



METHODS FOR TESTING EROSION THRESHOLD VELOCITY (ETV)

METHOD 2 – DIRECT LABORATORY-BASED ETV TESTING

Inland Rail Pty Ltd

April 2025

O-0080-900-IHY-00-PR-0002

Revision 1



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PREFACE

Landloch Pty Ltd has developed a procedure by which large undisturbed surface soils samples can be collected and subjected to overland flows in a laboratory setting, with the outcome being the generation of a dataset from which Erosion Threshold Velocity (ETV) values can be determined.

This document outlines the method for the determination of the critical shear stress for initiation of erosion scour and the associated ETV for a range of slope gradients. The method was originally developed in August 2023 and used for 10 sites in southern NSW to demonstrate that ETV values could be measured within a laboratory setting. This document was independently reviewed by Dr William (Bill) Elliot in 2023 and revised based on the review comments and the experience gained from the initial work, and assigned Revision A within IRPL's document management system.

Revision A of the document was further reviewed by two independent reviewers, Dr William (Bill) Elliot and Dr Malcolm Gillies. A synthesis of their reviews was produced by Dr Elliot and is given as Appendix A to this document, along with the review from Dr Gillies. The synthesis of the reviews found that...

"The procedures described in the methods report are reasonable and widely used by the scientific community. The report is well written with only minor editorial or grammatical concerns".

"The method of on-site soil sampling described to Gillies and Foley, and the soil sampling apparatus are robust, and the novelty is to be applauded. The method is a technically sound process that will capture representative large samples of the soil surface conditions from many sites."

"...the testing methodology used by Landloch to establish the erosion threshold velocities for soils along the Inland Rail corridor is generally sound and robust. The methodology is scientifically defensible for determining critical shears and erosion threshold velocities. The approach tends to err towards the worst-case scenario for erosion, i.e. bare soil, water with low salinity, and relatively rapid increases in water velocity over unsaturated samples. We have confidence in the ability of Landloch to conduct this testing in a robust and repeatable manner and to respond to the challenges posed by this task over the Inland Rail corridor.

Several recommendations were made, and Revision B of the testing procedure considered these comments and adjusted the method where appropriate. The recommendations and adjustments made in Revision B were incorporated in Revision C and are detailed in the table below. Revision C was then further refined to remove typographical errors and improve clarity, with the result being Revision 0. Revision 0 was further reviewed by IRPL, with the result being Revision 1 (this document). No changes were made between Revision 0 and Revision 1.

Recommendation from Reviewers	Adjustment Made to Revision A and Incorporated into Revision B
The authors should report the depth of these samples as depth influences soil wetting and may limit some soil testing protocols.	Sample depth has been added to the lists of measurements/tests in Section 6.2.
The document should note the materials used on the bottom of the flume and whether the flume is solid or porous.	This detail was added along with greater detail on the sample frame in Section 6.1.
One concern we have with the preparation of the samples is the variance in antecedent moisture content. This concern may be addressed by either conducting a sensitivity analysis of ETV results to antecedent moisture content and/or using a standardised moisture content for testing.	Additional measurements of soil moisture have been added. Soil moisture is now measured in the field at the time of sampling, prior to application of overland flow, directly after application of overland flow and 24 hours after application of overland flow (i.e. when the soil has reached field capacity). The testing method also now includes the initial application of overland flows ($0.1-0.2\text{L.s}^{-1}$) at low gradients ($\sim 1\%$) as a means of initially wetting the surface and bringing the samples to a more standardised moisture content prior to scour-producing flows being applied.
There is also some concern here with the highly subjective selection of measurement positions, and implications on repeatability. This has been partly addressed by using the same experienced and competent operator for each test.	Along with the test being conducted by experienced and competent operators, the method now requires fixed measurement positions to be used during each test. This will further reduce the subjectivity in the measurement of flow widths and depths.
The authors should note when and where the soil strength measurements will be made. Will they be measured on field sites when collecting samples, in the tray before runoff simulation, in the tray sometime after the runoff simulation, or on sample collected at the same time and from the same place as the trays.	This was already detailed in Revision 3 of the procedure and can be found in Section 7 of this document.
The direct cone penetrometer test may not be useful for this study. The standard that was cited describes the method as requiring a soil depth of 450 mm. If this study is going to use a variation of this test, like less cone penetration, the modified method should be described.	Reference to a required soil depth of 450mm was removed. Direct Cone Penetrometer tests record DCP results for each 100mm thickness of soil down to a suitable depth. Words outlining this have been added in Section 7.1.18.
The size of the foot on the pocket penetrometer should be noted.	This requirement has been added to Section 7.1.19.
One additional property the authors may wish to consider is the slope [gradient] of the site where the soil sample was collected.	Slope gradient information is already collected as part of the site sample collection and is considered in the interpretation of the results. It is not appropriate to include in this procedure because it is limited to the laboratory testing of the samples that have been collected.
On page 15, the report states that the initial gradient is 1% in step 5, but in step 8 it states that the gradients considered are 10–30%. I suggest the authors state the purpose of the 1% run. Is it to measure a potential low critical shear, or to prewet the sample before starting the test at 5%; or should step 8 state that gradients ranged from 1–30%?	The gradients used in the testing have undergone adjustment as learnings from the earlier testing have been incorporated into the procedure. Revision 4 now has now adjusted the gradients so that testing now starts at 1%.
Several references are listed that are not cited in the text.	The reference list has been adjusted to include only cited references.

