APPENDIX D, Oxide Stockpile Full-Scale Cover System 2009-10 Annual Performance Monitoring Report

Teck Resources – Red Dog Mine

Oxide Stockpile Full-Scale Cover System

2009-10 Annual Performance Monitoring Report

Final Version

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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. Field data being collected includes matric suction and temperature, *in situ* water content, and changes in water storage, rainfall, net radiation, and snowpack thickness.

The 2009-10 monitoring period represents the second 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 2009-10 was approximately 10-11% of annual precipitation. Percolation rates in 2009-10 were less than the 16-17% values measured in the 2008-09 monitoring period (OKC, 2010) and previous predictive numerical modeling (OKC, 2004) that estimated 15% net percolation over a four-year simulation period.

The 2009-10 period had the lowest total precipitation recorded in seven years of monitoring (12.8 inches (325 mm)); therefore, it is not unexpected that net percolation rates as defined by automated measurements at Plateau and West stations and the water balance were approximately 10% of annual precipitation. It is OKC's opinion that net percolation rates measured in 2009-10 represent the lower boundary of percolation rates anticipated for the Oxide stockpile cover system and net percolation will increase in future years if precipitation returns to average annual rates. Continued monitoring will show whether the net percolation rate varies greatly with magnitude of annual precipitation.

Recommendations:

OKC recommends the completion of a snow survey before the onset of spring melt as described in the Field Reference Manual (OKC, 2009a). OKC suggests a site visit during the early part of the 2011 field season in June 2011. 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 Performance Monitoring Report:

This performance monitoring report presents field data collected from the onset of monitoring in October 2009 to September 2010. 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 2009-10 monitoring period.

- Total precipitation measured at the Airport weather station during the monitoring period was 12.8 inches (325 mm), which was approximately 25% less than the 17.0 inch seven-year average at the site.
- Total precipitation estimated for Plateau and West stations (rainfall + snow water equivalent) was 10.2 inches (260 mm) and 17.8 inches (452 mm), respectively.
- Potential evaporation (PE) for the 2009-10 monitoring period was approximately 14.3 inches (363 mm). PE was substantially greater than rainfall in May and June 2010, slightly less than rainfall in July, and substantially less than rainfall in August and September.
- The depth of freezing at each monitoring location was similar in 2009-10 with the freezing front penetrating deeper than the deepest installed sensor at each location. Temperatures at the base of the overburden cover systems did not reach above 0°C until the middle of June 2010. The total depth of freezing at West station was much greater in 2009-10 than observed in 2008-09. It is likely the thinner, later developing snowpack at West station resulted in colder temperatures within the overburden cover system.
- Volumetric water content measurements collected with CS616 sensors show wetting and drying fronts develop at all stations in response to the seasonal climatic events. Each station showed distinct wetting fronts reaching the base of the overburden cover system from the rainfall events in July, August, and September.
- Moisture conditions as measured with the CS229 matric suction sensors were similar to measurements with the CS616 volumetric water content sensors. Matric suction values near the surface at Plateau station ranged up to 200 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 at the conclusion of the spring melt period, small downward or upward gradients (low flow) during the early summer season, and downward gradients in late July, August and September.
- Total net percolation measured at Plateau station from the large lysimeter tank was 1.4 inches (37 mm) or 11% of total precipitation. Net percolation estimated at West station was 1.2 inches (31 mm) or 10% of total precipitation.
- A water balance was used to estimate the actual evapotranspiration (AET) at each station during the monitoring period. AET ranged from 187 mm at Plateau station to 206 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 2009-10

2.1 Data Capture Rates

Data capture rates for various components of the performance monitoring system for the monitoring period are summarized in Table 2.1. The overall data capture rate for the October 2009 to September 2010 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 2009-10 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 performance monitoring systems operated without interruption through the 2009-10 winter season. Battery power was sufficient to operate the system during the winter months when there was limited sunlight hours to recharge the batteries through the solar panels. The data capture rate increased from 93% in 2008-09 to 96% during the 2009-10 monitoring period. The increase was due to the installation of net radiation and snow depth sensors at West Slope station.

OKC completed a site visit to Red Dog operations in August 2010. Regular maintenance included a diagnostic check of the power supply system, replacement of desiccant packs, and closure of gaps allowing air into the fiberglass enclosure. OKC anticipates that the data collection stations are ready for the 2010-11 winter season. Tasks completed during the site visit included:

- Replacement of both tipping bucket rain gauges which measure lysimeter flow. Metal precipitates from the lysimeter outflow collect on the tipping bucket mechanism during normal operation. OKC recommends annual replacement of the gauges to ensure a continuous data collection.
- Calibration of the rainfall gauge at the Plateau station.
- Calibration of both lysimeter tipping bucket gauges at the Plateau and West slope locations.

OKC and TAK personnel walked across the Oxide stockpile landform evaluating the vegetation and erosion rills on the stockpile side slopes. Re-vegetation has been largely successful with good ground cover achieved in the first two years after reclamation. To date, native grasses provide the majority of ground coverage. Current efforts include increasing the number and presence of native vegetation species including shrubs such as willows.

Erosion rills have developed on slopes of the landform, most notably on the eastern slope and on the southern end of the western slope. Figure 2.1 shows erosion rills that have developed on the eastern slope of the Oxide stockpile.

Figure 2.1 Areas of concentrated erosion rills on eastern slope of Oxide stockpile.

The Oxide stockpile landform incorporates a 1-2% slope on the plateau area sloping from west to east. The majority of erosion rills are on the eastern slope in areas where runoff flow concentrated on the plateau surface before overtopping onto the slope. There were no controls to stop runoff overtopping built into the Oxide stockpile landform; runoff water will continue to concentrate within the existing erosion rills. It is OKC's opinion that the existing rills should be repaired with rip rap material to prevent further downcutting and erosion. Simply repairing the existing rill with overburden is unlikely to adequately resist erosion until additional strengthening through re-vegetation can occur.

OKC and TAK personnel discussed additional reclamation that will be completed on the south end of the Main stockpile. It is OKC's understanding that the same cover system as utilized at Oxide stockpile will be constructed on the Main stockpile area. The cover system consists of a compacted waste rock surface, 0.5 m of compacted overburden cover material, and 0.5 m non-compacted overburden. In regards to future reclamation at the Main stockpile OKC recommends:

1) Preventing overtopping runoff flow onto the reclaimed Main waste stockpile slope. The slope distance and up-gradient contributing area at Main waste stockpile are much larger than Oxide stockpile, erosion rills will develop unless proper surface water management channels are constructed. Suggested measures include a berm along the crest of the reclaimed slope and an adequately armored surface water channel to convey flow down the waste rock slope to the tailings area.

2) Avoiding long planar slopes and creating a landform similar to the natural slope features surrounding the Red Dog site. OKC and TAK personnel discussed the development of a landform similar to the natural analogue within the Red Dog area, which is strongly recommended by OKC.

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 2009-10 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 2009 to September 2010. A total of 12.8 inches (325 mm) of precipitation were recorded, which is substantially less than the seven-year average annual precipitation (2003-10) of 17.0 inches (426 mm). The daily precipitation shows the majority of precipitation occurred in July, August, and September. There were several rainfall events larger than 0.5 inches including July 16/17th, July 21/22nd, August 11th, August 15th, September 2nd, and September 10th. The greatest rainfall events occurred in mid July with 2.8 inches (72 mm) of rainfall recorded between July 16th and July 22nd.

