

# ASSESSMENT OF WATER STORAGE COVER FOR QUESTA TAILINGS FACILITY, NEW MEXICO

by

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**Abstract.** A test plot study has been initiated to study the performance of a water storage cover consisting of alluvial soil over tailings proposed for final closure of a large 260 ha (640 acres) tailings facility located near the town of Questa, New Mexico. The test plot study has been designed to meet the following objectives (i) measure climatic conditions at the site; (ii) measure in-situ material properties (characteristic curves); and (iii) calibrate a soil-atmosphere model in order to predict net infiltration. The test plot study consists of two closed lysimeters covered with 0.25m (9”) and 0.60m (24”) of alluvial soil (silty gravel) over backfilled tailings, respectively, and an instrumented deep tailings profile with a 0.25m (9”) thick alluvial cover and existing vegetation and a fully automated weather station, which monitors all relevant climate parameters (including actual evapotranspiration). The lysimeters are free-draining and leachate from the test plot is collected and monitored using a tipping bucket. All test plots were instrumented with temperature/suction sensors and moisture content sensors to monitor moisture movement in the cover/tailings profile. This paper describes the design and installation of these test plots and summarizes monitoring results obtained to date. Initial results for the first five months of monitoring suggest that a 0.25m (9”) thick alluvial cover with mature vegetation is more effective in reducing net infiltration than either a 0.25m (9”) or 0.60m (24”) thick alluvial cover without vegetation.

Additional Key Words: store-and-release cover, semi-arid climate, lysimeter

## **Introduction**

Molycorp Inc. owns and operates a large tailings facility located near the town of Questa, New Mexico (Figure 1). Over the last 33 years a total of nearly 100 million tons of tailings from the Questa Molybdenum Mine have been discharged into this facility covering a total surface area of about 260 ha (640 acres) (as of 1997).

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The tailings originate from a hydrothermally altered molybdenum porphyry deposit of volcanic origin and are produced at the Questa mine, located some 8 km to the east of the Questa tailings facility.

Molycorp proposes to cover the tailings with locally available alluvial soils (silty gravel) after final closure of the facility (RGC, 1998). This soil layer would prevent erosion of the tailings, provide a growth medium for re-vegetation and, in conjunction with the underlying tailings, represent a water storage (or “store-and-release”) cover that would reduce infiltration into the deeper tailings profile.

This test plot study focuses on the function of the proposed alluvial cover to control infiltration. A water storage cover typically consists of a well-graded soil layer (or multiple soil layers) that stores precipitation during wet periods and releases the moisture back to the atmosphere via evapotranspiration during dry periods. The net effect is a significant reduction, or elimination, of

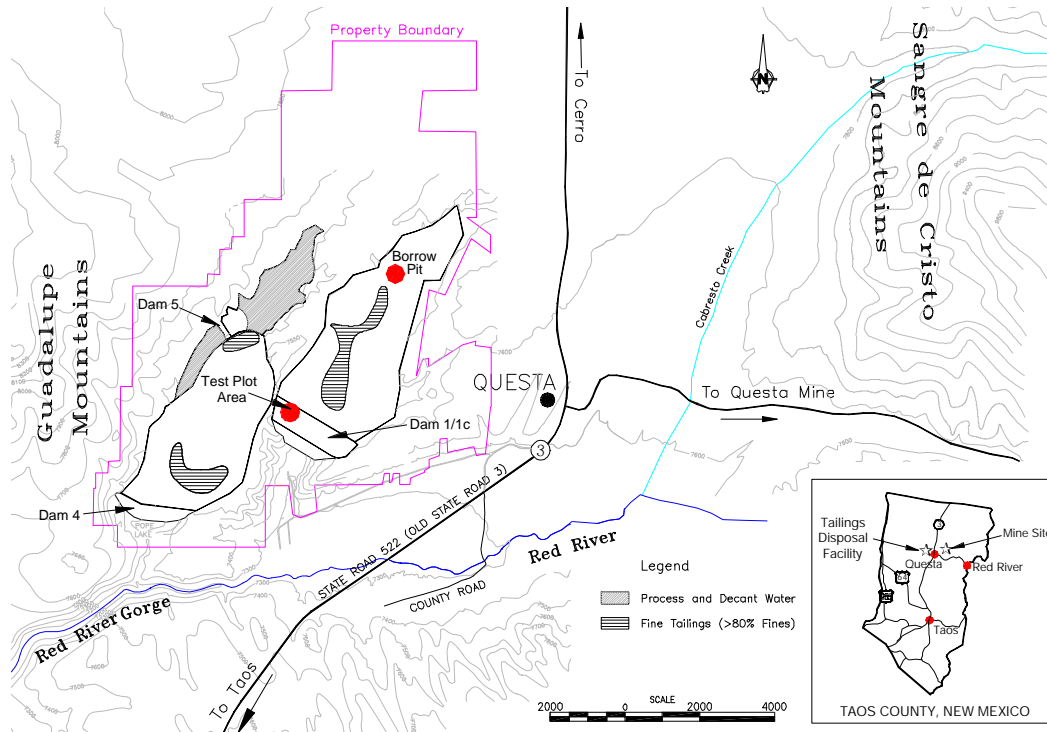


Figure 1. Location map of Questa tailings facility.

deep percolation (also called “net infiltration”), and ultimately seepage from the tailings impoundment. The semi-arid climate conditions experienced at Questa, New Mexico favor the use of the water storage cover over the more conventional water barrier (low permeability”) cover. While the dry climate generally improves the performance of the water storage cover (due to high rates of evaporation coupled with low precipitation) it often compromises the performance of a water barrier cover due to problems with desiccation (e.g. Swanson et al., 1997; Bews et al., 1997). Water storage covers have been designed for several mine sites in arid or semi-arid climates (e.g. PTI and WESTEC, 1996; GSM, 1995; and O’Kane et al., 1998).

The main advantages of the water storage cover compared to the alternatives (low permeability and capillary barrier covers) are:

- a water storage cover will require the least long-term maintenance and has the lowest potential for long-term degradation (and ultimately failure);
- the effectiveness of a water storage cover is expected to increase in time as the vegetation matures to the desired climax vegetation (here sagebrush and juniper); and

- the proposed water storage cover can be implemented for a fraction of the cost of more complex engineered cover types.

Molycorp has implemented a test plot study at the Questa tailings facility to evaluate net infiltration through the proposed water storage cover (RGC, 2000a). The test plot study was initiated to collect site-specific data of cover performance for the purpose of final design. Specifically, the test plot study was designed to meet the following objectives:

- measure climatic conditions at the site;
- measure in-situ material properties (characteristic curves); and
- calibrate a soil-atmosphere model in order to predict net infiltration.

