# Surface Runoff Observations at Rock Covered Overburden Stockpiles and Implications to Hydrologic Modeling

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## Abstract

This study evaluated the changes in catchment response to progressive reclamation of the Upper Wanagon overburden stockpiles at the Grasberg Mine in Indonesia. Reclamation activities alter surface water runoff and accounting for these alterations in predictive runoff models is a challenge for the Upper Wanagon reclamation design. A runoff test plot was constructed to measure rainfall runoff response within the reclaimed area. A rainfall gauge and a surface water runoff flume have also been installed to provide measurements of stormwater response. This paper demonstrates how these data sources have been leveraged to inform hydrologic models and improve reclamation designs.

**Keywords:** Mine Reclamation, Stormwater, Hydrology, Drainage Design

## Introduction

The Upper Wanagon overburden stockpiles (UWOBS) are located at the Grasberg Mine in Indonesia at approximately 4000 meters above mean sea level within the Maoke Mountain range in Central Papua. The climate of this area is wet, with rain falling almost daily and a total annual precipitation average of approximately 4 meters. Average daily rainfall depths range between 9- and 16 millimetres per day and the largest daily rainfall depths generally occur between January and March. The topography is steep, and the geology is dominated by formations of karstic limestone.

The UWOBS occupy approximately 350 hectares and store overburden stockpile (OBS) material produced in the Grasberg open pit. Progressive reclamation of the stockpiles commenced when OBS placement ended in 2018. As of 2024, reclamation work has been completed for approximately 250 hectares. Fig. 1 illustrates the stockpiles prior to the beginning of reclamation in 2018 and as reclamation work has progressed through areas of the stockpiles in 2021 and 2024.

Reclamation includes regrading to direct surface runoff into engineered channels that are armored with riprap. The regraded OBS surfaces are capped with a rock cover consisting of blasted limestone rock and then vegetated. The rock cover is coarse gravel to boulder material with interstitial sands mined from a nearby limestone quarry. The rock cover thickness is 5 meters.

Hydrologic models were developed to characterize runoff during storm events to aid design of stormwater conveyance infrastructure and to evaluate erosional stability of the rock cover. The hydrology models were calibrated to simulate runoff events during large storms recorded prior to 2018 at a rainfall gauge and flow monitoring flume (locations shown in Fig. 1). Typically, calibration of a hydrologic model using locally recorded data increases confidence in the model's ability to predict runoff rates during the design storm events. This may not be the case for a reclamation site such as the UWOBS because the closure activity alters surface water runoff characteristics. For example, UWOBS regrading alters drainage pathways and removes surface depressions that store water which is likely to increase runoff. Further, the rock cover is more coarse and more permeable than the overburden material and the cover could increase rainfall losses, causing total runoff rates to decrease. Accounting for the influence of the closure activities in predictive runoff models is essential for a robust and cost-effective closure design.

### Test Plots

A reclamation test plot was constructed to aid understanding of the influence of the rock cover on surface water hydrology. The test plot was instrumented to measure the hydrologic response during design rainfall events. The test plot was constructed on a 2:1 slope where rock cover was installed over OBS fill. A base channel with a low permeability geosynthetic liner was installed to capture surface runoff. In addition, a perforated pipe underlain by a geosynthetic liner was installed below the rock cover (at the rock cover – OBS interface) near the base of the slope such