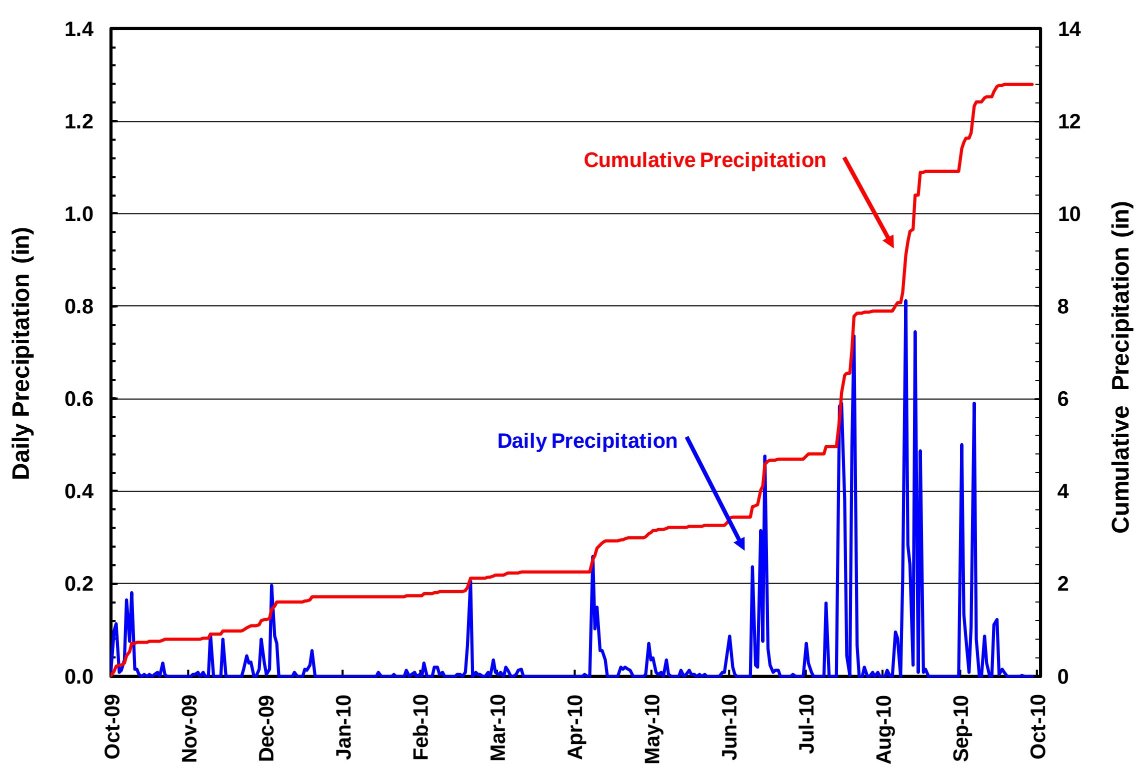

Figure 3.1 Precipitation measured at the airport weather station during the 2009-10 period.

Figure 3.2 compares the annual monthly precipitation to the 2003-10 average monthly precipitation. Precipitation for the first eight months of the monitoring period was substantially below average with decreased winter snowfall and spring rainfall. Rainfall in the frost-free months spanning June to September was normal within 0.5 inches of the seven-year average value for the month.

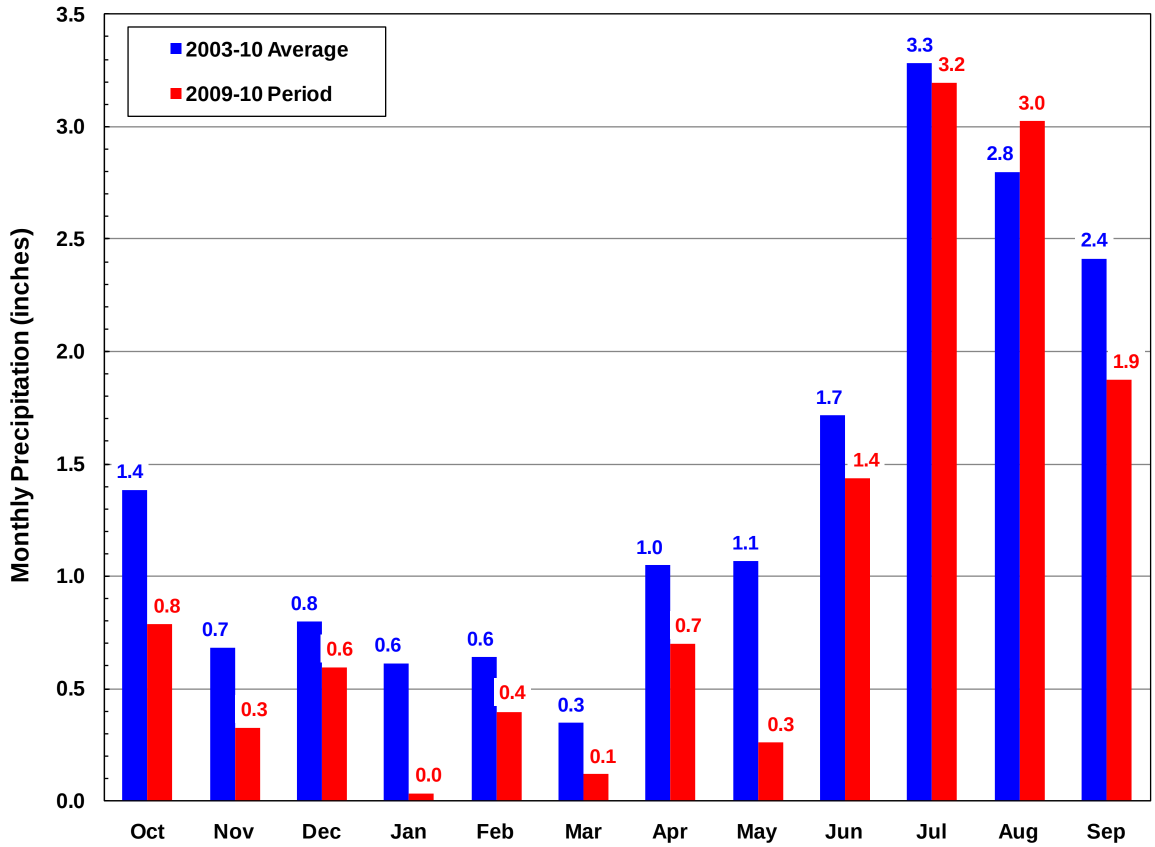

Figure 3.2 Comparison to 2009-10 monthly precipitation to the seven-year (2003-10) monthly averages.

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 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 thickness of 40 inches on April 14th before slowly melting and/or sublimating over a one-month period. The West station lies within a snow deposition area as measured snowpack has exceeded total snowfall over the winter for both the 2008-09 and 2009-10 monitoring periods. The snowpack thickness and corresponding snow-water equivalent (SWE) were estimated to be 40 inches and 8.0 inches (203 mm), respectively. The cumulative precipitation estimated for West station is shown in Figure 3.4. The estimated precipitation was 17.8 inches (452 mm) for the monitoring period.

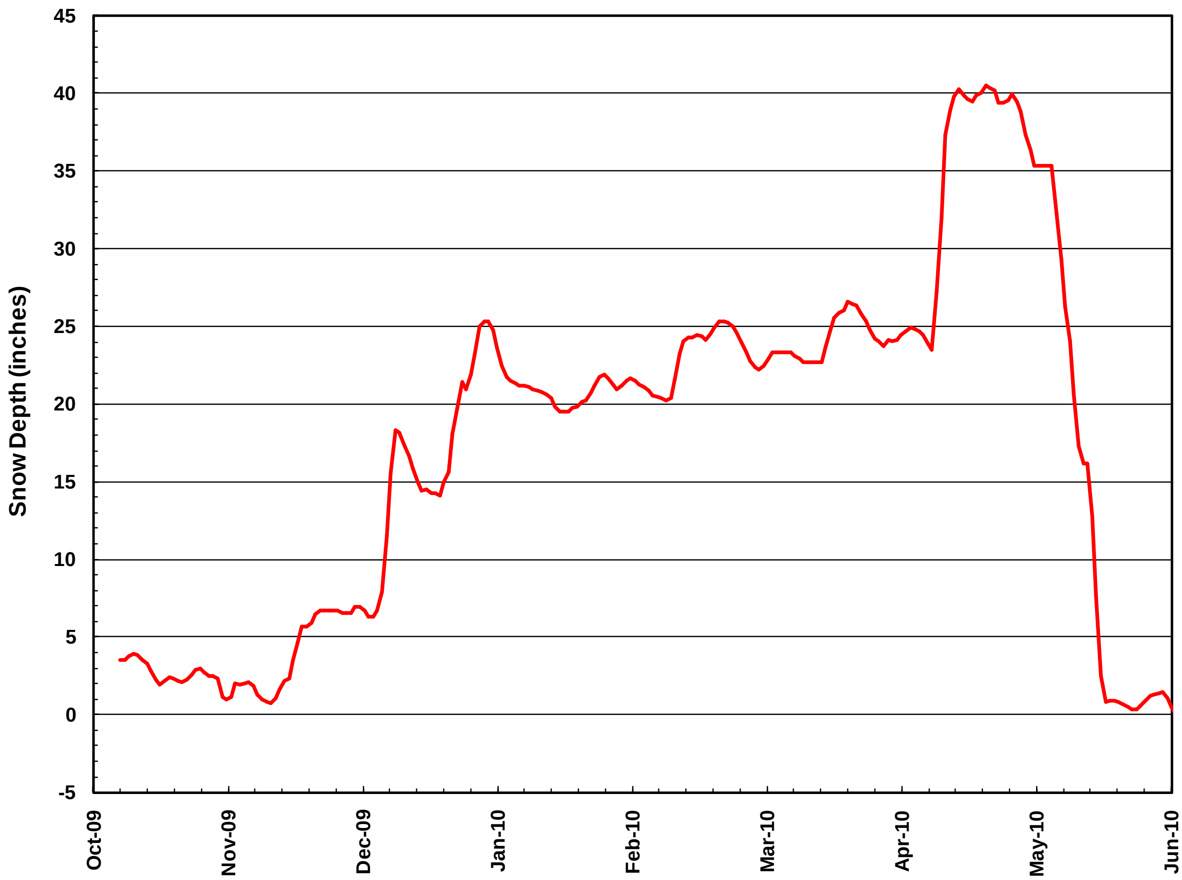

Figure 3.3 Total snowpack measured by snow depth sensor at West station.

