Performance of the PVR Rock Slope At Valdez Marine Terminal

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Five areas within Alyeska Pipeline Service Company's (Alyeska's) Valdez Marine Terminal (VMT) have steeply cut rock slopes that have been reinforced with rock bolts and monitored since the VMT was constructed. Monitoring has included regular reading of pneumatic piezometers that were installed in the slopes during construction. Flag levels were established for each piezometer on these slopes based on stability calculations or historical water levels.Annual reports are prepared to compare groundwater levels at each piezometer during that year to the established flag levels. If flag levels are exceeded, engineering reviews are made to assess the potential impacts of these excursions. Some piezometers have required maintenance and repair, and some rockbolts have required maintenance to maintain them to the standards assumed by the slope designers. Scaling and localized shotcreting have be required in some areas to control the potential for rockfall. This paper addresses the history of one of the VMT slopes, presents some of the long-term monitoring data, discusses the meaning of the data, and describes the maintenance activities that have taken place on the slope.

Introduction

The VMT was constructed from 1975 through 1977 on a series of rock cut excavations and benches, and rockfill benches. The larger facilities, including oil storage tanks, are generally located on bedrock foundations on the excavated benches. The Power and Vapor Recovery (PVR) Slope is the excavated rock slope immediately south of the Power and Vapor Recovery plant. It is the largest rock cut at the terminal and has been continuously monitored since it was completed. It has required periodic maintenance, and has been the subject of several engineering evaluations. Although other slopes at the VMT require monitoring and maintenance, this paper focuses on the monitoring and continuing evaluations of the PVR Slope.

A large failure developed during the initial excavation of the slope in 1975, as shown in Figure 1. The failure occurred largely along foliation planes of the phyllitic bedrock, although it was apparently initiated following exposure of some high-angle, cross-cutting structures near the toe of the excavation. A program of engineering evaluation and design was implemented to mitigate the risks of possible future slope failures. The final slope design included reinforcement of the phyllite slope with 30-foot long, 1-inch, resin anchored, fully grouted, tensioned high strength Dywidag threadbars. Lock-off loads of 60 kips were designed to produce an adequate safety factor against failure for the slope

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under static conditions for the documented geological and groundwater conditions. The bolt capacity between the lock-off load and the full design capacity of 100 kips is available to accommodate earthquake loads. The final slope design included:

- Excavating the slope to parallel the foliation planes,
- Rockbolting the slope to increase stability under static conditions and earthquake loading,
- Constructing a buttress at the toe of the slope to enhance toe stability and for rockfall protection, and
- Installing a groundwater monitoring system of pneumatic piezometers to enable confirmation that piezometric levels do not exceed those assumed for the slope design.

Alyeska has monitored the slope since construction, and has performed periodic maintenance. Maintenance has included regular scaling and cleanup of loose rock as necessary. Two major rock bolt replacement and re-tensioning programs were performed in 1992 and 2000. Rockbolts were replaced or re-tensioned in areas where weathering and degradation of the slope surface had removed the rock support from below the rockbolt bearing plates. This typically occurred in the vicinity of fault zones, where the sheared and altered rock is more susceptible to the effects of weathering. A coating of fiber-reinforced shotcrete was applied to some weathered zones to stabilize the slope by protecting the rock against further degradation.

Slope monitoring has included continual visual reconnaissance of the slope by terminal personnel, and regular detailed inspections of the slope by experienced rock engineering professionals. The monitoring has also included the regular measurement of groundwater levels behind the slope. The remainder of this paper focuses on this groundwater monitoring program and its results.

Pneumatic piezometers

A total of 15 Glötzl pneumatic piezometers were installed behind the PVR slope during construction to monitor groundwater pressures. Each piezometer was installed in a specially designed boring with a sand backfill around the piezometer in the sensing zone. Continuing reviews of the piezometer monitoring system have indicated that 14 of the original piezometers are still functioning reliably after some 25 years of service. Locations of the PVR slope piezometers are shown on Figure 2. The intake and return lines for piezometers at the PVR slope have been terminated in manifold boxes that are protected from snow and rockfalls, and enable readings to be taken from convenient locations.