1 SCOPE

This document describes the method for the determination of the critical shear stress for initiation of erosion scour and the associated Erosion Threshold Velocity (ETV) for a range of slope gradients. The method described is laboratory-based and uses the application of overland flows in a hydraulic flume.

2 RELATED DOCUMENTS

Landloch (2025) *Methods for testing erosion threshold velocity (ETV). Method 1 – Collection of an undisturbed soil sample suitable for laboratory-based ETV testing*, Revision 1, IRPL Document O-0080-900-IHY-00-PR-0001.

3 CONCEPTS

Management of scour potential in the engineering design of surface water control structures (e.g. channels, culverts) commonly use the concept that, for the soil at the location of the structure, there is a characteristic threshold value of flow velocity or bed shear stress that if exceeded, will produce scour. This threshold concept was described by Horton (1945) who stated that scour, 'only occurs where a threshold of soil resistance is exceeded'.

According to this threshold concept, the rate at which soil particles detach can be related to the amount by which a variable characterising the hydraulics of the flow exceeds a critical value of flow bed shear stress or velocity. The concepts of flow bed shear stress and velocity are briefly described below.

3.1 Flow bed shear stress

The threshold concept for flow bed shear was pioneered by M.P. du Boys (du Boys 1879), who expressed bedload sediment transport rate as a function of excess bed shear stress; that is the bed shear stress exceeding the threshold bed shear stress. A common expression of du Boys' sediment transport formula is:

$$D_c = K_c(\tau - \tau_c)^b \quad 1)$$

where D_c is flow detachment capacity¹ ($\text{kg.m}^{-2}.\text{s}^{-1}$), K_c is concentrated flow erodibility² (s.m^{-1}), τ is average bed shear stress (Pa), τ_c is critical bed shear stress (Pa), and b is

¹ The rate at which soil particles are detached when subjected to a clear water flow.

² Increase in soil detachment per unit increase in flow shear stress.

an exponent (unitless)³. Effectively, the bed shear stress (τ) exerted by the overland flow must exceed a critical shear stress (τ_c) to initiate movement of particles at the bed.

Determination of values for D_c , K_c , and b are not required in order to assess the critical flow bed shear stress (τ_c). All that is required is the application of sufficient flow bed shear stress (τ) such that the initiation of scour is achieved. At that point the applied flow bed shear stress (τ) is equal to the critical flow bed shear stress (τ_c).

3.2 Flow velocity

Velocity has historically been used as an indicator of conditions at which scour initiates. IECA (2008), Carey *et al.* (2015), and Christie (1982) are examples of Australian design guidelines that use velocity thresholds as a design criterion.

Despite the common use of flow velocity, bed shear stress is a more fundamentally related measure than flow velocity for the determination of the initiation of movement of bed particles. This is because bed shear stress is an independent, material-specific characteristic, whereas both flow velocity must be combined with slope gradient in order to estimate scour potential. That is, for a given flow velocity, the potential for scour is also dependent on slope gradient.

