Developing a method to define land slope surface treatments to minimise scour erosion potential - a case study using RUSLE method.

Sharma, D[1]. & Curtis, M[2].

1. *Engeny Australia, Level 1/500 Queens St, Brisbane City QLD, 4000*
2. *Engeny Australia, Level 1/500 Queens St, Brisbane City QLD, 4000*

Abstract

Land management has been an important aspect of sustainable development and ecological conservation. Within the land management a huge focus is to find an effective solution to manage expected surface runoff intensities and concentration. Historically few practices were implemented to overcome this issue which involved utilising turfs or chutes as a surface treatment. However, these methods aimed at managing surface runoff often failing to meet the requirements of ecological restoration and the rehabilitation of the native ecosystems.

This study came from a need to predict the scour accurately and erosion impacts resulting from overbank in the context of mined landform rehabilitation. The focus has been on the first principles i.e., Revised Universal Soil Loss Equation (RUSLE) to examine the variables across diverse conditions of the landform. The outcome exhibits considerable improvements in predicting erosion pattern leading to sustainable management practices.

Keywords

RUSLE, erosion, surface treatment, sustainable management practices, rehabilitation, overbank flow

Introduction

The challenges of managing land to prevent or minimise erosion can be traced back to early times of agriculture. In both engineered and natural landscapes, erosion control has been a main aspect of land management (Morgan, 2005), (Trimble, 2013). The prediction of erosion is crucial for the development of mitigation strategies and effective environmental management. Currently, there are known practices that are used to manage the erosion on the mining sites which includes turf, hydromulching, constructing chutes drains. These practices manage the intense flows coming down the slope or concentrate the flows to a single point which then can be managed by the sediment control structures. Though these practices are used commonly in Australian mine sites, the outcomes are not the best for the ecological restoration or native ecosystem rehabilitation. Often these practices are implemented with no understanding of the surrounding landscape conditions.

Overbank flow refers to the phenomenon where water overflows the natural or artificial banks of the river or drain, causing flooding in the adjacent land areas. This is a significant factor in causing scour and gully erosion, which can lead to server environmental degradation. These processes can degrade the land, affecting vegetation establishment, infrastructure stability and ecosystem health (Pimentel & Burgess, 2013). A good understanding of upslope hydrology can help in understanding the overbank flows and help in implementing appropriate surface treatment to manage the flows.

This study is focused on re-arranging the RUSLE equation to predict the scour and erosion impacts resulting from the overbank flows, in the context of mined landform rehabilitation. The design objectives for rehabilitating these landforms are typically to recreate or mimic the surrounding natural landforms, where hydrological function is often complex. After thorough research of the landform and surrounding areas, RULSE, which is an empirical model, is used to predict the potential soil loss of an area in units of tones lost per hectare per year (Renard K. , Foster, Weesies, & Yoder, 1997). The equation is based on five (5) site specific factors:

A = R x K x LS x C X P – Equation 1 (IECA, 2008)

The five factors are considered major drivers of erosion and therefore used to calculate soil loss rate for a given catchment. This method is relevant for ecosystem services related to soil erosion and protection and is widely used in Australia to assess soil loss from landforms.

Understanding and managing the issues of erosion requires an understanding of the site-specific factors. The focus has been on understanding and improving the P, K and C factors through soil amendment and amelioration, with the slope length and gradient factor (LS) usually overlooked. This case study explores the accuracy of RUSLE in predicting soil loss and highlights the influence that the LS factor has on the sustainability and longevity of rehabilitated landforms (Hancock & Loch, 2000).

The practicable solution to predict and manage erosion is to accurately identify the cause and implement better surface treatments which are tailored to the site-specific. It is known that there are not enough methodologies to define the quantity and scour depth expected on the land slopes, however the aim of this study is to predict erosion to better inform surface treatment designs for the rehabilitation landforms.