Flag Criteria

Alyeska assigned "Flag" piezometric levels for each piezometer in the PVR cut based on stability calculations representing site conditions during a contingency earthquake. Flag levels are defined as a total head above the site datum. Total head at each piezometer is the sum of the elevation head (the height of the piezometer above the site datum), and the pressure head that is measured by the piezometer.

Stability analyses used to develop flag levels are based on average piezometric levels through a slope section, so individual high piezometric readings do not necessarily indicate a stability or safety problem. Also, the volume of water retained in the joints (which are generally developed along the foliation planes) is limited by the size of the joints. This low fracture porosity resulting from discontinuous foliation joints, as illustrated in Figure 3, is suspected of preventing the effective drainage of the slope after the installation of the piezometers. No significant water flow or reduction in the piezometric pressure was noted when the slope designers first tried to reduce piezometric pressures with drainage. It is probable that any movement of rock blocks bounded by foliation or other joints would immediately reduce any locally high groundwater pressures. It is also probable that some of the joints are not hydraulically connected to other joints in the rock mass resulting in local, short-term high water levels which are not representative of the rock mass.

If the average piezometric levels in an area remain higher than the flag levels for a significant time, or continue to rise, a review of site conditions would be warranted before taking any remedial action such as drainage enhancements. To date this has not occurred on the PVR slope.

Piezometer Monitoring Results

Piezometers have been monitored regularly since they were installed. Flag levels and recent (September, 2000) piezometric elevations for the piezometers installed in the PVR slope are shown Table 1. The column "Flag minus Head" represents the amount by which the current reading is below (positive) or above (negative) the flag level.

Plots of individual piezometer measurements and annual averages of piezometer monitoring data are maintained for each piezometer from the time of installation until the present., which also show the flag levels. Plots of typical results for Piezometer 40 are presented in Figures 4 and 5.

Readings taken from 1975 through 1983 appear to be generally more consistent and are likely more reliable than those taken from about 1983 through 1994. Pronounced variability in measured piezometric levels for a number of piezometers during the period approximately 1983 through 1994 is interpreted to result largely from operator procedures and/or poor instrument performance. Substantially decreased variability in monitoring results is evident subsequent to 1994, when improved monitoring procedures and the exclusive use of a new Glötzl readout unit were implemented.

An evaluation of piezometer readings was undertaken to evaluate trends in changing groundwater conditions, and to identify problems with the pore pressure cells or measuring systems. The evaluation was undertaken by area because if significant variations in groundwater levels occur, they would influence and be detected by more than one piezometer within an area. This approach helps to identify individual anomalies that may result from instrument errors, or from local conditions that are not representative of a larger area that may be significant for slope stability. Important items addressed in this evaluation included:

- Performance of individual piezometers
- Historic trends and possible temporal trends
- Significance of monitoring results relative to flag levels

These items are discussed in the following sections.

Performance of Individual Piezometers

Field performance checks of pneumatic piezometers included checking the Inlet and Return lines for leaks. In general, both the field checks of the instrumentation, and the consistency of the recorded monitoring data, indicate that the piezometer monitoring system has performed reliably since it was installed more than 20 years ago. However, leaks have developed in some lines of the pneumatic system, or at the pneumatic piezometer diaphragms, and have affected some piezometer measurements.

Where the leak is only in the Return line, this should not generally affect the measurement taken using the Inlet line. Where the leak is only in the Inlet line, it is generally possible to obtain a valid reading by pressurizing the Return line. When leaks are indicated for both lines, which could also be caused by a leaking diaphragm, the accuracy of any estimate of piezometric head is unknown, but is probably reliable if the leakage rate is small. On the PVR slope the Return line was leaking on P-47 which had no impact on the readings except that the Return discharge could not be observed. Inlet line leaks on P-45 resulted in erroneous readings; subsequent readings made using the Return line for input produced more reasonable results. In addition, leaks that required repairs were noted for a number of lines for the piezometers monitored from the manifold boxes.

