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Validation of the revised universal soil loss equation parameters based on aerial imagery of gully formation lengths: a case study in Central Queensland

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Abstract

Effective surface water management and erosion control are essential for long-term stability of rehabilitated mine landforms. However, there is limited site-specific guidance available for estimating appropriate erosion thresholds for rehabilitated landforms in Central Queensland. To address this gap, an assessment of erosion features (gullies) following a 3-year exposure period was undertaken to inform surface treatment and slope design strategies. This study investigated the relationship between the observed gully initiation threshold and predicted annual soil loss rate using the Revised Universal Soil Loss Equation (RUSLE). By analysing geospatial data and validating results with the RUSLE, the study refined critical landform design parameters. This approach utilised aerial imagery, lidar, GIS analysis and field measurements to estimate erosion loss rates. Key outcomes include site-validated maximum slope lengths prior to gully formation and the development of soil loss curves based on observed gully development. The findings emphasise the importance of integrating field observations into erosion estimation and surface water management practices. For example, measuring gully length offers a practical metric for validating slope design relative to gradient and water flow. This work aims to contribute to the development of an improved implementation of erosion management strategies that support sustainable land use and environmental protection.

Keywords: *mine rehabilitation, soil erosion, Revised Universal Soil Loss Equation, landform design, gully formation, lidar, GIS*

1 Introduction

Erosion assessment is critical to the design and long-term stability of rehabilitated mine landforms. Erosion can compromise landform performance through gully development, increased sediment transport and degradation of rehabilitation outcomes (Loch 2025). Recent guidance by the Office of the Queensland Mine Rehabilitation Commissioner emphasises incorporating field observations, site-specific conditions and engineering judgement to improve confidence in rehabilitation design (Hancock et al. 2025). However, estimating soil erosion at local catchment-scale presents some challenges because of the many different natural factors and their effect on how the landform behaves (Joshi 2018). This is further compounded by the limited data on parameters for specific regions and soil types. By leveraging geospatial data analysis, aerial imagery and field observations, this study seeks to refine the estimation of soil loss rates and subsequently better inform surface treatment design strategies.

The Revised Universal Soil Loss Equation (RUSLE) is widely used to estimate long-term average soil loss from sheet and rill erosion and has been adapted for application to rehabilitated mine landforms (Renard et al. 1997). The model combines rainfall erosivity, soil erodibility, slope geometry, vegetation cover and erosion control practices to estimate potential soil loss. However, confidence in model predictions depends on the selection of representative input parameters and validation against field observations. The RUSLE method is

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originally an agricultural tool that has long been used to estimate total soil loss rates on landforms (Hancock et al. 2019). It has been used for estimation of gully formation length to better predict long-term erosional stability on embankments. The findings provide a practical basis for refining contour drain spacing. Contour drains are shallow channels constructed across rehabilitated slopes to intercept and safely convey surface run-off before it accumulates sufficient volume and velocity to initiate erosion. By limiting the contributing flow length, contour drains reduce run-off concentration, decrease flow velocity and minimise the potential for rill and gully development (International Erosion Control Association (IECA) Australasia 2008).

2 Method

2.1 Study area

The study was undertaken on a recently reshaped landform at a mine site in Central Queensland. The assessment was completed approximately 3 years after landform reshaping following rainfall events that resulted in the development of 5 prominent erosion gullies. This time frame provided an opportunity to assess erosion during the early establishment phase, before vegetation cover had fully developed. Figure 1 shows the study area and the extent of the reshaped landform assessed.