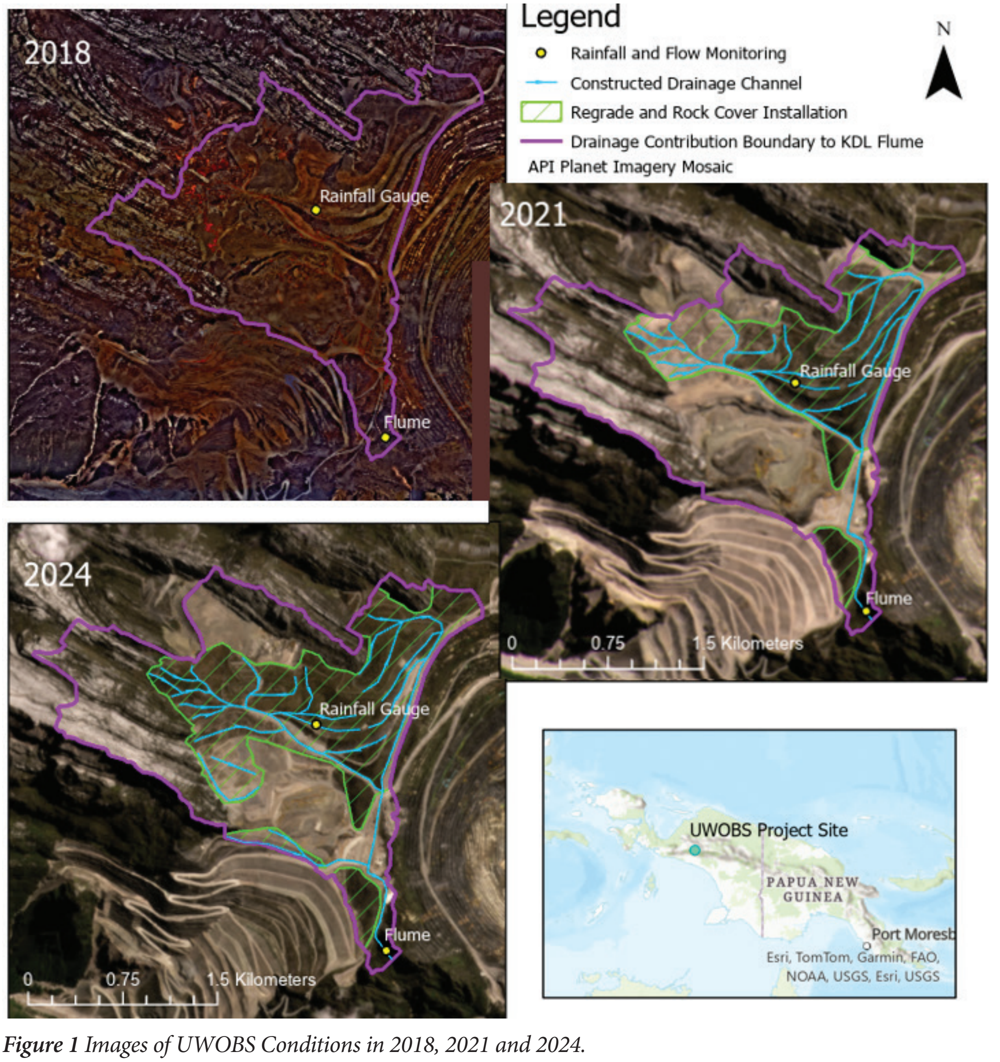


*Figure 1 Images of UWOBS Conditions in 2018, 2021 and 2024.*

that flow running along the rock cover – OBS interface also would be captured and measured. Flows from the base channel and the interface perforated pipe were directed to separate H-style flumes. Arrays of wobbler-type sprinklers were installed on the surface to simulate design rainfall intensities. Several pressure regulators were installed along the sprinkler delivery pipes so that the sprinkler spray would be uniformly distributed across the plot. Fig. 2 provides images of the test plot.

During testing, nearly zero runoff was observed on the rock cover surface even during the highest simulated intensity events (simulated rainfall intensity with an estimated annual exceedance probability 0.01). Runoff along the rock cover – OBS interface was observed and accounted for a substantial portion of the to total applied water during the highest simulated intensities (between 30% and 60%).

Based on these observations, a hydrologic conceptual model for the LWOBS area was hypothesized in which all precipitation infiltrates into the rock cover and, depending on the rainfall intensity, a portion of the infiltrated water is captured at the OBS surface beneath the rock cover and is re-expressed as surface water at the toe of the slope as illustrated in Fig. 3. Surface water is produced as accumulated flow along the rock cover - OBS interface saturates the rock cover layer.


***Figure 2** Test Plot Constructed to Simulate Runoff Response on Rock Covered Surface.*

## Rainfall and Runoff Observations

The UWOBS designers have continued to review rainfall and surface runoff measurements from the UWOBS area as reclamation work has been completed. The record extends from late 2013 (several years prior to the start of reclamation activities) and continues as reclamation work is completed. Fig. 4 provides a summary of average monthly flow rates measured at the KDL Flume and total monthly rainfall depths measured at the Rainfall Gauge.

Fig. 5 provides observations of daily average flow rates. Flow measurements shown using BLUE dots represent average daily flow measured below 650 L/s and RED dots represent daily average flow rates measured above. The data shown in Fig. 5 is summarized in Tab. 1.