Snowpack measured by the sonic sensor was never greater than 2-3 inches at Plateau station during the winter season. The flat, plateau area at the top of the Oxide Stockpile is exposed to winds from all directions, which redistributed the majority of snowfall. The first above-freezing temperatures of the season melted the thin 2 inch snowpack (0.4 SWE) in late April. Temperatures dropped below freezing for approximately a week and additional snowfall formed a second snowpack approximately 1 inch in thickness (0.2 inch SWE), which corresponds to a total of 0.6 inches (15 mm) SWE for the season. 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 10.2 inches (260 mm).

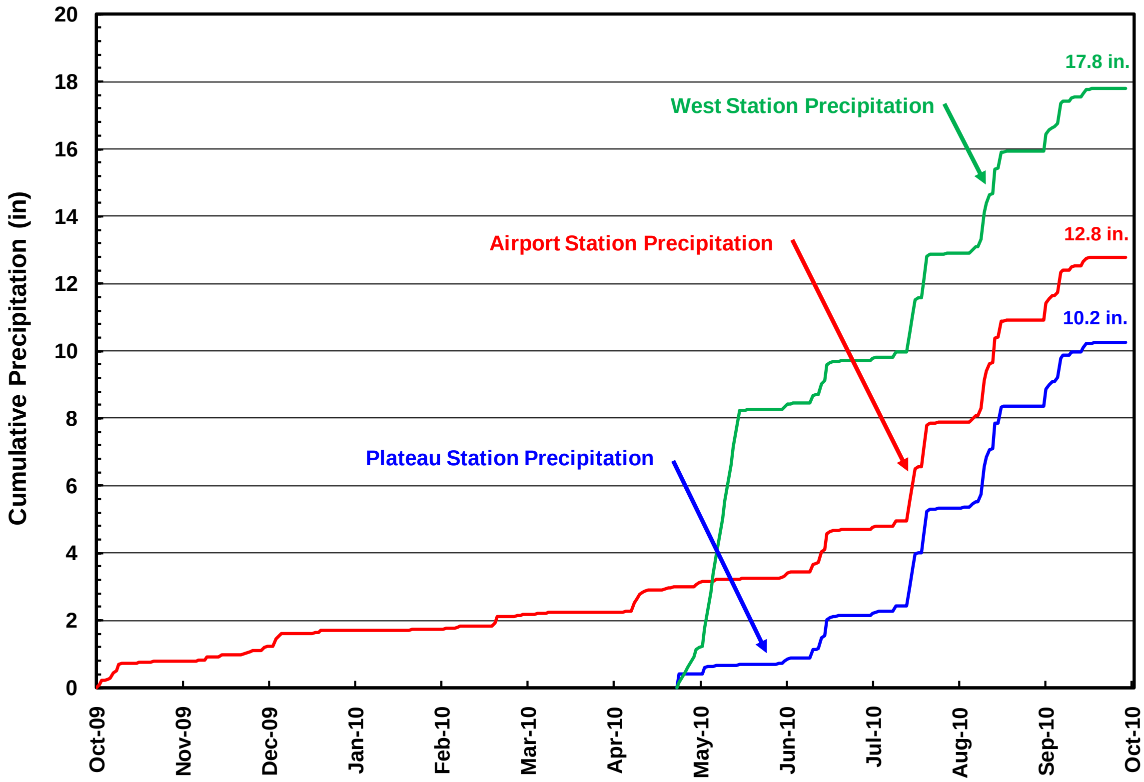

Figure 3.4 Comparison of precipitation measured at the Airport station and that estimated for Plateau station and West station during the monitoring period.

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 based on the Penman (1948) method and meteorological data collected at the site. 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.

Net radiation was measured at West station during the 2009-10 period and a total PE of 14.3 inches was estimated using net radiation values and air temperature, relative humidity, and wind speed measurements from the airport station. Pan evaporation data was collected from June 1, 2010 to September 26, 2010 during which 10.1 inches (257 mm) of pan evaporation was recorded. In comparison, the PE estimated during the same period was 9.80 inches (249 mm). The calculated pan coefficient (PE / Pan Evap.) is approximately 0.97, which is greater than previous years but still reasonable for a humid, northern Alaska site. To complete the PE data record for the 2009-10 monitoring period, the factored pan evaporation rates were used during its operational period and the calculated daily PE values were used for the early spring period before the evaporation pan was operational.

Figure 3.5 compares the monthly potential evaporation estimated in 2009-10 to precipitation. PE was much greater than precipitation in May and June as a result of the below average spring rainfall at the site. 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 slightly less than rainfall in July and substantially less than rainfall in 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.

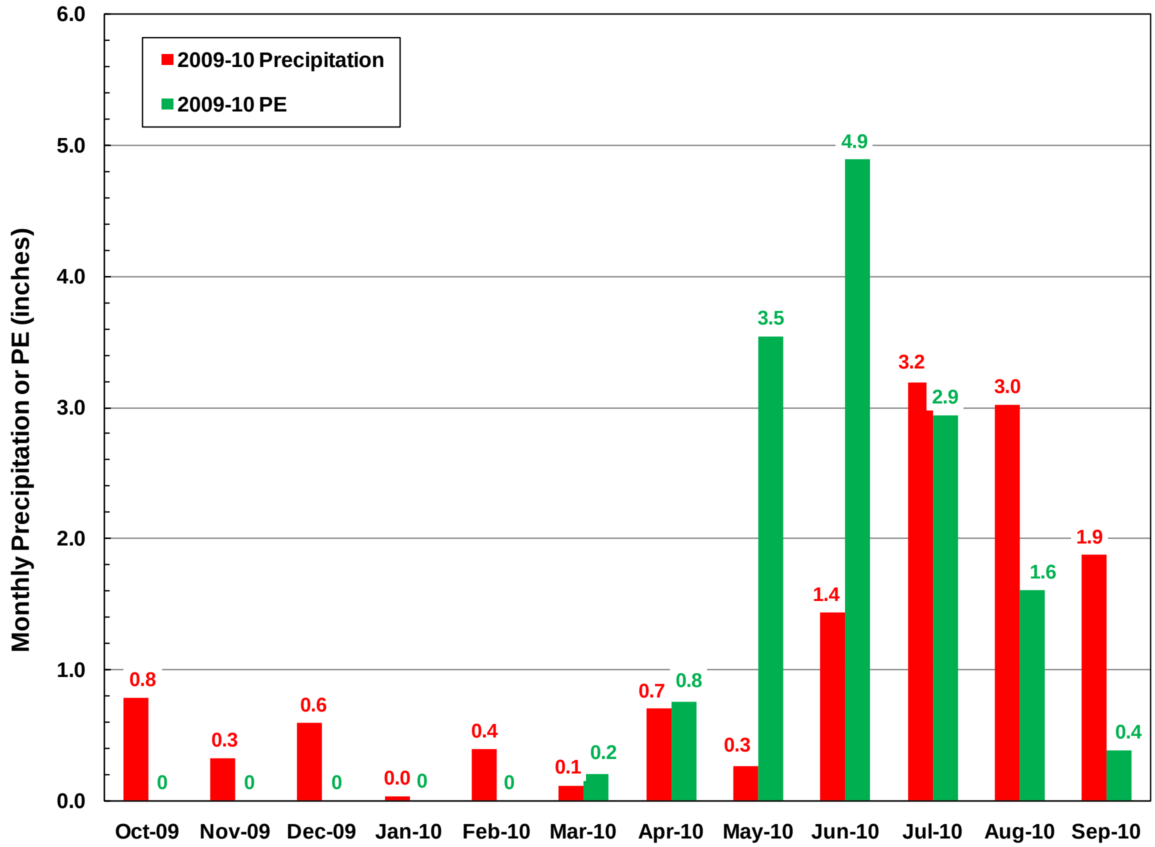

Figure 3.5 Monthly PE and precipitation measured during the monitoring period.

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 18°C in the summer. Deeper within the cover profile, *in situ* temperature is less influenced by seasonal surface temperatures. For example, slightly below the overburden / waste rock interface at a depth of 150 cm, the *in situ* temperature ranged from -12°C to 10°C. The freezing front developed to a considerable depth at Plateau station during the winter season. Temperature at the deepest sensor within the waste rock material (depth = 250 cm) was below 0°C from early-January to the middle of July 2010. In situ temperatures and freezing front depths recorded in the 2009-10 monitoring period were similar to measurements from the 2008-09 monitoring period.