It is important to recognize that the primary objective of the test plot study was not to measure cover fluxes *per se* but instead, to calibrate a soil-atmosphere model for known (measured) boundary conditions. The ultimate goal is to use the calibrated soil-atmosphere model to predict with a high degree of confidence the performance of the storage cover for conditions relevant to final closure (i.e. deep, unsaturated tailings profile; mature vegetation; range of climatic conditions). These final closure conditions cannot, of

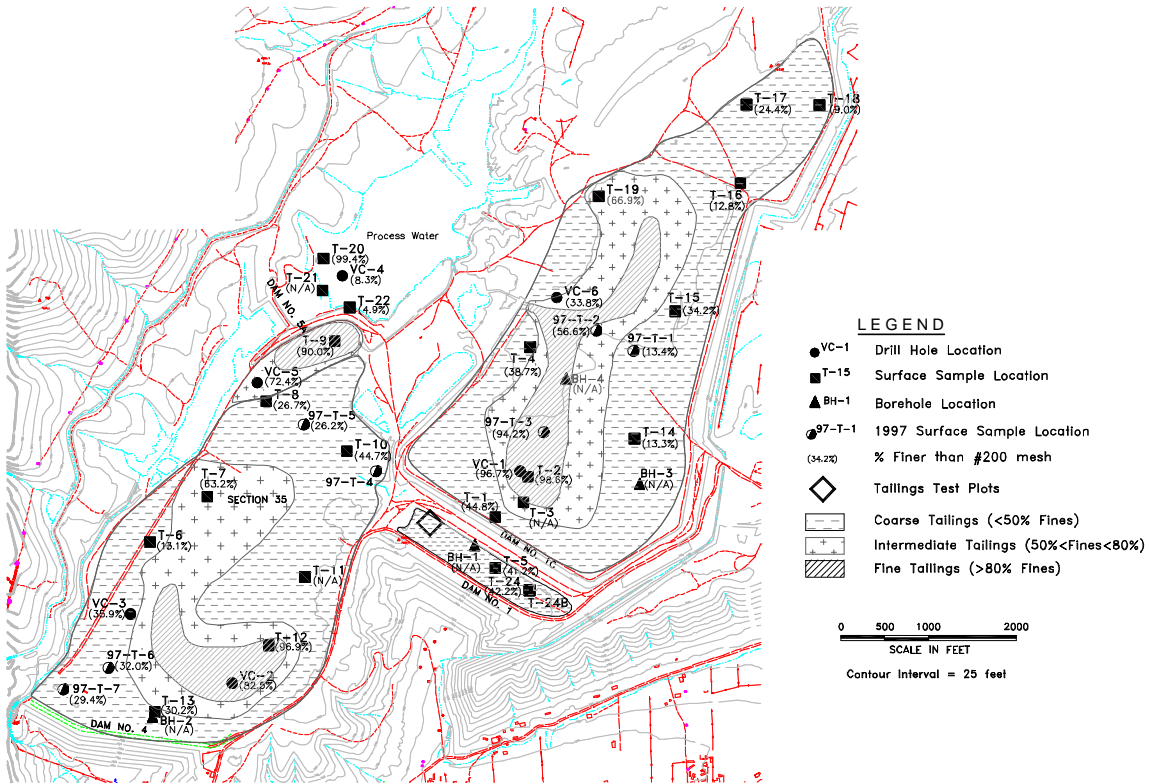


Figure 2. Tailings Characterization Plan for Questa Tailings Facility.

themselves, be duplicated in a field trial of only a few years, but instead have to be simulated.

### Site Description

The Questa tailings facility is located near the town of Questa in Northern New Mexico (Figure 1). The tailings facility lies in an alluvial plain at an elevation of about 2320m (7600 feet) a.m.s.l., bordered by the Sangre de Cristo Mountains to the east and the Guadalupe Mountains to the west. The tailings were impounded in two deeply incised valleys (so-called “arroyos”) behind two major earth fill dams (Dams 1/1C and Dam 4, respectively). Currently, tailings are discharged behind the smaller Dam 5 in the northwestern corner of the facility.

The test plots for this study were constructed on the tailings beach between Dam 1 and Dam 1C (Figure 2). Dam 1 was constructed in 1966 as an earthfill dam across an arroyo and was raised by downstream construction using earthfill. In 1975, “Old” Dam 1C was constructed of cycloned sand 200m upstream of Dam 1. In 1981 “New” Dam 1C was constructed at its present location (Figure 2). This ‘new’ dam replaces the old dam, which is

contained within the tailings deposited behind “New” Dam 1C.

During initial placement behind Dam 1 the discharge was made from the north end of the impoundment resulting in a beach forming at the northern end of the impoundment. This beach sloped towards a tailings pond that formed in the south against Dam 1. Tailings pond water was originally decanted from the Dam 1 pond through the decant conduit.

During later operation of the Dam 1 impoundment tailings were discharged from the Dam 1 embankment and from the east side of the impoundment perimeter from a series of spigots (small pipe discharges) to develop beaches from these locations. The beaches, sloping to the north from Dam 1, and to the west from the east perimeter resulted in the tailings pond being ‘driven’ to the central-west location from which it could decant to the west. A deep deposit of slimes developed at the new location of the pond against the west perimeter. The initial slimes deposit against Dam 1 was covered by a thick deposit of tailings sands.

Cyclone sand berms were also developed across the tailings impoundments to serve as separator dykes to allow the impoundments to be operated as separate areas. Tailings were spigotted into these management areas from perimeter discharge points to produce beaches, which would allow the tailings pool to be maintained at a desired location adjacent to the western perimeter from which discharge could be affected. The total quantity of tailings placed by cycloning methods is a relatively small portion of the total tailings.

Typical tailings beach slopes vary between 1 to 1.5% near the discharge to less than 0.5 % near the pond. At the pond edge the tailings profile would typically steepen to about 5%. As the tailings flow down the beach the tailings solids settle out and are deposited on the beach. The coarsest tailings (sands) are deposited near the discharge point while the finest fraction (slimes or fines) are carried to near the pond. This beach and pond formation is characteristic of all beached deposits in the Questa tailings impoundments.

The sand beaches drain rapidly and are trafficable to construction equipment. The slimes beaches are very soft with low shear strength and cannot be accessed when wet and saturated.

A detailed physical and geochemical characterization of the Questa tailings was carried out as part of the development of the revised closure plan for this facility (RGC, 1998). Briefly, the Questa tailings are geochemically similar mixtures of aplite and andesite tailings with low-moderate sulfide content (0.5–1.5% pyrite). The predominantly andesitic tailings have higher sulfide-sulfur contents and a higher potential to generate acid than the slimes tailings or aplite tailings. Despite the oxidation potential of sulfide minerals, the Questa tailings are currently not acid generating. The surface tailings, which have been most susceptible to oxidation processes, have remained grey in color and are consistently circum-neutral with respect to paste pH. The field and laboratory data suggest that the buffering capacity of the tailings is sufficient to maintain circum-neutral pH in the tailings pore water (Wels et al., 2000).