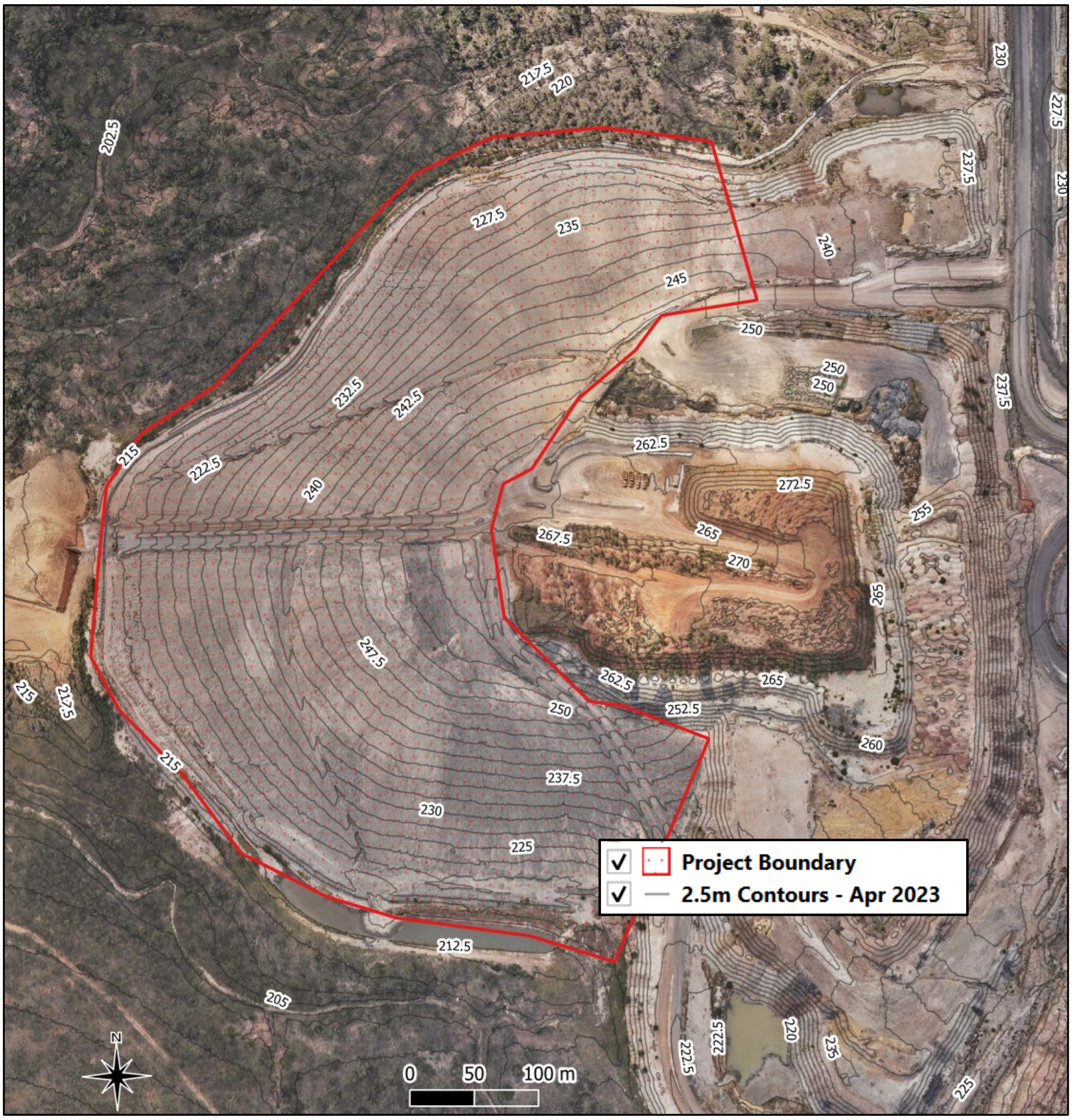

Figure 1 Aerial imagery of the study area

2.2 The Revised Universal Soil Loss Equation model

A first principles approach was adopted on current lidar and aerial imagery to obtain RUSLE model input parameters. The RUSLE model calculates soil erosion rate utilising the equation shown below (Rosewell & Loch 2002).

$$A = R*K*L*S*C*P \tag{1}$$

where:

A = average annual soil loss rate (t/ha/y)

R = average annual sum of erosion index (MJ mm/(ha.h.y))

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover management factor

P = support practice factor.

