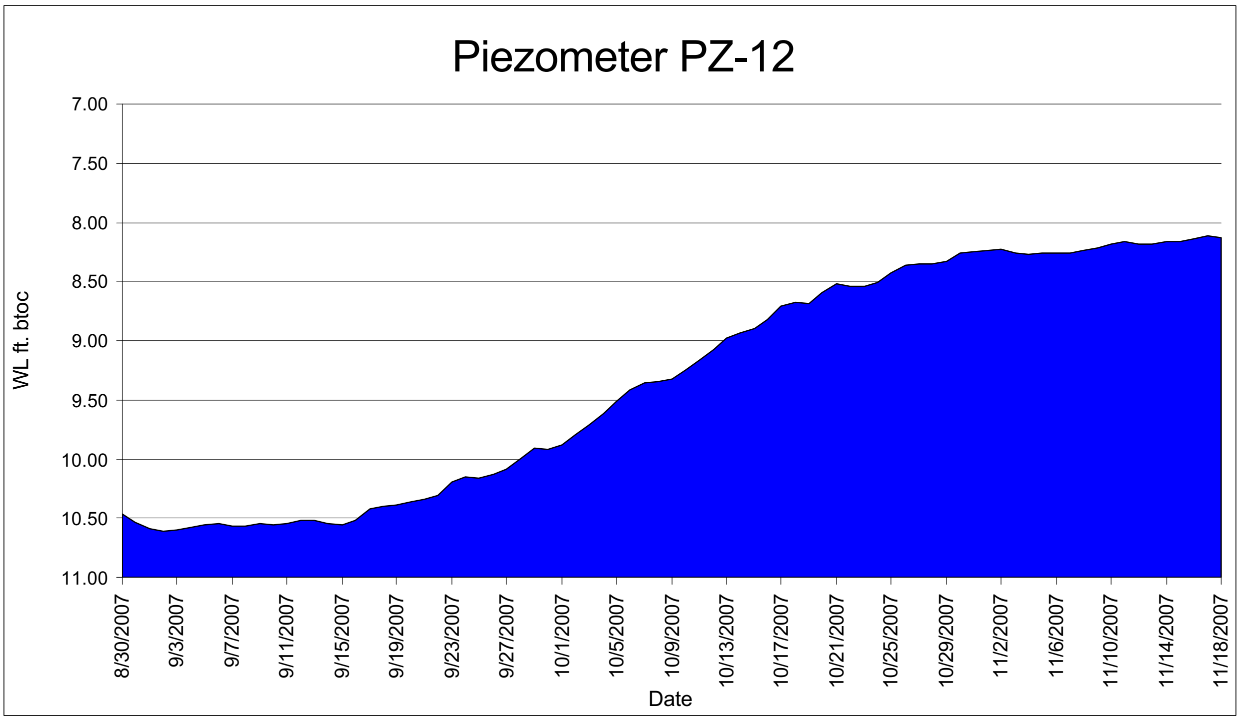

Figure 6-14. Piezometer PZ-12 Water Levels

6.1.2.14 Piezometer PZ-13

Two piezometers were installed at the PZ-13 location: a deep piezometer, PZ-13A, and a shallow piezometer, PZ-13B. Piezometer PZ-13A was completed on July 24, 2007 and PZ-13B was completed on July 26, 2007. Both piezometers are located on the middle south side of GHU-4 below the "Steep Slope Band", north of the "Axial Drainage" (Figure 6-1).

6.1.2.14.1 PIEZOMETER 13A

The borehole for piezometer PZ-13A was drilled to a depth of 75 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 80 feet bgs and Mancos Shale was encountered from a depth of 80 to 83 feet in the adjacent inclinometer I-13. Piezometer PZ-13A was completed to a depth of 40 feet (bgs) because the hole collapsed to that depth when the drill string was removed, and it contains 10 feet of screen at the bottom. The piezometer was screened in the lower water-bearing interval intercepted at this location, which was detected at about 34 feet bgs. Since the datalogger was installed in August 2007, the water level in PZ-13A has risen since mid-September and is currently (11/18/07) at 20.47 feet btoc. The water level in this piezometer is approximately 5 feet above the water level in the adjacent "Axial Drainage". The water level data collected to date cover a very short time period and are considered preliminary, but indicate that the drainage is gaining in this area. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-15. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