A total of 32 tailings samples were analysed for standard grain size analyses (ASTM D422) to characterize the spatial distribution of the tailings at the surface of the impoundments according to size fraction. Only those tailings samples collected

from the near surface were selected for analysis. Figure 2 shows the sampling locations.

The tailings were subdivided into three classes:

- i. coarse tailings with <50% fines content (where fines constitute silt and clay sized particles with a grain diameter smaller than 0.075 mm (# 200 mesh));
- ii. intermediate tailings with 50% < fines content <80%; and
- iii. fine tailings with >80% fines.

Figure 2 shows the spatial distribution of these tailings classes in the tailings impoundments behind Dam No. 4 and Dam No. 1/1C as inferred using the laboratory results, surface topography (indicating beaches), current extent of surface ponding and a general understanding of the operation of these tailings impoundments.

The estimated relative coverage of the coarse, fine and intermediate tailings in the two impoundments is shown in Table 1. Both tailings impoundments show very similar coverages of the three tailings classes. The coarse tailings dominate with about 2/3 of the total surface area. The fine tailings comprise only about 12% of the present tailings surface area.

It should be noted that the ‘fine tailings’ of the Questa impoundment are not as fine as observed elsewhere as a result of the overall coarse grind of the ore. According to the USCS classification the ‘fine tailings’ of the Questa impoundment are classified as silt (ML) with typically only about 30% clay (<0.002 mm).

The climate of the study area is semi-arid. Annual precipitation at near-by Cerro averages about 310 mm/yr with much of this precipitation occurring as summer thundershowers (43% of total precipitation occurs from July to September). The summers are moderately warm with maximum daily temperatures around 27°C. The winters are long with temperatures dropping below freezing almost every night from October through to April. However, typically clear skies bring sunshine during most days with temperatures rising to above the freezing point. During the winter much of the precipitation falls as snow. Nevertheless, a significant snow pack rarely develops due to intermittent snowmelt and/or sublimation. Based on frost data collected by the U. S. Weather Bureau at Cerro a growing season of 120 days is average for the study area. As expected for this semi-arid climate, the potential evaporation rates

far exceed precipitation rates during all months on record. The annual pan evaporation is estimated to be about 1650-1780mm per year.

### **Design Of Test Plot Study**

The test plot study was designed to evaluate factors controlling the performance of the cover and the net infiltration to the tailings, i.e. material properties, climate conditions and cover thickness (RGC, 2000a). A total of three test plots were constructed in the beach area between Dam 1 and Dam 1C of the Questa tailings facility (Figure 1). This tailings area has been covered for about 25 years, which allowed the establishment of a mature grass/shrub vegetation on the cover material. An initial reconnaissance survey indicated that the interim cover placed historically in this area was quite variable (ranging in thickness from 0.25m (9") to greater than 0.60m (24")). The test plot location finally selected (in the eastern portion, see Figure 1) was deemed most representative of the requirements for the deep in-situ test plot TP-1, i.e. an existing 0.25m (9") cover with mature grass/brush vegetation.

The three test plots were constructed and instrumented to measure the performance of three different combinations of cover thickness and vegetation development:

- Test Plot #1: Existing 0.25m (9") thick alluvial cover with mature grass/shrub vegetation overlying *in-situ* sandy tailings (very deep tailings profile);
- Test Plot #2: 0.25m (9") thick alluvial cover with no vegetation overlying back-filled sandy tailings (~2.5 m deep tailings profile); and
- Test Plot #3: 0.60m (24") thick alluvial cover with no vegetation overlying back-filled sandy tailings (~2.5 m deep tailings profile).

Test plot #1 is most representative of post-closure steady-state conditions, i.e. with mature vegetation established on the alluvial cover

overlying undisturbed hydraulically placed tailings. This test plot is designed as an open system, i.e. the monitoring instrumentation was installed into the existing cover and tailings profile (without prior excavation). Any excavation of the cover and tailings profile would destroy the root system of the vegetation, which is considered a vital component of this cover system, as well as the 'natural' soil structure and density of the hydraulically placed tailings. Test plot #1 will be used to calibrate the soil-atmosphere model (including effects of vegetation on evapotranspiration) against measured changes in soil moisture and soil suction over time. The calibrated soil-atmosphere model of test plot #1 will be used to predict the net flux through a mature cover system for post-closure steady-state conditions.

Test plots #2 and #3 represent free-draining "lysimeter plots", in which the rate of net percolation through the cover and shallow tailings profile is monitored directly and leachate is collected at the base of the lysimeter. Test plots #2 and #3 will be used to assess the influence of cover thickness on net percolation (initially without the influence of transpiration by plants). Both test plots will allow calibration of the soil-atmosphere model not only against observed suction/moisture content in the profile but also against measured net fluxes observed discharging at the base of the lysimeters.

Two sets of sensors were installed in the three test plot profiles to measure the in-situ soil temperature, matric suction and volumetric moisture content required for soil-atmosphere model calibration. The *in-situ* temperature and soil matric suction is measured using a thermal conductivity type sensor CS 229 (Campbell Scientific, 1998). The sensor consists of a thermocouple, which measures *in-situ* soil temperature. During a suction measurement the sensor is briefly heated and subsequently records the heat dissipation within the ceramic cup of the sensor, which can be converted into matric suction using a calibration curve.

The volumetric moisture content is measured indirectly using the capacitor-type sensors distributed by SENTEK Environmental Technologies, Adelaide, Australia. The capacitance of a soil increases considerably with an increase in

the number of soil water molecules, which are free to relax as their electric dipoles respond to the capacitor sensors field reversal (SENTEK, 1999). For the tailings test plots the EnviroSCAN system of SENTEK Environmental Technologies was used