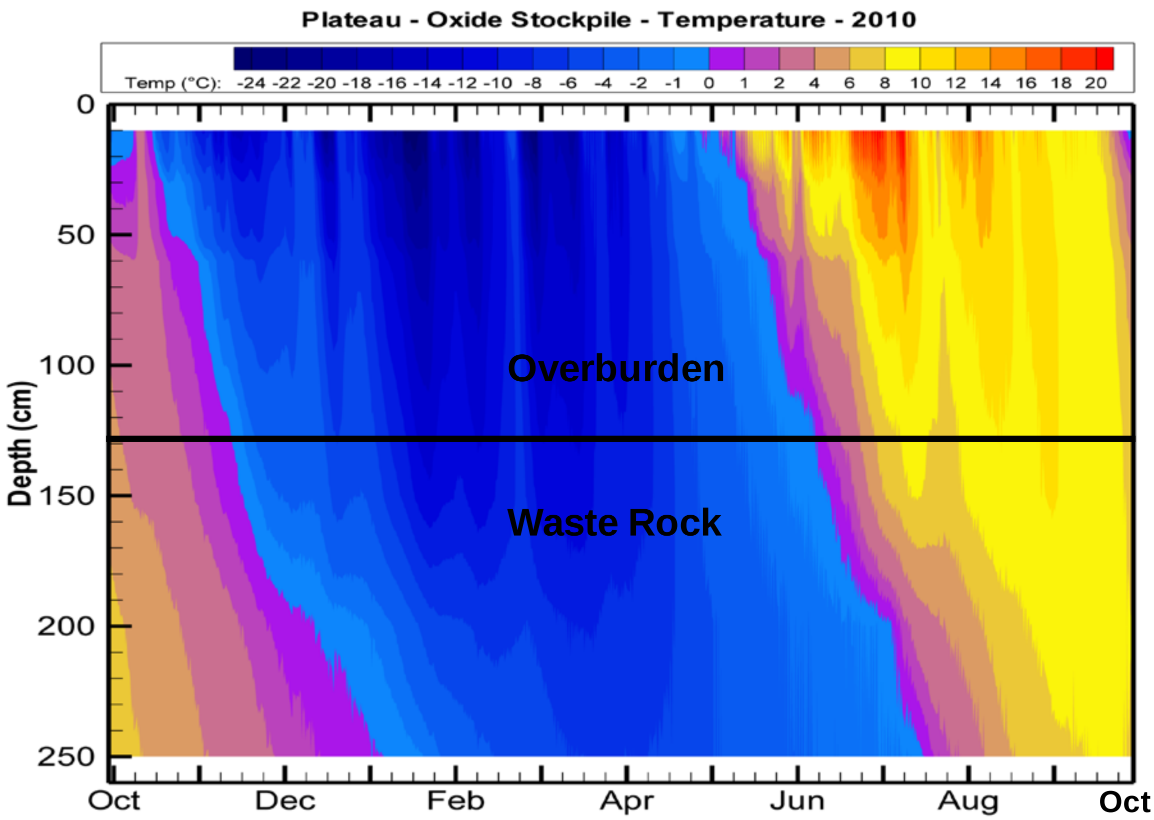

Figure 3.6 *In situ* temperature measured within Plateau station waste rock and overburden cover profile during the monitoring period.

Figure 3.7 shows temperatures measured within the profile at West station for two years of monitoring from October 2008 to October 2010. *In situ* temperatures within the overburden and waste rock were colder in 2009-10 than compared to 2008-09. Maximum depth of freezing was approximately 110 cm in 2008-09 but the frost line penetrated greater than the maximum 240 cm sensor depth in 2009-10. Temperatures at the overburden / waste rock interface ranged between 1°C and 14°C in 2008-09 and -4°C and 12°C in 2009-10. The increased depth of freezing is not explained by air temperature data from 2008-09 and 2009-10, which showed similar but slightly increased average temperature in 2009-10. Less snowpack developed at West station in 2009-10, which might provide an explanation for the deeper freezing fronts. A thinner snowpack delayed in development would provide less insulation from the freezing air temperature and produce deeper freezing fronts.

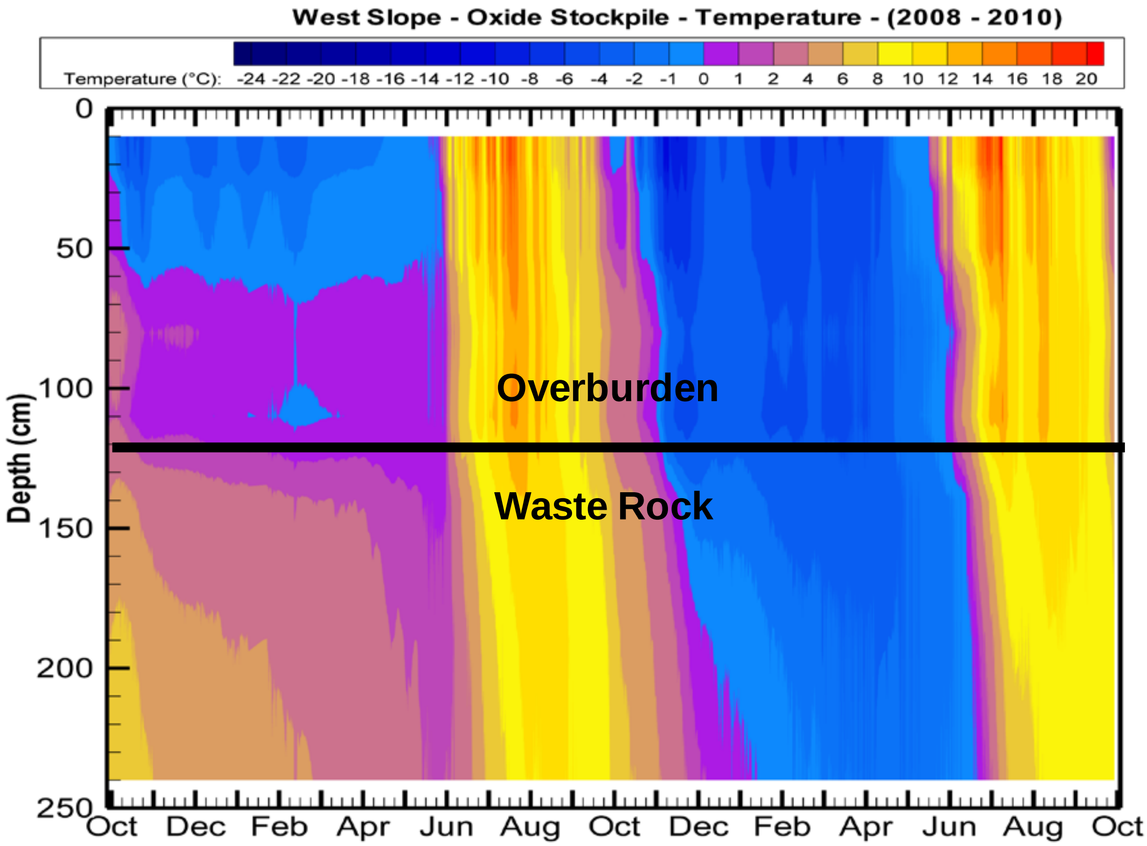

Figure 3.7 *In situ* temperature measured within West station waste rock and overburden cover profile during the monitoring period.

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 10 pairs of CS616 and CS229 sensors installed to a maximum depth of 250 cm. At West station, the sensor nest consists of 10 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, 2009c).

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 presents 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. Saturation levels were high within the overburden cover during the 2010 frost-free period. Water contents ranged from 0.22 cm^3/cm^3 and 0.35 cm^3/cm^3 in the overburden material where porosity is approximately 0.35 cm^3/cm^3. Distinct wetting fronts are visible due to rainfall events in July, August, and September. There were decreases in the near-surface water content after the rainfall events likely due to evapotranspiration of moisture from the surface and water drainage to deeper areas of the cover profile.