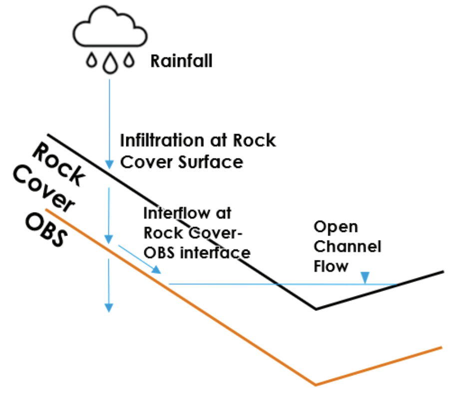


*Figure 3 Illustration of Conceptual Model for UWOBS Rainfall Runoff.*

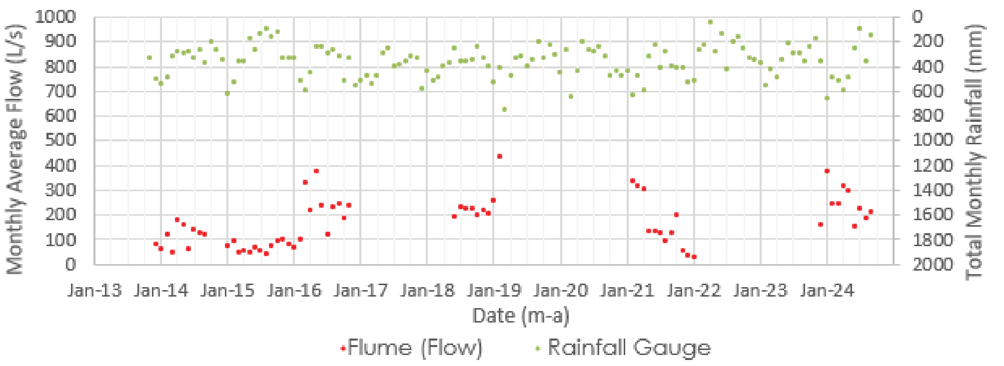


*Figure 4 Record of Average Monthly Flow Rate (Flume) and Monthly Total Rainfall Depths (Rainfall Gauge).*

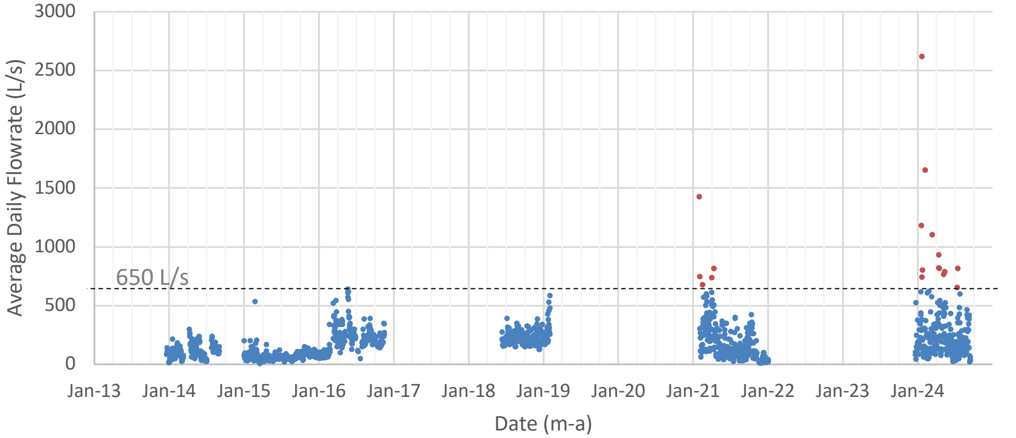


*Figure 5 Daily Average Daily Flow Rate at the Flume.*

*Table 1 Summary of Average Daily Flow Rate at the Flume.*

| Date Range | Days with Flow Measurements | Days with Average Measured Flow Greater than 650 L/s | Percent of Days with Average Measured Flow Greater than 650 L/s |
|---|---|---|---|
| 2013 through 2016 | 766 | 0 | 0.0% |
| 2018 through 2019 | 225 | 0 | 0.0% |
| 2021 through 2022 | 323 | 5 | 1.5% |
| 2023 through 2024 | 270 | 13 | 4.8% |

The monthly average flows show little change with time however, observations of the daily average flow rates show that the frequency of high daily flows (i.e. flow rates greater than 650 L/s) has increased as reclamation work has been completed. In fact, about 5% of the daily average flows recorded after significant reclamation had been completed between 2023 and 2024 are higher than the largest average daily flow recorded in the period prior to the start of reclamation and during the early reclamation period (i.e. prior to 2019).

The flume record and the observations from the test plot support a conceptual model where typical precipitation intensities are absorbed and attenuated within the rock cover material, resulting in a fairly constant long-term average flow rate through the flume. During rainfall events of relatively high intensity, a portion of the rainfall is captured on the OBS surface and accumulates as it runs downslope, eventually saturating the rock cover and surface water runoff is produced.