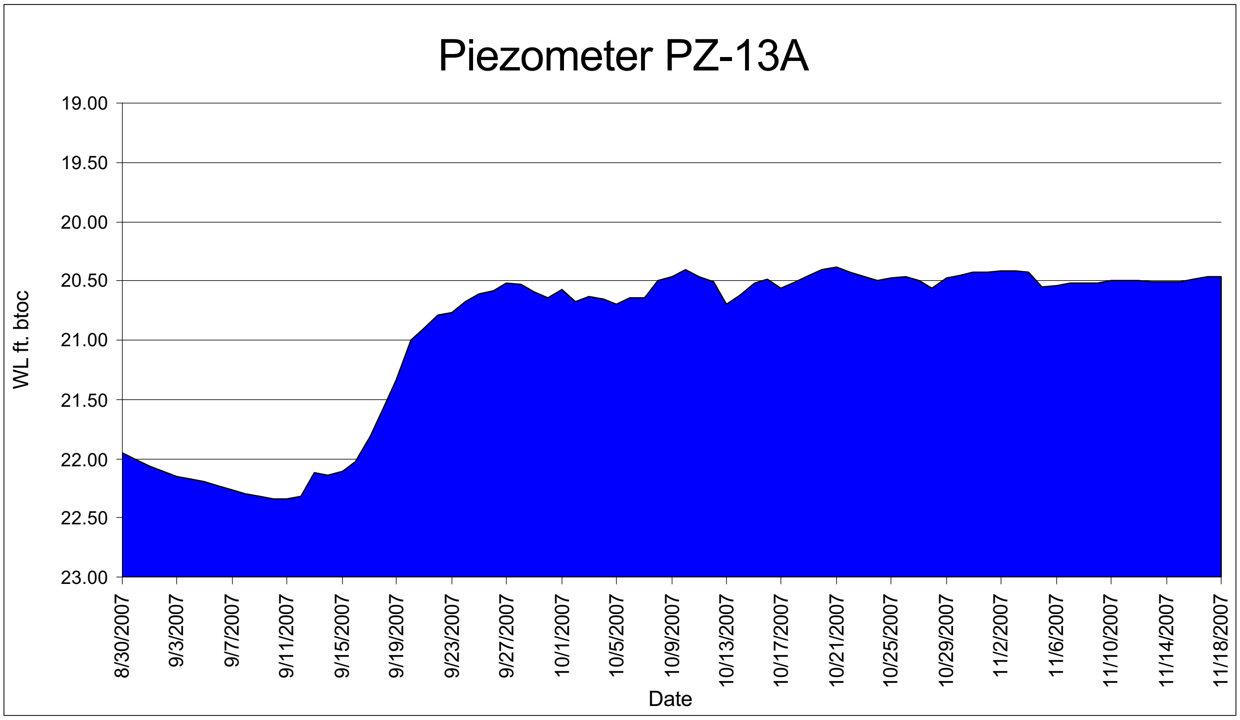

Figure 6-15. Piezometer PZ-13A Water Levels

6.1.2.14.2 PIEZOMETER 13B

The borehole for piezometer PZ-13B was drilled to a depth of 20 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 80 feet and Mancos Shale from 80 to 83 feet bgs in the adjacent inclinometer I-13. Piezometer PZ-13B was completed to a depth of 17 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the upper water-bearing interval intercepted at this location, which was detected at about 11 feet bgs. Since the dataloggers were installed in August 2007, the water level in piezometer PZ-13B has remained relatively steady and is currently (11/18/07) about 15.20 feet btoc. The water level in piezometer PZ-13B is approximately 12 feet above the water level in the adjacent "Axial Drainage". The water level data collected to date cover a very short time period and are considered preliminary, but indicate that the drainage is gaining in this area. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-16. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

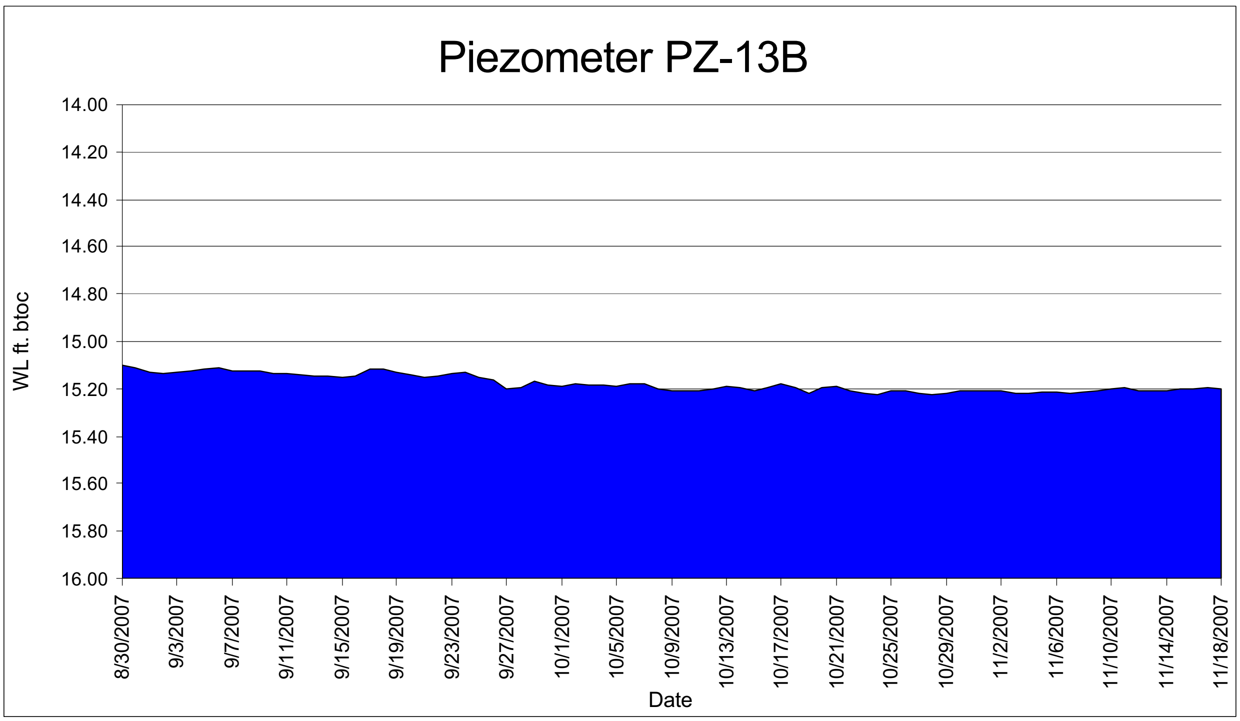

Figure 6-16. Piezometer PZ-13B Water Levels

6.1.2.15 Piezometer PZ-14

Piezometer PZ-14 was drilled and completed on July 28, 2007 and is located in the center of GHU-2 below the “Steep Slope Band” (Figure 6-1). The borehole was drilled to depth of 117 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 117 feet bgs. Mancos Shale was not encountered in this borehole. The borehole was not drilled deeper because of the limitation of the drilling rig. Piezometer PZ-14 was completed to a depth of 35 feet (bgs) because the hole collapsed to that depth when the drill string was removed, and it contains 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 31 feet bgs. Since the datalogger was installed in August 2007, the water level in piezometer PZ-14 has been gradually falling and is currently (11/18/07) at about 28.95 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-17. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