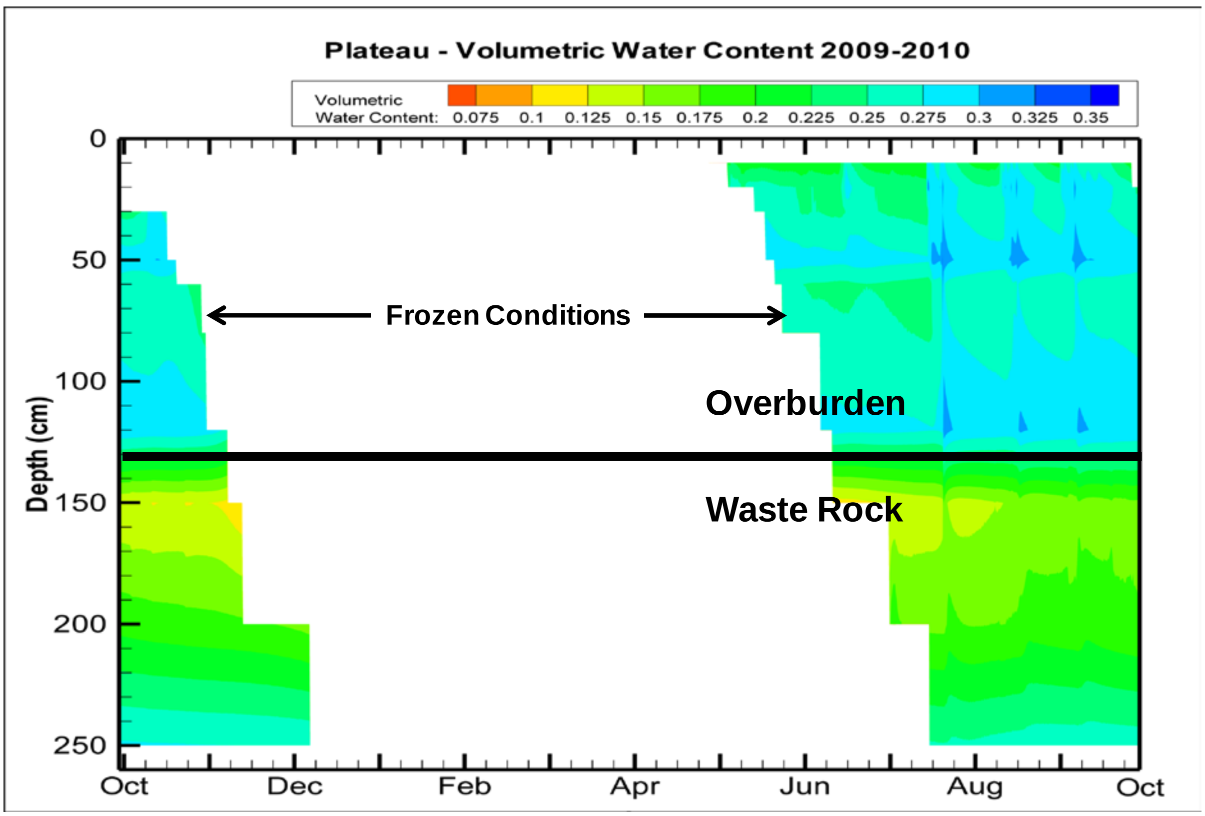

Figure 3.8 *In situ* volumetric water content measured at Plateau station during the monitoring period.

Figure 3.9 shows the response of water content sensors at West station. The *in situ* water content within the overburden profile increased to approximately 0.20 cm^3/cm^3 after spring thaw with water contents increasing to 0.30 cm^3/cm^3 in response to the July, August, and September rainfall events. Similar to Plateau station, wetting fronts developed within the cover profile due to the rainfall events and water contents within the waste rock increased accordingly.

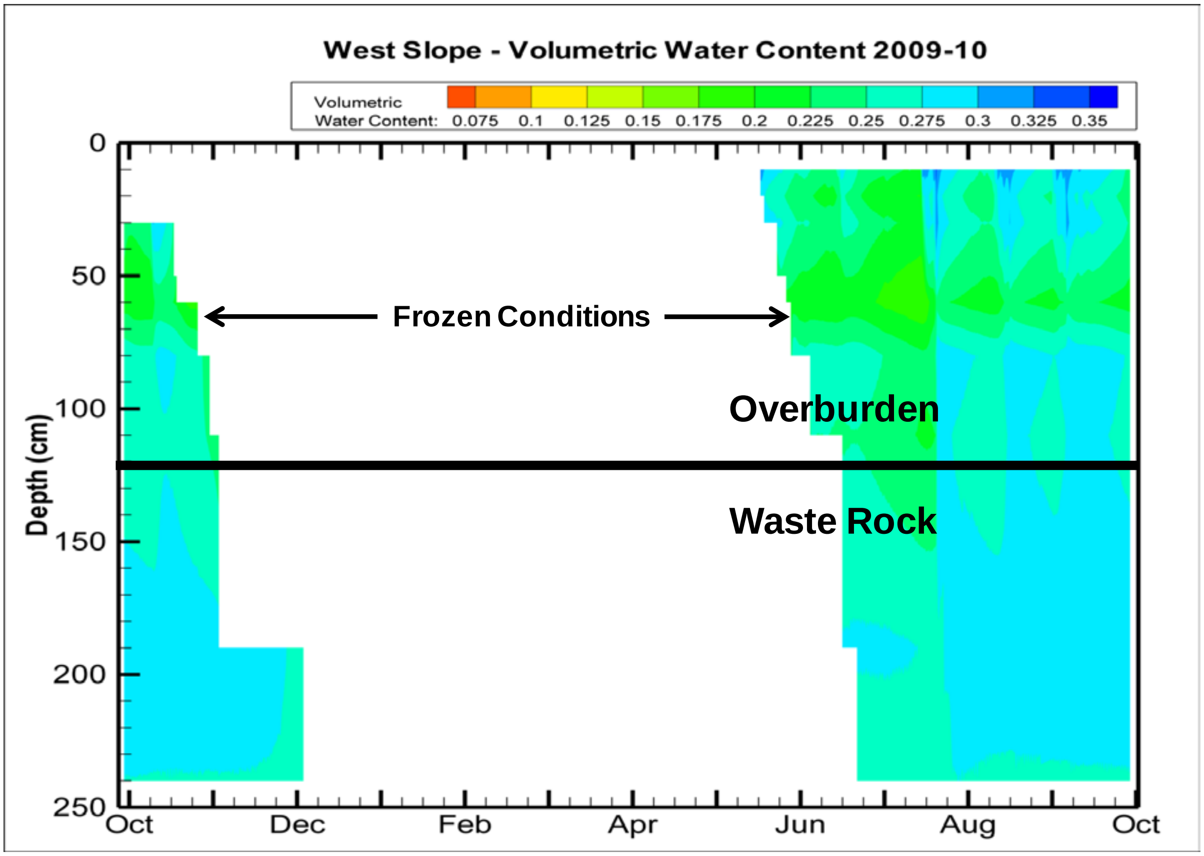

Figure 3.9 *In situ* volumetric water content measured at West station during the monitoring period.

Figure 3.10 presents the change in water storage within the overburden cover system for the monitoring locations for the 2008-09 and 2009-10 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 stations over the two-year span.

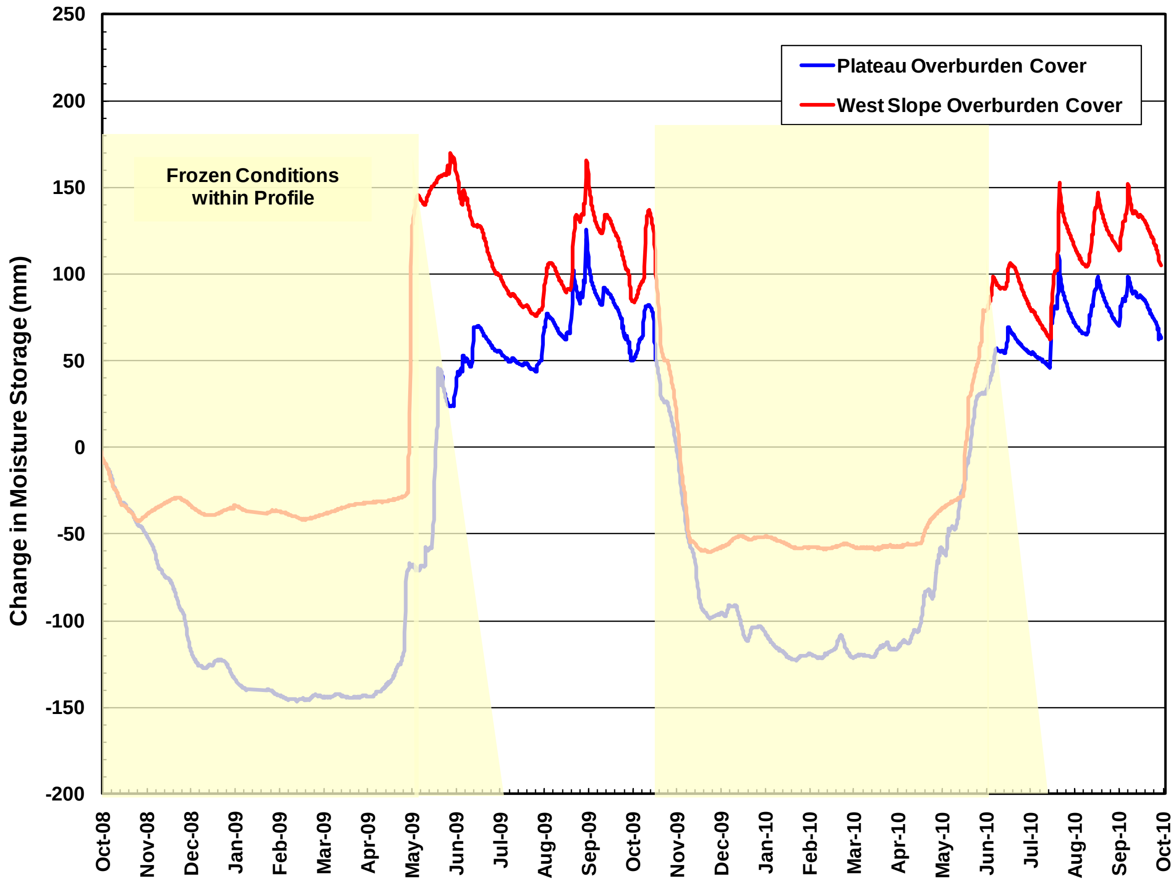

Figure 3.10 Change in water storage within the overburden cover profile at Plateau and West stations.