Data Review

Industry Standard Review

A comprehensive review of industry standards revealed the RUSLE as a robust model for predicting soil erosion. RUSLE is an advancement of the Universal Soil Loss Equation (USLE), developed in 1960s by the United States Department of Agriculture (USDA). The original USLE was designed to predict long-term average annual soil loss due to rainfall and associated runoff on agriculture fields. RUSLE was developed in 1960s, enhanced USLE by incorporating more complex interactions of various factors and updated databases, making it applicable to a broader range of environments and land uses (Renard K. G., Foster, Weesies, McCool, & & Yoder, 1997).

Components of RUSLE

RUSLE estimates soil erosion using the equation:

A=R x K x LS x C x P x A

where:

- **A** is the estimated average annual soil loss (tons per acre per year).
- **R** (Rainfall Erosivity Factor): Quantifies the effect of raindrop impact and the amount of runoff likely to occur, based on rainfall intensity and duration.
- **K** (Soil Erodibility Factor): Represents the susceptibility of soil particles to detachment and transport by rainfall and runoff, influenced by soil texture, structure, organic matter, and permeability.

- **LS** (Slope Length and Steepness Factor): Accounts for the topographical influence on erosion, with longer and steeper slopes increasing soil loss.
- **C** (Cover-Management Factor): Reflects the effect of cropping and management practices on soil erosion rates, with values varying significantly based on vegetation cover, crop type, and tillage practices.
- **P** (Support Practice Factor): Considers the impact of practices such as contouring, strip cropping, and terracing on reducing erosion.

The Revised Universal Soil Loss Equation (RUSLE) has several strengths that contribute to its widespread utilisation in soil erosion prediction and management. Its versatility is a significant advantage, allowing it to be applied across diverse environments such as agricultural fields, forests, rangelands, and disturbed sites. The user-friendly nature of RUSLE, with straightforward data requirements, makes it accessible to a broad audience, including farmers, engineers, and environmental planners. Additionally, RUSLE is supported by a comprehensive empirical database, which enhances the accuracy of its predictions across various regions and conditions. This database is continuously updated to incorporate new research findings and improved data, ensuring the model remains current and reliable. Moreover, RUSLE's adaptability is evident in its ability to integrate new information and technological advancements, maintaining its relevance in evolving environmental contexts. These strengths collectively make RUSLE a valuable tool for effective soil conservation and land management practices.

However, despite these strengths, RUSLE has its limitations. Its empirical nature means it does not capture all the complexities of erosion processes, particularly in heterogeneous landscapes. Accurate predictions require detailed input data, which may not always be available, especially in recently disturbed landforms or new development areas. Furthermore, RUSLE primarily predicts sheet and rill erosion, limiting its applicability in addressing gully, streambank, and wind erosion. These limitations highlight the need for ongoing refinement and adaptation to ensure the model remains effective in various environmental and land management scenarios.

Case Study

This study is focused on re-arranging RUSLE to more precisely predict the annual soil loss rate from a specific landform catchment. There are two approaches discussed and elaborated in the sections below, presenting the methodologies, findings and implications of each approach.

Desktop Analysis

The desktop analysis involves using existing geographical and climatic data, along with the digital terrain models, to estimate soil loss. This approach relies on remote sensing and Geographic Information System (GIS) tool to gather and analyse data, providing a broad overview of the catchment's erosion potential.

Methodology

A practical example is provided below. In this assessment, annual soil loss target of 20t/ha/yr is established as a tolerable limit for the landform. The factors influencing soil erosion, such as R (rainfall erosivity), K (soil erodibility), and P (support practices), are estimated based on the specific conditions of the site. This approach is particularly relevant for slopes > 9%.

Rainfall Erosivity (R-factor)

The R-factor, representing annual rainfall erosivity, can be selected from Table E1 or Table E2 provided by the International Erosion Control Association (IECA, 2008), or calculated using the following formula:

$R = 164.74(1.1177)^{S} S^{0.6444}$ (Rosewell & Turner, Rainfall erosivity in New South Wales, 1992)

S is the slope steepness (Rosewell & Turner, 1992).

