Appendix D Oxide Stockpile Full-Scale Cove System 2011-12 Annual Performance Monitoring Report

Teck Resources – Red Dog Mine

Oxide Stockpile Full-Scale Cover System

2011-12 Annual Performance Monitoring Report

FINAL

Report No. 694/5-01

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 on the west-facing slopes 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 2011-12 monitoring period represents the fourth 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 2011-12 was approximately 32% (Plateau) and 24% (West) of annual site specific precipitation. The net percolation rates were much greater than previously predicted from the numerical modelling program (OKC, 2004) or measured in the first three years of monitoring at the Oxide Stockpile. The increased net percolation was a result of substantially above average precipitation that exceeded the storage capacity of the overburden cover system.

A total of 28.1 inches of precipitation occurred during the 2011-12 monitoring period, which was substantially higher than any of the previous nine years and the 2004-12 short-term average of 18.0 inches per year. Precipitation during the autumn, winter, and spring months was below average, but rainfall during the summer was significantly greater than average. A total of 14.5 inches of rainfall were recorded in August approximately three times more than the monthly average. The rainfall occurred during a period where sunshine hours and PE rates per day were declining leading to high infiltration rates, low evaporation rates, and ultimately, high net percolation rates. This combination represents the worst-case scenario for cover system performance at the Oxide Stockpile, and accordingly, net percolation rates were much greater than previously measured.

Recommendations:

OKC recommends a site visit during the early part of the 2013 field season in May or June 2013. 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.

Summary of Key Performance Parameters:

This performance monitoring report presents field data collected from October 2011 to September 2012. 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 2011-12 monitoring period.

- Total precipitation measured at the Airport weather station during the monitoring period was 28.1 inches (715 mm), which was approximately 55% greater than the 18.0 inch (458 mm) nine-year average at the site.
- Total precipitation estimated for Plateau and West stations (rainfall + snow water equivalent) was 31.5 inches (802 mm) and 43.8 inches (1,112 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 did penetrate into the upper waste rock profile at the West Slope site reaching a depth of 22 inches. Temperatures at the base of the overburden Plateau station cover system did not increase above 0°C until mid-June 2012. Temperatures at the base of the West station cover system increased above 0°C in late May 2012.
- Automated volumetric water content measurements show wetting and drying fronts develop at all stations in response to the seasonal climatic events during the early 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 250 kPa during the dry spring / early 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 June – September 2012.
- Total net percolation calculated at Plateau and West stations were 10.2 inches (259 mm) and 10.6 inches (270 mm) respectfully. This equates to 36% and 38% of total airport precipitation, for the Plateau and West station, respectively. Taking site-specific precipitation into account, Plateau and West station net percolation was 32% and 24%, respectively.
- A water balance was used to estimate the actual evapotranspiration (AET) at each station during the monitoring period. AET ranged from 162 mm at Plateau station to 212 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 2011-12

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 2011 to September 2012 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 2011-12 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	1	1	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	***47***	***45***	***96%***

2.2 Maintenance Notes for the Oxide Stockpile Monitoring Systems

The data capture rate increased from 89% in 2010-11 to 96% during the 2011-12 monitoring period. The increase was due to maintenance completed during the June 2012 site visit. A brief summary of the tasks completed during the site visit is provided below.

- Replacement of lysimeter tipping buckets at Plateau and West slope stations to measure net percolation flow.
- A CSI 107 temperature sensor was installed near the top of the West slope station tower and at the Plateau station to aid in temperature correction of the SR50 snow depth sensors.
- Replacement of West slope station snow depth sensor.
- Replacement of the rainfall tipping bucket mounting bracket and funnel mesh screen at Plateau station.

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 2011-12 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 2011 to September 2012. A total of 28.1 inches (715 mm) of precipitation was recorded, which is substantially greater than the nine-year average annual precipitation (2003-12) of 18.0 inches (458 mm). Total rainfall in August was much greater than average as 14.5 inches were recorded, more than three times greater than average and by far the most precipitation measured in a single month during the nine year record. There were several rainfall events during the summer larger than 1.0 inch including July 29th, August 21st, and August 24th/25th. The greatest magnitude rainfall event occurred in mid-August when 5.4 inches of rainfall was recorded between August 14th and August 16th. It should be noted that the airport precipitation gauge includes a Wyoming windscreen and therefore the presented values are considered to account for undercatch due to wind currents.

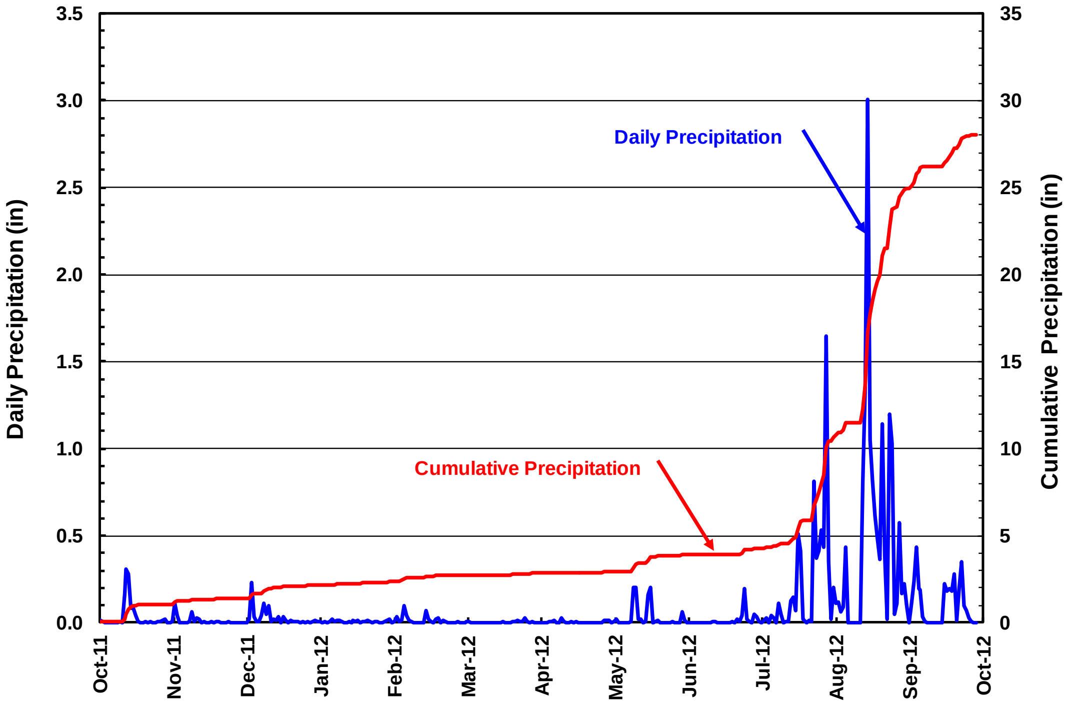

Figure 3.1 Precipitation measured at the Airport weather station during the 2011-12 period.

Figure 3.2 compares the annual monthly precipitation to the 2003-12 average monthly precipitation. Precipitation for the first nine months of the monitoring period was consistently equal to or below the nine-year average. Rainfall was greatly above average in July and August and slightly greater than average in September. July and August represent the highest monthly total rainfall values recorded during the Oxide Stockpile cover system monitoring program. To add perspective to the extreme rainfall accumulation in 2012, a statistical analysis was completed on the 'rainfall' months (June to September) from 2003 to 2012. The return period for the July rainfall (6.2 inches) was 1:6 years, which seems reasonable as six inches is a large amount of monthly rainfall for Red Dog, but not unprecedented. The return period for the August rainfall (14.5 inches) was 1:2,700,000 years; therefore, considering August 2012 as an 'extreme' rainfall period appears reasonable.