In the 2010 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. Compared to the 2009 frost-free period, the volume of water in storage during the spring is lower and slowly decreases, which is likely due to the decreased snow pack at West station and the below average rainfall conditions for May and June at the site.

The water content sensors showed strong responses to storm events on July 16-22, August 10-17, and September 2-7. Moisture storage decreased between the rainfall events due to evapotranspiration at the cover system surface and deep drainage from the base of the cover system to the waste rock below.

3.3.2 Summary of Moisture Conditions Measured with TC Sensors

Matric suction data measured by the CS229 sensors at Plateau 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. During the 2010 frost-free period, the near surface sensor (10 cm) responded to rainfall events with sharp drops in matric suction and the subsequent gradual increase in suction was due to the drying effects of surface evaporation and vegetation transpiration. During the late spring / early summer dry period, suction increased to approximately 200 kPa at a 50 cm depth below ground surface and suction was 10 – 25 kPa at the cover system / waste rock interface. After the large rainfall event in July, *in situ* moisture conditions within the cover system remained close to saturation for the remainder of the period. Suction near the cover system surface increased during the short drying periods between large rainfall events.

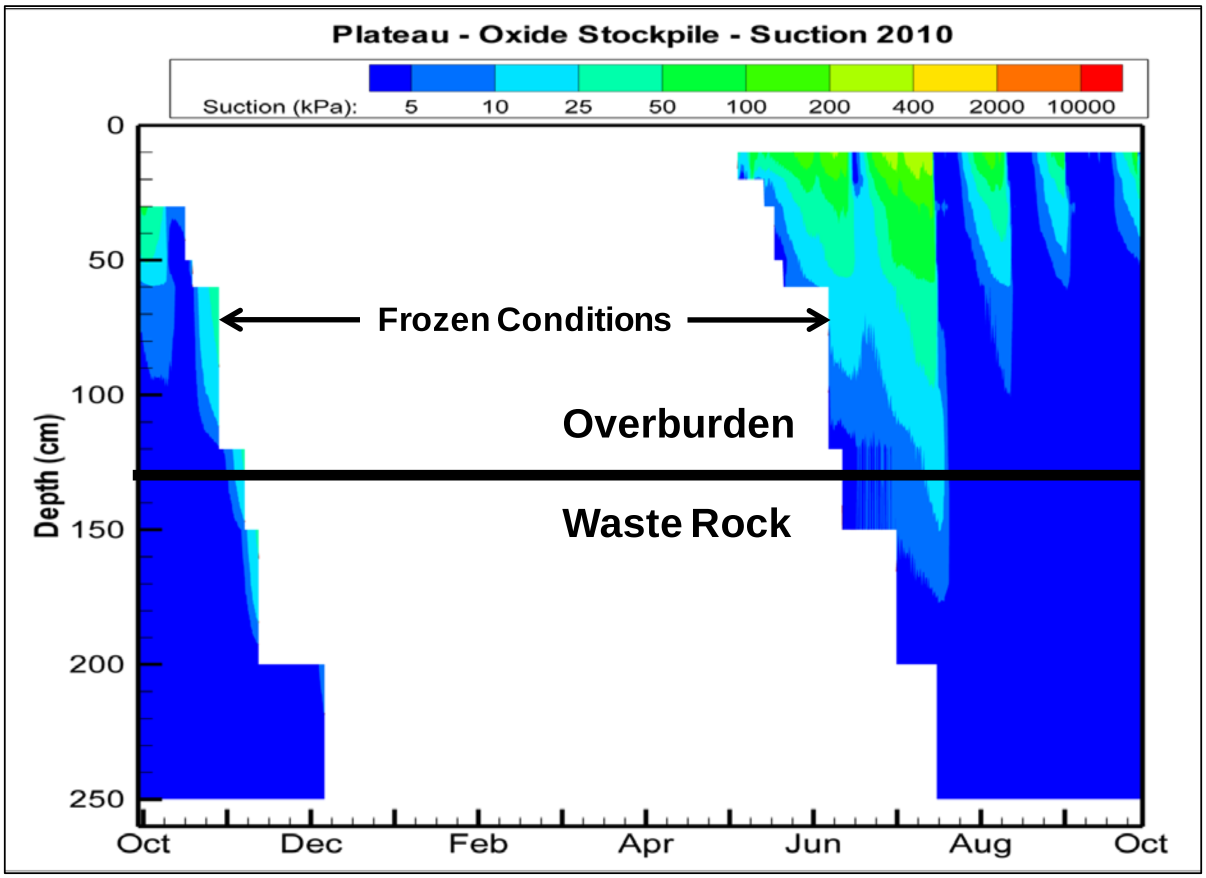

Figure 3.11 Matric suction measured within the overburden cover system and waste rock profile at Plateau station.

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 gradient became positive (indicating downward flow) immediately after spring thaw in mid-June 2010. The calculated gradient remained near 1 m/m until decreasing to a negative value (indicating upward flow gradient) in response to the drying period in June and July. 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 2010 at Plateau station.

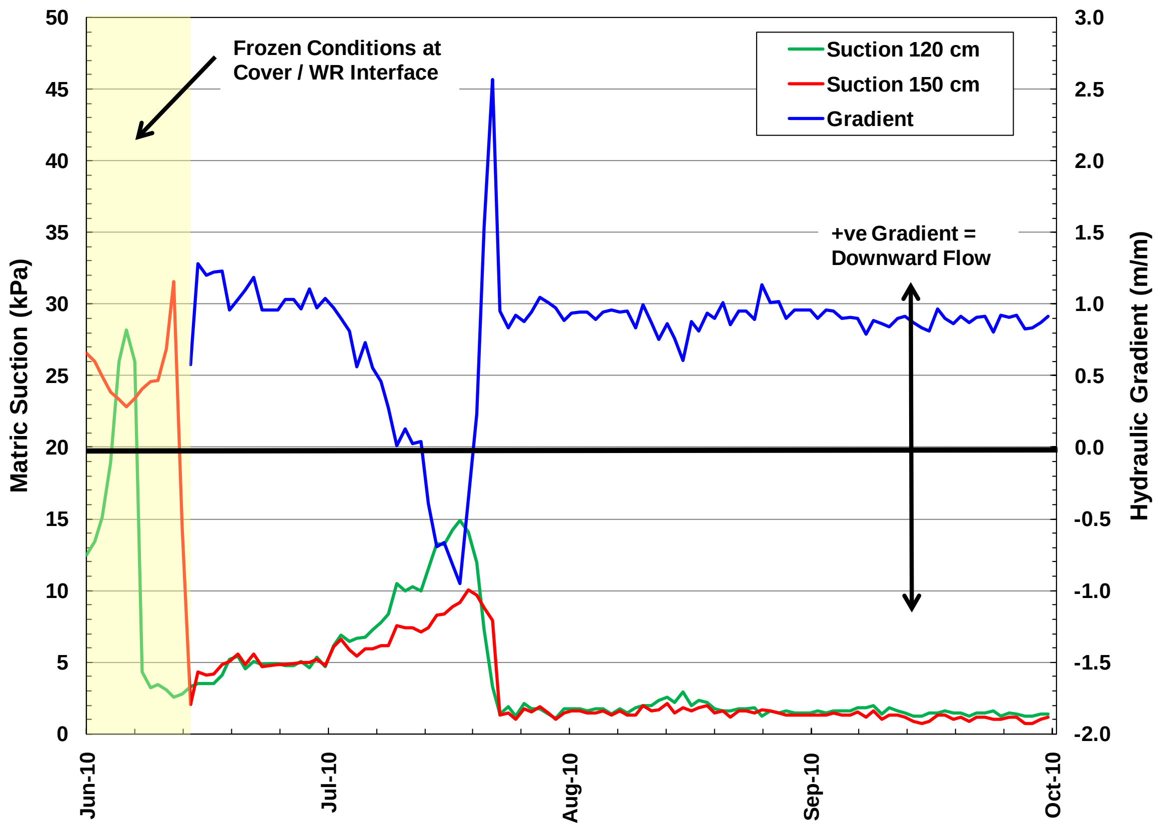

Figure 3.12 Matric suction measured at depths of 120 cm (overburden) and 150 cm (waste rock) and hydraulic gradient calculated at the overburden / waste rock interface at Plateau station.

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 was 1 m/m after the spring thaw, slowly decreased during the dry early spring and summer months, and increased to be consistently near 1 m/m for the remainder of the monitoring period. Hydraulic gradient at West station increased to a positive value in response to the mid-July rainfall events and slowly decreased back to zero for the remainder of the period, briefly interrupted by small increases due to subsequent rainfall events.