The rainfall-run-off erosivity factor, R, was derived from the rainfall pattern and intensity data of the area. It quantifies the effect of raindrop impact and the amount of run-off likely to be generated by a given rainfall event (Benavidez et al. 2018).

The slope length (L) and steepness (S) were obtained from aerial imagery and lidar in QGIS respectively. The corresponding LS factors were assigned using the look-up tables presented in the IECA Best Practice Erosion and Sediment Control Manual, which are based on the RUSLE (Renard et al. 1997; IECA Australasia 2008). They account for the effects of L and the gradient of the landform. Longer slopes with steeper grades tend to have higher soil loss rates due to the greater potential for water accumulation and increased velocity (Anjitha et al. 2019).

The cover management factor, C, which is representative of the effect of cropping and current management practices on the landform, was estimated as required after visual inspection of aerial imagery. Vegetative cover can significantly reduce soil erosion by protecting the soil surface from raindrop impact and reducing run-off velocity (Panagos et al. 2015).

The support practice factor, P, accounts for the influence of erosion control measures that modify run-off pathways and reduce erosion potential. The adopted value reflected the observed surface drainage conditions and erosion control measures present on the landform (Renard et al. 1997; Benavidez et al. 2018; Pan & Wen 2014).

The soil erodibility factor, K, which represents the inherent susceptibility of soil to detachment and transport by rainfall and run-off, was adopted from the nearest representative laboratory-tested soil sample. Soil erodibility is influenced by soil texture, structure, permeability and organic matter content (Rosewell & Loch 2002). The methodology adopted is illustrated in Figure 2.

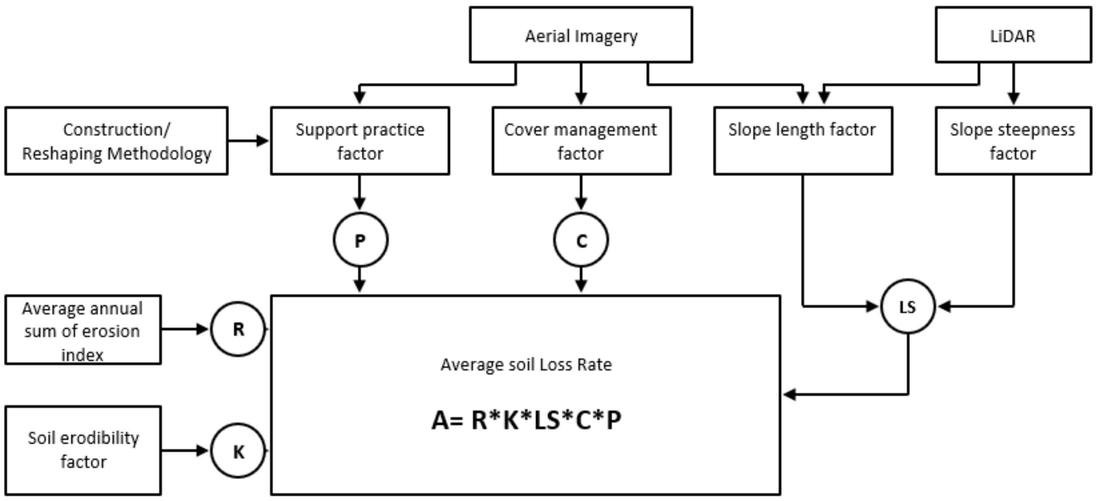

Figure 2 Flow chart showing the methodology adopted for this assessment

3 Model inputs

3.1 Vegetation cover, surface condition and soil erodibility

From observation, the estimated surface cover was 30% predominantly driven by large rock particles. The surface condition, from a visual inspection of the imagery, was observed as compacted and smooth. The nearest tested soil sample was approximately 2,000 m away and its soil erodibility factor (K = 0.026) was adopted. These inputs have been compiled and presented in Table 1.