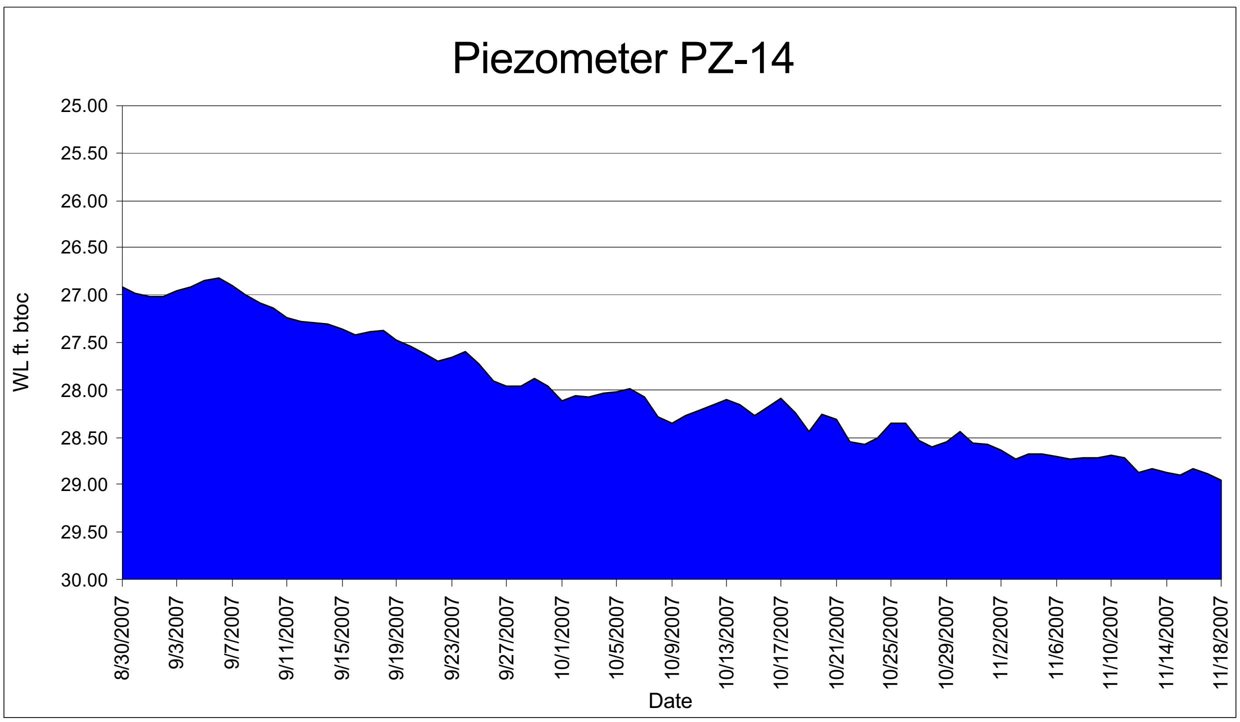

Figure 6-17. Piezometer PZ-14 Water Levels

6.1.2.16 Piezometer PZ-15

Piezometer PZ-15 was drilled and completed on November 14, 2006 and is located in the middle north side of GHU-4 below the "Steep Slope Band" (Figure 6-1). The borehole was drilled to depth of 46 feet bgs Unconsolidated landslide materials were encountered from the surface to a depth of 31 feet bgs and Mancos Shale was encountered from a depth of 31 feet to 46 feet. Piezometer PZ-15 was completed to a depth of 33 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 33 feet bgs. Since the datalogger was installed in January 2007, the water level in piezometer PZ-15 has shown typical seasonal changes with highest water levels recorded in April 2007 during spring snowmelt and the lowest level recorded in March 2007. The distinctive spike in water level in early April likely indicates a quick reaction to local snowmelt. The current (11/18/07) water level is 34.71 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-18. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

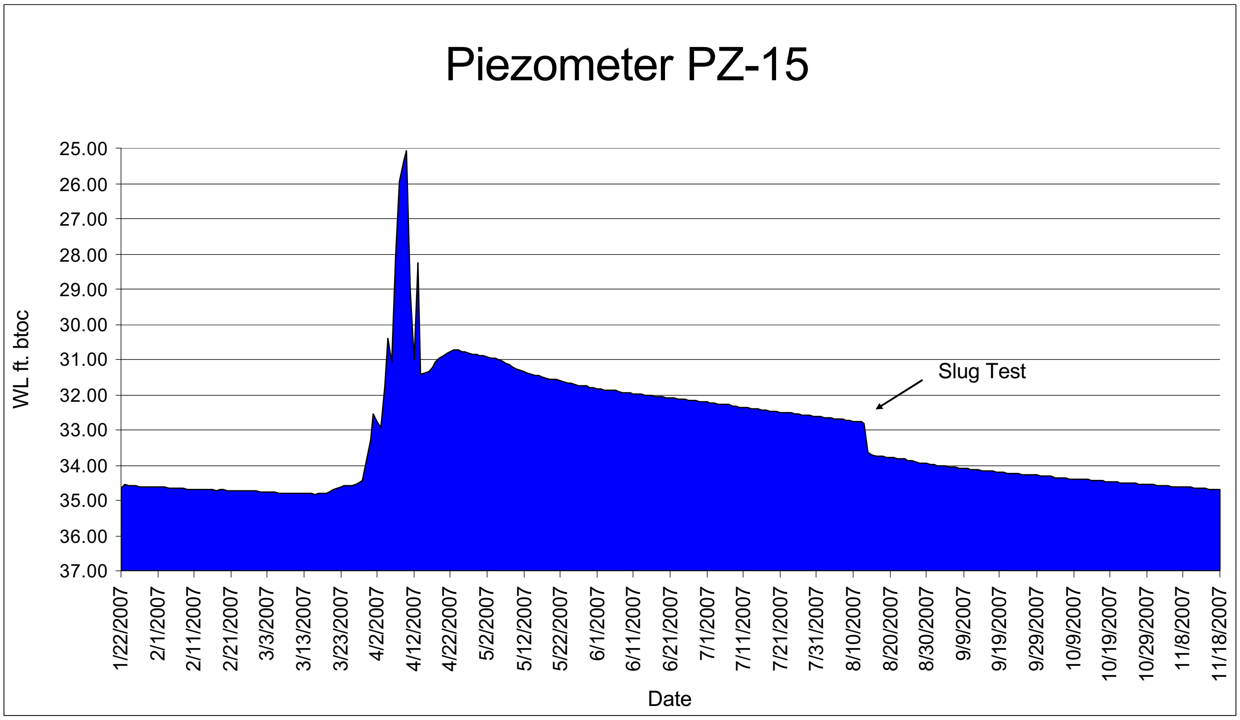

Figure 6-18. Piezometer PZ-15 Water Levels

6.1.2.17 Piezometer PZ-16

Piezometer PZ-16 was drilled and completed on November 14-15, 2006 and is located in the middle of GHU-5B below the "Steep Slope Band" (Figure 6-1). The borehole was drilled to depth of 50 feet bgs. Unconsolidated landslide materials were encountered from the surface to a depth of 38 feet bgs and Mancos Shale was encountered from a depth of 38 feet to 55 feet in the adjacent inclinometer I-16. Piezometer PZ-16 was completed to a depth of 40 feet (bgs) with 10 feet of screen at the bottom. The piezometer was screened in the only water-bearing interval intercepted at this location, which was detected at about 27 feet bgs. Since the datalogger was installed in January 2007, the water level in piezometer PZ-16 has shown typical seasonal changes with the highest water levels recorded in April 2007 during spring snowmelt and the lowest level recorded in March 2007. The current (11/18/07) water level is 19.57 feet btoc. Summaries of the piezometer completion details and water level data are presented on Tables 6-1 and 6-2, and Figure 6-19. Piezometer construction and geologic log diagrams are illustrated in Appendix 6-1.