Historic Trends

Since 1994, readings have been mostly consistent and generally similar to the pre-1984 readings. In a limited number of cases, there appears to be a change in piezometric level since construction, although such changes are generally small. Table 1 summarizes piezometric levels for piezometers that have been functioning reliably since construction., based on the “Average Annual Level” plots for each PVR piezometer. It is evident that most changes between the pre-1984 and current readings are small.

Possible Temporal Trends

Groundwater levels are often affected by short-term and long-term precipitation patterns. Annual precipitation at Valdez from 1973 through 2000 has varied between approximately 45 inches and 90 inches, averaging approximately 68 inches during this period. Annual rainfall at Valdez is shown in Figure 6. There appears to be a generally rising trend from the time of construction through about 1993. However, since that time, precipitation has been near or below average.

Total precipitation of 62.4 inches in 2000, the most recent monitoring year, was a little below average; precipitation was a little above average at 72.4 inches in the preceding year. Rainfall has generally been close to average over the past four years, so measure groundwater conditions over that period are likely a reflection of average groundwater level variations at the site.

As noted previously, identifiable changes in groundwater levels are generally small, seldom more than a few feet over a period of more than 20 years.

Significance of Excursions Above Flag Levels

Flag levels for the Power and Vapor Recovery Cut are based on stability analyses that include a contingency earthquake. This implies that slope stability may be compromised if piezometric levels exceed flag levels during a design-basis earthquake. Out of the 14 functioning piezometers in the PVR cut, the September 2000 monitoring identified the following piezometric levels at or above their flag levels.

The piezometric level at Piezometer 47 was always close to the flag level from the time of installation, but appears to have risen by approximately eight to ten feet in the more than 20 years since construction. The piezometric level at Piezometers 40, 49, and 50 were also always close to the flag level, and have risen approximately two to six feet since construction. These excursions are only local phenomena of limited magnitudes; the average piezometric levels throughout the slope are well below the flag and design levels as shown in Table 1. The slope is therefore considered to be in general compliance with the design-basis groundwater assumptions.

General Conclusions on Groundwater Conditions

The piezometer monitoring system has mostly performed well over the more than twenty years that it has been installed. Piezometer readings taken using suitable standard procedures with properly calibrated instruments indicate that most piezometer installations show little change in groundwater levels through the years. The minimal relative changes can be seen in the piezometer levels shown at the two cross section locations shown on Figure 2. These cross-sections with piezometric levels and flag levels shown are presented in Figures 7 and 8. These show that recent groundwater levels are generally close to the lowest levels measured at the time of construction; there has generally been little change in overall groundwater levels at the site since that time.

Most piezometers show little or no systematic seasonal variation in groundwater levels. Where seasonal variations may exist, they are generally small and of little practical significance, since they do not lead to excursions above flag levels. Apparent long-term changes in groundwater levels are indicated by some piezometers. However, the magnitudes of such changes are generally small, mostly only a few feet over a period of more than 20 years. There appears to be a trend toward slow increases in groundwater levels near the base of the PVR Cut.

Our reviews of monitoring data have concluded that piezometer measurements taken using proper procedures demonstrated that most piezometer installations showed little change in groundwater levels since the time the facilities were constructed, and that most piezometers show little or no systematic seasonal variations in groundwater levels. Four of the 14 functioning piezometers in the Power and Vapor Recovery cut indicate groundwater levels above flag levels. Three of these are between 0.3 and 3.3 feet above flag level, while the fourth is 9.1 feet above flag level. However, the average piezometric elevations in the PVR cut have remained below flag levels. The slope is therefore considered to be in compliance with the assumptions used for stability analyses on which the design is based.

Acknowledgements

There authors appreciate the support and assistance provided by Alyeska Pipeline Service Company in the preparation of this paper. The work reported in this paper has been developed as part of Alyeska's continuing maintenance and monitoring of this slope. Special thanks to Mr. Pat McDevitt and Mr. David Norton who were instrumental in making the information presented available. The photograph in Figure 1 was provided by Mr. Thomas Krzewinski.