Table 1 Revised universal soil loss equation (RUSLE) inputs of the soil erodibility factor (K), support practice factor (P) and cover management factor (C)

	Nearest soil sample		**Surface condition**		**Vegetation cover**	
	Observation	RUSLE input	Observation	RUSLE input	Observation	RUSLE input
Gully 1	Over 2,000 m away	K = 0.026	Compacted and smooth	P = 1.3	30% Grass canopy cover	C = 0.45
Gully 2						
Gully 3						
Gully 4						
Gully 5						

3.2 Slope length and upslope gradient

The S and L factors were obtained based on the varying upslope gradient and gully formation lengths as illustrated in the aerial imagery in Figure 3. The results are presented in Table 2.

The slope analysis results obtained from QGIS are shown in Figure 4. The slopes on the landform are generally greater than 10%. The corresponding upslope gradient at nominated locations as obtained from the profile tool are presented in Table 2.

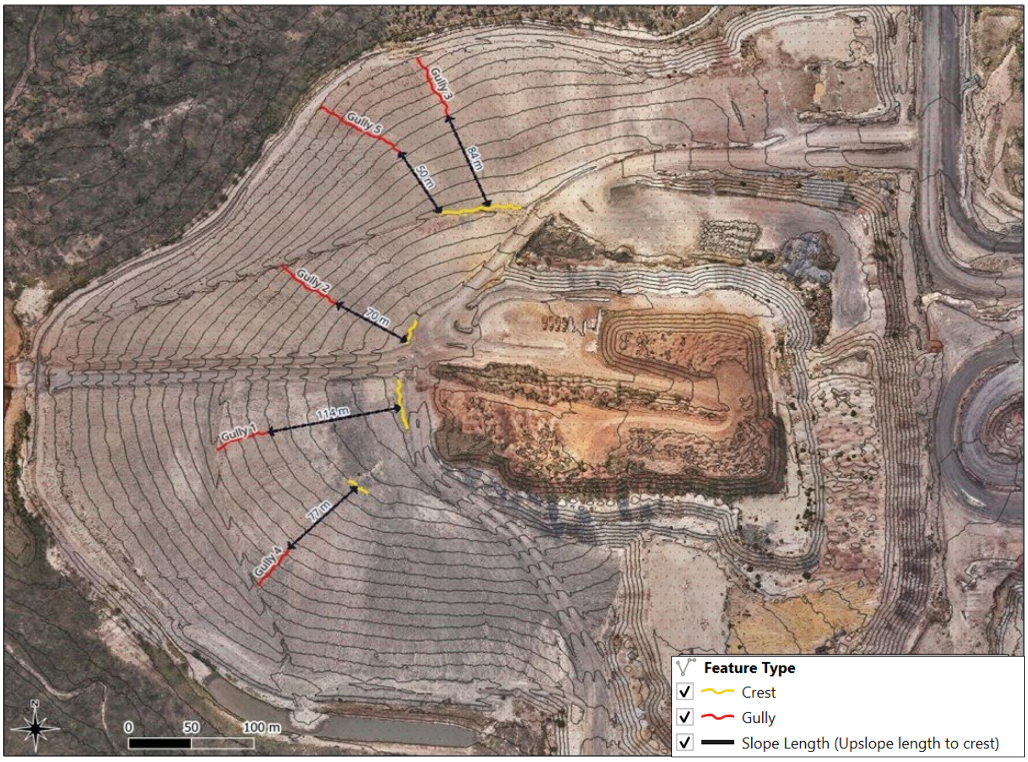

Figure 3 Aerial imagery showing selected gully locations and slope lengths