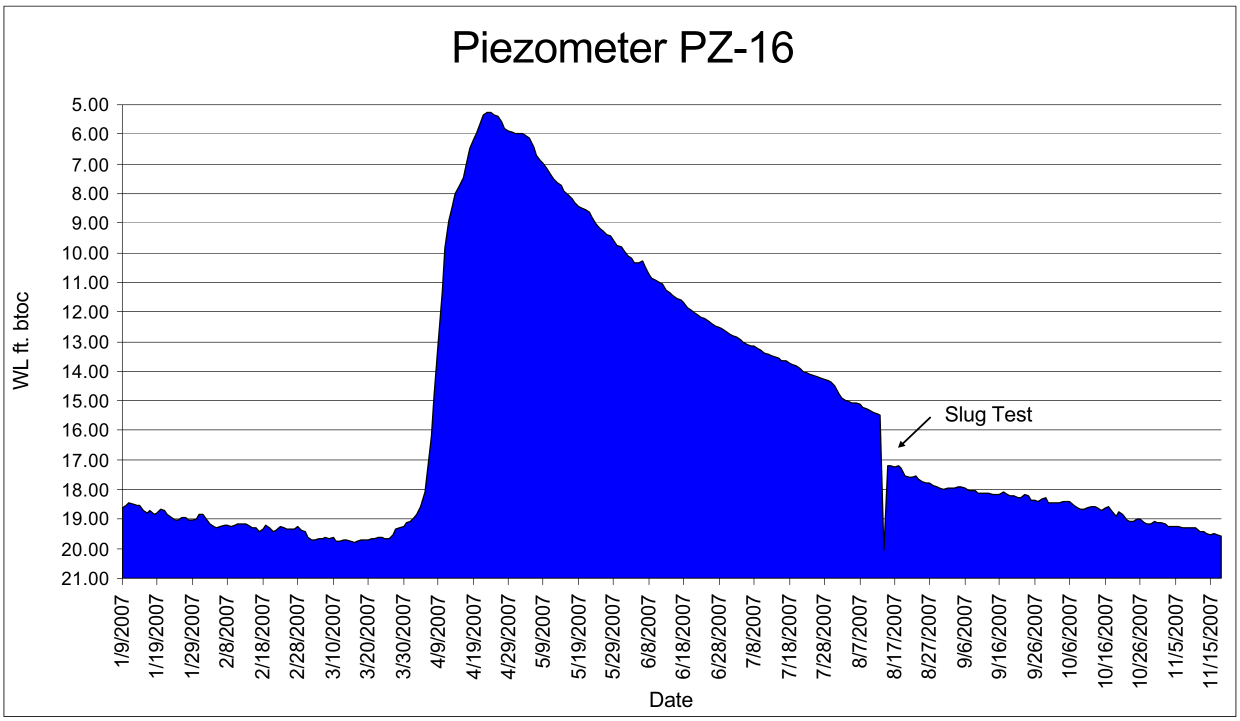

Figure 6-19. Piezometer PZ-16 Water Levels

6.2 Potentiometric Surface of the Groundwater

The groundwater in the unconsolidated Quaternary sediments on Snodgrass Mountain is generally found at the base of the landslide deposits directly above the contact with the Mancos Shale. The groundwater flow in this water-bearing zone generally follows the local topography, flowing downhill NW to SE at an average horizontal hydraulic gradient of about 0.18. In general, the water-bearing zones on Snodgrass Mountain are considered semi-confined to confined, as the static water level or head in the piezometers is generally above the top of the water-bearing zones identified during the drilling operations. The groundwater level in a confined water-bearing unit is known as the potentiometric surface of the groundwater. The potentiometric surface of the groundwater is defined as the level to which groundwater in water-bearing sediments or rock would rise in a well due to the natural pressure in the rocks or sediments. A potentiometric surface map of the groundwater on Snodgrass Mountain is presented on Figure 6-20. A summary of the water-bearing zones is presented in Table 6-3.