## Implications for Hydrologic Modeling

Stormwater hydrology models were updated to reflect the conceptual model. The most influential update was in characterizing the time for drainage runoff to accumulate at design points of interest (i.e. time of concentration). This was achieved in the model by estimating flow velocities within the interstitial voids of the rock cover material (Leps, 1973). The model estimates a contributing area at which the voids in the rock cover would saturate causing surface flow. Travel times below the estimated rock cover saturation point are estimated assuming surface flow velocity methods (e.g. Manning's equation).

Fig. 6 on the next page provides comparative results of observed runoff at the flume versus predicted runoff using the calibrated stormwater model during recorded rainfall events after reclamation work in areas of the LWOBS had been completed.

The calibrations results demonstrate the hydrology model's ability to reproduce observed runoff conditions during isolated rainfall events with elevated rainfall intensity. The modeled runoff peak times are within 30-minutes and the peak values are within 20% of the observed flow rate.

## Conclusions

Reclamation activities to regrade stockpiles and install a rock cover has affected the hydrologic response characteristics within the UWOBS area. Review of flow records presented herein suggest the affects can most clearly be observed by review of daily averaged runoff rates from the LWOBS area which have increased in correlation with progressing LWOBS reclamation. Insights to better understand these changes in site runoff patterns are provided by observations from a test plot constructed to study runoff characteristics on a rock covered slope. The test plot shows that high infiltration rates at the rock surface combined with interflow along the rock cover – OBS interface is the dominate flow path for the hydrologic response at the base of a reclaimed slope.

The information presented herein illustrates the importance of obtaining precipitation and runoff data for site-specific conditions. This study demonstrated how site-specific data can be leveraged to improve

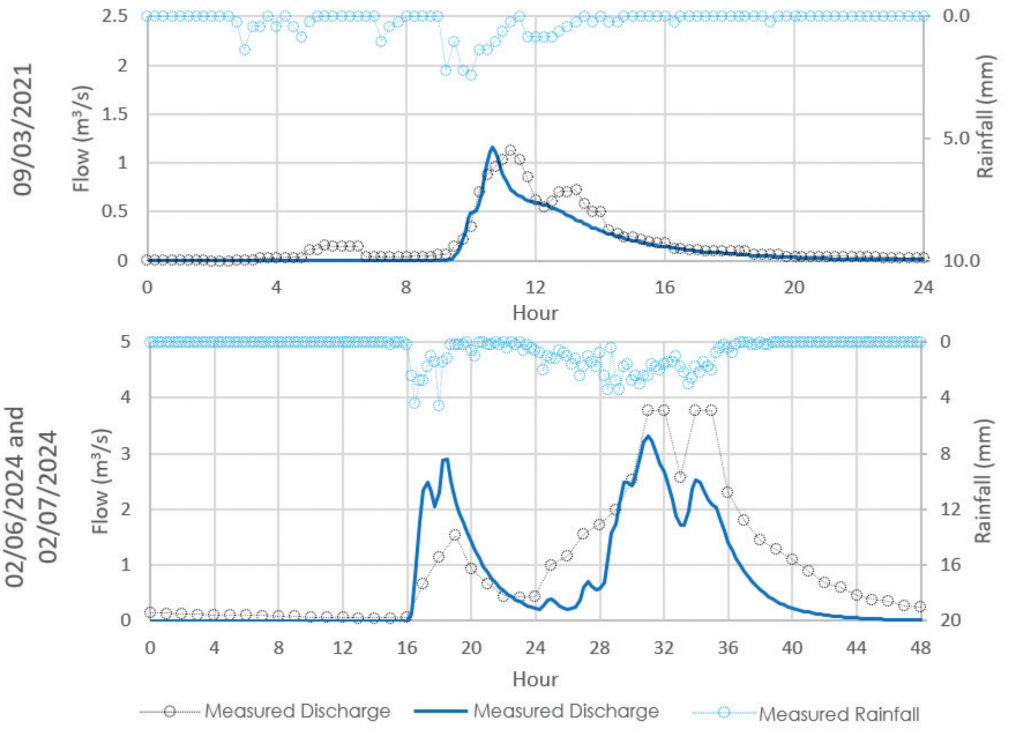


*Figure 6* *Stormwater Runoff Model Calibration Results during Rainfall Events in 2021 and 2024.*

hydrologic models and ultimately drainage design. The findings of this study are specific to the UWOBS reclamation but may be broadly relevant to reclamation design of mine facilities using a thick rock fill cover.

## References

Leps, T.M., "Flow through Rockfill." Embankment Dam Engineering, John Wiley and Sons, P. 87–107, 1973.