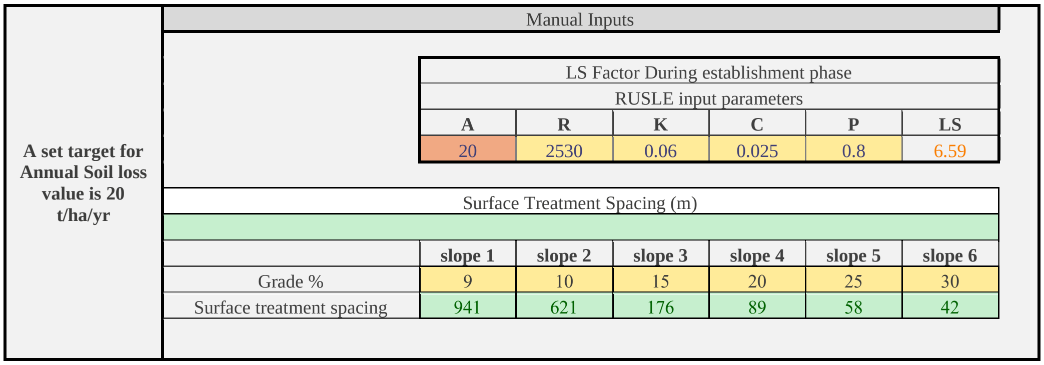
Soil Erodibility (k-factor)

K-factor is the numeric values representing the soil's ability to resist the erosive energy of rain (IECA, 2008). This value is derived through soil sampling and laboratory analysis, however if the soil chemistry and physical properties are known, k-value can be estimated (Rosewell & Loch, Estimation of the RUSLE Soil Erodibility Factor, 2002).

Support Practices (P-factor)

The P-factor accounts for the effects of various support practices and management strategies implemented on the landform to reduce soil erosion. This includes practices such as contouring, ripping, compacting, and other soil conservation techniques. The appropriate P-factor value can be selected from the standardized Table E11 (IECA, 2008).

By integrating these factors into the RUSLE model, the desktop analysis provides a robust estimation of soil loss for the catchment areas. This method is essential for preliminary assessment and planning which assists in identifying high-risk areas and implementing targeted soil conservation measures.



Manual Inputs

A set target for Annual Soil loss value is 20 t/ha/yr

LS Factor During establishment phase

RUSLE input parameters

A	R	K	C	P	LS
20	2530	0.06	0.025	0.8	6.59

Surface Treatment Spacing (m)

	slope 1	slope 2	slope 3	slope 4	slope 5	slope 6
Grade %	9	10	15	20	25	30
Surface treatment spacing	941	621	176	89	58	42

Figure 1 LS factor estimation through RUSLE to identify surface treatment – Desktop Analysis

Result explanation

As the slope becomes steeper, the potential for soil erosion increases due to the higher velocity of the surface runoff and the increased erosive force exerted by rainfall. Therefore, to reduce the erosion risk, it is essential to implement soil conservation measures more densely. These strategies may include contour drains, chutes, coir logs, and other erosion control structures that need to be constructed closer together on the steeper slopes.

Practical implications

In the context of a desktop analysis using the RUSLE model, when assessing a landform with varying slope gradients, the calculated LS factor (a combination of slope length and steepness) will be higher for steeper slopes. Consequently, to meet a tolerable soil loss target of 20 t/ha/yr, the spacing of contour drains or similar surface treatments must be reduced. This ensures that the increased erosive energy on steeper slopes is adequately managed.

Importance of Accurate Factor Estimation

Accurate estimation of the R, K, and P factors is important in this process:

R-Factor (Rainfall Erosivity): A higher R-factor on steeper slopes means more frequent and intense rainfall events, which increases the need for closer spacing of erosion control measures.