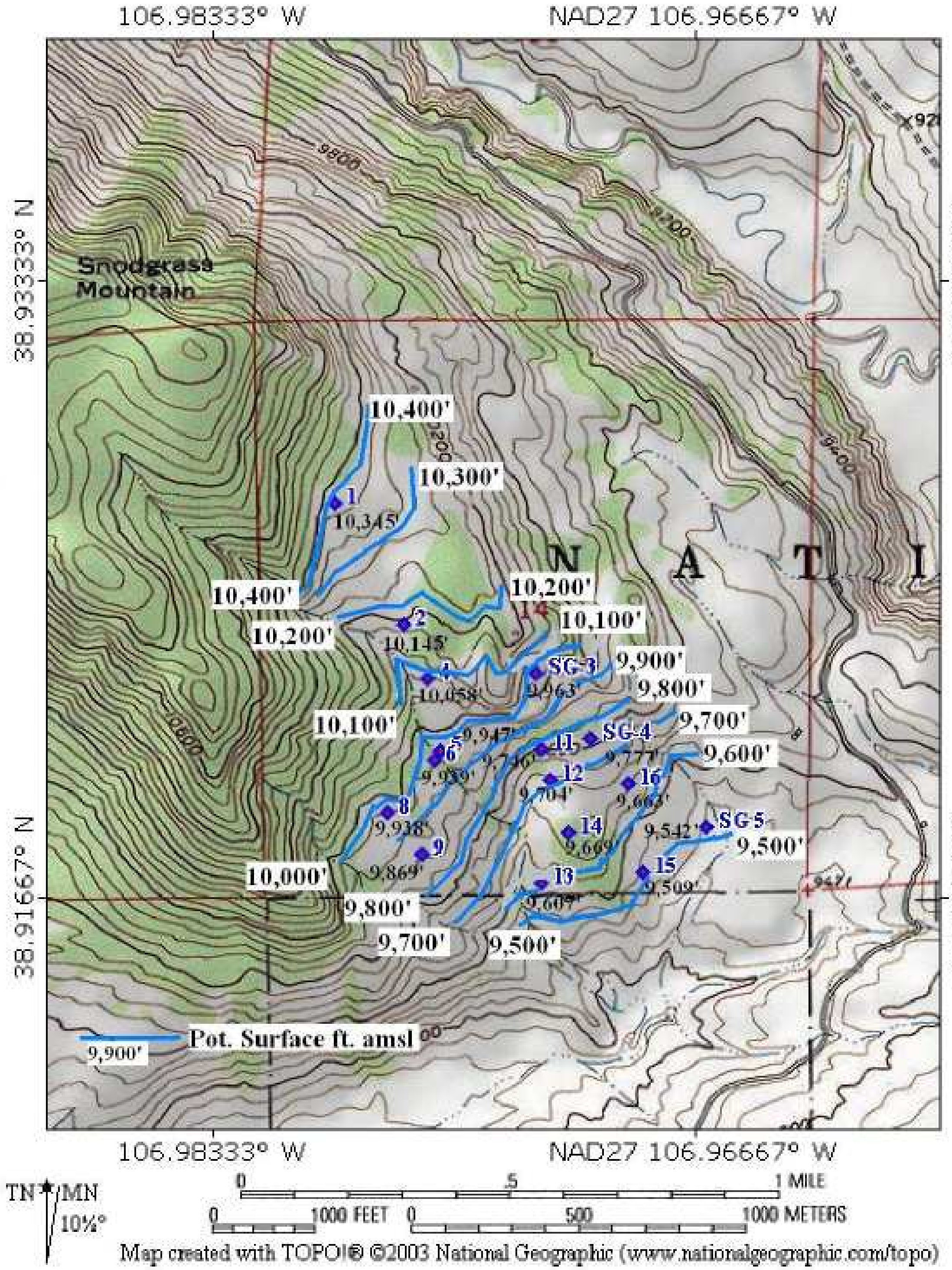

FIGURE 6-20. Potentiometric Surface Map for Snodgrass Mountain (September 29 2007)

Table 6-3. Summary of the Groundwater-Bearing Zones on Snodgrass Mountain

Piezometer	Depth to Top of Groundwater Bearing Zone (ft bgs) (1)	Ground-water Level Elevation (ft amsl) (2)	Ground-water Level Trend (3)	Groundwater Bearing Zone Type	Vertical Hydraulic Gradient	Axial Drainage Elevation (ft amsl)	Drainage Characteristic
Piezometers Above Steep Slope Band							
PZ-1	22.5	10,344.71(4)	Rising	Semi Confined to Confined			
PZ-2	10.5	10,145.39	Steady	Semi Confined to Confined			
PZ-4	38.0	10,057.55	Lowering	Semi Confined to Confined		10,055(4)	Gaining
PZ-5	64.0	9,947.02	Rising	Semi Confined to Confined		9,935(4)	Gaining
PZ-6A (deep)	60.0	Artesian ~9,960 ft)	Artesian	Confined	1.37\ up	9,935(4)	Gaining
PZ-6B (shallow)	21.0	9,938.13	Rising	Semi Confined		9,935(4)	Gaining
PZ-8A (deep)	41.0	9,945.71	Lowering	Confined	0.57\ up		
PZ-8B (shallow)	19.0	9,937.90	Lowering	Semi Confined			
PZ-9	26.0	9,868.79	Steady	Semi Confined to Confined			
Piezometers Below Steep Slope Band							
PZ-11	52.0	9,745.58	Rising	Semi Confined to Confined			
PZ-12	10.0	9,704.34	Rising	Semi Confined to Confined			
PZ-13A (deep)	34.0	9,599.64	Rising-Steady	Confined	0.38\ down	9,595(4)	Gaining
PZ-13B (shallow)	11.0	9,606.80	Steady	Semi Confined		9,595(4)	Gaining
PZ-14	31.0	9,668.72	Lowering	Semi Confined to Confined			
PZ-15	33.0	9,508.61	Lowering	Semi Confined to Confined			
PZ-16	27.0	9,662.52	Lowering	Semi Confined to Confined			
SG-3	42.0	9,962.54(4)	Lowering	Semi Confined to			

				Confined			
SG-4	11.5	9,775.78[4]	Lowering	Semi Confined to Confined			
SG-5	11.0	9,541.99	Lowering	Semi Confined to Confined			

(1) Depth at time of drilling
(2) September 29, 2007
(3) August 2007 to November 2007
(4) Estimated elevation, not surveyed

In some localized areas, a shallow perched water-bearing zone is present in the middle of the landslide deposit, well above the base of the landslides. These perched zones do not appear to be hydraulically connected to the groundwater at the base of the landslides, as the interburden sediments between the upper and lower water-bearing zones appear to be dry in the drill cuttings and they have a low hydraulic conductivity which forms an aquitard that limits groundwater flow, which isolates or confines the two zones. Evidence of this effect can be seen in areas with "twin piezometers", i.e., those with both shallow and deep water bearing zones (piezometers PZ-6A and PZ-6B, PZ-8A and PZ-8B, PZ-13A and PZ-13B), since the water levels in the "twin piezometers" have distinctly different water levels as shown in Tables 6-2 and 6-3. For example, the groundwater level in twin piezometers PZ-6A (deep) and PZ-6B (shallow) are at approximate elevations of ~9,960 (artesian) feet amsl and 9,938 feet amsl respectively, a difference of 22 feet, showing an upward vertical hydraulic gradient of 1.37 ft/ft. The groundwater level in twin piezometers PZ-8A (deep) and PZ-8B (shallow) are at approximate elevations of 9,946 feet amsl and 9,938 feet amsl, respectively, a difference of 8 feet, showing an upward vertical hydraulic gradient of 0.57 ft/ft. The groundwater level in twin piezometers PZ-13A (deep) and PZ-13B (shallow) are at approximate elevations of 9,600 feet amsl and 9,607 feet amsl respectively, a difference of 7 feet, showing a downward vertical hydraulic gradient of 0.58 ft/ft. These large vertical gradients indicate that the sediments separating the upper and lower water-bearing zones are likely unsaturated and, therefore, the upper zone is not hydraulically connected or "perched". An example of a perched groundwater system is shown on Figure 6-21.

