Teck Resources – Red Dog Mine

Oxide Stockpile Full-Scale Cover System

2012-13 Annual Performance Monitoring Report

FINAL

Report No. 694/6-01

Prepared for:

Teck Alaska

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EXECUTIVE SUMMARY

O'Kane Consultants Inc. (OKC) was retained by Teck Alaska – Red Dog Mine to design and install a performance monitoring system for the Oxide Stockpile cover system. Two automated monitoring stations were installed in 2008 on the west-facing slope and plateau of the Oxide Stockpile. Collected field data include *in* situ matric suction, temperature, and water content, rainfall, net radiation, snowpack thickness, and net percolation.

The 2012-13 monitoring period (2013 water year) represents the fifth year of monitoring for the overburden cover system constructed on the Oxide Stockpile. From examination of the meteorological and *in situ* soil temperature and water content measurements, net percolation in 2013 was approximately 42% (Plateau) and 30% (West) of annual site specific precipitation. This is an increase from the 2012 net percolation of 32% and 24%, respectively. The 2013 net percolation rates were much greater than previously predicted from the numerical modelling program (OKC, 2004) and were a result of extreme 2012 rainfall followed by above average 2013 rainfall that exceeded the storage capacity of the overburden cover system.

A total of 22.1 inches of precipitation occurred during the 2012-13 monitoring period, which was the second highest of the previous nine years, and also greater than the 2004-13 short-term average of 18.4 inches per year. Precipitation during the winter months was near average, but rainfall during the autumn, spring, and summer months was significantly greater than average. The summer months also experienced much lower sunshine hours and PE rates per day than the short-term monthly averages. This led to low evaporation rates, and ultimately, high net percolation rates. This combined with a high volume of water in storage from the previous water year represents the worst-case scenario for cover system performance at the Oxide Stockpile, and accordingly, net percolation rates increased.

Recommendations:

OKC recommends that site monitoring continue in an effort to understand the ability of the cover system to dry out following the wettest two years on record. OKC recommends a site visit during the 2014 field season in June. This will allow OKC personnel to complete regular annual maintenance and ensure all components of the monitoring system including the lysimeter tipping buckets are operational following the winter and spring season. A minimal site snow survey is requested to obtain a more accurate estimate of precipitation. A 5-year monitoring review is recommended to compare cover system field performance to modeling predictions, and evaluate any need to modify the cover system design.

Summary of Key Performance Parameters:

This performance monitoring report presents field data collected from October 2012 to September 2013. The overall data capture rate for all the monitoring systems was 96%. The following is a summary of key data and trends in the performance of the overburden cover system for the 2012-13 monitoring period.

- Total precipitation measured at the Airport weather station during the monitoring period was 22.1 inches (561 mm).
- Total precipitation estimated for Plateau and West stations (rainfall + snow water equivalent) was 21.5 inches (546 mm) and 53.5 inches (1,358 mm), respectively.
- The depth of freezing at the Plateau monitoring location was similar to previous years with the freezing front penetrating deeper than the deepest installed sensor (98 inches). The freezing front also penetrated through the upper waste rock profile at the West Slope site, reaching the lowest sensor at a depth of 98 inches. Temperatures at the base of cover system at both the Plateau and West Slope station did not increase above 0°C until late June 2013.
- Temperatures at the base of the Plateau station lysimeter did not increase above 0°C until the first week of August 2013. Temperatures at the base of the West station lysimeter increased above 0°C in mid July 2013. The time period from the start of the cover system freezing to the lysimeters completely thawing was the longest on record.
- Automated volumetric water content measurements show wetting and mild drying fronts develop at both stations in response to the seasonal climatic events during the summer months. Each station showed distinct wetting fronts reaching the base of the overburden cover system from the rainfall events in July, August, and September.
- Matric potential suction measurements responded in a similar manner as volumetric water content measurements. Matric suction values near the surface at West slope station ranged up to 100 kPa during the summer period, but decreased to near saturated conditions for the remainder of the monitoring period after substantial rainfall events.
- Matric suction values near the overburden cover / waste rock interface were examined to determine the magnitude and direction of flow gradients throughout the monitoring period. While timing was slightly varied due to the influence of frozen conditions, each station showed a downward flow gradient during the frost-free months of July – September 2013.
- Total net percolation calculated at Plateau and West stations were 9.0 inches (228 mm) and 16.1 inches (410 mm) respectfully. This equates to 41% and 73% of total airport precipitation, for the Plateau and West station, respectively. Taking site-specific precipitation into account, Plateau and West station net percolation was 42% and 30%, respectively.
- A water balance was used to estimate the actual evapotranspiration (AET) at each station during the monitoring period. AET ranged from 135 mm at Plateau station to 125 mm at West station.

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1 INTRODUCTION

O'Kane Consultants Inc. (OKC) was retained by Teck Alaska – Red Dog Mine to design and install a performance monitoring system for the Oxide Stockpile cover system at the Red Dog mine. The instrumentation, which was installed and commissioned in October 2008, allows performance of the cover system to be evaluated over time under site-specific climate conditions. Two automated monitoring stations were installed on the west-facing slopes and plateau of the Oxide Stockpile. Complete as-built details for the Oxide Stockpile performance monitoring systems can be found in OKC (2009b).

1.1 Report Organization

Section 2 of this report discusses data collection and maintenance issues for the various automated and manual components of the performance monitoring system. Field data collected during the monitoring period are presented and discussed in Section 3, while a summary of the field monitoring data is provided in Section 4. In this report precipitation and net percolation values will be reported in inches; however, metric units will be used to report all other values.

2 DATA COLLECTION IN 2012-13

2.1 Data Capture Rates

Data capture rates for various components of the performance monitoring system are summarized in Table 2.1. The overall data capture rate for the October 2012 to September 2013 period is 96%. Data capture rates for automated sensors are based on the number of sensors operating compared to the total number of sensors installed.

Table 2.1
Performance monitoring system data capture rates for the 2012-13 monitoring period.

Component	No. of Automated Sensors Installed	No. of Automated Sensors Operating	% of Sensors Operating
Meteorological Monitoring			
Tipping bucket rainfall gauge	1	1	100%
Sonic snow depth gauge	2	2	100%
Air temperature	2	2	100%
Net radiation	1	1	100%
Plateau Station			
Thermal conductivity sensor	10	9	90%
Water content sensor	10	10	100%
Lysimeter tipping bucket gauge	1	1	100%
West Slope Station			
Thermal conductivity sensor	10	10	100%
Water content sensor	10	9	90%
Lysimeter tipping bucket gauge	1	1	100%
Totals	***48***	***46***	***96%***

2.2 Maintenance Notes for the Oxide Stockpile Monitoring Systems

The data capture rate was maintained at 96% from the 2011-12 and 2012-13 monitoring periods. This level of data capture was made achieved due to proper site maintenance completed during the June 2013 and September 2013 site visits. A brief summary of the tasks completed during the site visit is provided below.

- Replacement of lysimeter tipping buckets, and maintenance of the tipping bucket enclosures at Plateau and West slope stations.
- Replacement of Plateau and West slope stations snow depth sensor transducers.
- Repair of the severed net radiometer sensor cable.
- A CSI 109 temperature sensor was installed to replace the CSI 107 sensor on the top of the West slope station tower. This sensor features a greater measurement range, and is better suited for cold climate measurements.

- Replacement of the sensor tower at the West Slope station with a CSI CM115 tripod. The new tripod features a much higher mast to prevent the solar panel and snow depth sensor from being buried. The damaged sensor enclosure at the West Slope station was also replaced.

3 PRESENTATION AND DISCUSSION OF FIELD DATA

Substantial amounts of data are collected from the monitoring stations on the Oxide Stockpile. The key sets of data are presented in this section to evaluate the performance of the overburden cover system over the 2012-13 monitoring period.

3.1 Meteorology

A complete meteorological weather station is operated and maintained at the Red Dog airport. The instrumentation includes a heated precipitation gauge and air temperature, relative humidity and wind speed sensors.

3.1.1 Precipitation

Figure 3.1 shows the cumulative precipitation recorded at the airport precipitation gauge from October 2012 to September 2013. A total of 561mm (22.1 inches) of precipitation was recorded, which is much closer to the ten-year average annual precipitation (2003-13) of 467 mm (18.4 inches) than the previous water year. It should be noted that the airport precipitation gauge includes a Wyoming windscreen and therefore the presented values and those of previous reports were considered to account for undercatch due to wind currents; however, TAK has recently developed an additional factor snowfall undercatch that is believed to be occurring. This factor will be adopted in future monitoring reports.

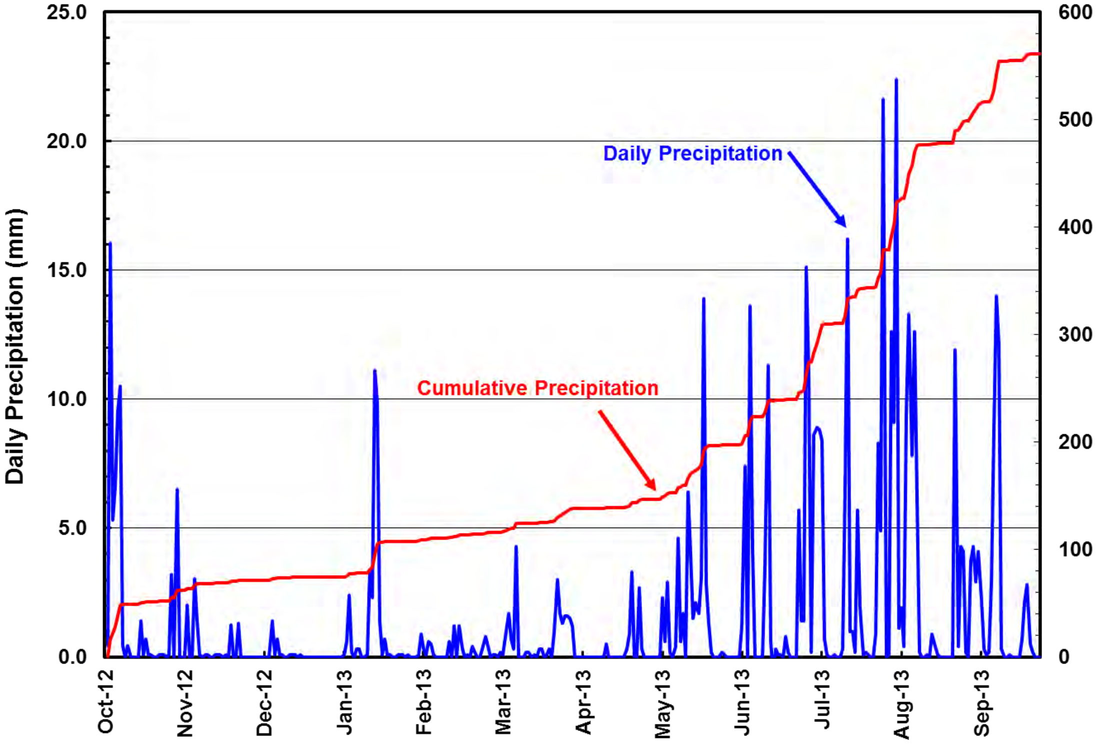

Figure 3.1 Precipitation measured at the Airport weather station during the 2012-13 period.