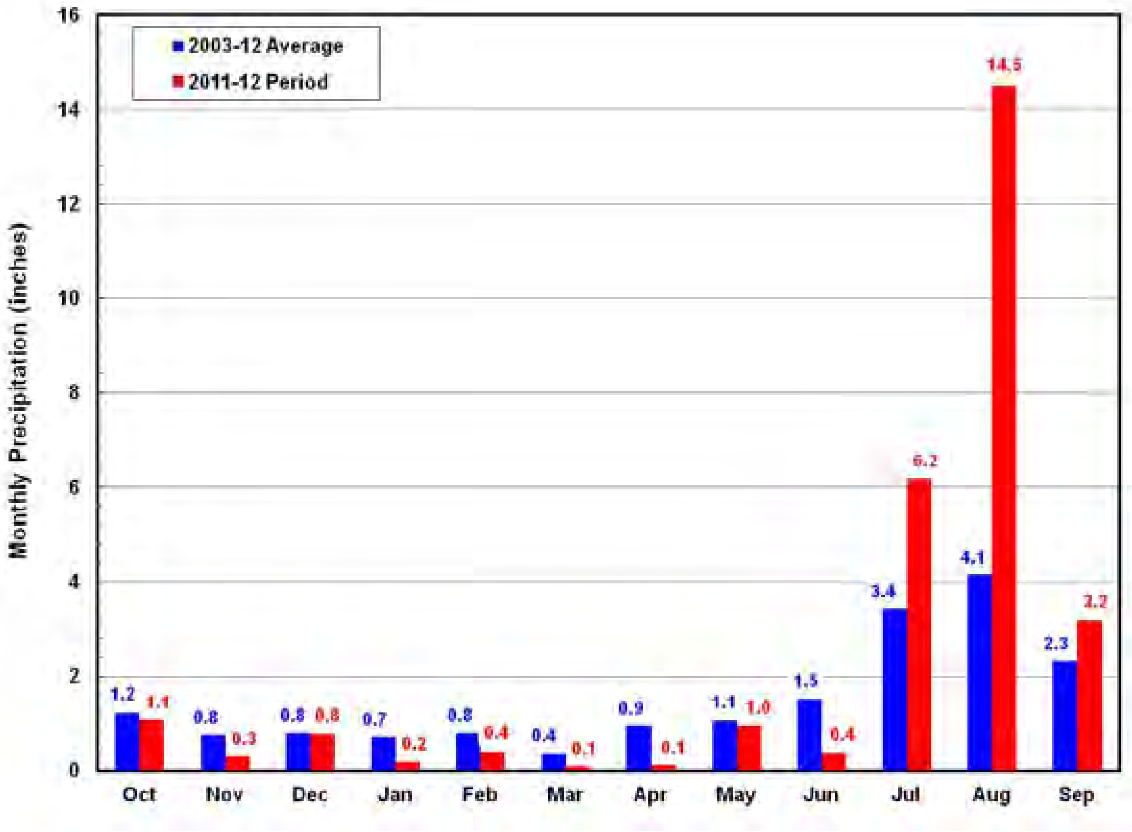

Figure 3.2 Comparison of Red Dog Airport 2011-12 monthly precipitation to the nine-year (2003-12) monthly averages.

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 86 inches (2.2 m) in April 2012 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 13 inches (330 mm) using an average snow density of 0.15 inches (water) / inch (snow). The cumulative precipitation (rainfall + SWE) estimated for West station was 43.8 inches (1,112 mm) for the monitoring period.

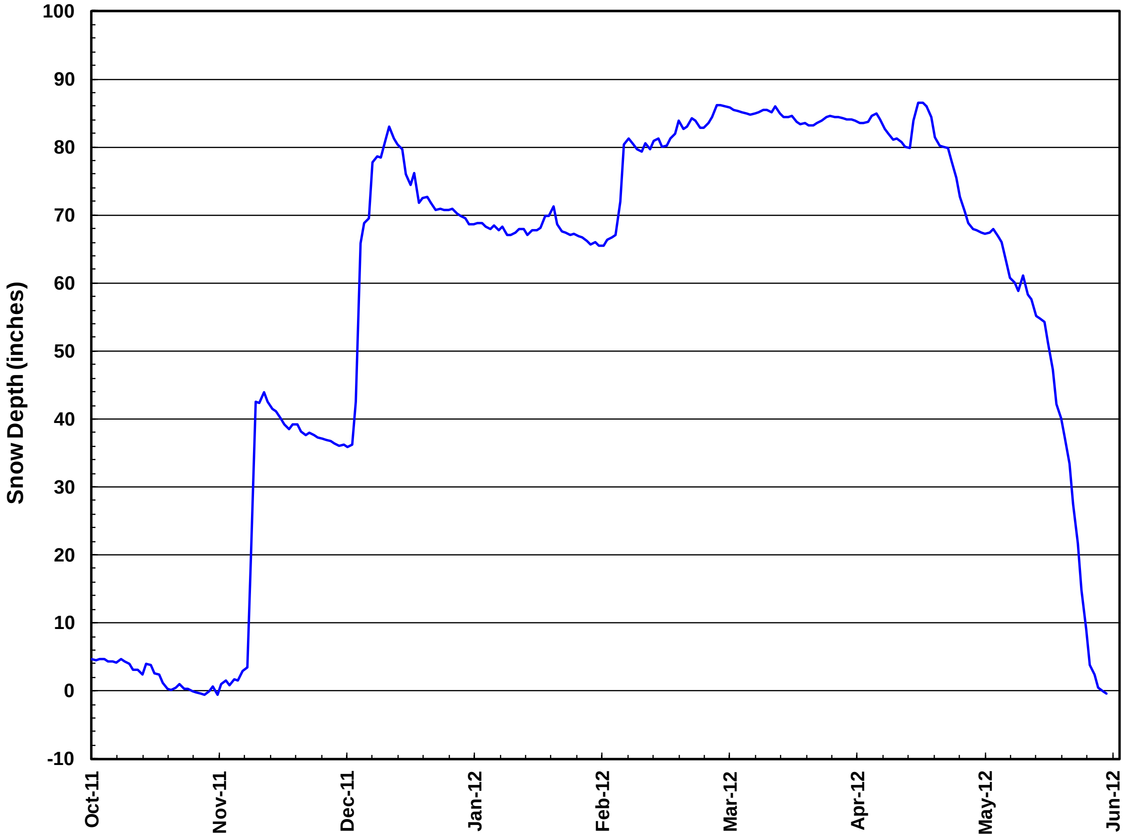

Figure 3.3 Total snowpack measured by snow depth sensor at West station.

Snowpack measured by the sonic sensor reached a maximum of 10 inches (0.3 m) at Plateau station during the winter season. The Oxide Stockpile plateau is exposed to wind, which redistributes snowfall. The snowpack fluctuated between 5 inches and 10 inches during the winter months before the above freezing temperatures in late April began the snowmelt; it is assumed that 0.8 inches (20 mm) of SWE contributed to Plateau cover moisture. Figure 3.4 summarizes the total precipitation at Plateau station. Due to the absence of a substantial snowpack, the estimated precipitation (rainfall + SWE) at Plateau station is 31.5 inches (802 mm).