K-Factor (Soil Erodibility): Steeper slopes often correlate with specific soil types that may be more prone to erosion, necessitating more frequent interventions.

P-Factor (Support Practices): Implementing effective support practices like contouring and terracing is more critical on steeper slopes, and their effectiveness must be reflected in the chosen P-factor.

In-situ Analysis

This analysis aims to assess the current soil loss rate of a specific landform to determine necessary erosion control measures. The desktop assessment sets an annual soil loss rate target, proposing controls to achieve this target. If the implementation of these controls is not feasible, the actual soil loss rate under existing conditions is documented.

Case-study

A specific steep area was selected for detailed assessment which seems to be forming gully erosion. The following data and factors were used to calculate the actual annual soil loss rate from this catchment.

Rainfall Erosivity (R-factor) is used as above.

Soil Erodibility (k-factor) is used as above.

Support Practices (P-factor) is used as above.

Slope length and steepness (LS-factor), combines the slope length and gradient to quantify the impact on erosion. For this specific landform, with a 16% slope gradient and 150m slope length, the LS factor of 8.78 was selected from the Table E3 -Slope-length, LS-factors for RUSLE (IECA, 2008).

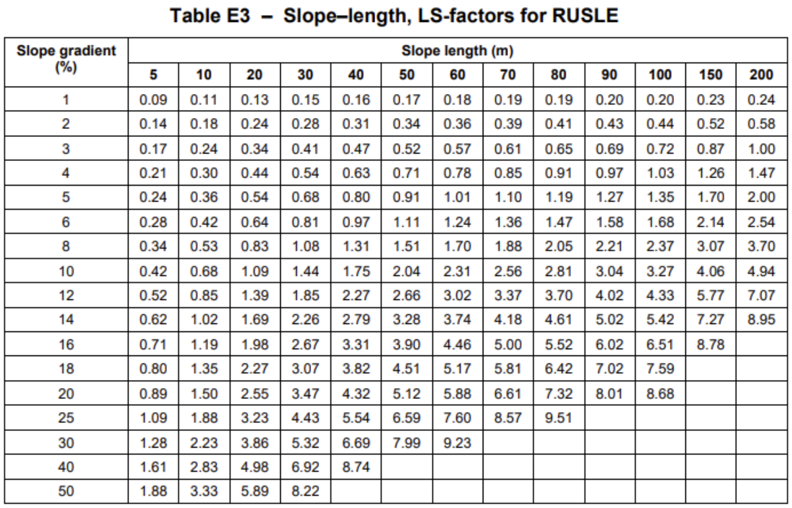
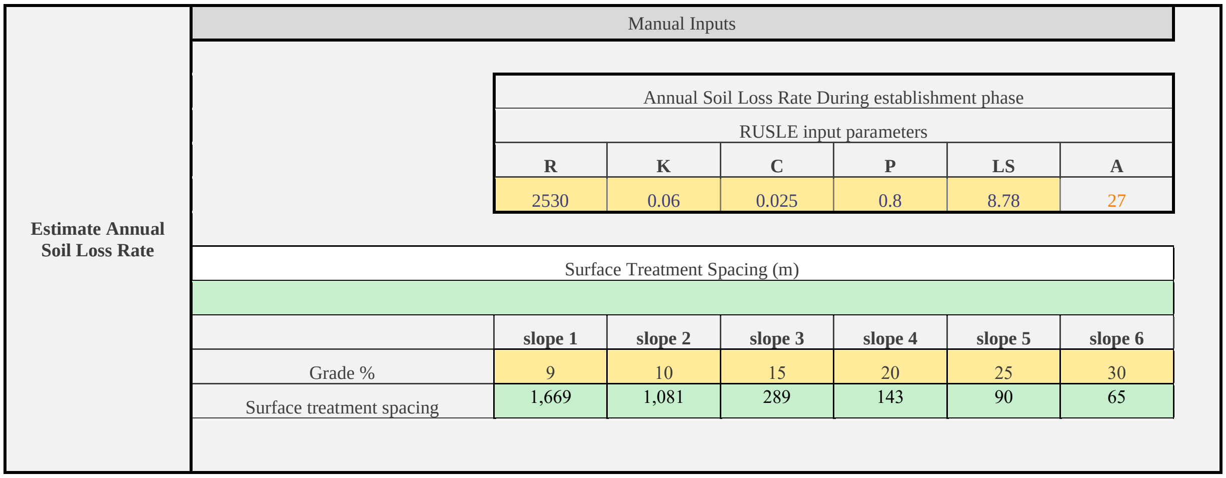