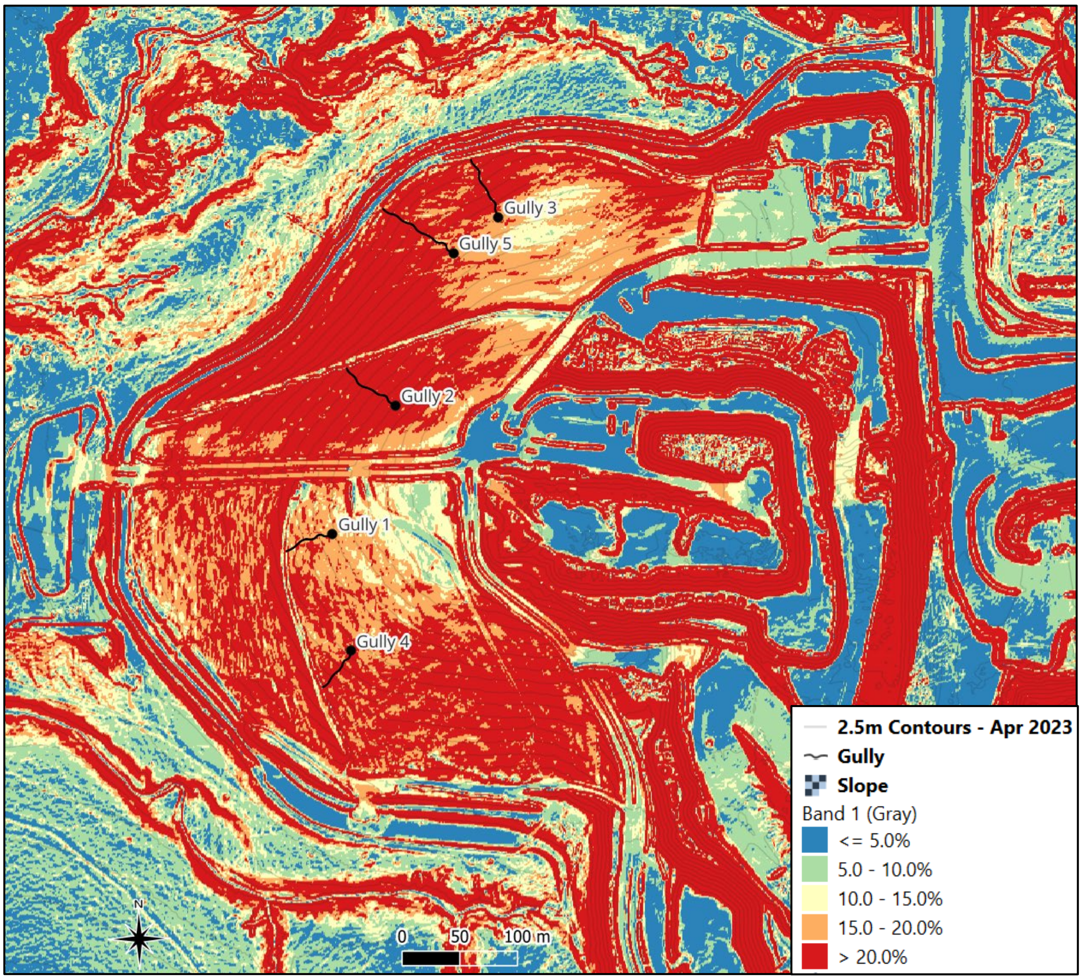

Figure 4 Slope grade analysis of the recently reshaped landform

Table 2 Revised Universal Soil Loss Equation (RUSLE) inputs for slope length (L) and steepness (S) factors

	Average upslope gradient (%)	Gully formation length (m)	RUSLE input, LS
Gully 1	14	114	3.52
Gully 2	19	70	4.14
Gully 3	17	84	4.04
Gully 4	18	77	5.31
Gully 5	20	50	4.42

4 Results

The results indicate that the annualised soil loss rate associated with observed gully initiation varied with upslope slope length. The 5 assessed gullies developed over slope lengths ranging from 50 to 114 m, with corresponding annualised soil loss rates ranging from 140 to 212 t/ha/y. For example, Gully 1 initiated after a slope length of 114 m with a predicted annualised soil loss of 140 t/ha/y, whereas Gully 2 initiated over 84 m at 160 t/ha/y. Similarly, gullies with slope lengths of 77, 70 and 50 m were associated with predicted soil loss rates of 165, 173 and 212 t/ha/y, respectively. This is illustrated in Figure 5.