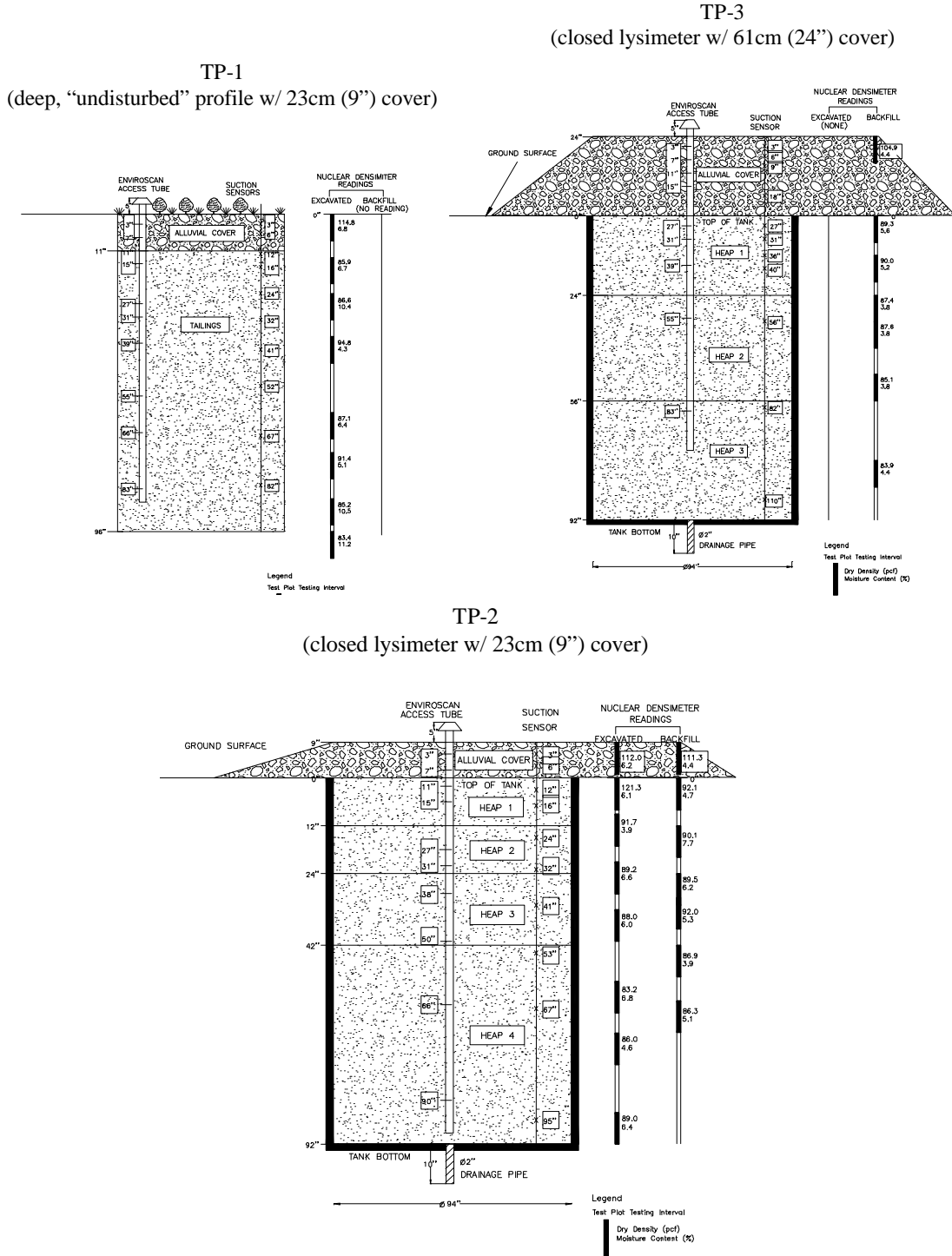


Figure 3. As-built drawings for test plot lysimeters TP-1, 2, 3.

(SENTEK, 1997). In this system the capacitor sensors are mounted on a track and installed into the soil profile within a 50 mm diameter PVC housing (“access tube”). The sensors are hooked up to the EnviroSCAN data logger, which controls data acquisition and presentation (SENTEK, 1999).

### Construction And Instrumentation

#### Test Plot Construction

Figure 3 shows the as-built drawings for test plots TP-1, TP-2 and TP-3 illustrating lysimeter dimensions, *in situ* testing results and instrumentation. The figure also shows details of the drain discharge system from the lysimeter to the manhole (for TP-2). At each test plot site, a foot print area of approximately 4.6mx4.6m was staked out and the tailings excavated to a total depth of about 2.4m. The excavated material was then stockpiled for later backfilling (for test plots TP-2 and TP-3 only). The mine rock profile encountered in the excavation was photographed and logged with respect to material type, texture, color, and moisture content. Paste pH and electrical conductivity measurements were taken at representative depths of the soil profile. In addition, representative samples were collected for calibration of the SENTEK moisture content sensors and for further physical and geochemical testing. *In situ* density and moisture contents were measured at representative depths during excavation (typically every 30-90cm and/or where a change in material properties was observed during excavation).

The construction and instrumentation varied between the deep, “undisturbed” profile (test plot TP-1) and the closed lysimeters (test plots TP-2 and TP-3). For test plot TP-1 an access ditch was excavated along one side of the test plot to a depth of approximately 2.7m. The access ditch was used to determine *in-situ* material properties, collect representative samples, and to provide access to the revegetated, undisturbed tailings profile for lateral installation of the suction-temperature sensors (Figure 3). The suction sensors were installed progressively from bottom to top during backfilling of the excavation trench. First, a pilot hole was drilled with a T-bar drill and then the suction sensor was pushed into the slightly undersized drill hole using a specifically designed installation tool to ensure good soil/sensor contact. The volumetric moisture content sensors were installed at the perimeter of test plot TP-1. A 3.5m long PVC access tube (50mm diameter) was pounded into the soil profile using a sledgehammer. Once in place, the soil and tailings present in the access tube were removed using a hand auger and the volumetric water content sensors inserted into the access tube (mounted on a rail).

For construction of the lysimeter test plots TP-2 and TP-3, thick walled (19mm) HDPE tanks with a diameter of 2.4m and a height of 2.3m were used. The tank was lowered into the excavation and backfilled with tailings stockpiled in 3-4 piles according to material properties (Figure 3). The tailings were lowered into the lysimeter using the backhoe, spread out by hand using a shovel and compacted by foot. Nuclear densometer readings

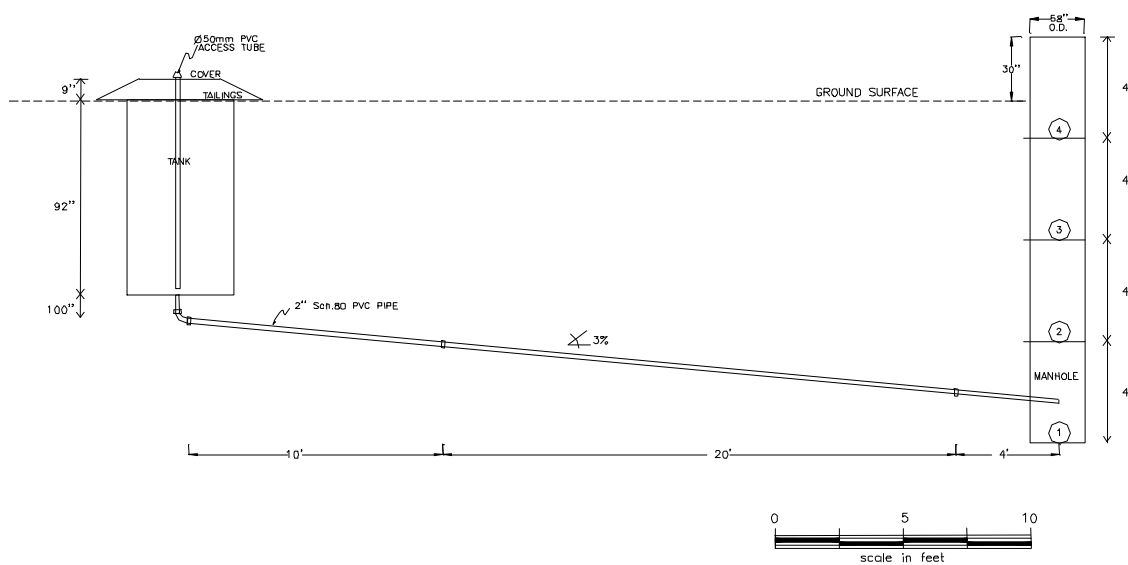


Figure 3 cont'd. As-built drawings of drain discharge system (for TP-2).