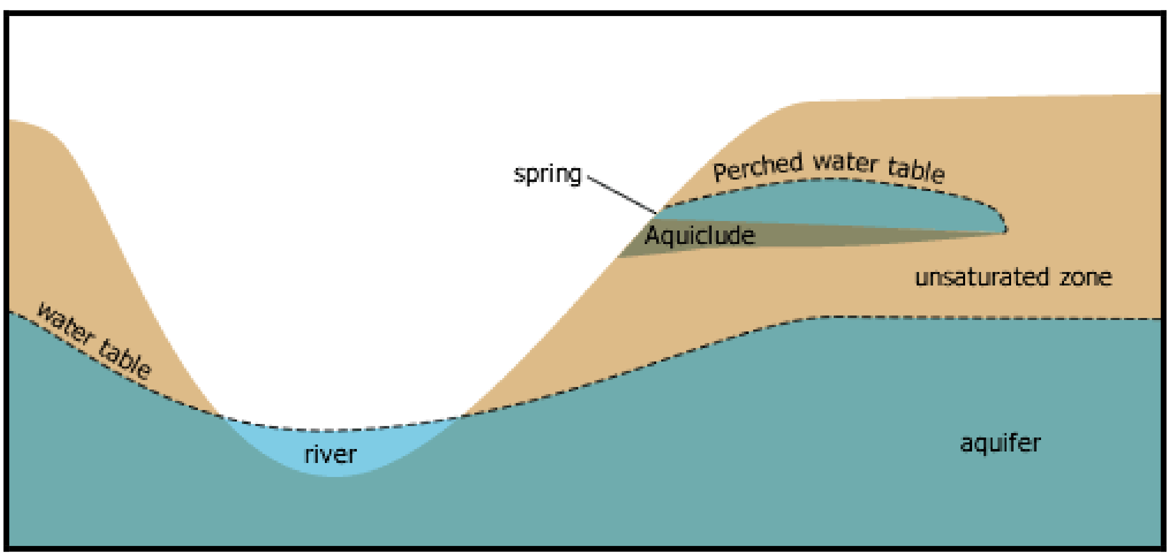

Figure 6-21 – Typical Perched Groundwater System (adapted from Wikipedia.com).

6.3 Slug Tests

In August 2007 following installation of the piezometers, HydroGeo completed rising head permeability tests (slug tests) in all of the piezometers installed in 2006 and 2007 except piezometer PZ-6A, in order to determine the hydraulic conductivity or velocity of the groundwater in the water bearing strata. Slug tests were not conducted on piezometer PZ-6A because it has artesian flow. Slug tests were not conducted on the three SG piezometers (SG-3, SG-4, and SG-5) installed by RCE in 1995, because comprehensive details on the well completion data were not available.

The permeability testing involved the following procedures:

- Measure distance from the ground surface to the top of the PVC casing.
- Measure the static water level depth from the top of the PVC casing.
- Bail several gallons of water from the piezometer, using a hand bailer.
- Measure the water level recovery in the piezometer at regular intervals until the water level in the piezometer recovers to about 80 to 90 percent of the pre-testing water level.

Data from the slug tests were analyzed using the software program, AquiferTest (Waterloo Hydrogeologic, 2003), and the Bouwer & Rice (1976), Cooper-Bredehoeft-Papadopulos (1967), and the Hvorslev (1951) analytical methods. The test analyses provide information on the hydraulic conductivity and transmissivity of the water-bearing zones. Hydraulic conductivity, symbolically represented as K, is a property of soil or rock that describes the ease with which water can move through pore spaces or fractures. The K value is typically given as a velocity such as centimeters per second (cm/sec) or feet per day (ft/day). Transmissivity (T) is the hydraulic conductivity times the thickness of the water-bearing zone, generally expressed as cm^2/sec.

The water-bearing zones tested on Snodgrass Mountain are generally considered semi-confined to confined, as the static water level or head in the piezometers is generally above the top of the water-bearing zones identified during the drilling operations. The volume of water that can be released from pore space or storage in a semi-confined or confined water-bearing zone is known as storativity (S). The storativity values on the test sheets in Appendix 6-3 are inaccurate and should be disregarded, because no observation wells were used for the testing. Therefore, based on typical published values and professional judgment, the estimated storativity of the water-bearing units on Snodgrass Mountain ranges from 0.01 to 0.005 (released unit volume per unit volume of pore space, dimensionless) (Freeze & Cherry, 1975). A summary of the slug test analyses is presented in Table 6-4 and copies of the slug test data results and analyses are presented Appendix 6-3.

Table 6-4. Summary of Slug Test Analyses

Piezometer Number	Slug Test Date	Bouwer & Rice Conductivity K (cm/sec)	Cooper, Bredehoeft, Papadopulos Conductivity K (cm/sec)	Hvorslev K (cm/sec)	Mean K (cm/sec)	Cooper, Bredehoeft, Papadopulos T (cm^2/sec)	Estimated Storativity[1] S (dimensionless)
Piezometers Above Steep Slope Band							
PZ-1	8/10/2007	$4.41x10^{-6}$	$7.35x10^{-6}$	$1.21x10^{-5}$	$7.95x10^{-6}$	$5.26x10^{-3}$	0.01 to 0.005
PZ-2	8/10/2007	$2.99x10^{-5}$	$7.99x10^{-5}$	$3.57x10^{-5}$	$4.85x10^{-5}$	$1.52x10^{-2}$	0.01 to 0.005
PZ-4	8/10/2007	$1.27x10^{-5}$	$1.73x10^{-4}$	$1.65\text{-}10^{-5}$	$6.74x10^{-5}$	$1.58x10^{-2}$	0.01 to 0.005
PZ-5	8/10/2007	$1.10x10^{-5}$	$3.21x10^{-5}$	$1.40x10^{-5}$	$1.90x10^{-5}$	$8.79x10^{-3}$	0.01 to 0.005
PZ-6A (deep)	Artesian	- -	- -	- -	- -	- -	- -
PZ-6B (shallow)	8/10/2007	$1.52x10^{-5}$	$2.62x10^{-5}$	$2.16x10^{-5}$	$2.10x10^{-5}$	$8.78x10^{-3}$	0.01 to 0.005
PZ-8A (deep)	8/10/2007	$6.14x10^{-6}$	$8.13x10^{-6}$	$5.83x10^{-6}$	$6.70x10^{-6}$	$1.24x10^{-3}$	0.01 to 0.005
PZ-8B (shallow)	8/10/2007	$6.06x10^{-7}$	$7.82x10^{-7}$	$7.31x10^{-7}$	$7.06x10^{-7}$	$2.68x10^{-4}$	0.01 to 0.005
PZ-9	8/10/2007	$1.21x10^{-6}$	$1.14x10^{-6}$	$1.44x10^{-6}$	$1.26x10^{-6}$	$6.97x10^{-4}$	0.01 to 0.005
Average					$2.16x10^{-5}$		
Piezometers Below Steep Slope Band							
PZ-11	8/14/2007	$1.69x10^{-5}$	$1.96x10^{-4}$	$1.51x10^{-5}$	$7.60 x10^{-5}$	$1.19x10^{-2}$	0.01 to 0.005
PZ-12	8/13/2007	$9.98x10^{-7}$	$5.39x10^{-7}$	$1.24x10^{-6}$	$9.26x10^{-7}$	$4.93x10^{-4}$	0.01 to 0.005
PZ-13A (deep)	8/13/2007	$7.71x10^{-7}$	$8.74x10^{-7}$	$8.67x10^{-7}$	$8.37x10^{-7}$	$2.93x10^{-4}$	0.01 to 0.005
PZ-13B (shallow)	8/13/2007	$3.41x10^{-7}$	$1.79x10^{-6}$	$5.35x10^{-7}$	$8.89x10^{-7}$	$8.74x10^{-4}$	0.01 to 0.005
PZ-14	8/13/2007	$4.65x10^{-5}$	$1.96x10^{-5}$	$7.11x10^{-5}$	$4.67x10^{-5}$	$2.04x10^{-2}$	0.01 to 0.005
PZ-15	8/14/2006	$2.71x10^{-7}$	$7.99x10^{-7}$	$4.17x10^{-7}$	$4.96x10^{-7}$	$2.92x10^{-4}$	0.01 to 0.005
PZ-16	8/14/2006	$4.47x10^{-6}$	$1.27x10^{-5}$	$4.43x10^{-6}$	$7.20x10^{-6}$	$1.55x10^{-3}$	0.01 to 0.005
SG-3	Not Tested	- -	- -	- -	- -	- -	- -
SG-4	Not Tested	- -	- -	- -	- -	- -	- -
SG-5	Not Tested	- -	- -	- -	- -	- -	- -
Average					$1.89x10^{-5}$		