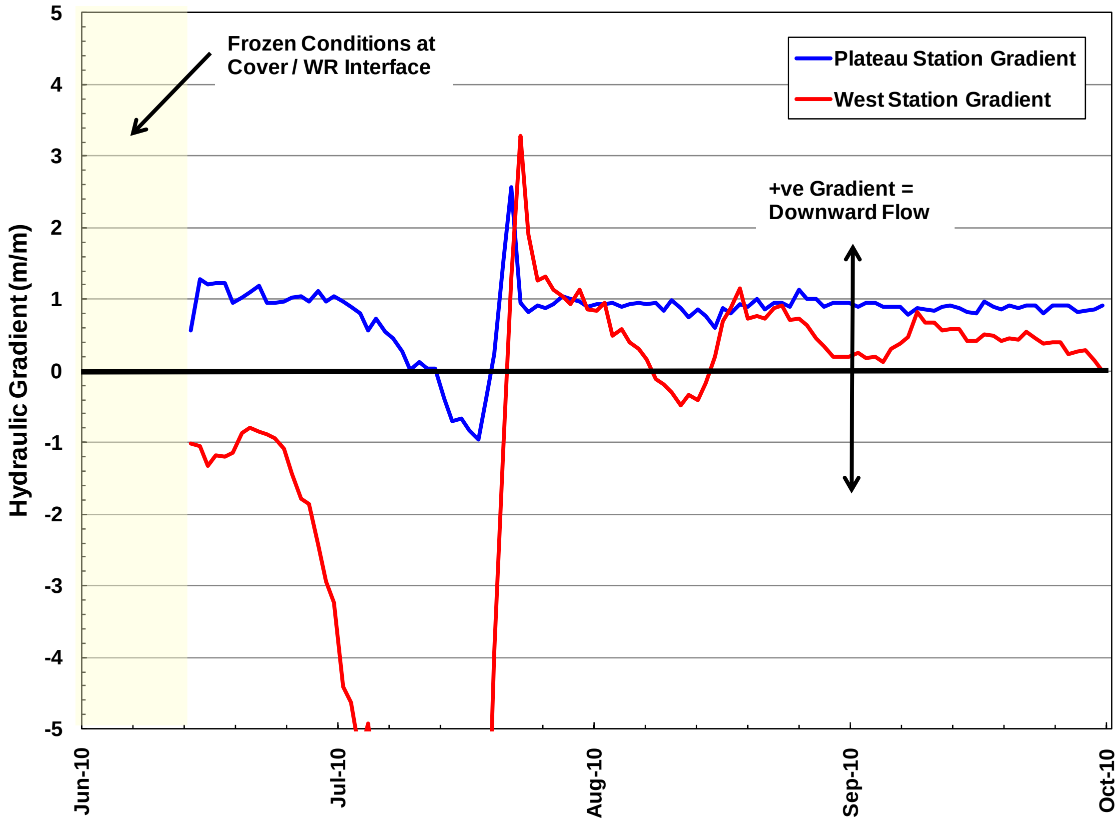

Figure 3.13 Hydraulic gradient calculated at the overburden / waste rock interface at the monitoring locations.

3.3.3 Net Percolation

Net percolation is measured by the automated monitoring system from the lysimeters installed at both Plateau and West stations. The large lysimeter tanks are underdrained to a 2 inch PVC pipe that leads into a monitoring hut on the East and West slopes of the Oxide Stockpile. An automated tipping bucket gauge provides measurement of the total volume of percolation that passes through the lysimeter, allowing an estimation of total net percolation.

The total net percolation measured at Plateau station was 1.4 inches (37 mm), which is approximately 11% of the 12.8 inches of precipitation recorded at the Airport weather station. The total net percolation at West station was 1.2 inches (31 mm) or 10% of total precipitation. These measurements are substantially less than measured in the 2008-09 field season and are attributed to the below-average rainfall conditions experienced at the site in 2010. Both lysimeter tipping buckets received maintenance during the August 2010 site visit to ready the stations for the 2011 field season.

3.4 Water Balance

A simple water balance was completed for the cover system field trials to quantify the volume of water percolating through the cover system in the 2009-10 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):

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

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 site with a weighing tipping bucket gauge to measure rainfall and snow water equivalent. 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 measured at the site but was estimated for the snowmelt and summer rainfall events. At the sloping West station, the initial snowmelt runoff coefficient was assumed to be 80% and the rainfall runoff coefficient increased with rainfall intensity but averaged approximately 15% for rainfall events greater than 5 mm. The assumed coefficients were lower at Plateau station due to its relatively flat surface; the snowmelt coefficient was 35% and the rainfall coefficient was 10%. The selected runoff coefficients are based on OKC's experience at sites with similar climates and slopes. The initial runoff coefficients were adjusted as required on a daily basis to complete the water balance.

Actual evapotranspiration (AET) was estimated based on rates of potential evaporation (PE) and climate data from the stations. Different ratios of AET to PE were applied during each month 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 much 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) was measured directly from the tank lysimeters and the timing and quantity passing the cover system / overburden interface (approximately 2 m above the base of the lysimeter tank) can be estimated based on water content and suction sensor data. Values were determined based on hydraulic head gradients at the base of the cover, as well as changes in moisture storage in 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. When the gradient was negative, there was an upward flux caused by evapotranspiration drawing water toward the surface. If the gradient was positive, indicating a downward flux, any loss of water in the lower layer of the cover profile was assumed to be net percolation.

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:

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

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 Plateau station, shown in Figure 3.14, 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 23 mm (0.9 inches) or approximately 8% of the total precipitation. The average AET/PE ratio for the monitoring location was 0.54 and the net percolation (measured from the tank lysimeter) for the 2009-10 period was approximately 37 mm (1.4 inches), or 11% of the 12.8 inches of total precipitation measured at the Airport station.

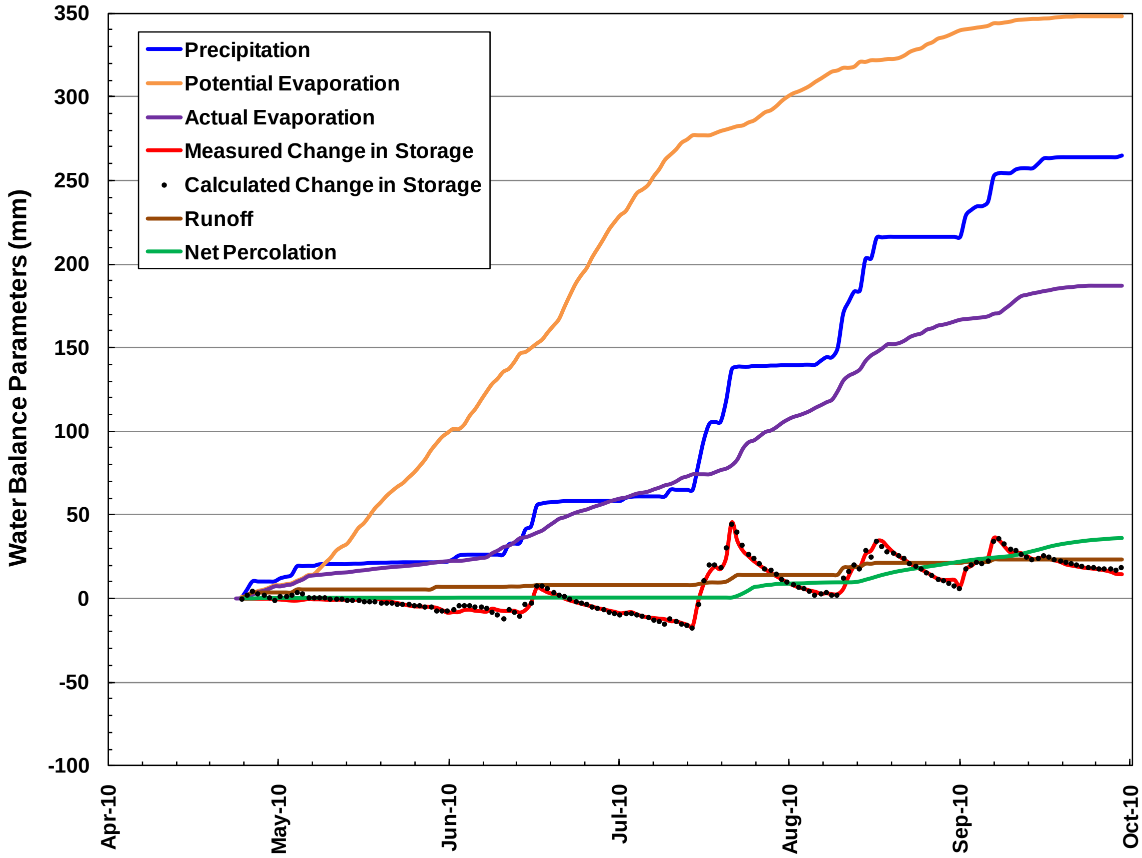

Figure 3.14 Cumulative water balance fluxes for Plateau station in the 2010 frost-free period.