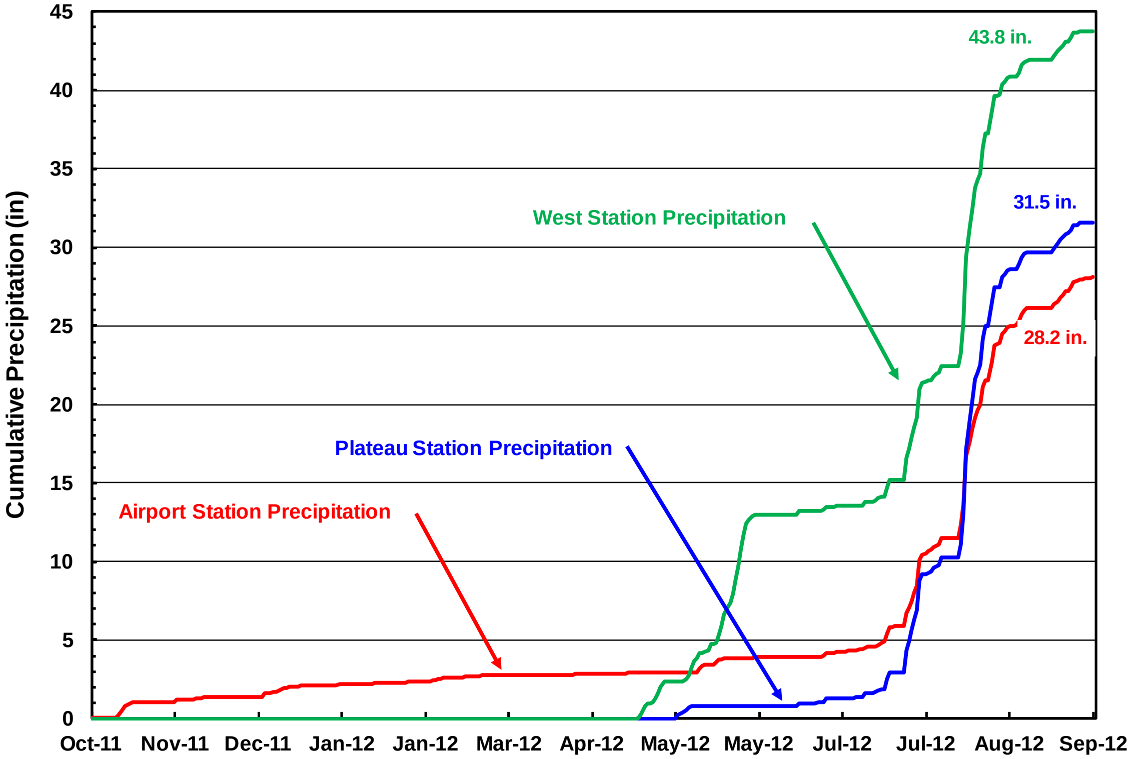

Figure 3.4 Comparison of precipitation measured at the Airport station, Plateau station, and West station during the monitoring period.

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 12.9 inches. Figure 3.5 compares the monthly potential evaporation estimated in 2011-12 to precipitation. PE was much greater than precipitation in May and June due to the long periods of sunlight and the typically low rainfall experienced during those 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.

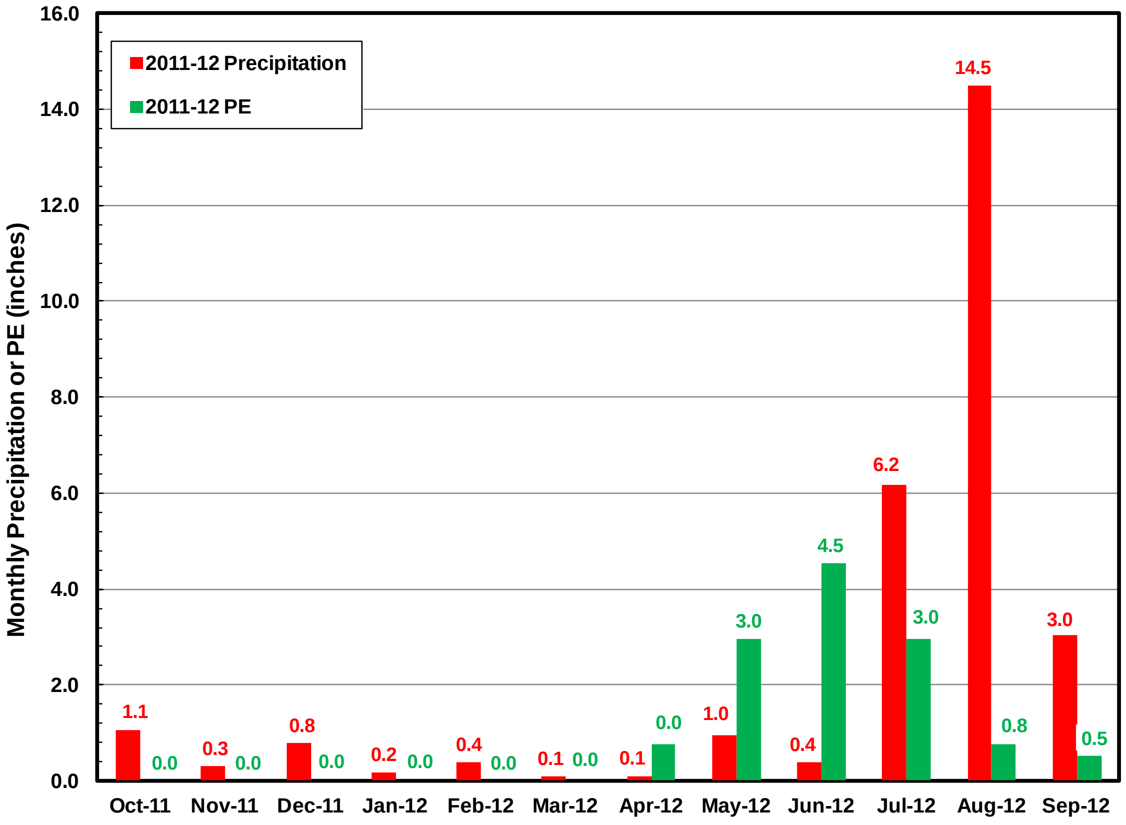

Figure 3.5 Monthly PE and precipitation measured during the monitoring period.

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 2011 to mid-June 2012. 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. 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 May, June and July.

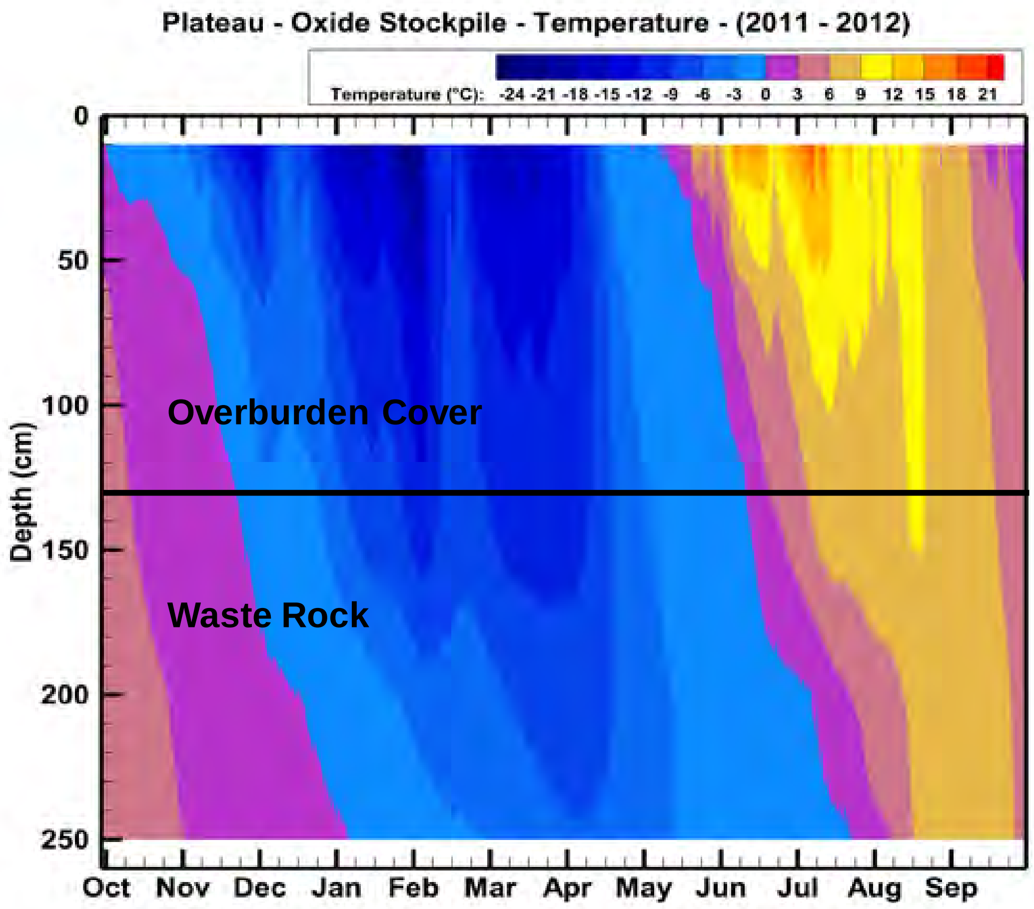

Figure 3.6 *In situ* temperature measured within Plateau station waste rock and overburden cover profile during the monitoring period.