The deep water-bearing sediments on Snodgrass Mountain are variable, which is typical of landslide deposits, and they have moderate to very low hydraulic conductivities ranging from 10^{-5} cm/sec to 10^{-7} cm/sec. This range of hydraulic conductivity values is typical for silty clay to silty sand sediments (Freeze and Cherry, 1975).

At the sites with twin piezometers (shallow and deep), the shallow perched water-bearing sediments have generally lower hydraulic conductivities, compared to the deeper water-bearing zone above the Mancos Shale, of about one-half order of magnitude, indicating more clayey sediments. For example, the average hydraulic conductivity (including all 3 methods of analysis) of the "deep" piezometers PZ-8A and PZ-13A is 7.53×10^{-6} compared to the average hydraulic conductivity of 3.77×10^{-6} at the "shallow" piezometers PZ-6B, PZ-8B and PZ-13B. It should also be noted that the water-bearing sediments on Snodgrass Mountain are not considered aquifers because of the low hydraulic conductivities and the resulting minimal potential yield to a well.

6.4 Groundwater Recharge, Groundwater Discharge and Water Balance

6.4.1 Groundwater Recharge from Infiltration of Precipitation and Snowmelt

Recharge to the groundwater system in the landslide deposits on Snodgrass Mountain is primarily derived from infiltration of direct precipitation and snowmelt. A minor amount of groundwater recharge also occurs from infiltration of flow in losing reaches of the drainages. A losing reach occurs when the level of water in a streambed is higher than the adjacent groundwater table and water from the stream infiltrates into the ground, thereby recharging the aquifer.

A generalized calculation of the potential recharge to the groundwater system can be made by multiplying the estimated recharge rate, stated as percent of annual average precipitation, times the average annual precipitation times area. The average annual precipitation used in the recharge calculations was derived from synthesized precipitation values specific to Snodgrass Mountain (REI, 2007). This value was based on the range of the study area elevations, i.e., from 9,600 feet to 11,100 feet. The mean watershed elevation was calculated to be 10,347 feet. This elevation is about half way between the Crested Butte SNOTEL and Independence Pass SNOTEL sites (NRCS, 2007). Based on a spline curve analysis, the average precipitation for the study area was calculated to be 29.08 inches at this mean elevation (REI, 2007). A typical value for the estimated recharge to groundwater expressed as a percentage for the Rocky Mountain area is 10 to 15 percent of annual precipitation (Walton, 1970).

Based on these assumptions, the estimated potential average recharge rate per acre to the groundwater system on Snodgrass Mountain ranges from 0.15 gpm/acre (10% recharge) to 0.23 gpm/acre (15% recharge).

10% Recharge

Recharge Rate = % Ave Annual Precip x Ave Annual Precip x Watershed Area

= .10 x 29.08 inches per year x 1 acre

= .10 x 29.08 inches per year x 6.27264 x 10^6 in^2

= .10 x 1.82x108 in^3 per year

= 1.82 x 10^7 in^3 per year or 79,005 gal per year

= 0.15 gpm/acre

15% Recharge

Recharge Rate = % Annual Ave Precip x Ave Annual Precip x Watershed Area

= .15 x 29.08 inches per year x 1 acre

= .15 x 29.08 inches per year x 6.27264 x 10^6 in^2

= .15 x 1.82x10^8 in^3 per year

= 2.73 x 10^7 in^3 per year or 118,507 gal per year

= 0.23 gpm/acre

The groundwater recharge rates will vary seasonally and during wet or dry precipitation years. Long-term monitoring of the Snodgrass Mountain piezometers will provide data to better evaluate the site-specific recharge rate due to snowmelt and infiltration of precipitation.

6.4.2 Groundwater Discharge

Discharge from the groundwater system flows to baseflow in gaining reaches of local drainages, such as those occurring in the lower reaches of the Snodgrass Mountain Axial Drainage and area springs. Baseflow refers to the portion of stream flow that comes from groundwater, but is not the result of surface water runoff. A gaining reach occurs when the level of water in a streambed is lower than the adjacent groundwater table and groundwater infiltrates into the steam as baseflow. Typically about 50% of the water that percolates down to shallow groundwater contributes to baseflow (Maidment, 1992). Based on 50% of the total recharge being discharged to baseflow, (50% of 0.15 gpm/acre, 10% recharge; 50% of 0.23 gpm/acre, 15% recharge), the potential average overall baseflow to the drainages on Snodgrass Mountain is estimated to range from 0.075 gpm/acre (10% recharge) to 0.115 gpm/acre (15% recharge).