3.3 Erosion threshold velocity

The Erosion Threshold Velocity (ETV) can be determined by combining the flow bed shear stress equation rearranged to solve for flow depth (equation 2), and the Manning's flow equation (equation 3).

$$D = \frac{\tau_c}{\gamma \times S} \quad 2)$$

where D is average flow depth (m) required to achieve the critical flow bed shear stress, τ_c is critical flow bed shear stress (Pa), γ is the specific weight of water (N.m^{-3}), and S is slope gradient (m.m^{-1}).

$$ETV = \frac{1}{n} R_h^{\frac{2}{3}} S^{\frac{1}{2}} \quad 3)$$

where ETV is Erosion Threshold Velocity (m.s^{-1}), n is the Manning's coefficient, R_h is the hydraulic radius (m), and S is the slope gradient (m.m^{-1}).

For broad flows (>20m), as are common for floodplain flows, the flow width and wetted perimeter can be taken as essentially the same (Ponce 1989). This implies that the

³ The exponent b is used to fit the equation to experimental data. A value for b of 1.0 is often used, though 1.5 often better fits the data and facilitates simpler mathematical solutions of the Darcy-Weisbach flow equation (Foster 1982).

average flow depth (D) from equation 2 can be substituted for the hydraulic radius (R_h) in equation 3⁴ (Carey *et al.* 2015). This simplifies equation 3 to equation 4.

$$ETV = \frac{1}{n} D^{\frac{2}{3}} S^{\frac{1}{2}} \quad 4)$$

where n is the Manning's equation coefficient, D is average flow depth (m) to achieve the critical flow bed shear stress, and S is the slope gradient ($\text{m} \cdot \text{m}^{-1}$).

Within a flume study, the flow area required to achieve the critical shear (A) can be determined by using equation 5:

$$A = D \times W \quad 5)$$

where D is the average flow depth (m) required to achieve the critical bed shear stress (τ_c) (equation 2) and W is the width of the flow (m).

In using these equations, it is noted that the calculated ETV remains a function the critical bed shear stress and the slope gradient. Therefore, in this procedure ETV is reported for a material tested for a range of slope gradient values.

It is also noted that at low gradients, such as those observed on floodplains, the flow depths and volumes required to achieve the necessary critical bed shear stress and ETV values can be large, making field-based methods of assessment both difficult, costly, and unsuitable. Therefore, a laboratory-based method using hydraulic flumes has been developed. This approach allows for slope gradients to be increased so that the critical bed shear values can be applied with less water. The critical bed shear values can then be used to calculate the corresponding ETV value for a range of slope gradients.

4 APPARATUS

4.1 Previous studies

Assessment of ETV values using laboratory-based methods requires the application of overland flow to an undisturbed sample within a hydraulic flume. A wide range of flume studies have occurred and have used an equally wide range of sample sizes. Table 1 summarises a range of flume studies that assessed flow bed shear and the sample dimensions used.

⁴ R_h can be determined using the equation $R_h = \frac{A}{P}$, where A is the flow area (m^2) required to achieve the critical bed shear stress and P is the wetted perimeter (m). The wetted perimeter (P) is determined using equation $P = 2D + W$ where D is the flow depth (m) required to achieve the critical bed shear stress (equation 2) and W is the width of the test flume (m).

Table 1: Summary of flow studies and the sample dimensions used.

Reference	Sample shape	Sample size (m)
Nearing <i>et al.</i> (1991)	Circle	0.127
McNeil <i>et al.</i> (1996)	Rectangle	0.15 X 0.10
Briaud <i>et al.</i> (2001)	Circle	0.075
Le Hir <i>et al.</i> (2008)	Circle	0.08
Mahalder (2018)	Circle	0.3 X 0.1
Mostafa <i>et al.</i> (2008)	Square	approx. 0.15 X 0.15
Nachtergaele and Poesen (2002)	Circle	0.05
Roberts <i>et al.</i> (2003)	Rectangle	0.15 X 0.10
Schaaff <i>et al.</i> (2006)	Circle	0.15

4.2 Hydraulic flume used for ETV determination

The hydraulic flume used in the determination of ETV for IRPL contains a testing area that houses the undisturbed soil sample (Figure 1). The testing area has a nominal length of 1.0m, width of 0.4m, and depth of 0.2m. This sample size is larger than the samples outlined in Table 1. The benefit of the use of a larger sample is that changes in soil properties that can occur over small distances and their impact on ETV can be incorporated into the testing of a single sample. It also minimises potential edge effects, such as the initiation of detachment from the disturbed soil surface at the interface between the sample and the testing area boundary⁵. The impact of disturbance of this interface area was further reduced through application of a tackifier to the disturbed zone prior to testing.