Table 1

September 2000 Piezometer Summary

Piezometer Number	Elevation Head (ft)	Pressure Head (ft)	Total Head (ft)	Flag Level (ft)	Flag Level minus Head(ft)	Change since Pre-1984 Readings (ft)
36	467.8	28.3	496.1	504	7.9	1
37	441.9	77.6	519.5	522	2.5	1
40	390.3	60.0	450.3	450	(0.3)	2
41	384.5	82.2	466.7	470	3.3	1
42	377.7	75.0	452.7	465	12.3	(8.0)
43	381.4	42.6	424.0	430	6.0	0
44	360.9	35.4	396.3	400	3.7	7
45	358.2	3.1	361.3	410	48.7	1
46	361.0	28.2	389.2	390	0.8	6
47	338.7	130.4	469.1	460	(9.1)	11
48	371.6	11.7	383.3	390	6.7	0
49	337.9	43.7	381.6	380	(1.6)	6
50	328.5	54.8	383.3	380	(3.3)	5

Figure 1. Failure of the PVR Slope in 1976

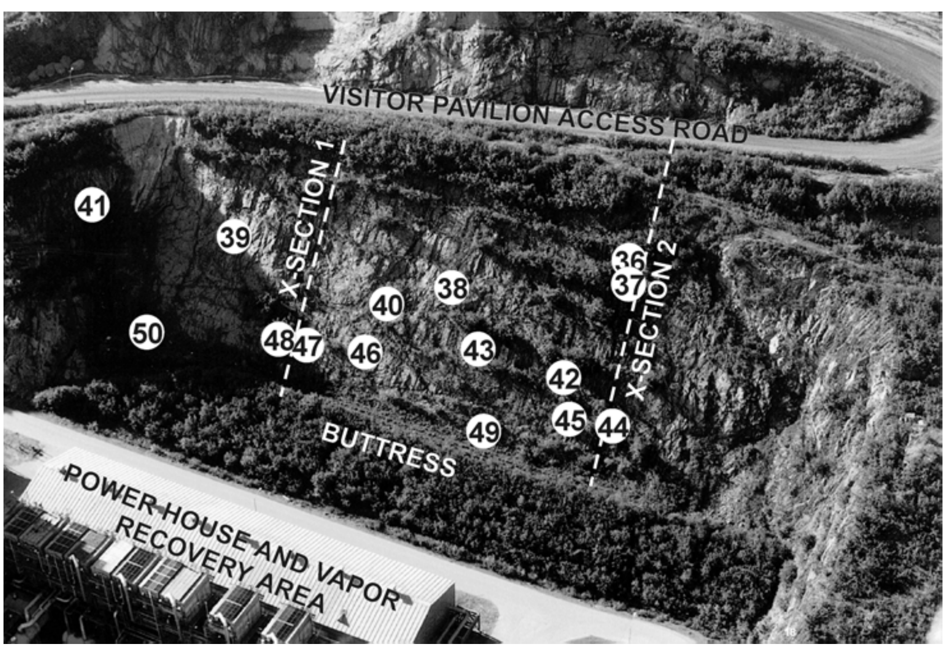

Figure 2. Locations of Piezometers on PVR Slope

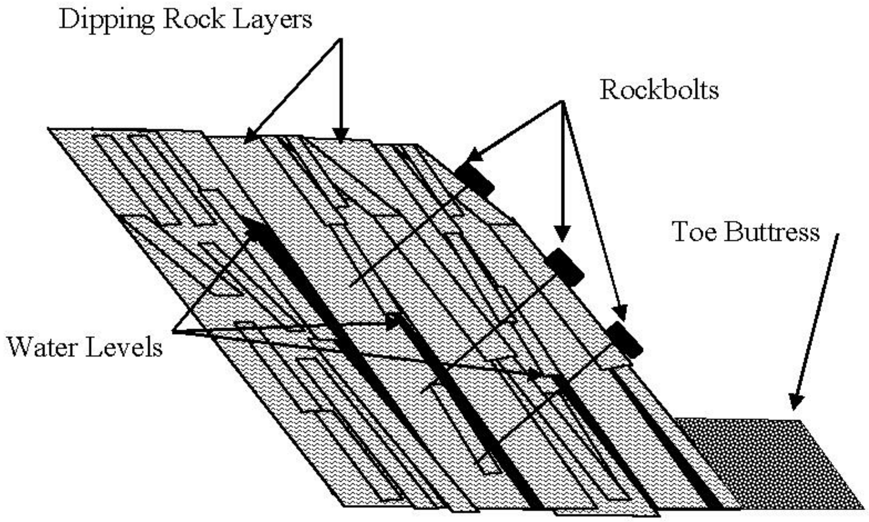

Figure 3. Conceptual Water Levels in Steeply Dipping Rock Strata

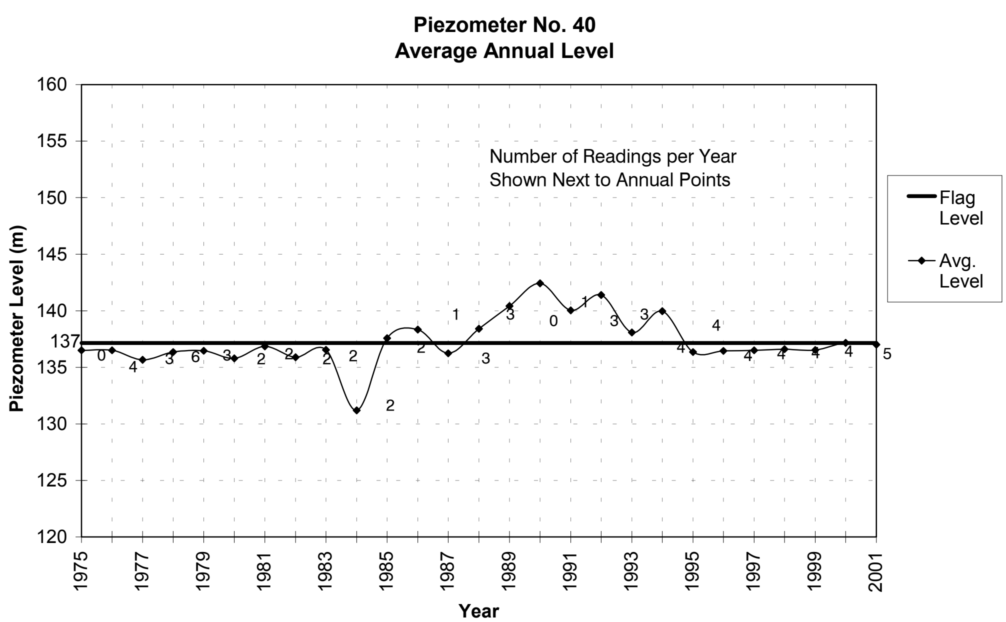

Figure 4. Average Annual Water Level at Piezometer 40

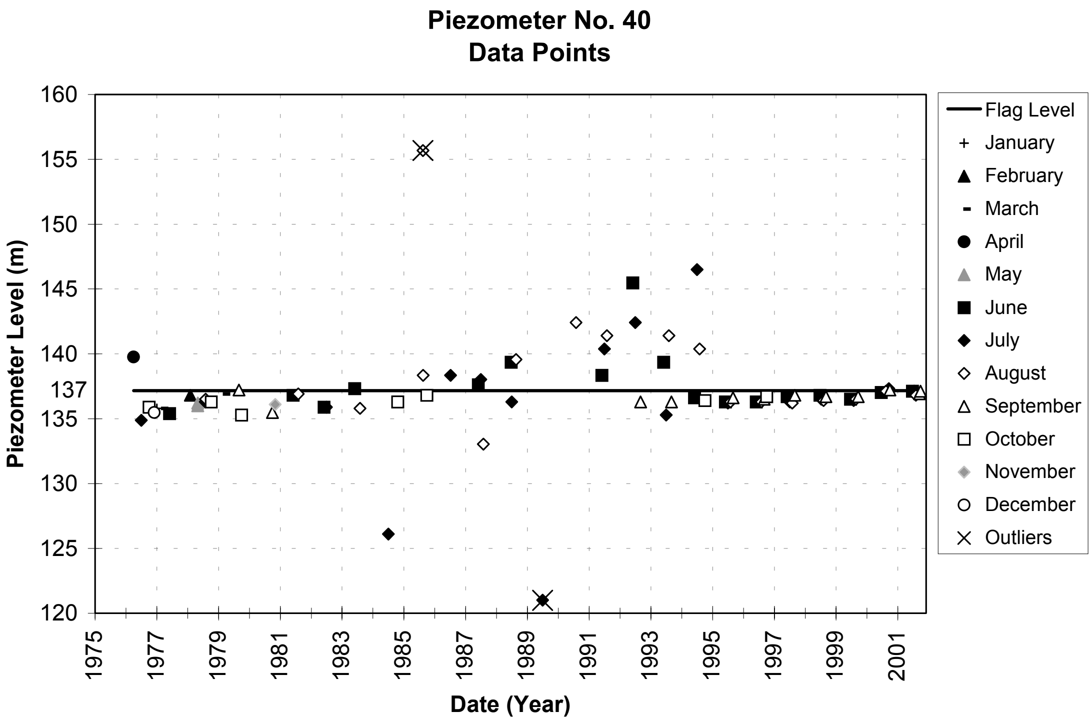