Figure 3.2 compares the annual monthly precipitation to the 2003-13 average monthly precipitation. The water year began with precipitation in October being nearly double that of the ten-year average. This is consistent with the extreme rainfall period observed in August and September of 2012. After a brief dry period in November and December, January and March recorded precipitation twice that of the ten-year average. Rainfall was above average in May, June, July and August and slightly greater than average in September. Months that are likely to see snow recorded below average precipitation. All months that commonly see rain recorded above average precipitation.

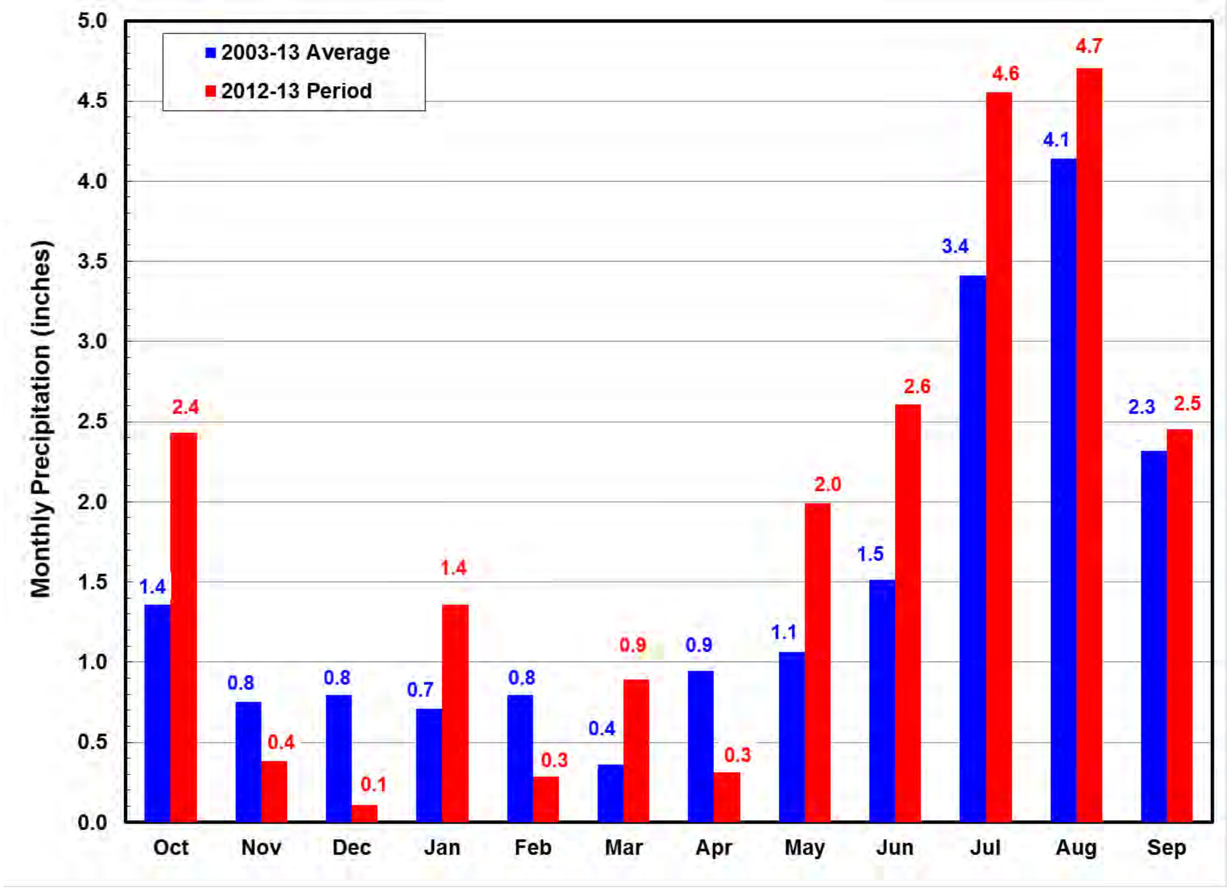

Figure 3.2 Comparison of Red Dog Airport 2012-13 monthly precipitation to the ten-year (2003-13) monthly averages.

3.1.2 Snow Measurements (Snowfall Equivalent)

The heated precipitation gauge at the Red Dog airport station provides an accurate measurement of the annual snowfall. The total snowpack that developed at the Plateau station and the West slope station greatly differed from the measured snowfall precipitation due to loss of moisture through sublimation over the winter period and drifting or redistribution of snow across the landscape. Sonic snow depth sensors monitored the development of snowpack at Plateau and West stations.

A substantial snowpack developed at West station during the winter period as shown in Figure 3.3. The snowpack reached a maximum of 2.6m (102 inches) in late May 2013 before snowpack melt began. The West station lies within a snow deposition area as West station measured snowpack has exceeded total airport snowfall over all project monitoring periods. The corresponding snow-water equivalent (SWE) was estimated to be 806mm (32 inches) using an average snow density of 0.31 inches (water) / inch (snow) obtained from the snow survey data collected by TAK. (It is noted that the 2013 snow density is significantly different than the 2012 snow density of 0.11, which is assumed attributed to winter weather differences between the two years.) The cumulative precipitation (rainfall + SWE) estimated for West station was 1,358 mm (53.5 inches) for the monitoring period.

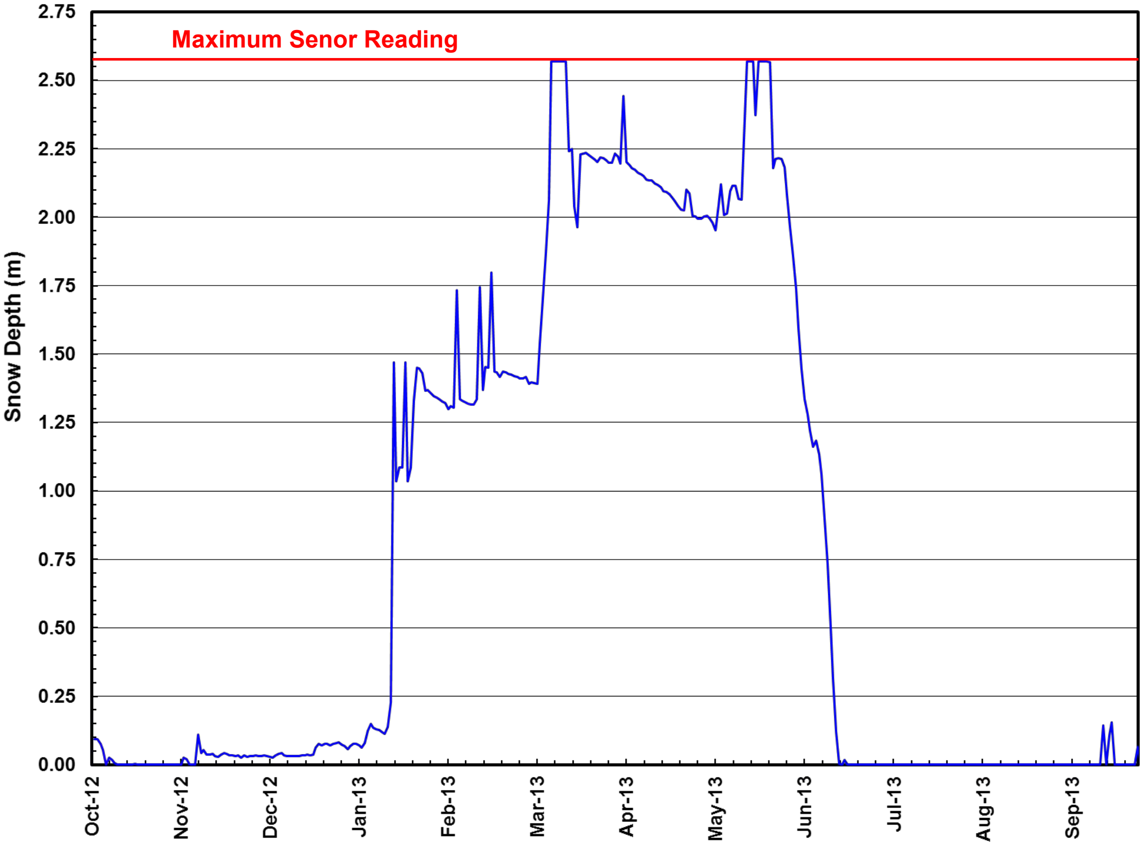

Figure 3.3 Total snowpack measured by snow depth sensor at West station.

Snowpack measured by the sonic sensor reached a maximum of 210mm (8.3 inches) at Plateau station during the winter season. The Oxide Stockpile plateau is exposed to wind, which redistributes snowfall. The snowpack fluctuated between 50 mm and 250 mm during the winter months before the above freezing temperatures in late April began the snowmelt; it is assumed that 65mm (2.6 inches) of SWE contributed to Plateau cover moisture. Figure 3.4 summarizes the total precipitation at the Airport, Plateau, and West Slope stations. Due to the absence of a substantial snowpack, the estimated precipitation (rainfall + SWE) at Plateau station is 546 mm (21.5 inches).