At the upslope edge of the testing area, an inlet area is installed that contains a stilling well (Figure 2) that discharges overland flow onto a 0.3m long section of inlet channel (Figure 1). The stilling well is used to ensure that water is supplied in a low turbulence state with an even flow depth across the width of the flume.

The bed of the inlet channel is roughened by the presence of a rough sandpaper. The roughness of the sandpaper was tested and found to have a Manning's coefficient (n) of ~0.02–0.04 for flume gradients ranging from 6–25%. This Manning's coefficient is consistent with coefficients measured for undisturbed soil samples tested in the study. Use of the roughened inlet channel ensures that the overland flow is introduced to the test surface at a similar velocity to that which will occur on the test surface itself. This reduces the possibility of scour occurring through turbulence caused by a difference in roughness. The inlet channel is rested on top of the testing area using an overlap of ~100mm. The join is sealed using bentonite so that overland flow cannot flow between the test surface and the inlet channel.

⁵ This area of disturbance is in the order of 1cm, resulting in a disturbance of 5% of the plot area (2cm of the 40cm plot width). Use of a narrower plot would increase this proportion of disturbance.



Figure 1: Hydraulic flume showing overland flowing being applied to the testing area.

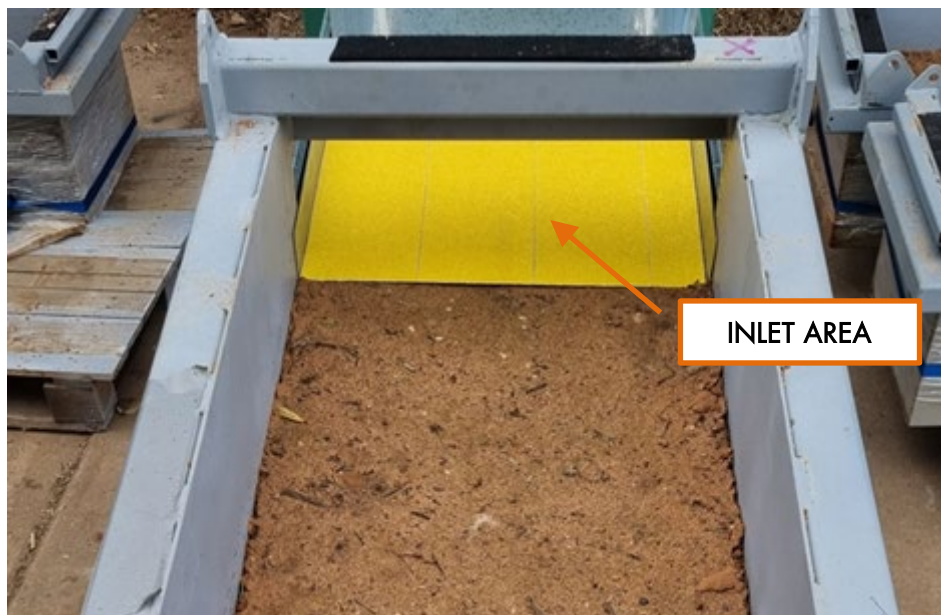


Figure 2: Inlet area roughened using sandpaper allows uniform overland flow to be introduced to the sample.

At the downslope edge of the testing area, an outlet structure is installed. It is trapezoidal in shape (Figure 3) and concentrates the flow prior to it being discharged to a sump (Figure 4). This is done to allow for easier sediment sample collection. The interface between the bottom end of the testing area and the outlet area is also sealed using bentonite so that overland flow cannot flow between the test surface and the outlet area.



Figure 3: Outlet area shaped to allow for easier collection of samples.