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. Maximum depth of freezing was approximately 130 cm in 2011-12 which is similar to previous years. Temperatures at the overburden / waste rock interface ranged between -1^{o}C and 12^{o}C. The cover system was seasonally frozen in the same manner as the Plateau station which had a similar impact on cover system performance.

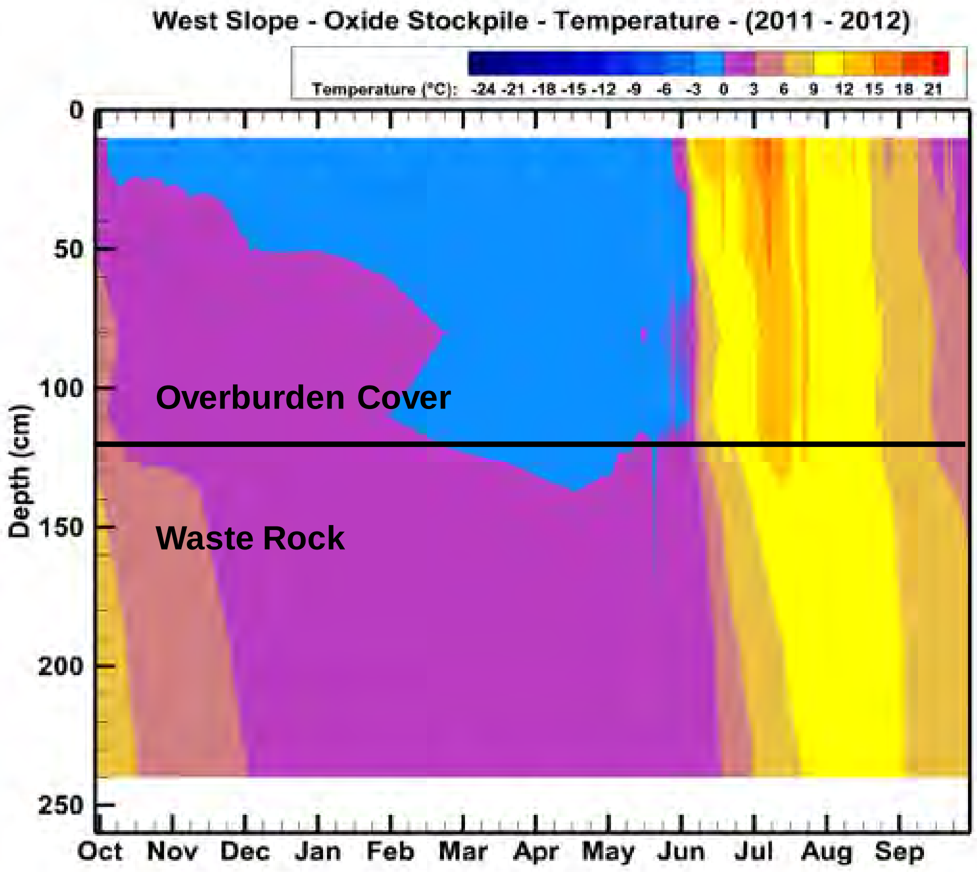

Figure 3.7 *In situ* temperature measured within West station waste rock and overburden cover profile during the monitoring period.

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 Plateau station during the monitoring period. The blank areas within the figure indicate that the sensors are frozen and therefore not providing accurate measurement. Saturation levels within the cover material were high immediately after the spring thaw. Volumetric water content decreased during June and early-July in response to the long sunlight periods and relatively high PE rates and low rainfall of the early summer. 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 heavy rainfall events in July, August, and September.

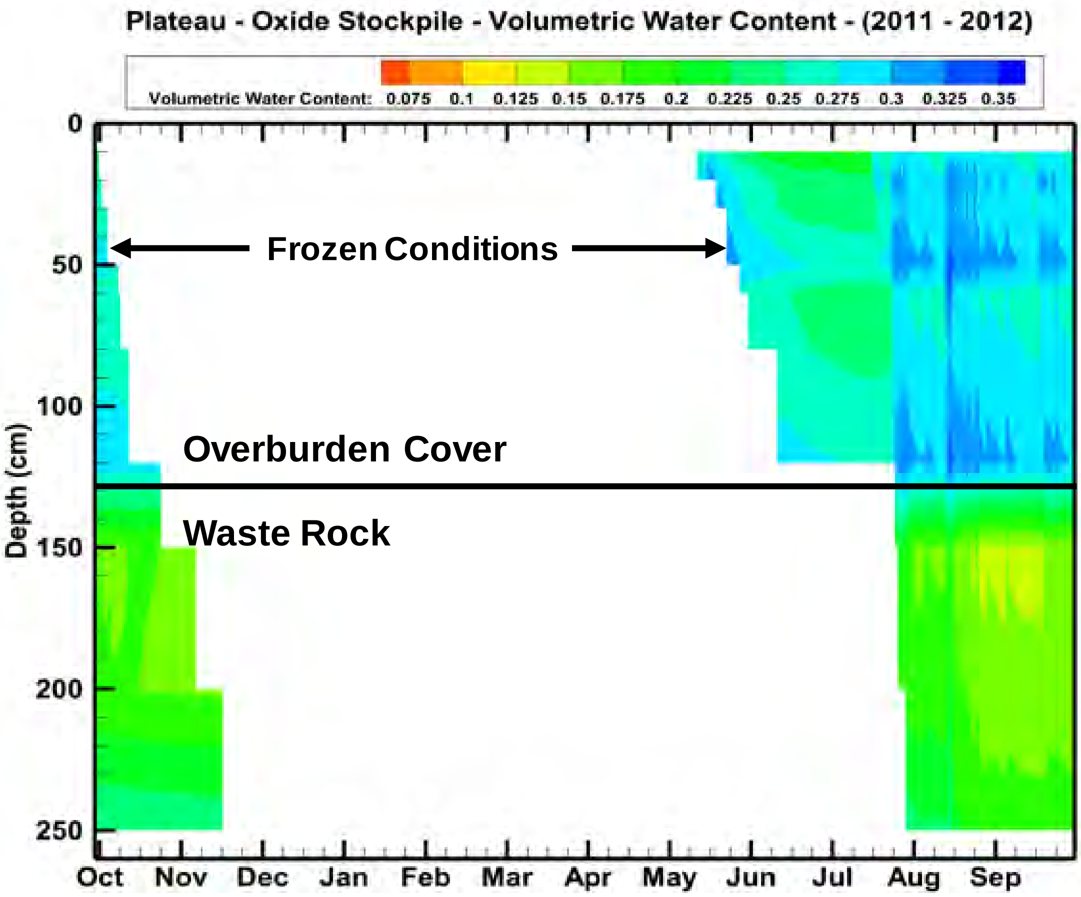

Figure 3.8 Volumetric water content measured at Plateau station during the monitoring period.