Table E3 – Slope–length, LS-factors for RUSLE

Slope gradient (%)	Slope length (m)												
	5	10	20	30	40	50	60	70	80	90	100	150	200
1	0.09	0.11	0.13	0.15	0.16	0.17	0.18	0.19	0.19	0.20	0.20	0.23	0.24
2	0.14	0.18	0.24	0.28	0.31	0.34	0.36	0.39	0.41	0.43	0.44	0.52	0.58
3	0.17	0.24	0.34	0.41	0.47	0.52	0.57	0.61	0.65	0.69	0.72	0.87	1.00
4	0.21	0.30	0.44	0.54	0.63	0.71	0.78	0.85	0.91	0.97	1.03	1.26	1.47
5	0.24	0.36	0.54	0.68	0.80	0.91	1.01	1.10	1.19	1.27	1.35	1.70	2.00
6	0.28	0.42	0.64	0.81	0.97	1.11	1.24	1.36	1.47	1.58	1.68	2.14	2.54
8	0.34	0.53	0.83	1.08	1.31	1.51	1.70	1.88	2.05	2.21	2.37	3.07	3.70
10	0.42	0.68	1.09	1.44	1.75	2.04	2.31	2.56	2.81	3.04	3.27	4.06	4.94
12	0.52	0.85	1.39	1.85	2.27	2.66	3.02	3.37	3.70	4.02	4.33	5.77	7.07
14	0.62	1.02	1.69	2.26	2.79	3.28	3.74	4.18	4.61	5.02	5.42	7.27	8.95
16	0.71	1.19	1.98	2.67	3.31	3.90	4.46	5.00	5.52	6.02	6.51	8.78	
18	0.80	1.35	2.27	3.07	3.82	4.51	5.17	5.81	6.42	7.02	7.59		
20	0.89	1.50	2.55	3.47	4.32	5.12	5.88	6.61	7.32	8.01	8.68		
25	1.09	1.88	3.23	4.43	5.54	6.59	7.60	8.57	9.51				
30	1.28	2.23	3.86	5.32	6.69	7.99	9.23						
40	1.61	2.83	4.98	6.92	8.74								
50	1.88	3.33	5.89	8.22									

Figure 2 Slope Gradient, Slope Length, LS-factors for RUSLE (IECA, 2008)



Estimate Annual Soil Loss Rate

Manual Inputs

Annual Soil Loss Rate During establishment phase

RUSLE input parameters

R	K	C	P	LS	A
2530	0.06	0.025	0.8	8.78	27

Surface Treatment Spacing (m)

	slope 1	slope 2	slope 3	slope 4	slope 5	slope 6
Grade %	9	10	15	20	25	30
Surface treatment spacing	1,669	1,081	289	143	90	65

Figure 3 Annual soil loss rate estimation to identify surface treatment – in-situ Analysis

Analysis and Results

The results imply that the current soil loss rate for the assessed landform is 27 t/ha/yr. This rate exceeds the initially targeted rate of 20 t/ha/yr, indicating significant erosion issues that required immediate attention.