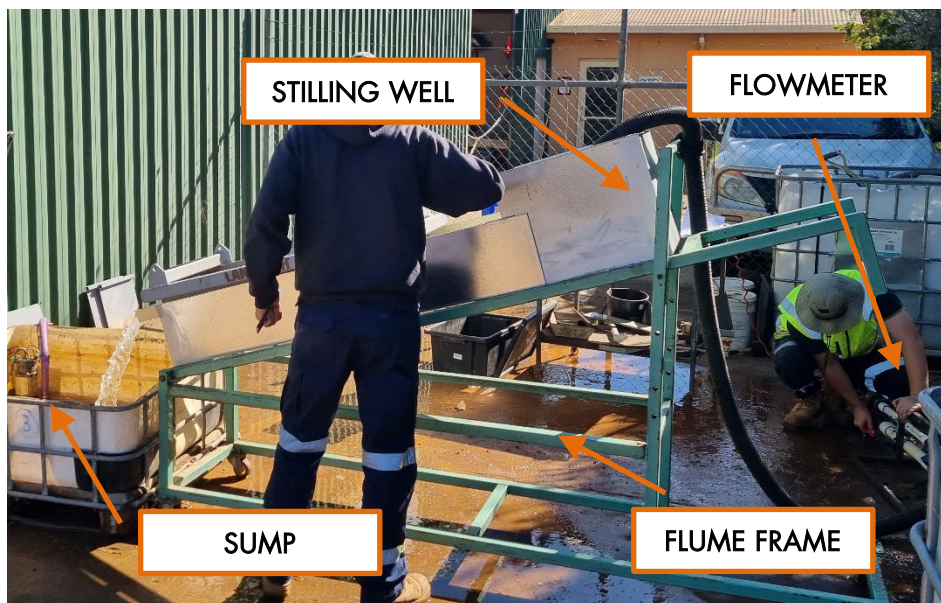


Figure 4: Hydraulic flume placed in an adjustable frame

The hydraulic flume is set in a frame that can be tilted to achieve a range of slope gradients, ranging from 0–40% (Figure 4). Water is supplied to the stilling well, with the flow rate measured using turbine flow meters, capable of applying flow rates of 38–380L.min⁻¹ (0.6–6.3L.s⁻¹) at a manufacturer's stated accuracy of ±3%. The flow rate is regulated using a regulator valve positioned between the pump and the flowmeter (Figures 4 and 5).

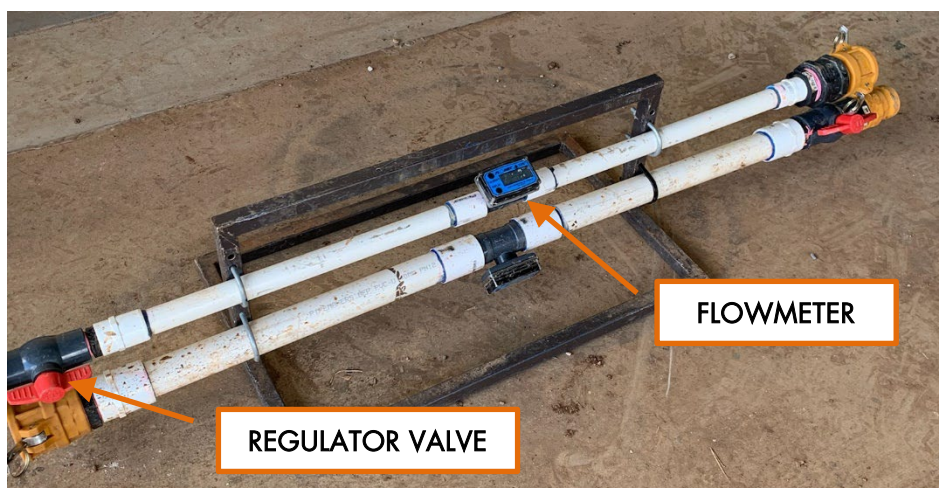


Figure 5: Flowmeter assembly used to regulate (note the valve) and measure (note the flowmeters) the applied flow rate. The assembly shown has two flowmeters with different ranges of measurable flow rates, allowing for a wider range of flow rates to be applied if necessary.

5 WATER

Rainwater is used in the application of overland flow. Rainwater has low salinity ($<0.3\text{dS}\cdot\text{m}^{-1}$). This is to ensure that the chemistry of the water applied does not influence the detachability of particle from the test surface.

6 UNDISTURBED SOIL SAMPLE

The method for collecting an undisturbed soil sample including more detail on the apparatus is described in Landloch (2025), IRPL Document 0-0080-900-IHY-00-PR-0002, Revision 0. Key aspects of the undisturbed sample are described below.

6.1 Sample frame

The sample is collected in a custom-fabricated, reinforced metal sampling frame that ensures that the sample is delivered to the testing laboratory in the same condition as it was collected.