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 the late-July and August rainfall events. The measured water contents indicate a period of high infiltration and net percolation to the underlying waste rock material.

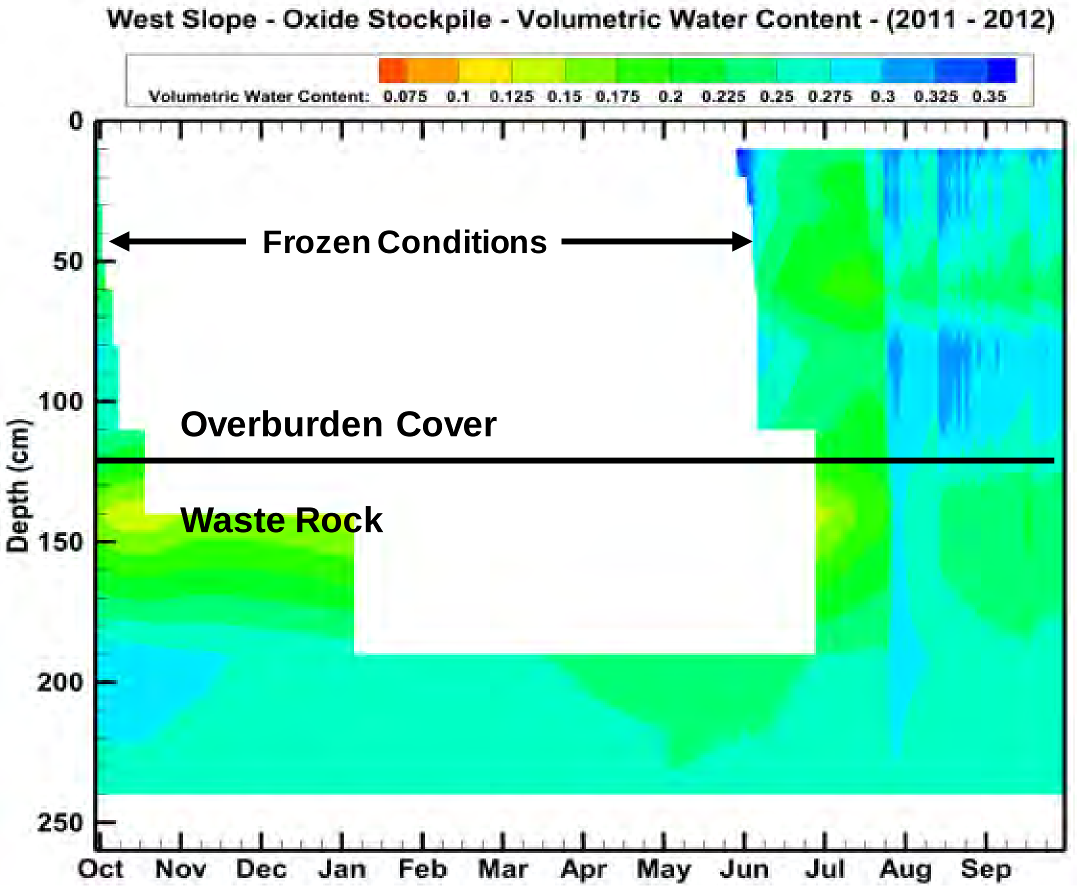

Figure 3.9 Volumetric water content measured at West station during the monitoring period.

Figure 3.10 presents the change in water storage within the overburden cover system for both monitoring locations during the 2008-09, 2009-10, 2010-11, and 2011-12 monitoring periods. 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.

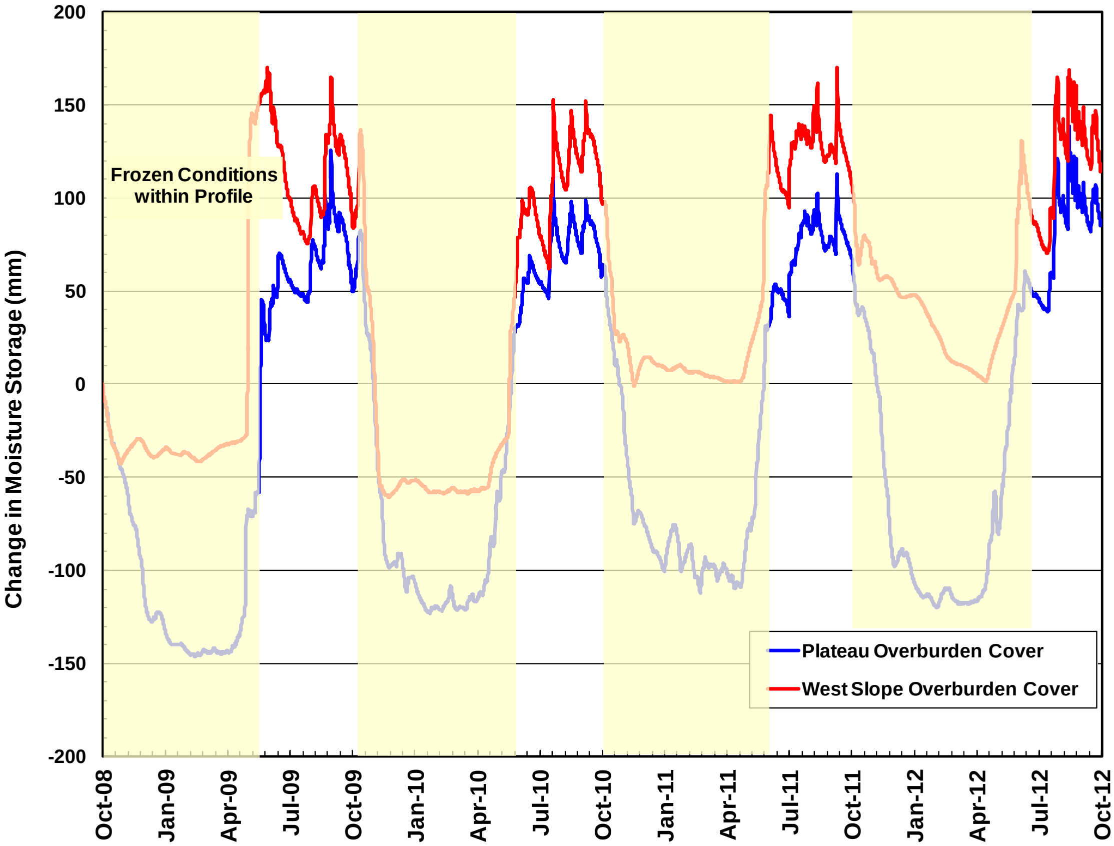

Figure 3.10 Change in water storage within the cover system profile at Plateau and West stations.

In the 2012 frost-free period, the responses of the overburden cover system to climatic conditions at the stations were similar, which indicates both sets of sensors are providing consistent water content measurements (i.e – responding to rainfall events and drying periods at the same time with similar magnitude. This is to be expected as the monitoring stations are only 100 m apart and likely receive similar rainfall and evaporative conditions. The total of water stored within the cover system was greater in 2011-12 compared to previous years. As discussed in the water content summary, the cover system was near its field capacity storage from mid-July to the end of the monitoring 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) during June and early-July before low suction (< 5 kPa) measurements for the remainder of the monitoring period.