Due to the higher observed soil loss rate, the implementation of surface treatments becomes even more critical. The increased tolerance for soil loss provides some flexibility in applying these treatments. For instance, instead of introducing controls every 58m on a landform with 25% slope, controls can now be spaced every 90m.

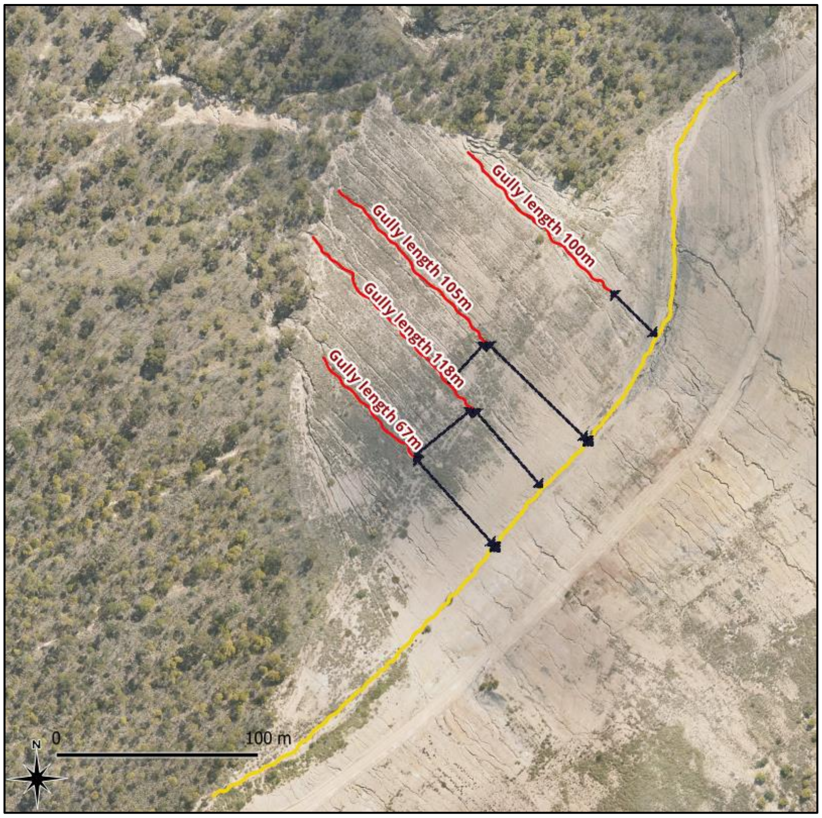


Figure 4 Visual assessment of existing gully erosion through aerial image

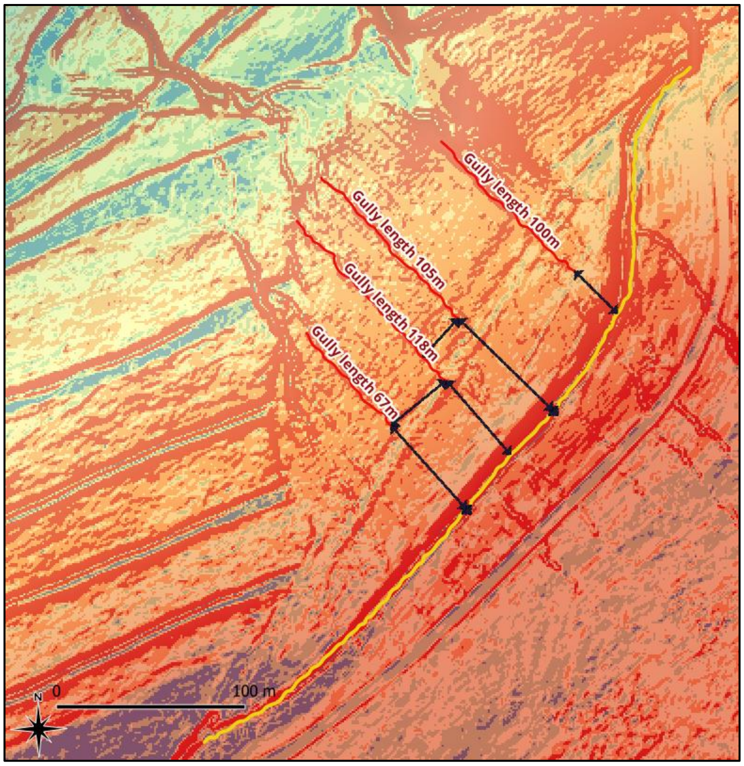


Figure 5 Slope assessment of the landform

Practical Implications

Surface treatment implications: With an actual soil loss rate of 27 t/ha/yr, there is still an increased urgency to implement surface treatments such as contour drains, chutes, and terracing. These interventions need to be applied more frequently and strategically across the landform to mitigate erosion effectively.

Vegetation establishment: the higher soil loss rate affords some flexibility to implement erosion control measures at certain spacing while allowing time for vegetation to establish. Vegetative cover is crucial for long-term erosion control, as it reduces the impact of raindrops on the soil surface and enhances soil stability through root systems.

Importance of this Analysis

Accurate Assessment: By accurately determining the current soil loss rate, the analysis provides a clear picture of the severity of soil erosion on the landform. This information is essential for designing effective erosion control measures.

Informed Decision-Making: The results inform the necessity and urgency of implementing surface treatments. With precise data on soil loss rates, they can prioritise areas for intervention and allocate resources efficiently.

Tailored Erosion Control Measures: Understanding the specific contributions of slope length and steepness (LS factor) allows for the design of tailored erosion control measures. These measures can be more effective in mitigating erosion by addressing the primary factors driving soil loss.

Long-Term Sustainability: Implementing surface treatments while vegetation establishes ensures that the landform remains stable in the short term, while also promoting long-term sustainability through natural vegetation growth. This dual approach enhances the resilience of the landform against future erosion.

Further Discussion

Potential discussion points:

Soil Amendment / Amelioration (Changing the K-Factor)