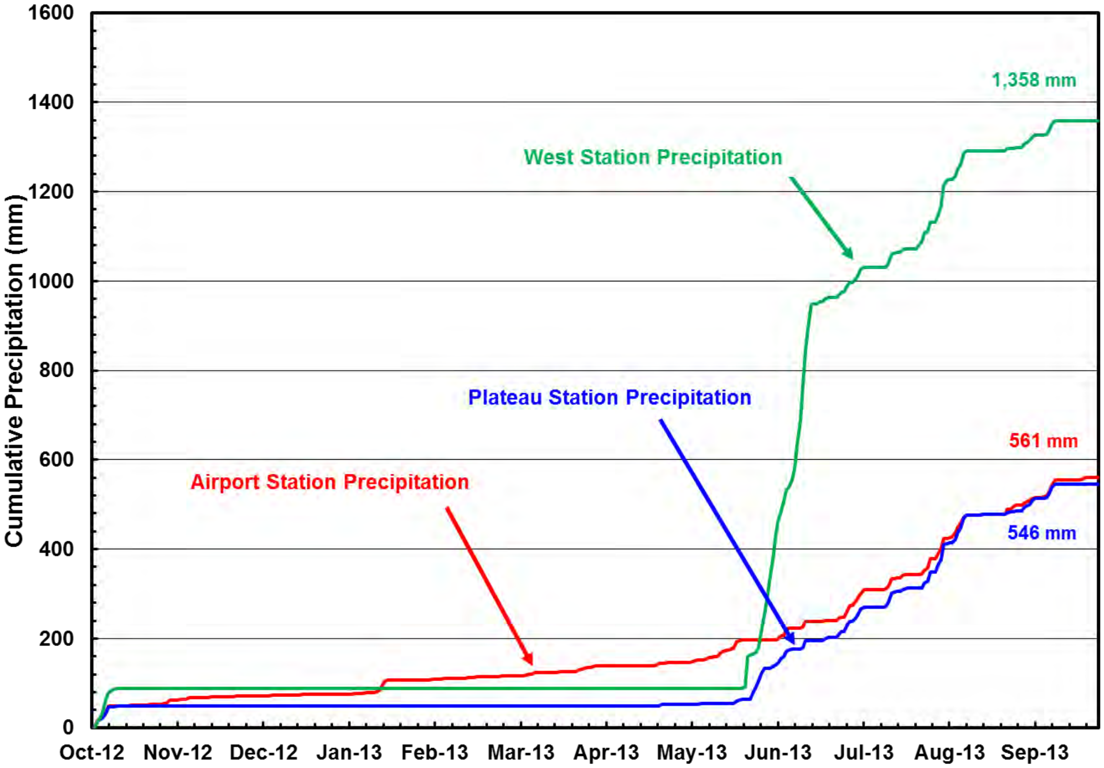

Figure 3.4 Comparison of precipitation measured at the Airport station, Plateau station, and West station during the monitoring period.

3.1.3 Potential Evaporation

The principal drivers of cover system performance are precipitation and energy available for evaporation. Potential evaporation (PE), which is a theoretical maximum assuming free water on the surface at all times, was estimated using the Penman (1948) method and meteorological. Previously, PE has also been estimated based on pan evaporation rates measured in the tailings pond. In 2012, these reading were greatly affected by the large rainfall rates resulting in a poor pan evaporation dataset. Actual evapotranspiration (AET) represents the actual water lost to the atmosphere, either through surface evaporation or plant transpiration, as a result of PE. In general, when plants are very active and surface soils are near saturation, AET and PE rates will be similar (AET/PE ~ 1). As plant activity declines and the soil surface dries out, more energy is required to evaporate water resulting in lower AET/PE rates.

The total PE estimated for the monitoring period was 237 mm (9.3 inches). Figure 3.5 compares the monthly potential evaporation estimated in 2012-13 to precipitation. Due to the late melt and colder than average spring months, no PE was developed until June 2013. PE was much greater than precipitation in June due to the long periods of sunlight and the typically low rainfall experienced during this months. When PE is greater than precipitation, the capacity for the cover system to store precipitation and release it back to the atmosphere during non-rainy periods is greatly improved, thereby improving the performance of the cover system. However, PE was substantially less than rainfall in July, August, and September. During these periods, infiltration into the cover system profile is expected as total precipitation is greater than the potential evaporative energy to remove it.

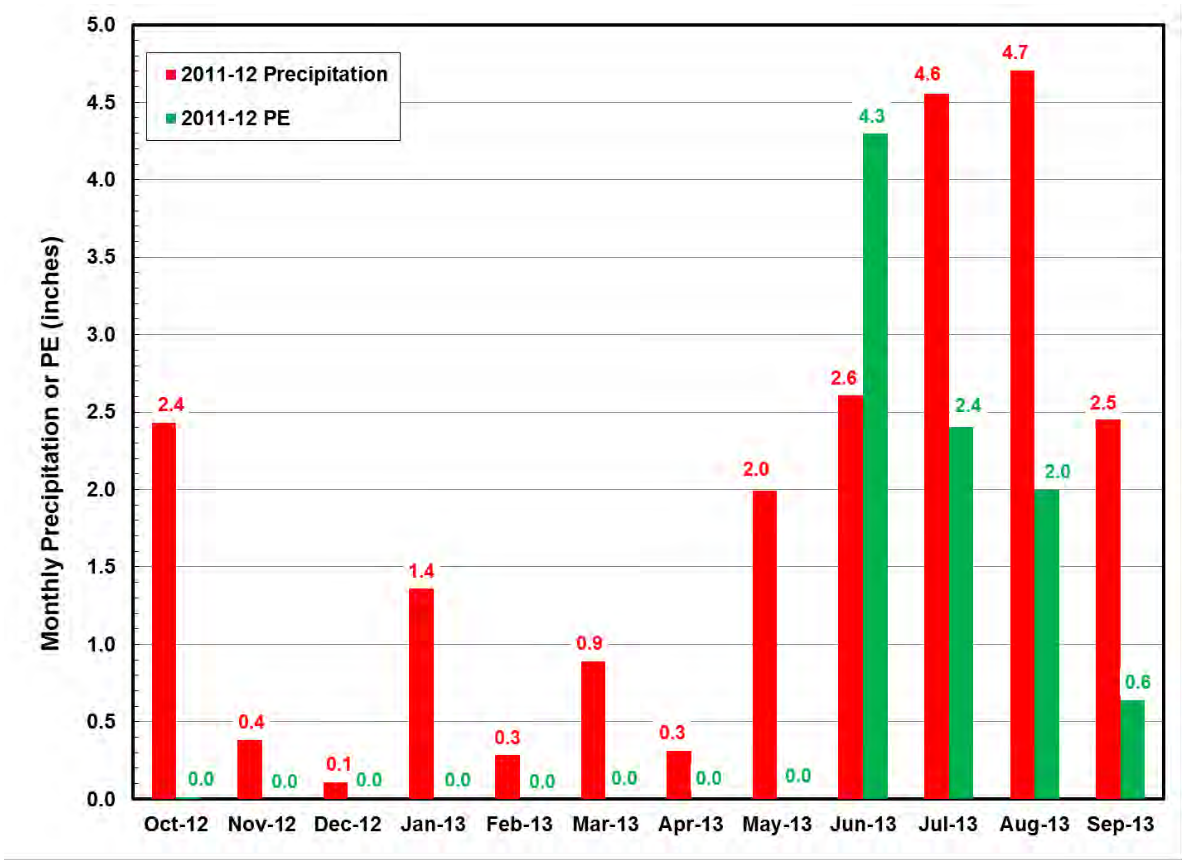

Figure 3.5 Monthly PE and precipitation measured during the monitoring period.

3.2 *In Situ Temperature*

In situ temperatures are continuously monitored with a profile of thermal conductivity (TC) sensors within each monitoring location. Figure 3.6 shows *in situ* temperatures measured to a maximum depth of 250 cm at Plateau station within the waste rock and overburden cover system profile. *In situ* temperature near the surface changes with season, ranging from -20°C in winter to 20°C in the summer. Deeper within the cover profile, *in situ* temperature was less influenced by seasonal surface temperatures. For example, slightly below the overburden/waste rock interface (130 cm) at a depth of 150 cm, the *in situ* temperature ranged from -10°C to 10°C.

The development of the deep freezing front at Plateau station during the winter season has a substantial effect on the performance of the cover system. The base of the cover system was frozen from late-November 2012 to late-June 2013. The delayed thaw of the cover system reduces the deep infiltration of snowmelt and early spring rainfall. In addition, saturation levels within the cover system are often high due to autumn rainfall events from the previous year. This is especially true for the 2013 water year due to the exceptionally wet summer and fall of 2012. The frozen conditions impede its downward migration during the spring period, allowing surface evaporation to occur during the peak sunshine hours and PE rates of June and July.