Figure 5 Gully threshold erosion rate versus slope length

On the other hand, the soil loss rate increased with upslope gradient, as illustrated in Figure 6. Steeper slopes were associated with higher predicted soil loss. For example, a gully with an average slope grade of 14% was associated with a predicted annualised soil loss of 140 t/ha/year, whereas gullies with average slope grades of 17, 18, 19 and 20% were associated with progressively higher annualised soil loss rates of 160, 165, 173 and 212 t/ha/y, respectively. These observations indicate that gully initiation did not occur at a single annualised soil loss value across the landform.

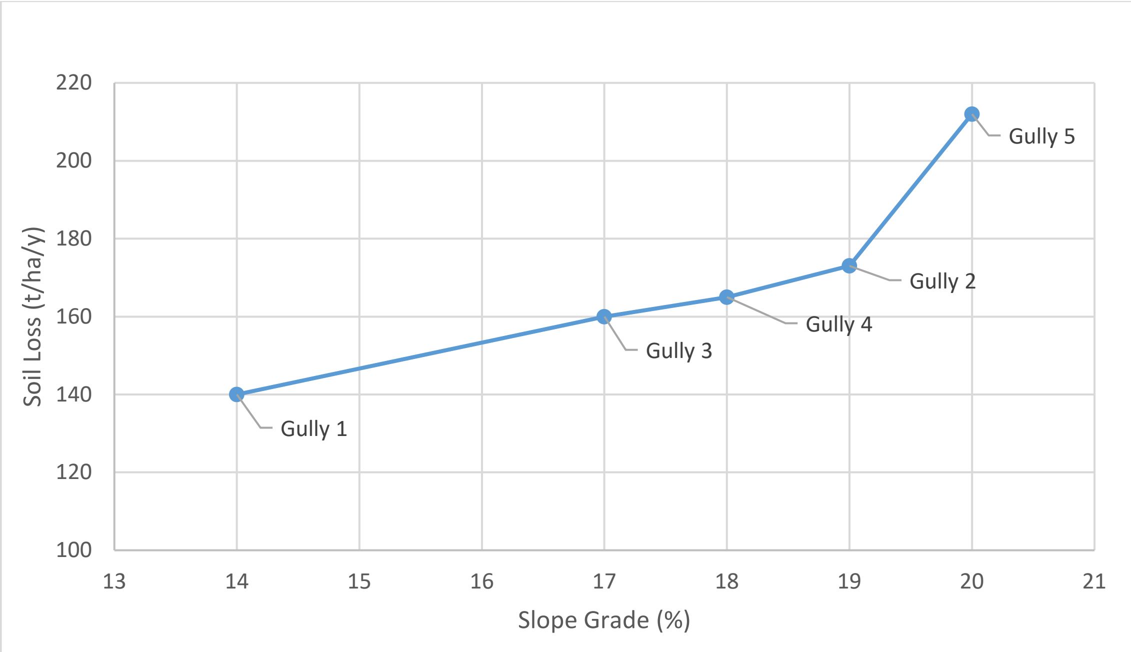

Figure 6 Gully threshold erosion versus slope gradient

Figure 7 illustrates the relationship between upslope gradient, observed gully formation length and the annualised soil loss associated with gully initiation for the 5 locations assessed. The results show that gully initiation occurred over a range of annualised soil loss rates rather than a single soil loss threshold across the entire landform.