The sampling frame has a length of 1.0m and a width of 0.4m. Samples are nominally 0.2m thick, leaving a space within the channel above that sample surface that is $\sim 0.2\text{m}$ high. The frame consists of an open channel section and two end plates that are inserted once the sample is taken to enclose the sample on all sides except the top surface (Figure 6). The open channel section and end plates are made from solid steel.

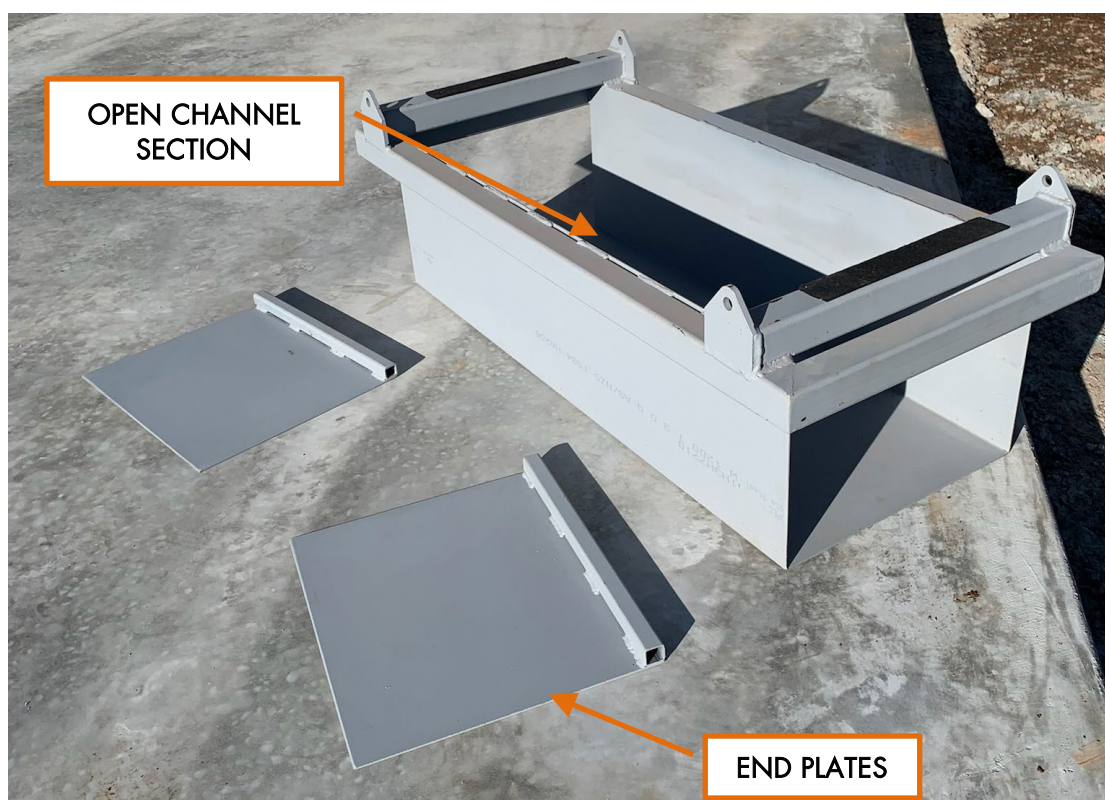


Figure 6: Sampling frame.

6.2 Sample collection

A small (3.5 tonne) tracked excavator is used to create an access trench in which the frame is placed in preparation for sampling. Sleepers are used to assist in guiding the frame during sampling (Figure 7).

The frame is then pushed laterally through the soil being sampled (Figure 8). The end plates are then installed and the sample lifted from the sampling location and prepared for transport. An overview of a sampling site is shown in Figure 9.

The top surface (i.e., the surface that is tested in the laboratory) is protected prior to transport to the laboratory by placement of a foam layer that fills the void between the sample surface and the top of the frame. A board is placed over the foam prior to the sample being wrapped in plastic wrap. The sample is wrapped to maintain its moisture content. An example of that data is given in Figure 10 and confirms that moisture content is maintained during transport, with the absolute mean variation between field and laboratory moisture content being 1%.

Bulk density of the sampled soil, both in the field and as delivered to the laboratory, are measured. An example of that data is given in Figure 11 and shows that bulk density is well maintained, with the absolute mean variation between measured field and sample bulk density being 0.01g.cm^{-3} .