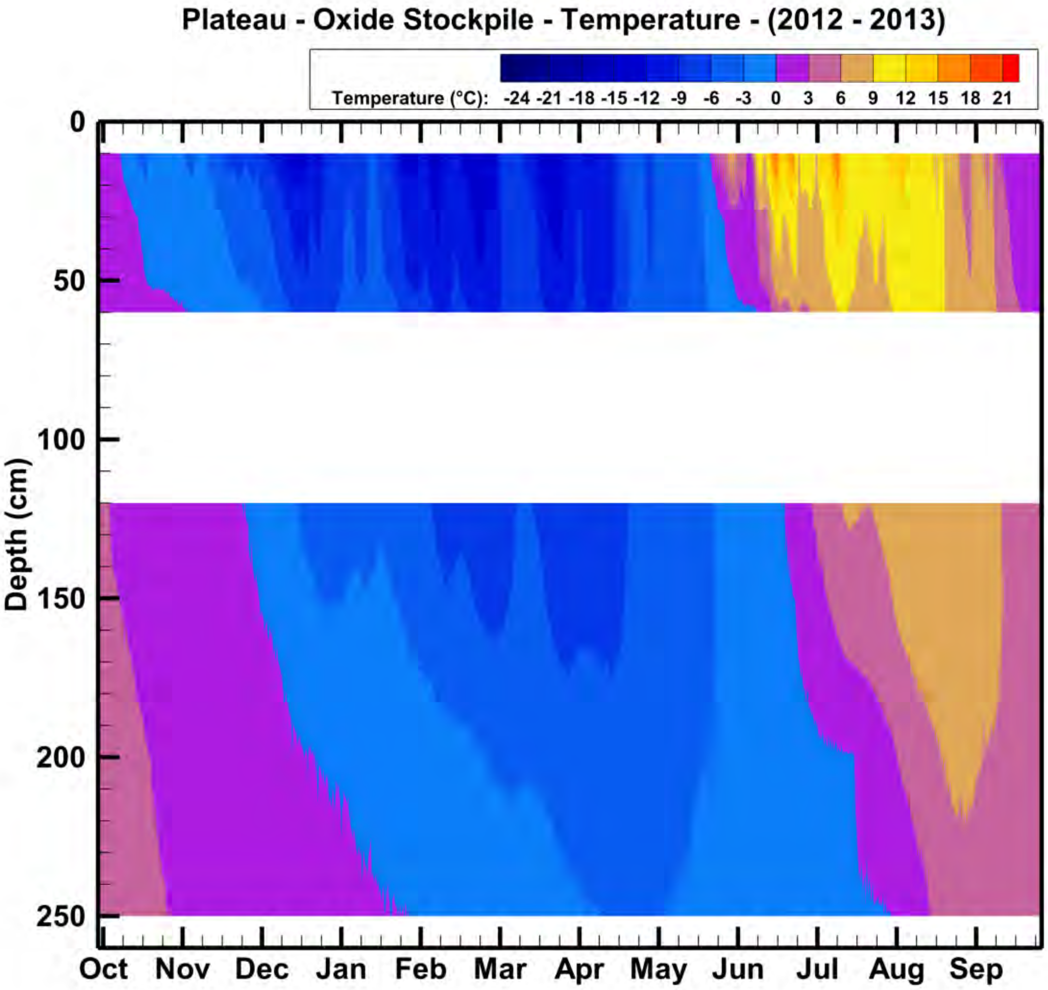

Figure 3.6 *In situ* temperature measured within Plateau station waste rock and overburden cover profile during the monitoring period.

Figure 3.7 shows *in situ* temperatures measured to a maximum depth of 240 cm at West Slope station within the waste rock and overburden cover system profile. During the 2012-13 monitoring year freezing occurred to the depth of the lowest sensor at 240 cm depth. The winter of 2010-2011 is the only other year on record where freezing occurred at this depth. Other monitoring years recorded depths of freezing of 110-130 cm. Temperatures at the overburden / waste rock interface ranged between -3°C and 6°C. The cover system was seasonally frozen in the same manner as the Plateau station which had a similar impact on cover system performance.

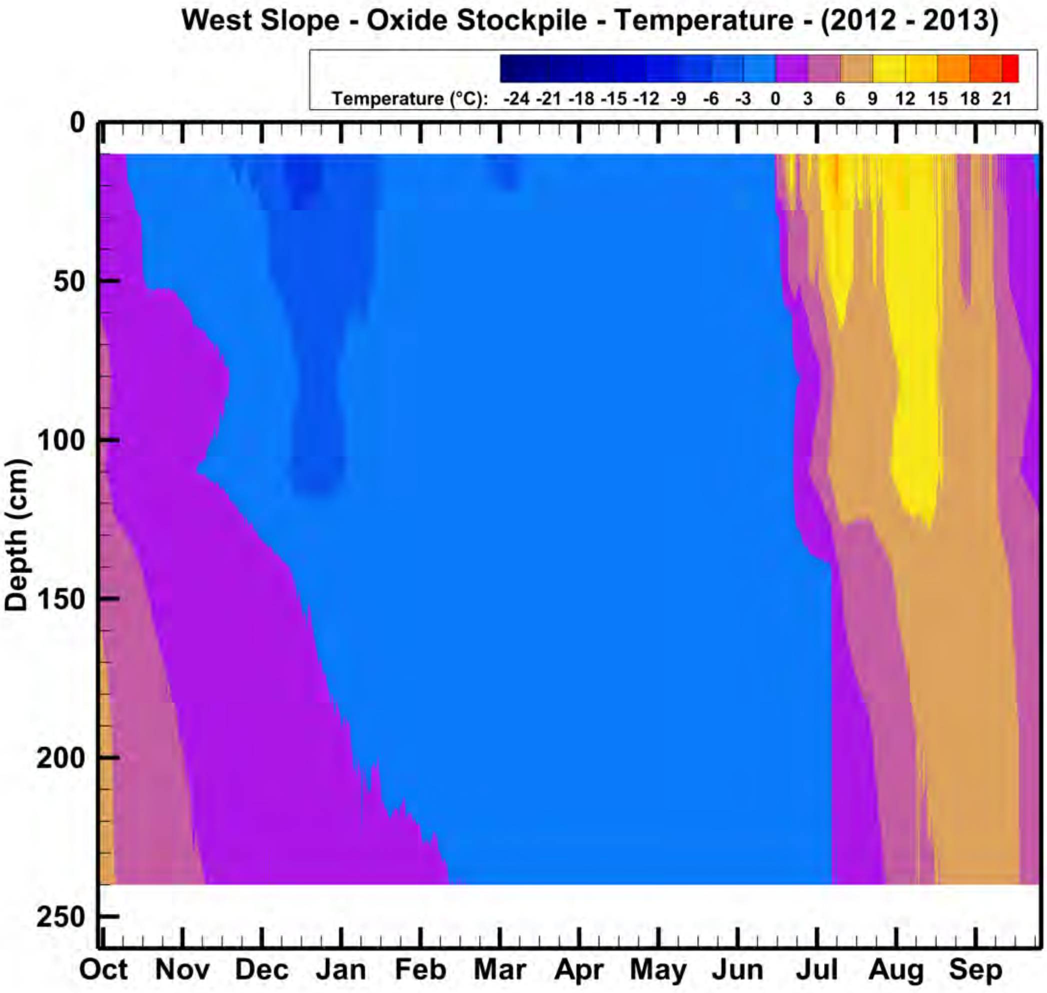

Figure 3.7 *In situ* temperature measured within West station waste rock and overburden cover profile during the monitoring period.

3.3 Cover System Water Dynamics

Matric suction and volumetric water content are indirectly measured using the CSI Model CS229 thermal conductivity (TC) sensors and CSI Model CS616 time domain reflectometry (TDR) sensors, respectively. Material-specific calibration curves are used to convert frequency readings obtained from each TDR sensor into volumetric water content values, while a sensor-specific calibration curve was developed for each CS229 sensor. At Plateau station, the sensor nest consists of ten pairs of CS616 and CS229 sensors installed to a maximum depth of 250 cm. At West station, the sensor nest consists of ten pairs of sensors installed to a depth of 240 cm. Depths of each sensor vary according to the depth of the overburden cover material / waste rock interface and are summarized in the record of installation report (OKC, 2009).

3.3.1 Summary of Moisture Conditions Measured with TDR Sensors

Volumetric water content profiles were examined at both monitoring stations on the Oxide stockpile. This section presents the water contents observed within the profiles during the monitoring period and the change in moisture storage within the overburden cover system.

Figure 3.8 shows the water content profile for the Plateau station during the monitoring period. The blank areas within the figure indicate that the sensors are frozen and therefore not providing accurate measurement. Volumetric water content in the upper cover was at its lowest of the year following the spring thaw through June. Water content greatly increased and remained near the field capacity (approximately 0.28 cm^3/cm^3 to 0.32 cm^3/cm^3) for the remainder of the monitoring period due to the greater than average rainfall events in July, August, and September of 2013.

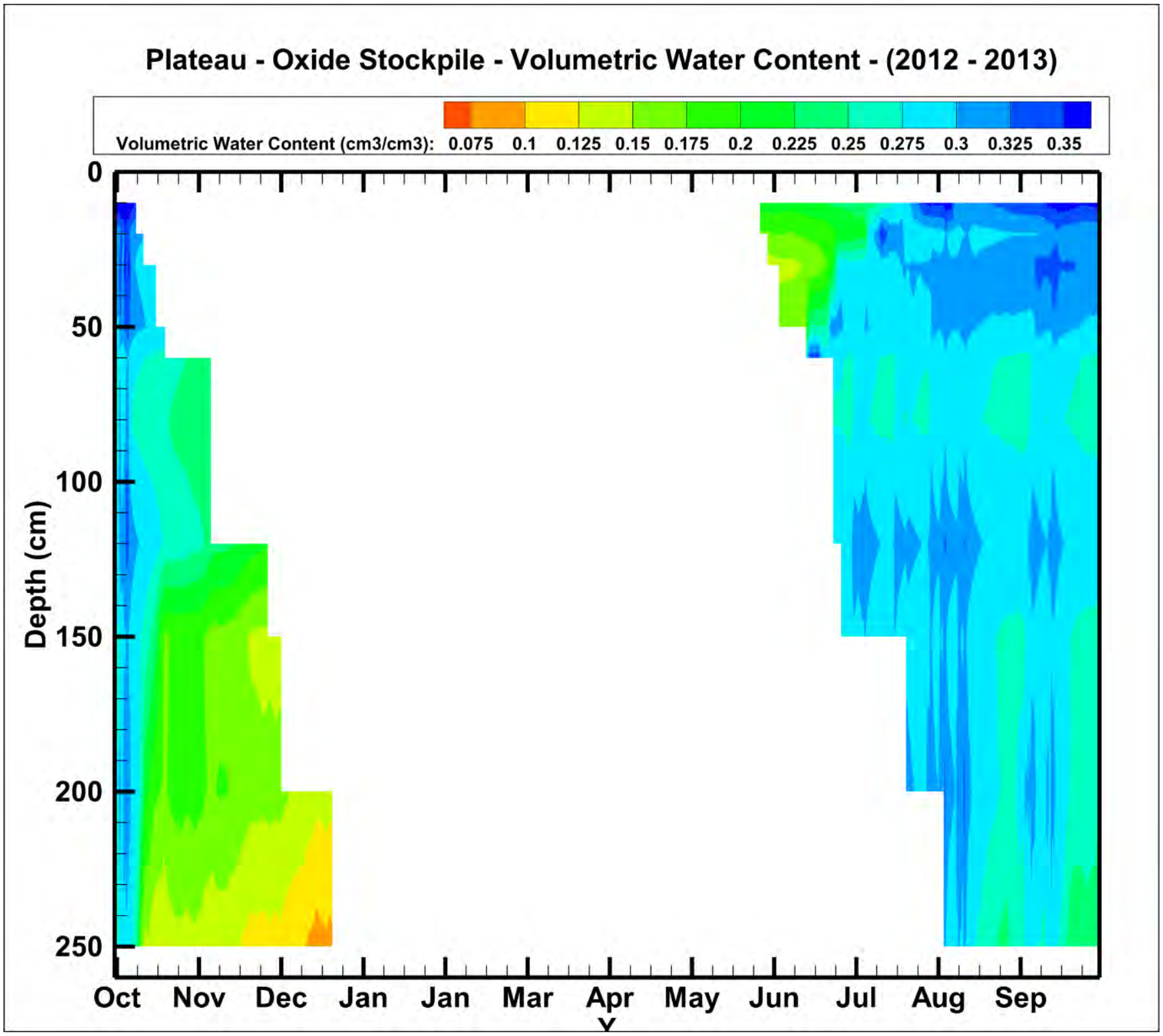

Figure 3.8 Volumetric water content measured at Plateau station during the monitoring period.