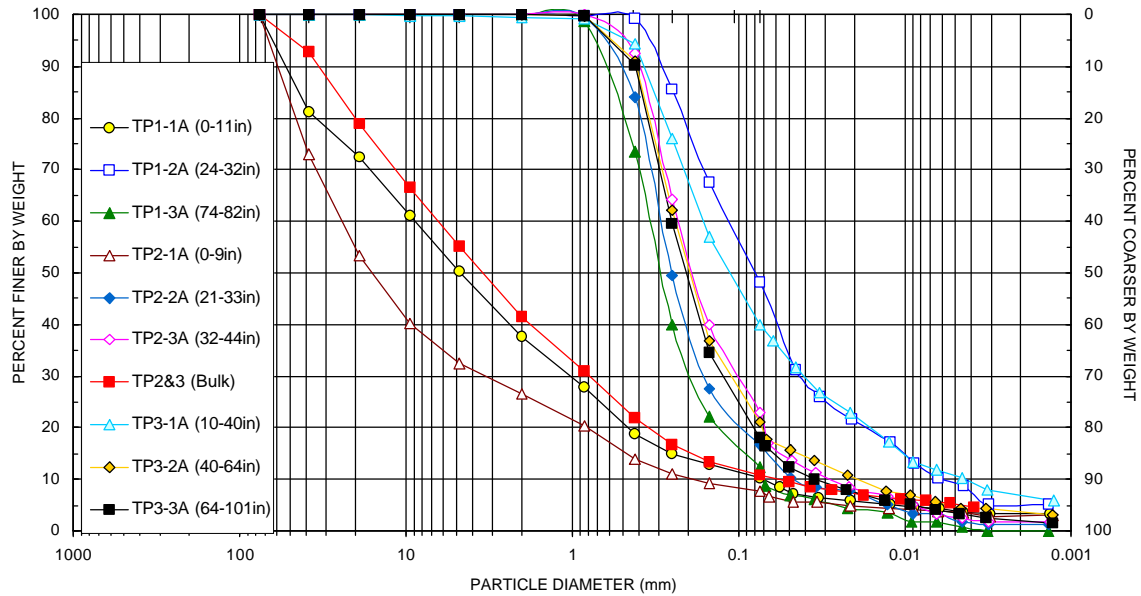


Figure 4. Particle Size Distributions for test plot samples.

at representative depths indicated that this backfill method resulted in compaction values very similar to those observed during excavation of the tailings (Figure 3). The resulting moisture content in the backfilled tailings was also very similar to the average moisture conditions observed during excavation (Figure 3).

A 50mm diameter PVC tube (for access of the SENTEK volumetric moisture content sensors) was placed in the center of the lysimeter and the tank backfilled in layers of 30-60cm with *in-situ* density and moisture content testing at designated depths (Figure 3). At the appropriate depths the suction-temperature sensors were laid out and carefully buried in the backfilled tailings. The area immediately around the PVC access tube was compacted by hand to achieve a good seal. In addition, an annulus bypass ring was installed around the PVC access tube near the surface of the alluvial cover to prevent preferential channeling into the lysimeter.

Once the lysimeter was backfilled with tailings back to surface a small trench was dug on one side of the excavation holding the lysimeter in order to install the discharge pipe, which connects the drain at the base of the lysimeter to a manhole (Figure 3). The discharge pipe was laid out on a 3% slope to allow easy drainage from the lysimeter. A 50mm  $\varnothing$  elbow at the end of the discharge pipe directs any drain flow downward into a tipping bucket flow gauge and a sampling bucket.

After backfilling of the lysimeter and construction of the discharge/manhole system the alluvial cover material was placed in a single lift without compaction using the backhoe. The alluvial cover was placed over a foot print area of about 6.0m $\times$ 6.0m, i.e. about eight times the foot print area of the lysimeter in order to minimize boundary effects. The alluvial material used for cover construction on the lysimeter test plots (i.e. TP-2 and TP-3) was taken from a local (small) borrow pit with alluvial soil deemed representative of the alluvial soils proposed for final cover of the tailings facility (see Figure 1 for location of borrow pit for test plots). Several samples of this alluvial cover material were taken for calibration of the SENTEK sensors and future analyses in the laboratory.

A detailed description of the data acquisition system for the test plots is provided in RGC (2000b). Briefly, the soil temperature/suction sensors and the tipping bucket flow gauges and volumetric moisture content sensors are hooked up to separate data logger systems (CR10X and Sentek, respectively). Soil temperature/suction and water content measurements are taken automatically every two hours. The tipping bucket flow gauge records the discharge from the test plots (TP-2 and TP-3 only) on an event basis.

#### Metrological Station

A fully automated meteorological station was constructed at the test plot area to properly evaluate atmospheric boundary conditions for future



Table 1. Relative coverage of coarse, intermediate and fine tailings, Questa tailings facility.

| Tailings Impoundment | Surface Area<br>(in ha) | Relative Coverage by Tailings Class (in%) |                                       |                               |
|----------------------|-------------------------|---|---------------------------------------|-------------------------------|
|                      |                         | coarse tailings<br>(<50% fines)           | intermed. tailings<br>(50%<fines<80%) | Fine tailings<br>(>80% fines) |
| behind Dam Nos. 1/1C | 119                     | 65%                                       | 23%                                   | 12%                           |
| behind Dam No. 4     | 102                     | 61%                                       | 27%                                   | 12%                           |
| TOTAL                | 221                     | 63%                                       | 25%                                   | 12%                           |

Table 2. Summary climate statistics for the tailings station for period August 9, 2000 to January 6, 2001 (based on daily average values).

| Met Station |         | Average Daily<br>Air<br>Temperature | Average<br>Daily RH | Average<br>Daily Wind<br>Speed | Total Daily<br>Net<br>Radiation | Cumulative<br>Precipitation | Cumulative Potential<br>Evapotranspiration |
|-------------|---------|-------------------------------------|---------------------|--------------------------------|---------------------------------|-----------------------------|--|
|             |         | (°C)                                | (%)                 | (m/s)                          | (MJ/m <sup>2</sup> )            | (mm)                        | (mm)                                       |
| TP1,2,3     | Average | 6.6                                 | 55.2                | 2.4                            | 3.65                            | 154.9                       | 356.6                                      |
|             | Min     | -9.6                                | 23.5                | 0.4                            | -2.74                           |                             |  |
|             | Max     | 24.4                                | 97.6                | 4.7                            | 14.63                           |                             |  |

numerical model calibration. The weather station consists of an all-weather rain gauge, relative humidity/temperature probe, wind sensor, and radiometer. All sensors were mounted on a 3m tripod anchored to the surface using anchors and guy wires. The sensors were arranged to measure climate parameters at a nominal height of 1.8m above ground surface. In addition, a fully automated Bowen Ratio System (BRS) was installed for measuring actual evapotranspiration (Campbell Scientific, 1995). The Bowen Ratio is the ratio of sensible heat loss from the surface to the atmosphere and the energy utilized for evaporation. The latter term is calculated based on measurements of net radiation, total soil heat flux, and the gradient of temperature and vapor pressure above the surface.