The baseflow rates will vary seasonally and during wet or dry precipitation years. Preliminary groundwater level data collected to date from the Snodgrass Mountain piezometers indicate that the Axial Drainage is gaining throughout the study area, that is, groundwater is contributing to the stream's baseflow (Table 6-3).

6.4.3 Water Balance

An estimated water balance of the groundwater\surface water system was calculated for the "Chicken Bone and Middle Landslide" complexes (Upper Landslide Complex) above the Steep Slope Band on Snodgrass Mountain. This area is of particular interest, because it is an integral component of the proposed CBMR ski area and snowmaking activities, and it includes reaches of the Axial Drainage. The water balance in the Upper Landslide Complex area consists of three parts:

1. Recharge to the ground water system in the landslide deposits resulting from direct precipitation and snowmelt
2. Groundwater flow passing through the saturated sediments in the landslide complex
3. Discharge from the groundwater system to surface water including baseflow to streams and springs

6.4.3.1 Recharge to the Groundwater System from Direct Precipitation

As discussed in Section 6.4.1, the predicted recharge to the Snodgrass Mountain shallow groundwater system from direct precipitation is 0.15 gpm/acre (10% recharge rate) to 0.23 gpm/acre (15% recharge rate). Given that the area of the Upper Landslide Complex is approximately 170 acres, the predicted recharge rates to the groundwater system in this area for 10% and 15% recharge rates are about 25.5 gpm to 39.1 gpm, respectively.

10% Recharge (see calculations Section 6.4.1)
= 0.15 gpm/acre x 170 acres
= 25.5 gpm

15% Recharge (See calculations Section 6.4.1)
= 0.23 gpm/acre x 170 acres
= 39.1 gpm

6.4.3.2 Groundwater Flow in the Saturated Sediments in the Upper Landslide Complex

Groundwater flow in the saturated sediments in the Upper Landslide Complex was calculated using a simple Darcy analysis (Darcy, 1856) as follows:

Q=KiA

Where:

Q= Groundwater Flow

K= Average hydraulic conductivity of the saturated sediments ($2.0x10^{-5}$ cm/sec or $1.2x10^{-3}$ cm/min)

i= Hydraulic Gradient (0.18)

A= Cross-Sectional Area at the Steep Slope Band (77,724 cm x 914 cm) or (2,550 ft x 30 ft) = 71,039,736 cm^2 or 76,500 ft^2

Q = $2.0x10^{-5}$ cm/sec x 0.18 x (77,724 cm x 914 cm)
= 255.74 cm^3/sec
= 4.05 gpm

6.4.3.3 Discharge from the Groundwater System to Surface Water

Based on the assumption that about 50% of the water that percolates down to shallow groundwater contributes to baseflow to local drainages (Maidment, 1992), the potential average total baseflow to the drainages on Snodgrass Mountain is estimated to range from 0.075 gpm/acre (50% of 0.15 gpm/acre assuming 10% recharge) to 0.115 gpm/acre (50% of 0.23 gpm/acre assuming15% recharge). The watershed area of the Upper Landslide Complex is estimated to encompass approximately 170 acres. Using the assumption presented in Maidment (1992), the estimated discharge from the groundwater system in the Upper Landslide Complex to the Axial Drainage baseflow can be calculated as follows:

<u>10% Recharge</u>
Baseflow = 50% x recharge x area
= (.50 x 0.15 gpm/acre) x 170 acres
= 12.75 gpm

<u>15% Recharge</u>
Baseflow = 50% x recharge x area
= (.50 x 0.23 gpm/acre) x 170 acres
= 19.55 gpm

These calculated baseflow values are very close to the 2006-2007 low flow data measured in the Axial Drainage at the upper and lower flume sites that ranged from about 10 to 20 gpm. Low flow periods typically represent baseflow.

The combined flow of the Upper Landslide Complex groundwater and baseflow in the Axial Drainage ranges from 16.8 gpm at a 10% recharge rate (4.05 gpm + 12.75 gpm = 16.8 gpm) to 23.6 gpm (4.05 gpm + 19.55 gpm = 23.6 gpm) at a 15% recharge rate. The remaining discharge volume in the Upper Landslide complex water balance is likely contributing to area spring flows as follows:

10% Recharge
Spring Flows = Total recharge from Direct Precipitation for Upper Landslide Complex - (Groundwater Flow in Upper Landslide Complex + Baseflow in Upper Landslide Complex)
= (0.15 gpm/acre x 170 acres) – (4.05 gpm +12.75 gpm)
=25.5 gpm – 16.8 gpm
= 8.7 gpm

15% Recharge
Spring Flows = Total recharge from Direct Precipitation for Upper Landslide Complex - (Groundwater Flow in Upper Landslide Complex + Baseflow in Upper Landslide Complex)
= (0.23 gpm/acre x 170 acres) – (4.05 gpm +19.55 gpm)
=39.1 gpm – (4.05 gpm + 19.55 gpm)
= 15.5 gpm

Spring flows of 8.7 to 15.5 gpm are considered reasonable for this area.

It should be noted that the Upper Landslide Complex water balance calculations did not consider a potential groundwater contribution from the Snodgrass Mountain laccolith area (located above the Upper Landslide Complex), as the water balance was quite reasonable without this input. It is assumed that the groundwater from the laccolith likely discharges to strata below or adjacent to the Upper Slide Complex.

6.5 Monitoring and Maintenance

Monitoring and maintenance of the piezometers and the upper and lower flume sites on Snodgrass Mountain are an integral and on-going part of this study. Global Water WL-16 dataloggers have been installed in all of the monitored piezometers and at the upper and lower flumes. Currently, the dataloggers are monitored monthly and recalibrated to groundwater or surface water level, if necessary. The dataloggers will be downloaded monthly for the first three months after installation to assure proper operation. After the initial three month monitoring period, the monitoring schedule frequency will be reduced and the dataloggers will be checked and downloaded once every three months to ensure proper operation and calibration and to collect and compile the data. The three month monitoring schedule will be maintained for at least one year. After one year, the monitoring schedule will be reviewed and may be reduced to a semi-annual frequency. Data from the dataloggers will be compiled into an electronic database and summarized in annual and/or quarterly or semi-annual reports.