Figure 3.9 shows the response of water content sensors at West station. The *in situ* volumetric water contents had a similar pattern to the Plateau station. Water contents increased to the field capacity of the overburden material in response to rainfall events in June through September. The measured water contents indicate a periods of infiltration and net percolation to the underlying waste rock material.

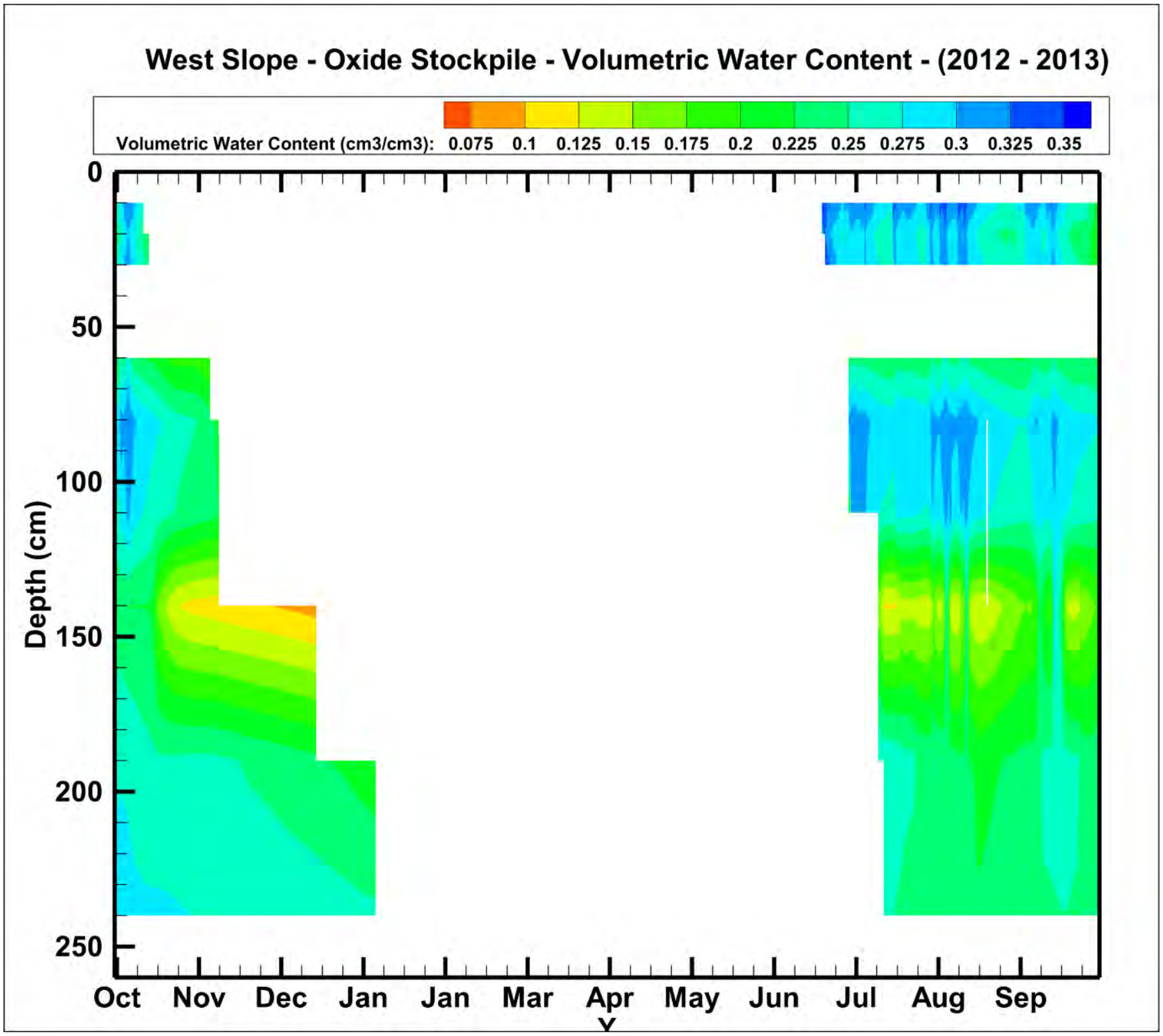

Figure 3.9 Volumetric water content measured at West station during the monitoring period.

Figure 3.10 presents the change in water storage within the overburden cover system for both monitoring locations during the five monitored water years. The volume of water stored within the overburden cover system is estimated by discretizing the cover profile into multiple layers each with a CS616 sensor at its center. The total volume of water within the cover profile is calculated by summing the product of the volumetric water content and its elemental thickness. The change in water storage from the initial total water volume is presented to allow comparison between the Plateau and West Slope stations over the four-year span.

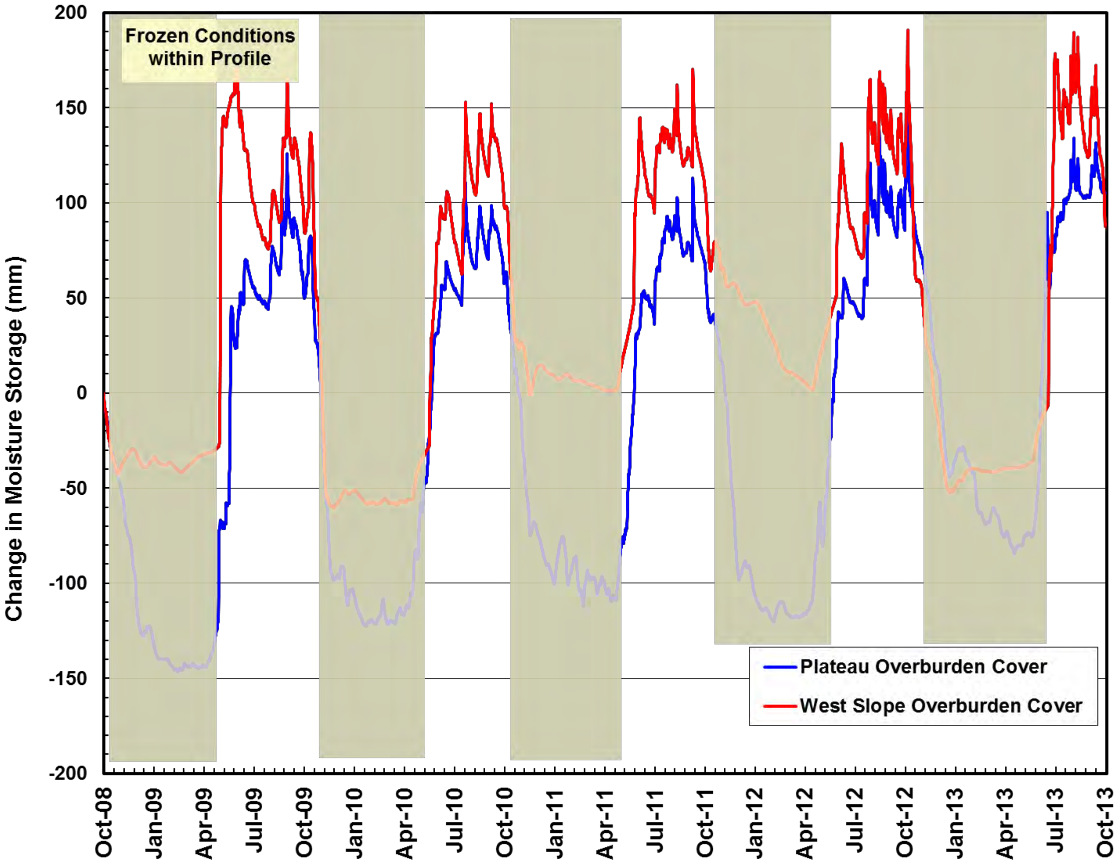

Figure 3.10 Change in water storage within the cover system profile at Plateau and West stations.

The 2013 water year continues established cover system moisture storage behavior: the responses of the overburden cover system to climatic conditions at the stations were similar, which indicates both sets of sensors are responding to rainfall events and drying periods at the same time. This is to be expected as the monitoring stations are only 100 m apart and likely receive similar rainfall and evaporative conditions. In addition, the West Slope station generally is wetter than the Plateau. The total of water stored within the cover system in 2013 is similar to that seen in 2012; both years generally feature more storage than any of the first three years of monitoring. As discussed in the water content summary, the cover system was near its field capacity storage for much of the unfrozen period.

3.3.2 Summary of Moisture Conditions Measured with TC Sensors

Matric suction data measured by the CS229 sensors at West Slope station are shown in Figure 3.11. The blank areas within the figure indicate that the sensors are frozen and therefore not providing accurate measurement. The pattern of matric suction measurements is similar to the volumetric water content measurements in that there was a short period of increased suction (i.e. drying) from July to September (to as much as approximately 100 kPa) before low suction (< 5 kPa) measurements for the remainder of the monitoring period.