### **Material Testing**

Representative samples of tailings and alluvial cover material were taken during construction of the test plots and submitted for laboratory testing to determine hydraulic properties and soil water characteristic curves (see RGC, 2000b for details). The geotechnical characterization includes grain size analysis, moisture content, standard proctor compaction, permeability, and soil water characteristics (i.e. moisture retention). Figure 4 shows the particle size distribution (PSD) of the various tailings and alluvial cover samples taken

from the three test plots. The alluvial cover material represents a fairly well-graded silty/clayey gravel (GM-GC) with a fines content ranging from 7.8 to 10.9%. In contrast, the tailings encountered at the test plots represent a poorly graded silty sand (SM) with a fines content ranging from 12.4% to 48.2%. Hence the cover performance test plot study is most representative for the coarser beach areas that cover about 2/3 of the total tailings area at the Questa tailings facility (Table 1). Based on a review of the PSD data pertinent samples have been selected for standard proctor compaction, permeability, and soil water characteristics testing (RGC, in progress).

### **Initial Monitoring Results**

#### **Climate Data**

Figure 5 shows time trends of air temperature and relative humidity (daily min/max) as well as daily precipitation for the first five months of monitoring (August 9, 2000 to January 6, 2001). Table 2 provides summary climate statistics for this period. The amount of total precipitation over the 5-month period (155mm) was only slightly above the long-term average for this period (150mm) for the near-by weather station of Cerro (RGC, 1997). The majority of precipitation fell in mid-August and October to mid-November. The air

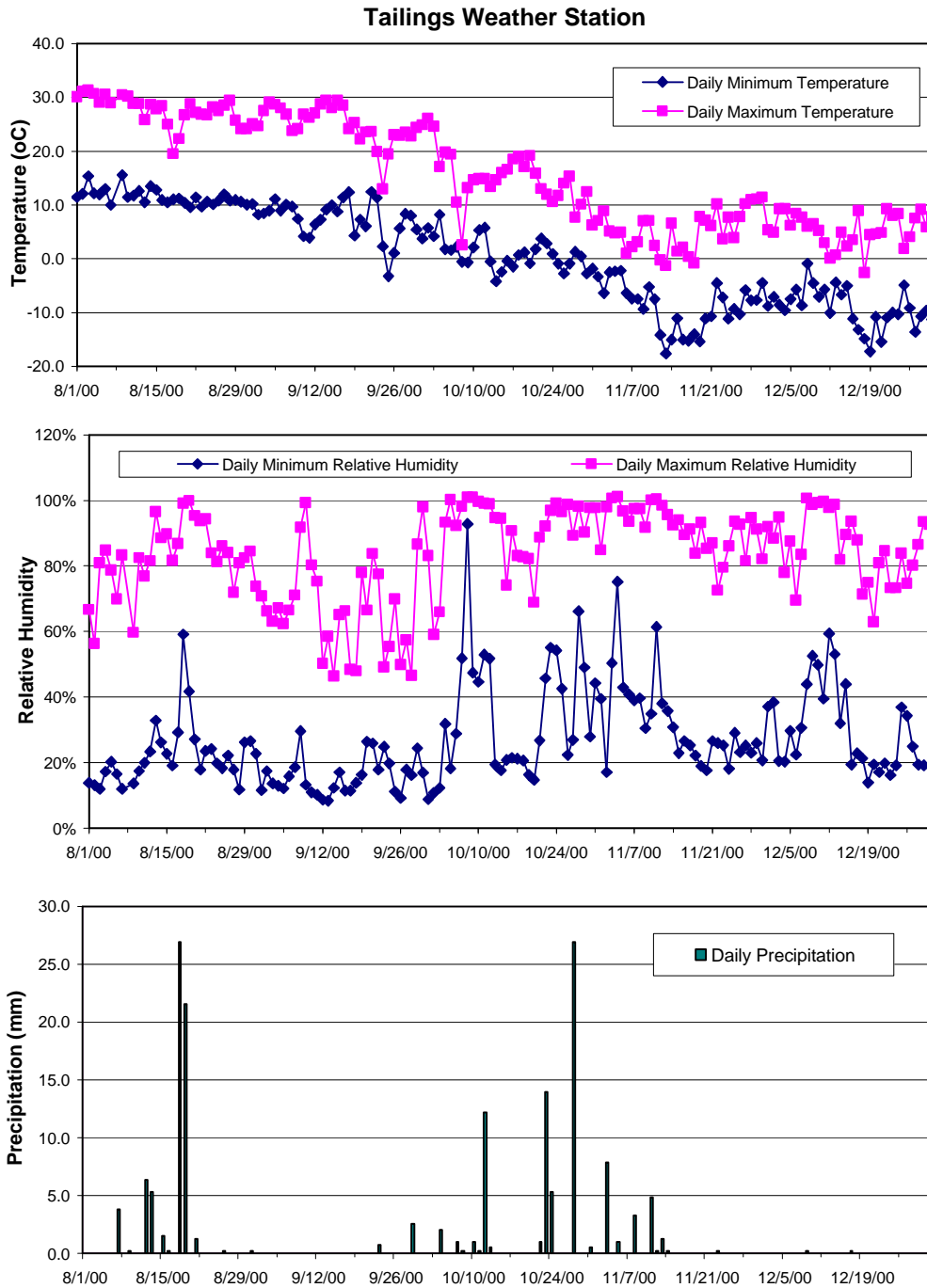


Figure 5. Time trends of temperature and relative humidity (daily MIN/MAX) and precipitation for the five months monitoring period.

temperature and relative humidity showed significant daily variations characteristic for this semi-arid climate. From mid-October onward, air temperature dropped consistently below the freezing point during the night while rising well above the freezing point during the day.