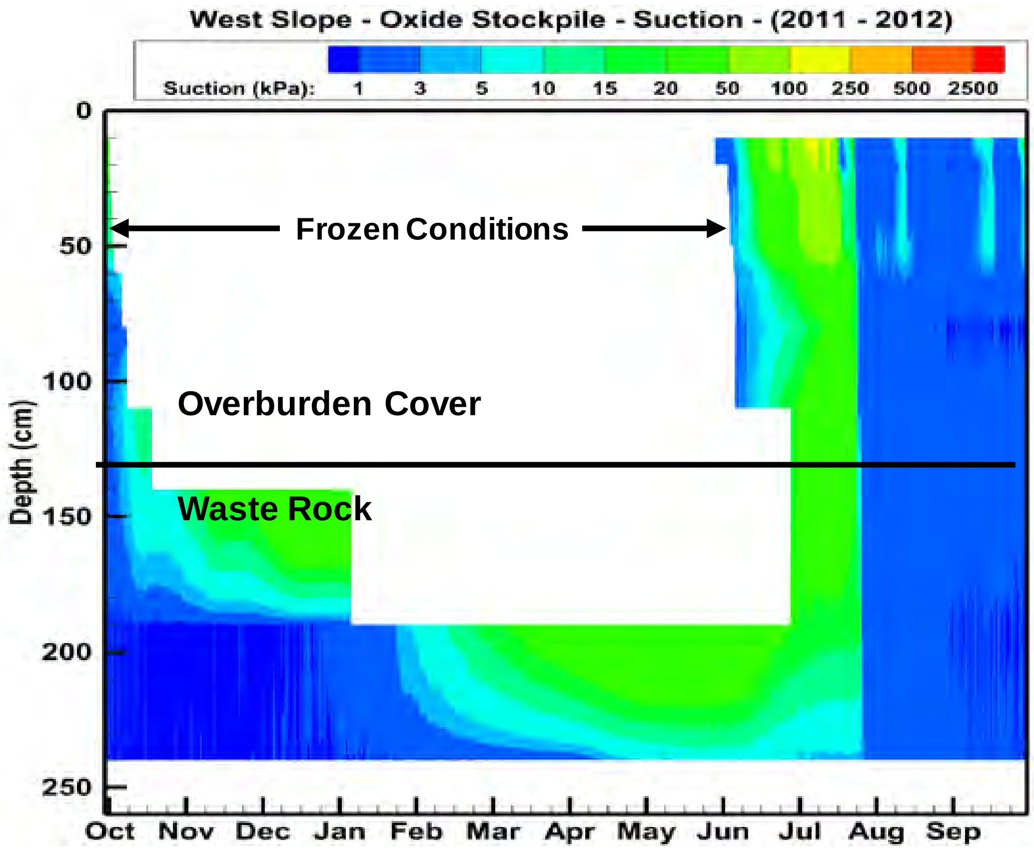

Figure 3.11 Matric suction measured within the overburden cover system and waste rock profile at West slope station.

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 2012 at Plateau station.

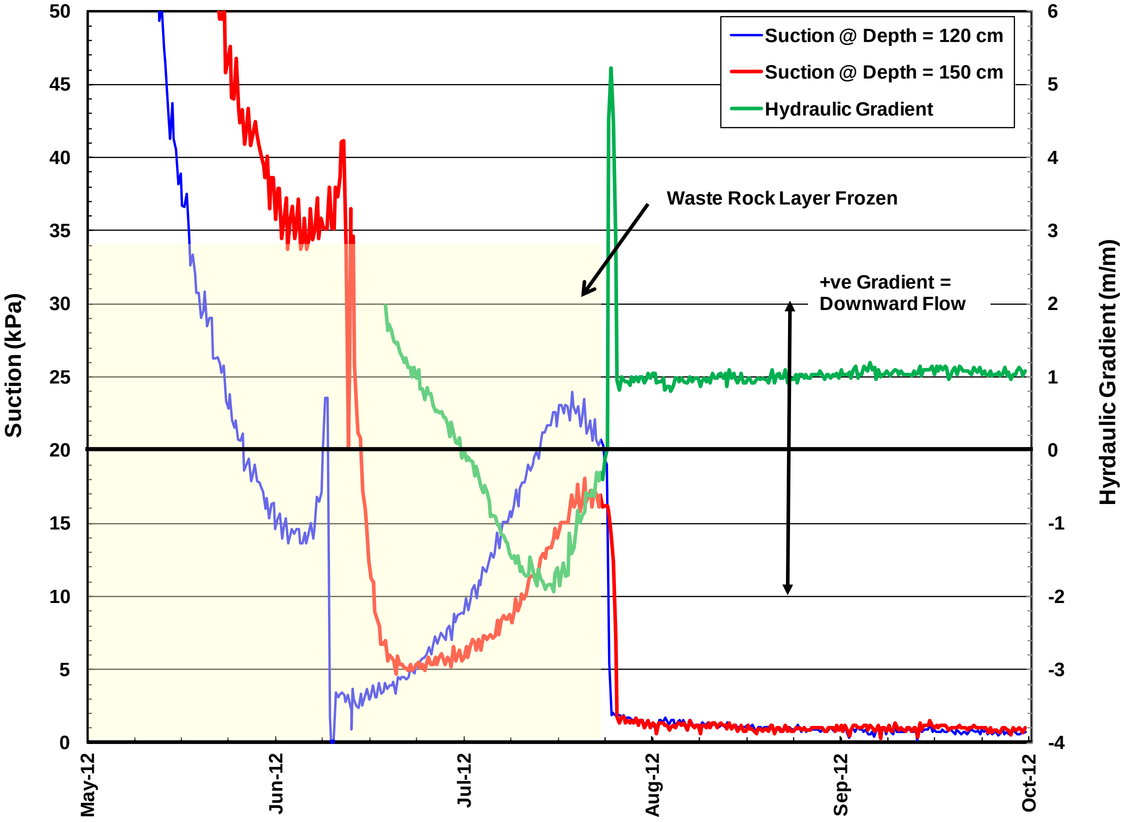

Figure 3.12 Matric suction measured at depths of 120 cm (overburden) and 150 cm (waste rock) and hydraulic gradient calculated at the overburden / waste rock interface at Plateau station.

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 Plateau station remained consistently near 1 m/m during the cover system frost-free period. Hydraulic gradient calculated for the West station was similar remaining near 1 m/m during the frost-free period.

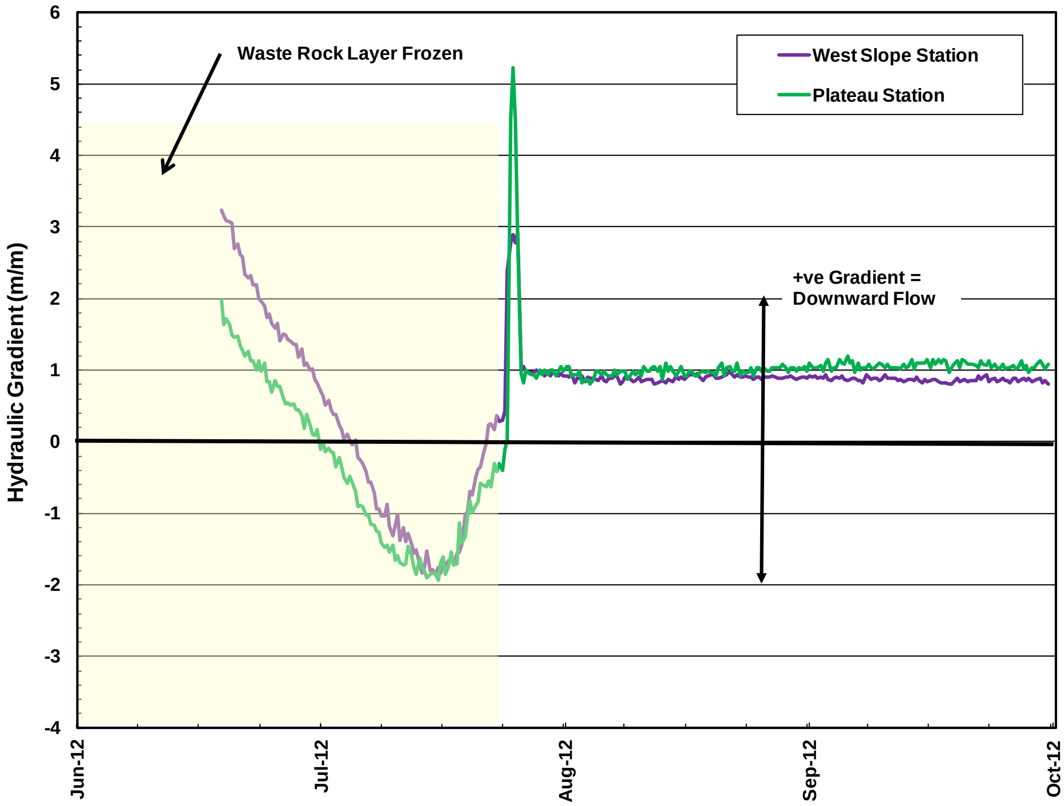

Figure 3.13 Hydraulic gradient calculated at the overburden / waste rock interface at the monitoring locations.