Figure 7: Sampling frame placed into access trench between the guide sleepers.



Figure 8: Sampling frame being pushed through the soil using the excavator blade.

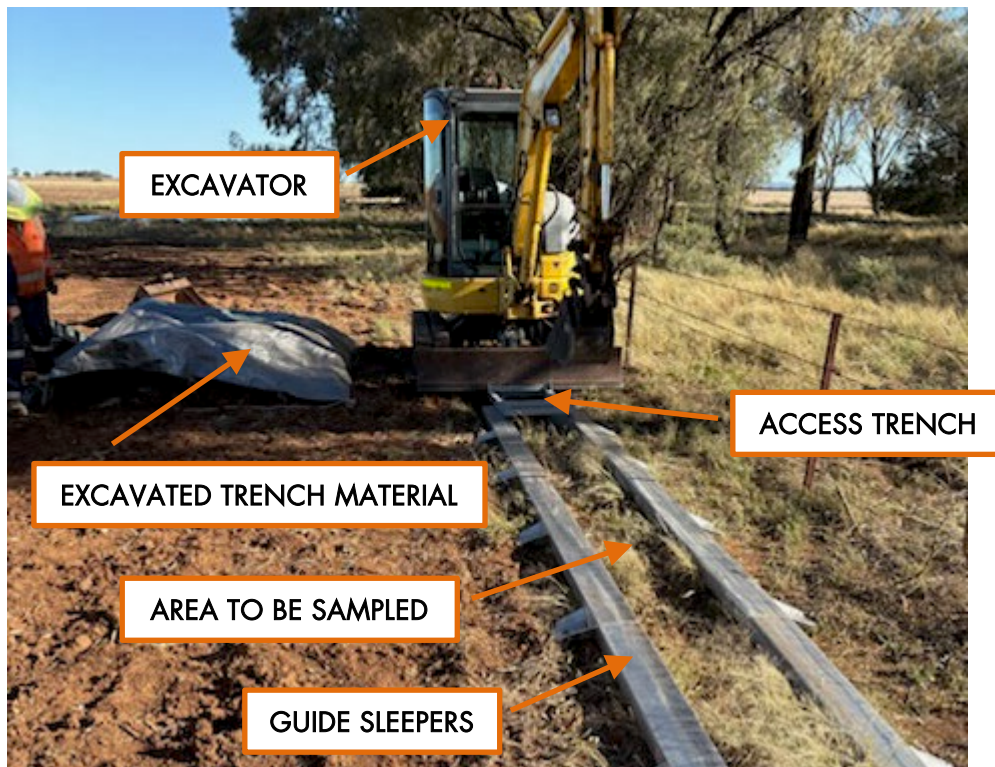


Figure 9: Overview of a sampling site.

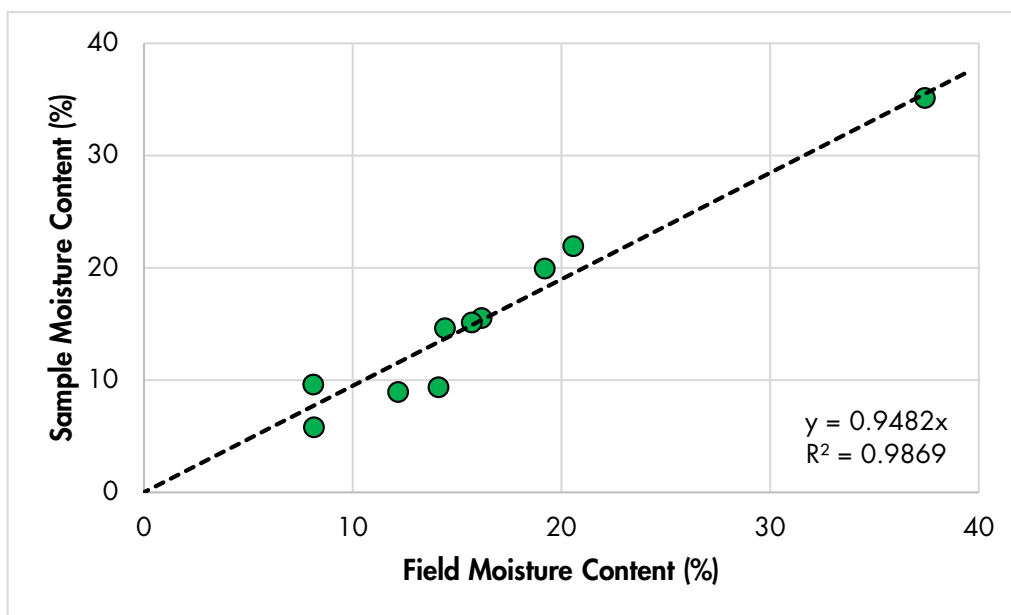


Figure 10: Example relationship between field and laboratory moisture content.