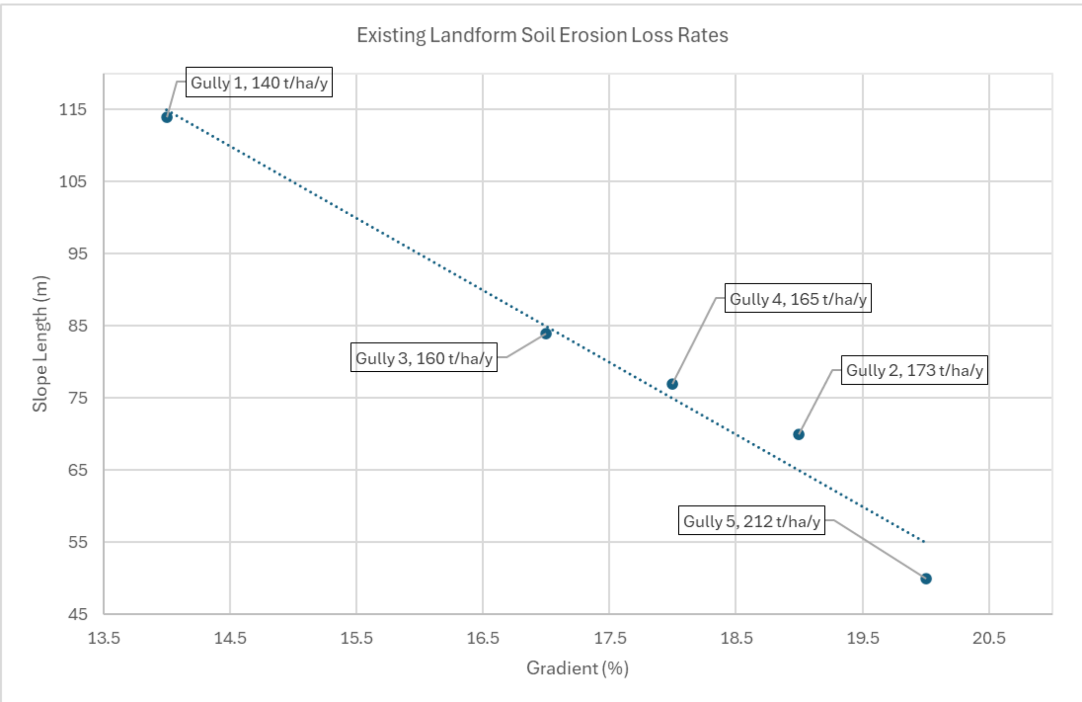

Figure 7 Validated soil loss rates

5 Discussion of results

The 5 gullies were considered representative of the most advanced erosion features present approximately 3 years after landform reshaping and therefore provided a conservative basis for evaluating gully formation lengths and corresponding RUSLE-predicted soil loss rates. Although smaller erosion features were present, the selected gullies represented the highest observed erosion response and provided a practical basis for assessing erosion conditions associated with gully formation.

The results indicated that the RUSLE-predicted soil loss rate associated with gully initiation varied with average slope grade and slope length across the landform. This finding supports the adoption of slope-specific contour drain spacing to manage erosion rather than applying a uniform spacing across the landform using a single generalised annual soil loss rate.

The integration of aerial imagery, lidar and GIS analysis with RUSLE provided a practical framework for comparing predicted soil loss with observed field conditions. While RUSLE estimates sheet and rill erosion rather than gully erosion, comparison with observed gully initiation provided confidence that the selected model parameters were representative of site conditions and suitable for informing landform design and landform management strategies.

6 Conclusion

This study assessed the relationship between observed gully formation lengths and RUSLE-predicted soil loss on a recently rehabilitated mine landform in Central Queensland. The assessment demonstrated that the annualised soil loss rate associated with the gully initiation threshold was not constant but varied with upslope gradient and slope length, indicating that the erosion conditions associated with gully initiation thresholds vary with landform geometry.

Integrating field observations with RUSLE provides a practical approach for refining model input parameters and improving confidence in erosion assessments for rehabilitated mine landforms. The methodology developed in this study offers a repeatable framework for supporting landform design, reducing erosion risk and improving long-term rehabilitation performance.

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