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.

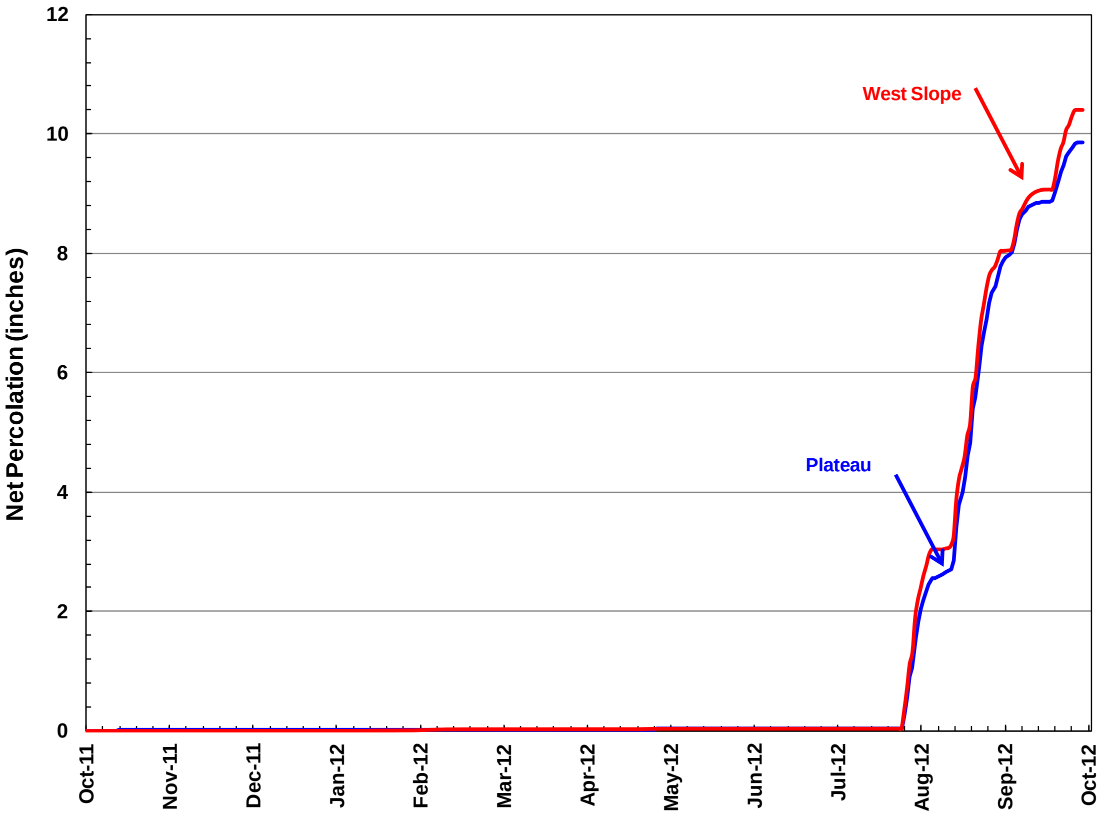

Figure 3.14 Net percolation collected with the automated tipping bucket system.

The total net percolation collected was 9.9 inches (250 mm) at Plateau station and 10.4 inches (264 mm) at the West station. These measurements are substantially more than measured in any of three previous monitoring periods. The greatly above average rainfall in July, August, and September 2012 lead to increased infiltration and net percolation of meteoric water.

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):

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

where:

PPT = precipitation (rainfall plus snow water equivalent (SWE)),
RO = runoff,
AET = actual evapotranspiration,
NP = net percolation,
DS = 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.

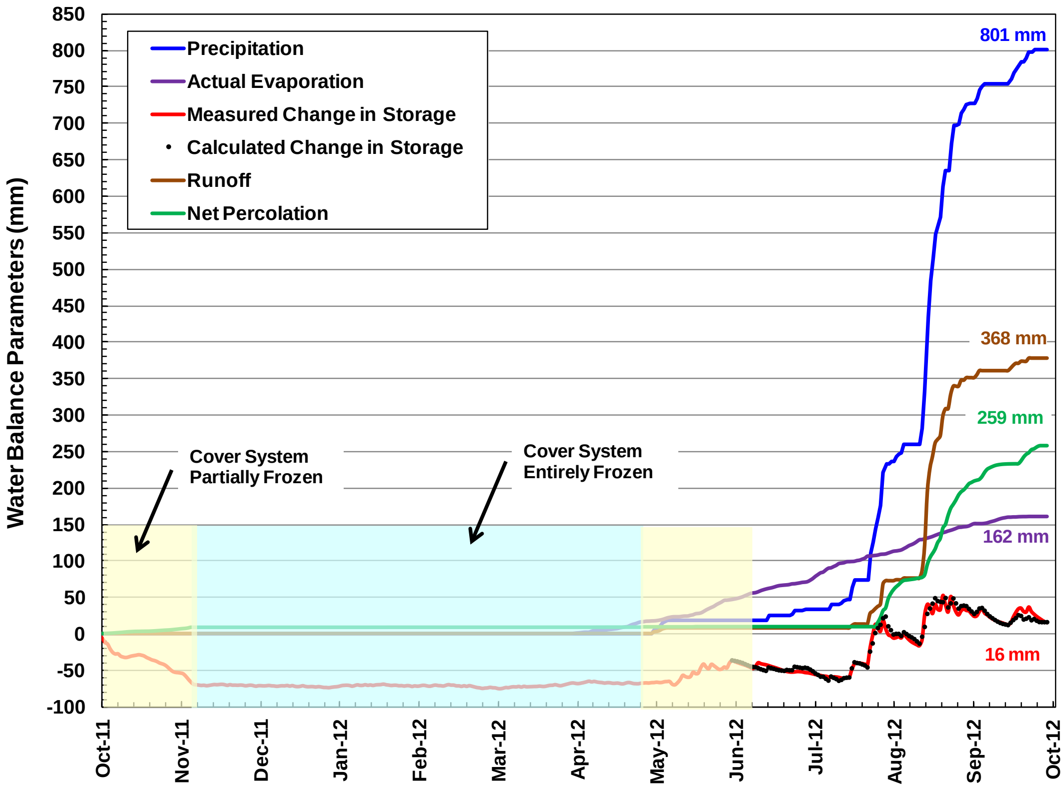

Figure 3.15 Cumulative water balance fluxes for Plateau station in the 2011-12 monitoring period.