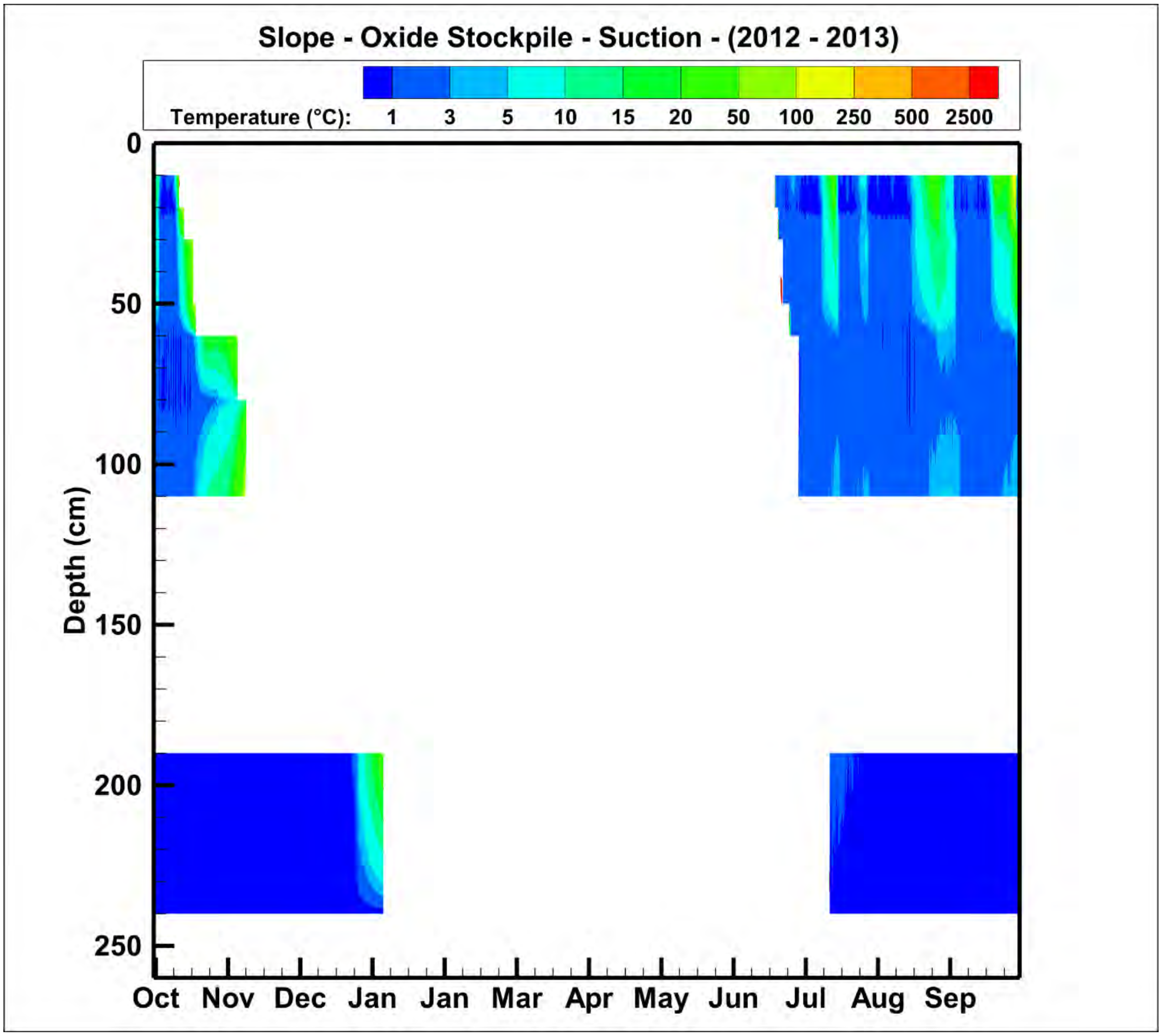

Figure 3.11 Matric suction measured within the overburden cover system and waste rock profile at West slope station.

Figure 3.12 presents the matric suction measured at 120 cm and 150 cm depth at Plateau station as well as the calculated hydraulic gradient across the overburden cover / waste rock interface. The calculated hydraulic gradient increased to approximately 1 m/m due to the mid-July rainfall events and remained until the end of the monitoring period in September. The gradient data indicates that downward movement of water (i.e. net percolation) occurred during the frost-free period of 2013 at Plateau station.

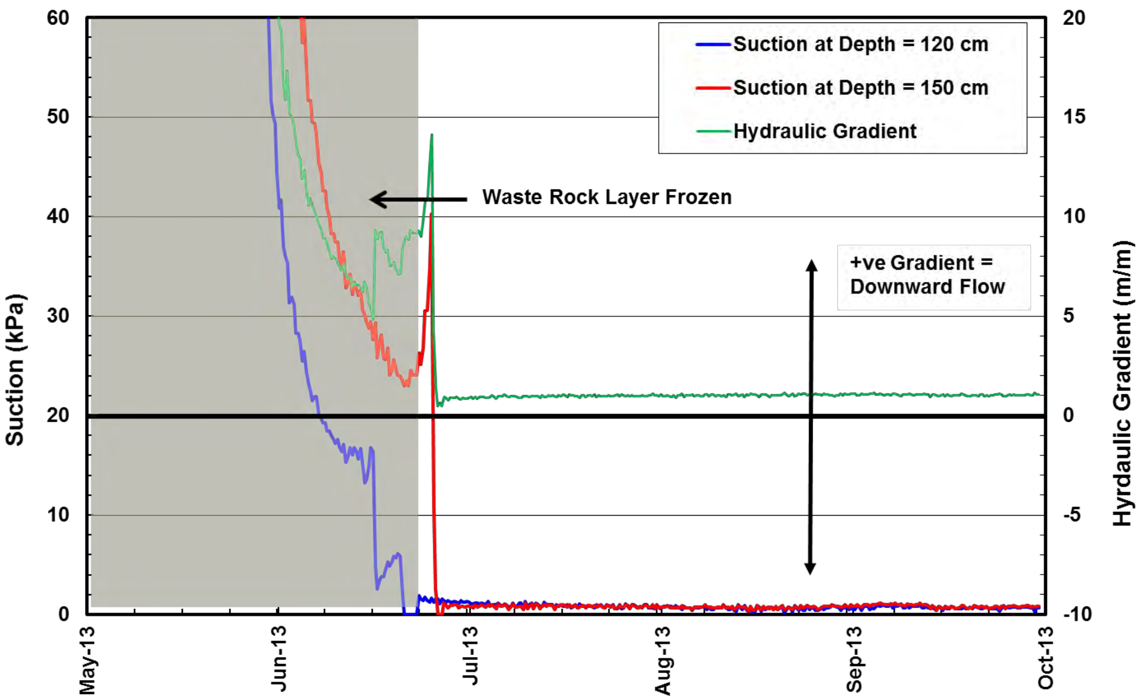

Figure 3.12 Matric suction measured at depths of 120 cm (overburden) and 150 cm (waste rock) and hydraulic gradient calculated at the overburden / waste rock interface at Plateau station.

Figure 3.13 shows the hydraulic gradient calculated at the overburden cover system / waste rock interface at Plateau and West stations. As discussed previously, hydraulic gradient at the Plateau remained consistently near 1 m/m during the cover system frost-free period. Hydraulic gradient calculated for the West was similarly near 1 m/m during the frost-free period, but at times approached 2 m/m, showing the West to be wetter, possibly influenced by runon or interflow from the 2D slope.

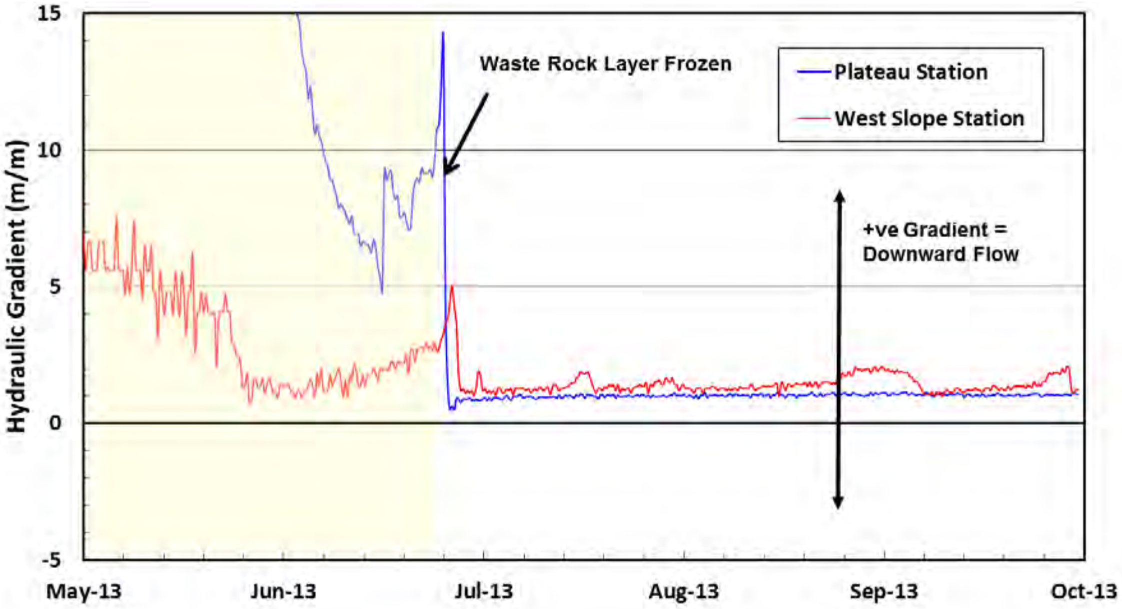

Figure 3.13 Hydraulic gradient calculated at the overburden / waste rock interface at the monitoring locations.

3.3.3 Net Percolation

Net percolation is measured by the automated monitoring system from the lysimeters installed at both Plateau and West stations. An automated tipping bucket gauge provides measurement of the total volume of percolation that passes through the lysimeter. Examination of the monitoring data found that the tipping buckets operated reliably during the entire monitoring period. It is anticipated that the net percolation reported by the tipping buckets slightly underestimates the true net percolation through the cover system. Net percolation collected in the large-scale lysimeters drains to unheated sheds on the Oxide Stockpile surface. The tipping buckets can 'freeze' up and stop recording tips before the water from the underdrain pipe freezes for the winter period. This small portion of net percolation will be estimated from the water balance method presented in the next section. The net percolation values provided in this section should be considered as uncorrected net percolation values while the true net percolation rate will be presented in the water balance section.