Figure 5. Monthly Water Levels at Piezometer 40

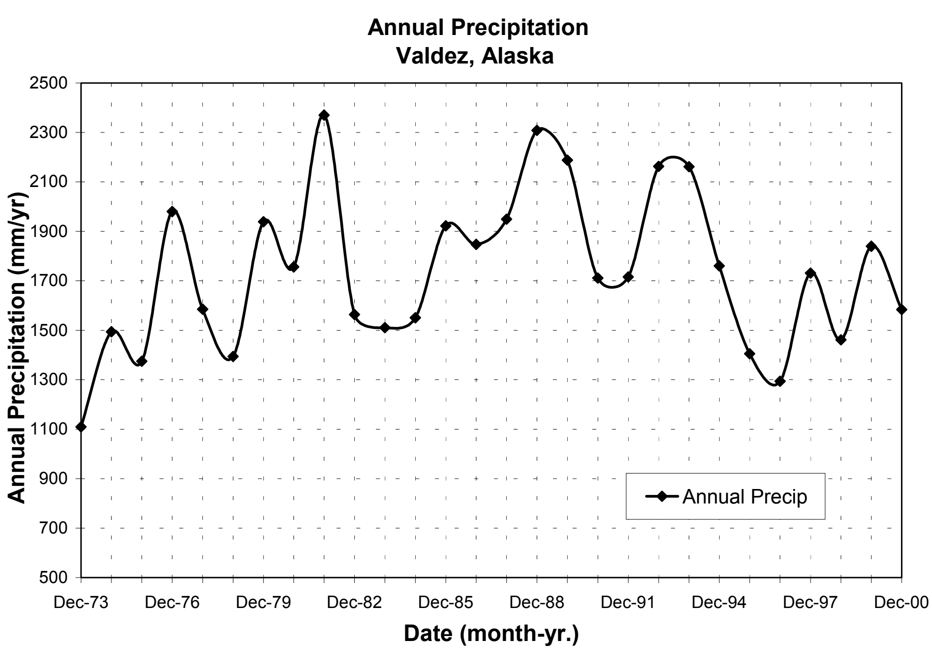

Figure 6. Average Precipitation at Valdez

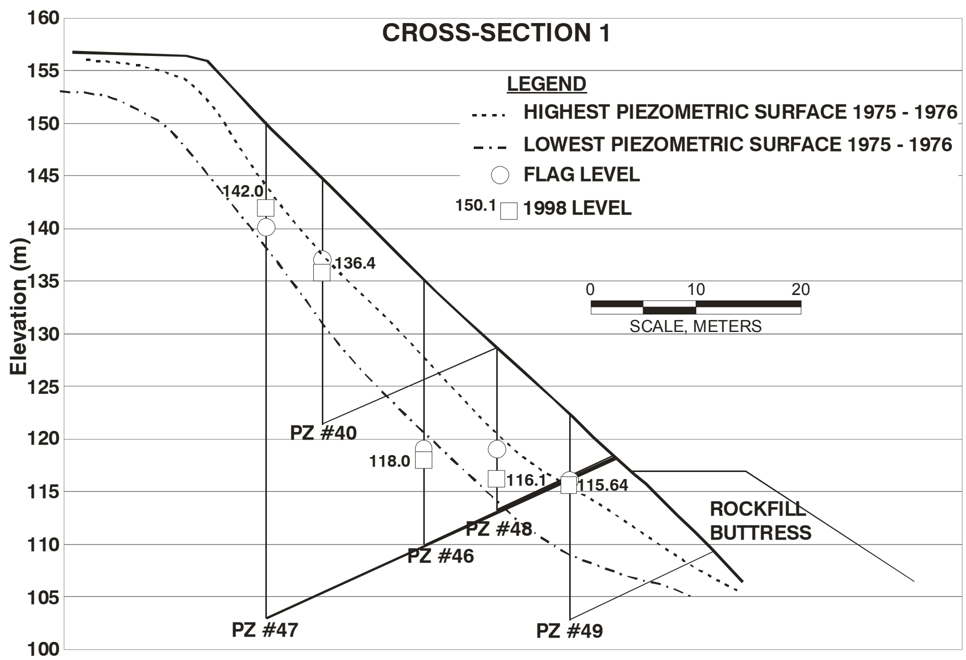

Figure 7. Comparison of 1999 Water Levels to Flag Levels

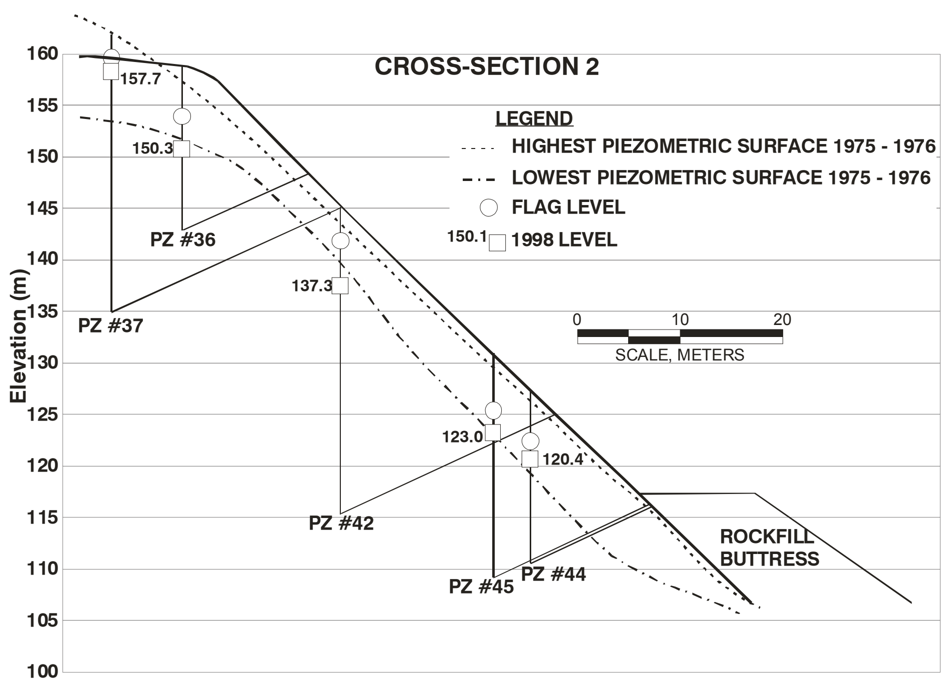

Figure 8. Comparison of 1999 Water Levels to Flag Levels