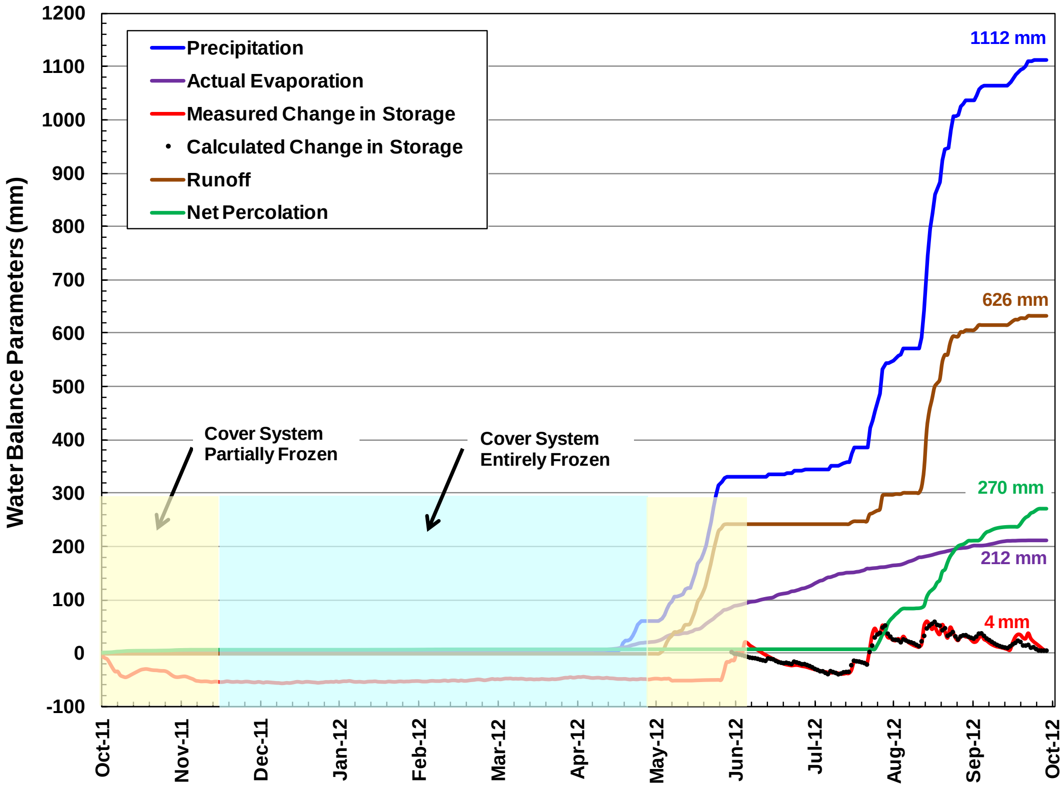

Figure 3.16 Water balance fluxes for West station in the 2011-12 monitoring period.

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)	801 mm (31.5 inches)	1,112 mm (43.8 inches)
Runoff	368 mm (46%)	626 mm (56%)
Actual Evaporation	162 mm (20%)	212 mm (19%)
Net Percolation	259 mm (32%)	270 mm (24%)
Change in Storage	16 mm (2%)	+4 mm (<1%)

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. 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				Station Precipitation
	Year 1 2008-2009	Year 2 2009-2010	Year 3 2010-2011	Year 4 2011-2012	2011-2012
Plateau	16%	11%	16%	36%	32%
West	17%	10%	24%	38%	24%

3.5 *Comparison of 2011-12 Period to Short-Term Monitoring Record*

In order to characterize the performance of the cover systems in the 2011-12 monitoring period, it is useful to examine their response within the context of the short-term monitoring record from 2003-04 to 2011-12. Figure 3.17 presents the precipitation recorded in each monitoring period at the Airport weather station.

The 28.1 inches of precipitation during the 2011-12 monitoring period was substantially higher than any of the previous nine years and the short-term average of 18.0 inches. Precipitation during the autumn, winter, and spring months was below average, but rainfall during the summer was significantly greater than average. It is estimated that the 14.5 inches of rainfall recorded in August represents a 1:2,700,000 year extreme rainfall period (note that the nine year sample size can lead to a large error in return period estimation). The rainfall occurred during a period where sunshine hours and PE rates per day were declining leading to high infiltration rates, low AET rates, and ultimately, high NP rates. This combination represents the worst-case scenario for cover system performance at the Oxide Stockpile, and accordingly, NP rates were much greater than previously measured.

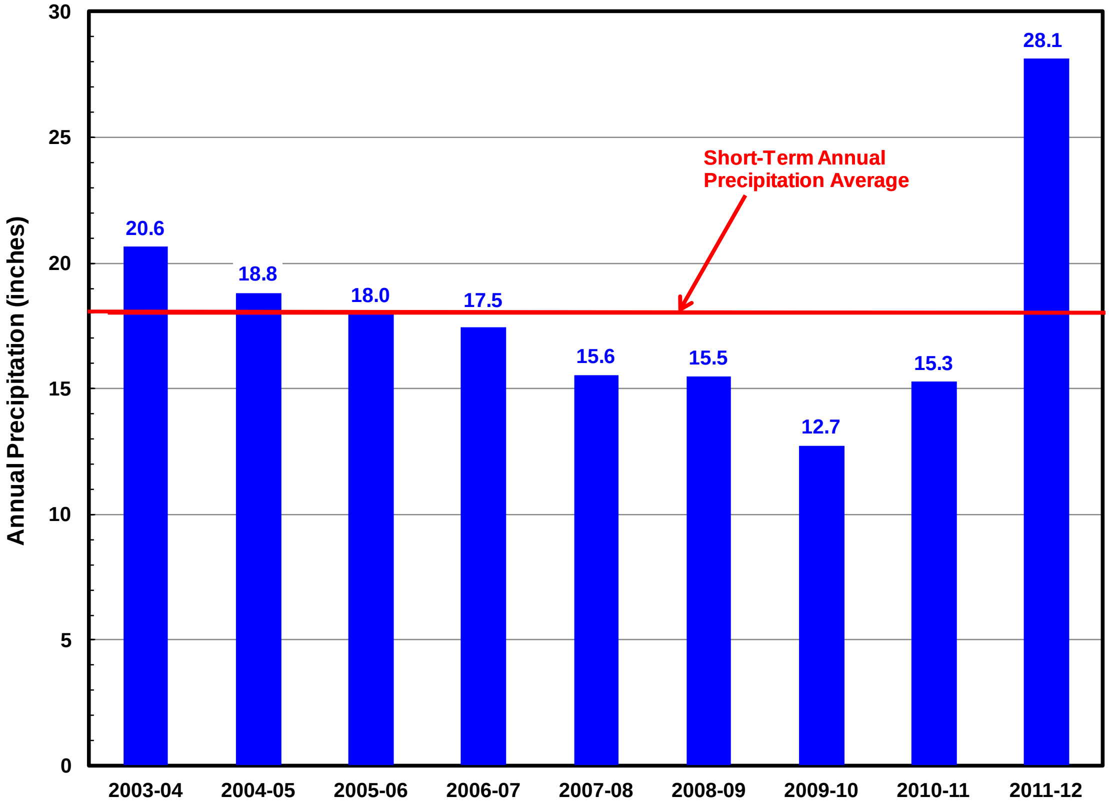

Figure 3.17 Rainfall recorded during each monitoring period since the onset of monitoring.

4 RECOMMENDATIONS

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

1. Continuation of monitoring program to examine the impact of the 2012 above average rainfall season and the ongoing performance of the Oxide Stockpile cover systems.
2. A site visit in June 2013 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. Re-establish the collection of water content data from the Diviner access tubes. Measurements in 15 of the 16 installed Diviner access tubes were completed during the June 2012 site visit.
4. 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.
5. Re-visit the design of the existing runoff measurement system to consider either maintenance of the existing flume area or moving the system to a new location on the West slope or to a potential new monitoring area. It is recommended that OKC and Red Dog personnel discuss the options for the runoff flume and associated automated monitoring equipment. It is OKC’s opinion that improved runoff monitoring will benefit the overall monitoring program at the Oxide Stockpile.

5 REFERENCES

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