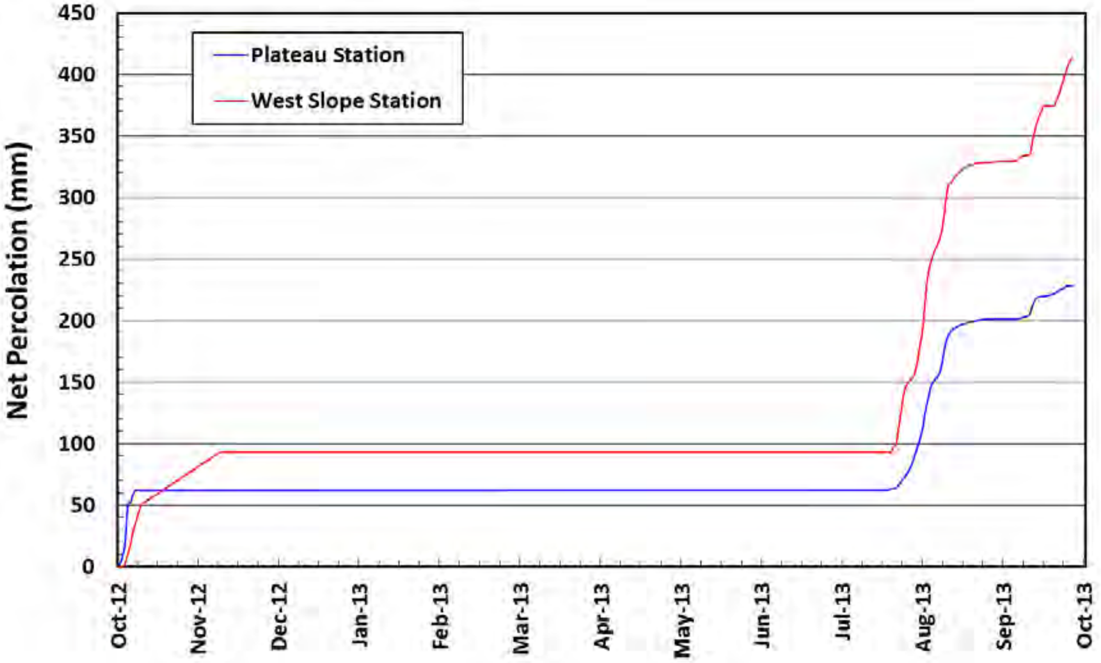

Figure 3.14 Net percolation collected with the automated tipping bucket system.

The total net percolation collected was 10.4 inches (265 mm) at Plateau station and 14.1 inches (357 mm) at the West station. These measurements are more than measured in any previous water year monitoring period, and are the result of the extreme rainfall at the end of 2012, as well as the above average rainfall during the 2013 summer.

3.4 Water Balance

A water balance was completed for the cover system field trials to quantify the volume of water percolating through the cover system in the 2011-12 monitoring period. A water balance was completed for both monitoring locations based on field measurements and solving the water balance equation on a daily basis during the frost-free period.

The water balance for a sloping cover system consists of the following components (expressed in mm):

$$PPT = RO + AET + NP + \Delta S + ITF \qquad [1]$$

where:

PPT = precipitation (rainfall plus snow water equivalent (SWE)),
RO = runoff,
AET = actual evapotranspiration,
NP = net percolation,
ΔS = change in moisture storage, and
ITF = interflow or lateral drainage within the cover profile.

The estimation and application of each of these components in calculating the water balance is discussed briefly below.

Precipitation is measured at the Plateau site and at the Airport station with a tipping bucket gauge to measure rainfall precipitation. The depth of the snowpack, and therefore snow water equivalent, was estimated with a sonic ranger at Plateau and West stations.

Runoff (RO) is not accurately measured at the site but was estimated for the snowmelt and summer rainfall events. The selected runoff coefficients are based on OKC's experience at sites with similar climates and slopes.

Actual evapotranspiration (AET) was estimated based on rates of potential evaporation (PE) and climate data from the stations. Different AET:PE ratios were applied at five day intervals of the frost-free period to arrive at reasonable AET rates. Also, a different AET/PE ratio was applied depending on precipitation occurrence on that day. This is an approximation as AET/PE ratios would likely change more frequently based on vegetation, available soil water, and other conditions. The ratio was then adjusted to match the calculated versus measured change in soil moisture storage as closely as possible.

Net percolation (NP) during the frost-free period was measured with the automated tipping bucket systems. Net percolation values were also determined based on hydraulic head gradients and changes in moisture content at the base of the cover. Hydraulic head gradients define the direction and magnitude of water flowing through the covers, and were used to determine if net percolation through the cover was realized. NP estimated from the hydraulic head gradients was used when the cover system surface was frozen but the cover system / waste rock interface was still thawed.

Generally, interflow, or lateral flow (ITF), can be assumed to be negligible if the infiltration and percolation of water is limited to vertical 1D flow. This assumption was made for both Plateau and West stations.

The measured change in moisture storage (ΔS) in the cover profile was calculated using volumetric water content data recorded at each monitoring station, as described in Section 3.3.1 and shown in Figure 3.10.

3.4.1 Water Balance Calculation

Net percolation, AET/PE ratios, and runoff were manipulated in order to provide a calculated change in moisture storage value that best matched the measured change in storage using Equation 2:

$$\Delta S_{calc} = PPT - AET - ITF - RO - NP \approx \Delta S_{meas} \qquad [2]$$

The completed water balances presented in Figures 3.14 and 3.15 show a reasonable match between the measured change in storage (Measured ΔS), which is based on volumetric water content readings, and calculated change in storage (Calculated ΔS), which is based on solving the water balance equation for each monitoring site.

For the Plateau, shown in Figure 3.15, there was a good match between the measured and calculated change in storage for the frost-free monitoring period. The measured change in storage increased sharply due to the high rainfall events in July, August, and September and the calculated change in storage matched well during those periods which indicates the estimations of AET, runoff, and net percolation are reasonable. Total runoff during the monitoring period was 368 mm (14.5 inches) or approximately 46% of the total precipitation. The average AET/PE ratio for the monitoring location was 0.49 and the net percolation for the 2011-12 period was approximately 259 mm (10.2 inches), or 32% of the 31.5 inches of total precipitation measured at the Plateau station.

The water balance completed for West station is shown in Figure 3.16. Similar to Plateau station, there was a good match between the measured and calculated change in storage for the majority of the period. The total precipitation (1,112 mm or 43.8 inches) at West station was greater than at Plateau station due to SWE. The total runoff estimated for the slope (626 mm / 24.6 inches) was also greater than estimated for the Plateau area due to the larger snowpack. The average AET/PE ratio for this monitoring location was 0.65. The estimated net percolation (measured and estimated) for the 2011-12 period was approximately 270 mm (10.6 inches), or 24% of the total precipitation measured at the West station.

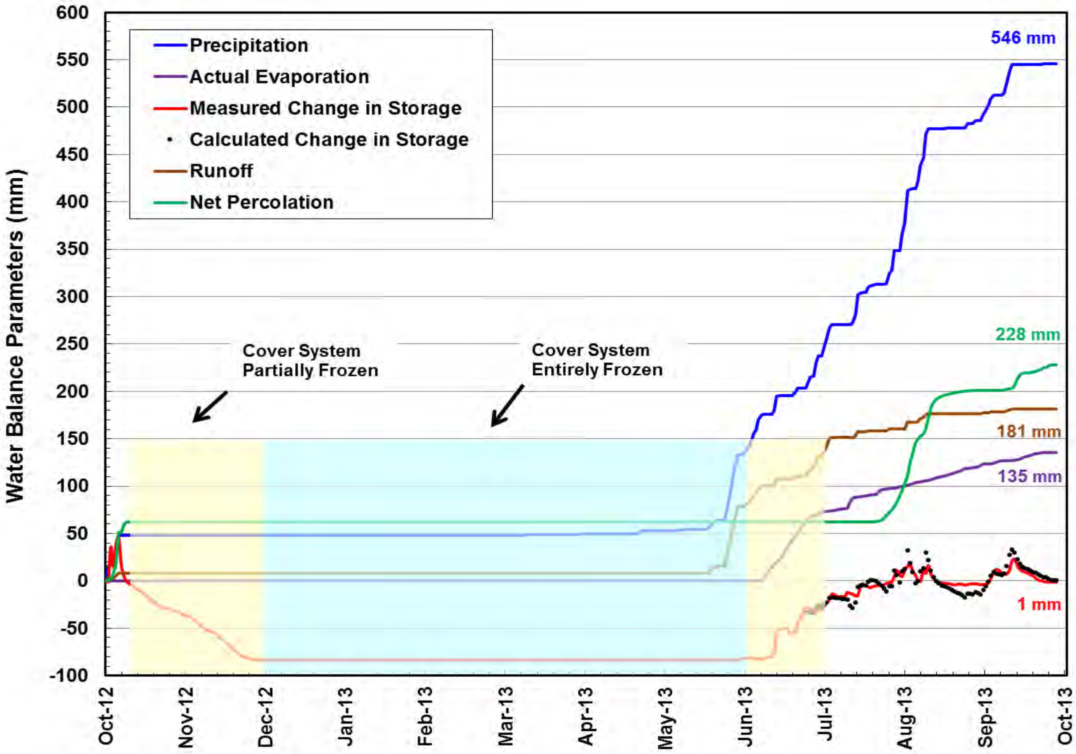

Figure 3.15 Cumulative water balance fluxes for Plateau station in the 2012-13 monitoring period.