Lack of Quantitative Data: There is a significant gap in quantitative data demonstrating improvements in other RUSLE factors when soil amendments are applied. Progressively testing the landform for soil data helps in understanding soil better. This can help optimise the controls and provide site-specific measures.

Changing the P-Factor

Large-Scale Implementation Challenges: Adjusting the P-factor, which involves implementing various support practices like contouring, strip cropping, and terracing, can be difficult to achieve on a large scale. The logistical and operational challenges associated with widespread adoption of these practices need careful planning and resource allocation.

Earthworks Solutions

Ease of Application: Earthworks solutions, such as constructing contour drains and chutes, are generally easier to implement, especially in engineered settings where scour and erosion are prevalent. These solutions provide immediate physical barriers to erosion and can be designed and deployed relatively quickly.

Integrated Approach

Combining Factors for Best Results: For optimal erosion control, it is crucial to use surface treatments in conjunction with improvements in other RUSLE factors. An integrated approach that addresses rainfall erosivity (R-factor), soil erodibility (K-factor), slope length and steepness (LS-factor), and support practices (P-factor) will yield the best results in mitigating soil loss.

Use of model/software

Software tools such as Geographic Information Systems (GIS) can be employed to calculate soil loss rates on a cell-by-cell basis across a landform. This granular approach can significantly enhance the accuracy and effectiveness of erosion management strategies, especially when dealing with large-scale landforms characterized by diverse slopes, lengths, practice factors (P-factor), and soil erodibility factors (K-factor). The model results will provide precision, accuracy, visual analysis, data integration and allow for handling variability.

Acknowledgments

We would like to express our sincere gratitude to the Closure and Remediation team at Engeny for providing the opportunity and resources necessary to conduct this study. Special thanks to Matt Curtis for his invaluable supervision, guidance, and support throughout this project. His expertise and insights were instrumental in the successful completion of this work.

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