**Test Plot Response**

Figure 6 shows the time trends of volumetric water content for the deep, undisturbed test plot profile (TP-1). The daily precipitation is also shown for comparison. The first significant wetting occurred in response to heavy precipitation in mid-

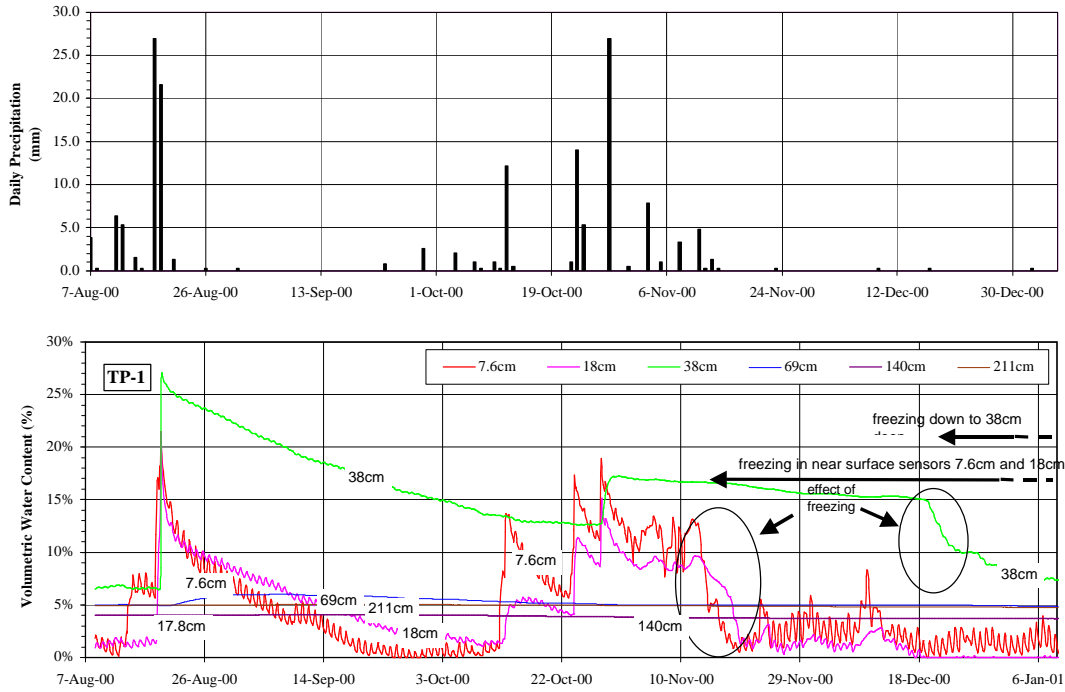


Figure 6. Time trend of Volumetric Water Content for TP-1 and associated precipitation.

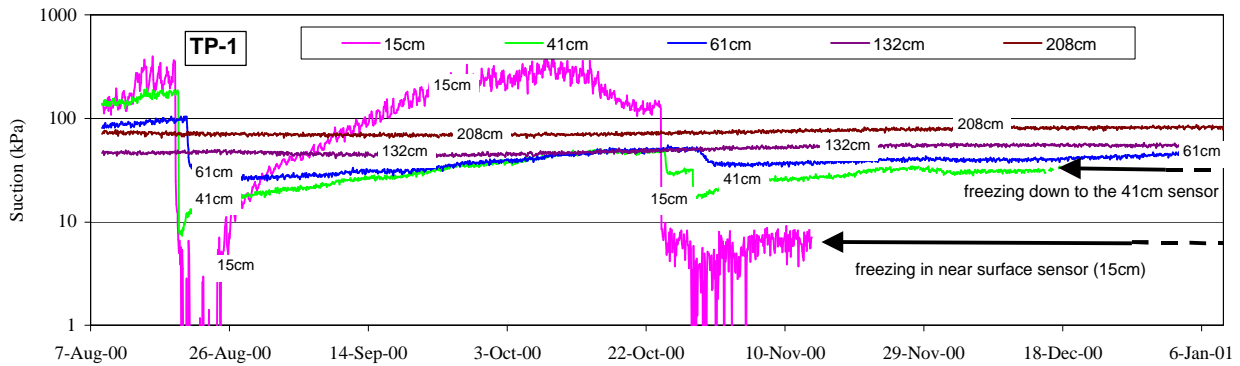


Figure 7. Time trends of soil suction for test plot TP-1.

August when 48mm fell in 2 days. In the near-surface layers (top 38cm) of the cover/tailings profile the volumetric moisture contents exhibited a very rapid increase (during the rainfall period) followed by a very gradual decline due to subsequent evapotranspiration and drainage. Similar wetting/drying patterns were observed in subsequent precipitation events (Figure 6). Note that infiltration during this five-month period was limited to the near-surface layers. The deepest moisture content sensor recording any appreciable increase in moisture content was located at a depth of 68cm (Figure 6). The deeper tailings profile did not show any change in moisture content throughout this period.

Figure 7 shows the time trends of soil suction for the deep, undisturbed test plot profile (TP-1). Note that high suction values indicate dry conditions and low suction values indicate wet conditions. As expected the suction values declined sharply in the near-surface layers (up to about 60cm) in response to heavy precipitation and then gradually increased due to subsequent evapotranspiration and drainage. In other words, soil suction is inversely correlated with volumetric moisture content (Figures 6 and 7). Note that the tailings remained unsaturated (suction  $\gg$  1 kPa, e.g. at 41cm depth) whereas the alluvial cover material approaches saturation (suction  $<$  1 kPa, e.g.