The water balance completed for West station is shown in Figure 3.15. 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 at West station was greater than at Plateau station due to the increased SWE on West slope. The total runoff estimated for the slope (213 mm) was also greater than estimated for the plateau area due to the larger snowpack. The runoff co-efficient for spring snowmelt and summer rainfall was approximately 65% of total precipitation. The average AET/PE ratio for this monitoring location was 0.60, which is slightly higher than estimated at Plateau station due to the increased moisture in the cover profile due to the larger snowpack. The estimated net percolation for the 2009-10 period was approximately 31 mm (1.2 inches), or 10% of the 12.8 inches of total precipitation measured at the Airport station.

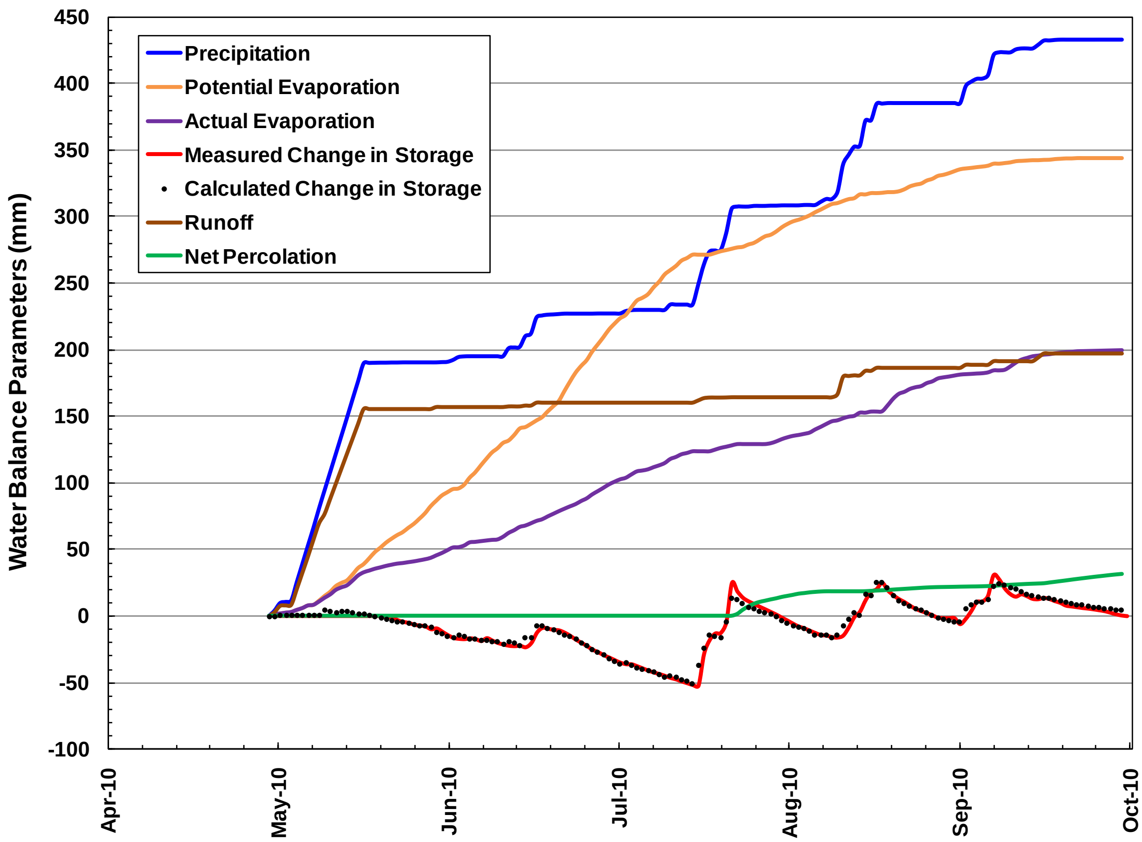

Figure 3.15 Cumulative water balance fluxes for West station in the 2010 frost-free period.

Table 3.1 summarizes the components of the water balance at Plateau and West stations. The difference between station precipitation and precipitation measured at the Airport station is represented by the loss or gain of water through snow sublimation and drifting. The percentages shown in the table are based on the Airport precipitation (325 mm).

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

Water Balance Parameter	Plateau Station	West Station
Precipitation (Airport Station)	325 mm (12.8 inches)	325 mm (12.8 inches)
Station Precipitation (Rainfall + SWE)	260 mm (10.2 inches)	452 mm (17.8 inches)
Loss / gain SWE (due to sublimation / drifting)	- 65 mm (-20%)	+ 127 mm (+39%)
Runoff	23 mm (8%)	213 mm (65%)
Actual Evaporation	187 mm (57%)	206 mm (63%)
Net Percolation	37 mm (11%)	31 mm (10%)
Change in Storage	18 mm (5%)	4 mm (1%)

3.5 Comparison of 2009-10 Period to Short-Term Monitoring Record

In order to characterize the performance of the cover systems in the 2009-10 monitoring period, it is useful to examine their response within the context of the short-term monitoring record from 2003-04 to 2009-10. Figure 3.16 presents the precipitation recorded in each monitoring period at the Airport weather station.

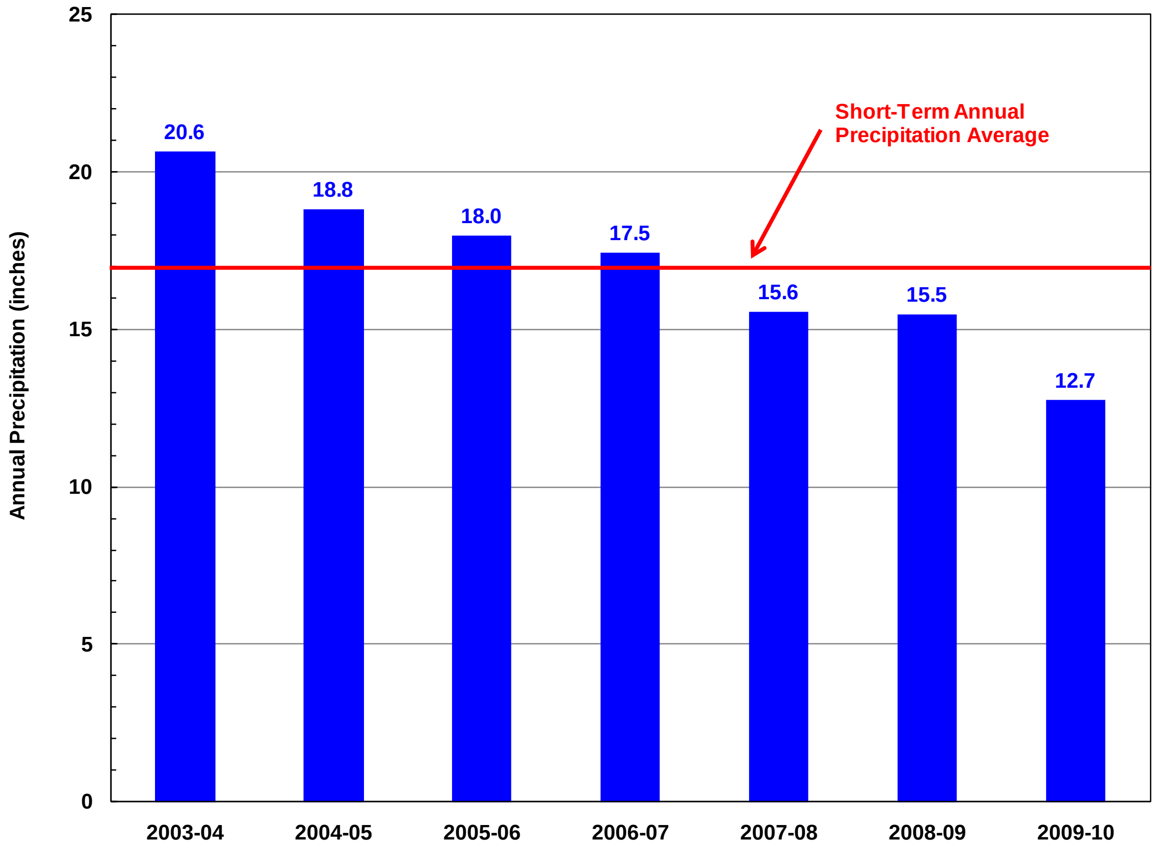

Figure 3.16 Rainfall recorded during each monitoring period since the onset of monitoring.

The 2009-10 period had the lowest total precipitation recorded in seven years of monitoring; therefore, it is not unexpected that net percolation rates as defined by automated measurements at Plateau and West stations and the water balance were approximately 10% of annual precipitation. In 2008-09, net percolation rates were approximately 17% and precipitation was closer to the short-term average. It is OKC's opinion that net percolation rates measured in 2009-10 represent the lower boundary of percolation rates anticipated for the Oxide stockpile cover system and net percolation will increase in future years if precipitation returns to average annual rates.

4 REFERENCES

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