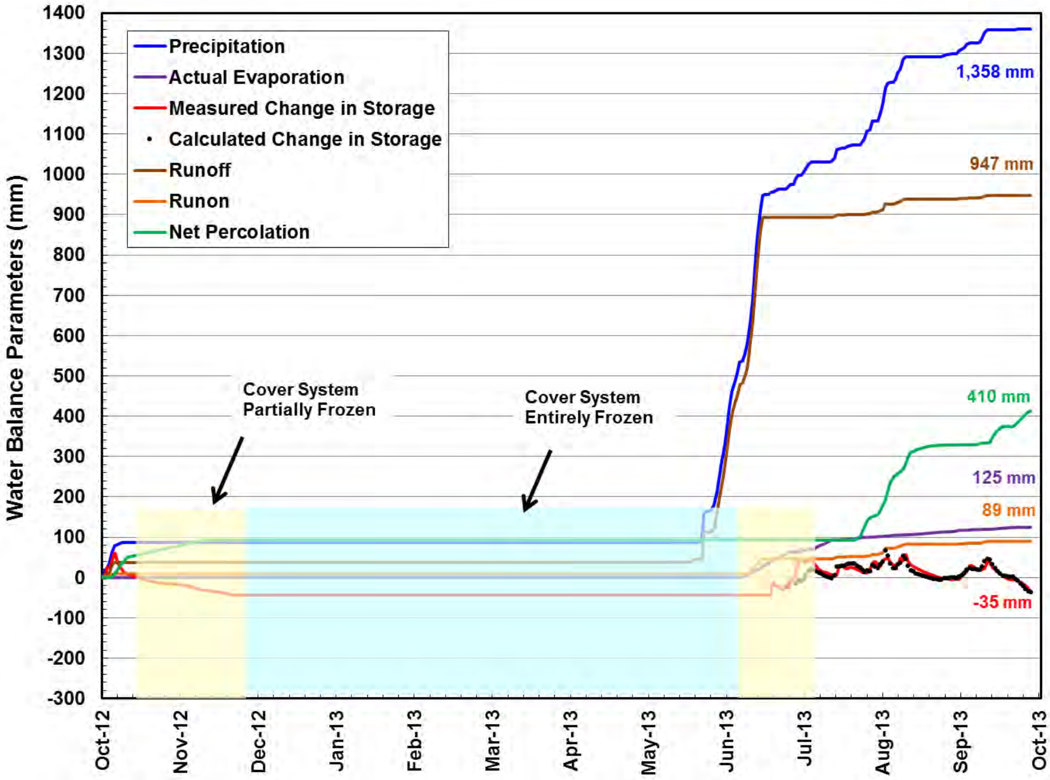

Figure 3.16 Water balance fluxes for West station in the 2012-13 monitoring period.

Table 3.1 summarizes the components of the water balance at Plateau and West stations. The percentages shown in the table are based on the site specific precipitation at each location.

Table 3.1
Summary of the key parameters of the water balance for Plateau and West stations.

Water Balance Parameter	Plateau Station	West Station
Station Precipitation (Rainfall + SWE)	546 mm (22.1 inches)	1,358 mm (53.6 inches)
Runoff	181 mm (33%)	947 mm (70%)
Actual Evaporation	135 mm (25%)	125 mm (9%)
Runon	N/A	89 mm (7%)
Net Percolation	228 mm (42%)	410 mm (30%)
Change in Storage	+1 mm (<1%)	-35 mm (3%)

The water balance parameters for each location are roughly similar with some small differences due to the presence of snowpack or the sloping nature of the West station, which required a runon component for the first time in order to close the water balance. The differences in total precipitation and runoff are attributable to the larger snowpack that collects on the West station slope. Almost the entire snowpack runs off in the spring as the cover system surface is frozen and little surface infiltration occurs.

The percentage of actual evaporation (AE) is similar for the Plateau and West station; however, more AE was estimated to occur from the West station. The bulk of the difference in AE between stations occurred during the spring snowmelt as the snowpack melted and evaporated at the West station. There was a much smaller snowpack at the Plateau station and AE rates decreased once the snow melted and the upper surface of the cover system dried.

Table 3.2 presents a summary of net percolation results as a percentage of precipitation for the two stations. Consistent with previous reports the net percolation is shown as a percentage of the airport precipitation, while the percentage of actual station precipitation is shown for the most recent monitoring period. Year 4 (2011-12) experienced substantially higher net percolation than the previous monitoring periods.

Table 3.2
Net percolation summary.

Station	Airport Precipitation as Net Percolation					Station Precipitation as Net Percolation
	Year 1 2008-09	Year 2 2009-10	Year 3 2010-11	Year 4 2011-12	Year 5 2012-13	2012-13
Plateau	16%	11%	16%	36%	41%	42%
West	17%	10%	24%	38%	73%	30%

The plateau and the airport station's precipitation were similar over the monitoring period. This lead to similar values of the percentage of precipitation as net percolation for the airport (41%) and plateau (42%) stations. The West slope station had a substantially greater snowpack than either of the plateau or airport due to drifting snow. This greater snow pack was a contributing factor to the higher net percolation rate. The combination of higher net percolation and precipitation at the West slope station accounts for the difference between the percent of precipitation as net percolation for the airport (73%) and the West slope (30%) station.

3.5 Comparison of 2012-13 Period to Short-Term Monitoring Record

In order to characterize the performance of the cover systems in 2013, it is useful to examine their response within the context of the short-term monitoring record from 2004 to 2013. Figure 3.17 presents the precipitation recorded in each monitoring period at the Airport weather station.

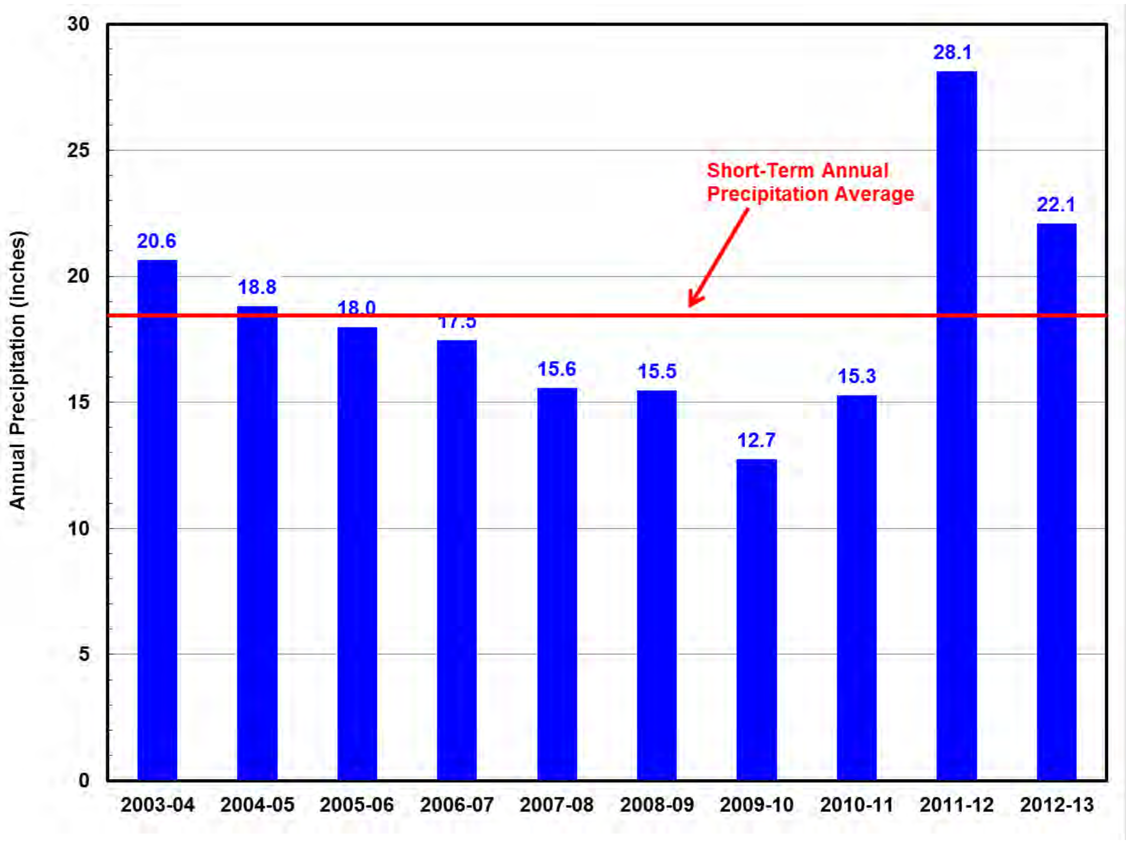

Figure 3.17 Rainfall recorded during each monitoring period since the onset of monitoring.

The net percolation recorded in 2013 is greatest of the monitoring program, both in terms of volume and as a percentage of precipitation. This is the result of extreme rainfall at the end of the previous monitoring period, which continued with greater than average precipitation in October 2012. The cover then froze in a very wet condition; in addition, the normal freezing of net percolation outlet drain prevents reporting of net percolation that is likely the result of 2012 water year precipitation. It is not unusual for events in one monitoring year to influence the next, but the magnitude and timing of the 2012 precipitation greatly affects the 2013 results.

The cover systems in 2013 are then presented with not only an extended freezing period, but also above average rainfall during the 2013 field season. The monitoring profiles, both cover and waste, thawed at an elevated water content with little available moisture storage. The 2013 rain events quickly produced net percolation and the cover systems were unable to dry. Given the expected low PE in October 2013, it is likely that the 2014 water year results will also be substantially influenced by the previous year(s).

4 RECOMMENDATIONS

The following recommendations are made for the Oxide Stockpile monitoring system:

1. Continuation of monitoring program to examine the lingering effects of the 2012 and 2013 water years in 2014 on the Oxide Stockpile cover systems.
2. A site visit in June 2014 to complete annual maintenance with a focus on replacement of the lysimeter tipping buckets at the Plateau and West slope. Annual replacement of the tipping buckets will ensure quality, continuous data is collected at the lysimeter outlets.
3. Completion of a snow survey in the area immediately adjacent to both the Plateau and West slope monitoring stations once per year near the end of the winter season when snow depth is at a maximum. The snow survey would include a minimum of three snow depth measurements and snow density measurements at each location. While most snow water equivalent becomes runoff, local snow survey results would confirm similar conditions as the airport and provide a more accurate estimate of site precipitation.
4. A 5-year monitoring review is recommended to assess the cover system field performance relative to the modeling predictions, and evaluate any need to modify the cover system design.

5 REFERENCES

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