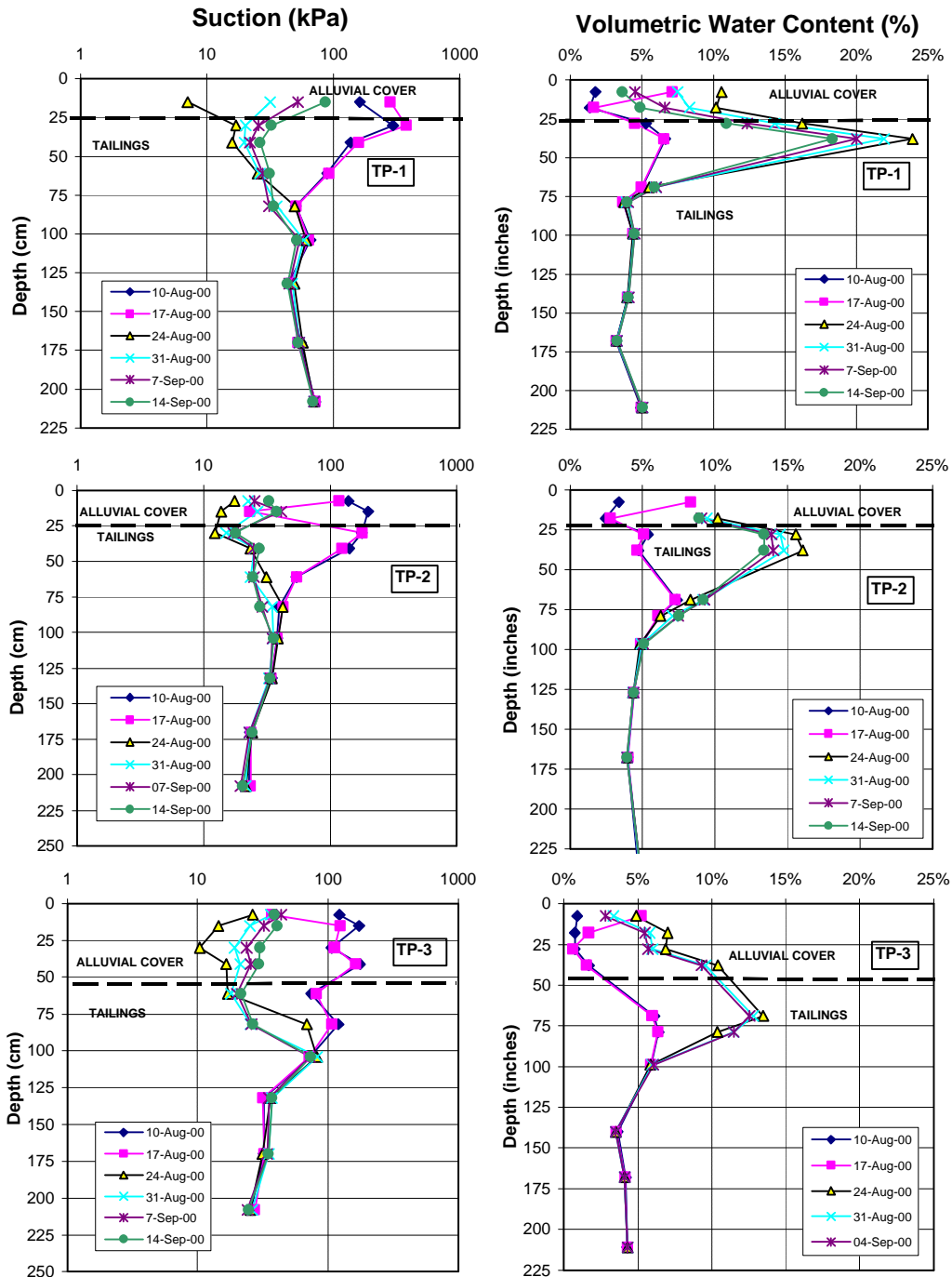


Figure 8. Suction and Volumetric Water Content profiles for TP-1, TP-2 and TP-3.

at 15cm depth) during the heavy precipitation in August (Figure 7).

Figure 8 compares suction and moisture content profiles in all three test plots during the period August 10 – September 14, 2000, i.e. the

period bracketing the first significant infiltration event (Figures 6 and 7). The depth of the alluvial cover is shown in these profiles for comparison. The suction and moisture content profiles are generally very similar in all three test plots. The heavy precipitation on August 18-19 resulted in a

wetting of the cover/tailings profile to a depth of about 75-100cm. The volumetric moisture content in the alluvial cover was generally significantly lower than in the underlying tailings despite similar, if not lower, suction values (Figure 7). This is a result of the much coarser soil texture and hence lower porosity of the cover relative to the tailings (Figure 4). The lower porosity of the alluvial cover also results in a deeper wetting front for the case of a 0.60m thick cover (up to 1m wetting in TP-3) compared to the case of a 0.25m (9") cover (~75cm wetting in TPs 1 & 2). These observations highlight the fact that the tailings have a much better water storage capacity than the alluvial cover.

A comparison of the suction and moisture content responses in test plots TP-1 and TP-2 illustrates the influence of vegetation on cover performance. The presence of a mature grass and brush vegetation in test plot TP-1 resulted in increased drying of the alluvial cover and the underlying tailings compared to the barren test plot TP-2, as illustrated by higher suctions and lower moisture content readings following the rainfall events (Figure 8). These observations support the contention that the upper layers of the tailings are part of the active root zone and can function as an important component of a "store-and-release" cover (RGC, 1998).

The volumetric moisture content and suction values showed very little, if any, variation at depths greater than say 100-125cm below ground surface throughout the first five months of monitoring. These results are consistent with observations in the manholes of the closed lysimeter test plots TP-2 and TP-3, where no discharge was recorded for the first five months of monitoring. Based on the observed rates of net infiltration it may take as much as 1-3 years (or more) before there will be any measurable discharge from the base of the lysimeters (at a depth of ~280-330cm).

The volumetric moisture content profiles can be integrated to estimate the amount of water stored in the cover/tailings profile at any given time. A comparison of volumetric moisture content profiles over time then provides an estimate of the amount of water stored or released over a given time period. Using this technique, the total amount of water stored during the heavy precipitation of August 18-19 was estimated to be 48-51mm in the three test plots. This estimate is very close to the observed precipitation during this period (48mm) suggesting that losses due to

surface runoff and/or evapotranspiration were negligible. In the four weeks following this heavy precipitation all three cover/tailings profiles accrued significant losses of soil moisture as a result of evapotranspiration. The highest loss (27mm) was observed in the undisturbed, vegetated test plot TP-1. The estimated losses for the two barren lysimeter test plots TP-2 and TP-3 were 13mm and 16mm, respectively. These preliminary results would suggest that the performance of the water storage cover is much more influenced by vegetation than by the thickness of the alluvial cover.

## **Conclusions**

This paper describes the design and installation/instrumentation of cover performance test plots designed to study the performance of a water storage ("store-and-release") cover for final closure of the Questa tailings facility. Initial results for the first five months of monitoring suggest that a 0.25m (9") thick alluvial cover with mature vegetation is more effective in reducing net infiltration than either a 0.25m (9") or 0.60m (24") thick alluvial cover without vegetation. The field data support earlier modeling results, which suggested that the tailings are an important component of the water storage cover (RGC, 1997). The high porosity and good moisture retention capacity of the tailings results in storage of incoming precipitation during wet periods which can be removed back to the atmosphere by evapotranspiration during drier periods. The presence of a mature grass/shrub vegetation on top of a 0.25m (9") alluvial cover appeared to improve the removal of moisture from the cover and underlying tailings profile significantly.

Modeling work is currently in progress to calibrate the soil-atmosphere model SoilCover using the observed test plot data. The detailed climate monitoring at the test plot site allows the use of the "detailed weather option" of SoilCover where potential evaporation is calculated internally based on daily precipitation, daily min/max air temperature and relative humidity, average daily wind speed, and daily net radiation (Geoanalysis 2000 Ltd., 2000). The hydraulic properties of the cover/tailings profile (porosity, soil water characteristic curve, Ksat) will be modified during calibration until a good fit with the temporal trends of soil suction, volumetric moisture contents and measured outflow from the lysimeter is obtained. Once calibrated, this soil atmosphere model can be

used to assess the influence of cover thickness and vegetation on cover performance for a range of climate conditions.

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