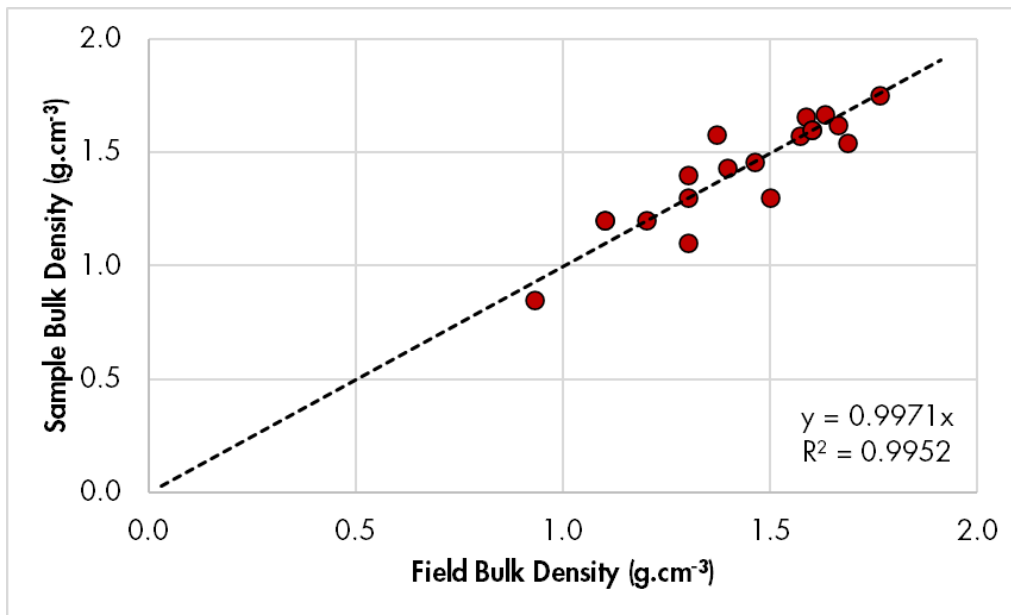


Figure 11: Example relationship between field and laboratory bulk density.

6.3 Soil surface condition

IRPL requires that the ETV assessment of a soil be for a 'worst case scenario' from a detachment perspective. For soils with naturally low vegetation groundcover levels (i.e. more arid zones), this is a soil that is bare of surface groundcover and that has little to no root mass. Such a condition could occur after a drought or fire, or may occur naturally given the rainfall-limiting environment. For soils with naturally high vegetation groundcover levels (i.e. higher rainfall zones), this is a soil that is bare of surface groundcover but that does contain a root mass. Such a condition could occur after a drought or fire that would remove the surface groundcover but leave a root mass behind that would have an impact on the detachability of soil particles. In both cases, the soil surface assessed aims to represent a surface that could exist in the long-term within or adjacent to the rail corridor, and excludes disturbed soils that exist soon after construction of the rail line.

For the samples taken that have a surface groundcover present, the vegetation is initially sprayed out prior to testing using glyphosate mixed as per the manufacturer's recommendation. The plots are then left for 1–2 weeks to allow for the spray to take effect. The remaining vegetation is then manually clipped using garden scissors. The remaining grass tufts were then burned off using a butane torch at low heat (red flame) applied only to the grass tuft areas (Figure 12). The vegetation residue produced is brushed from the plot using a banister brush or blown from the plot using a leaf blower (Figure 13).



Figure 12: Burning off grass tufts using a butane torch on low heat (red flame)



Figure 13: Removing excess vegetation debris using a leaf blower.

Vital Bon-Matt Stonewall is applied to the disturbed edges of the plot (Figure 14) at the application rate recommended by supplier (1 part Stonewall to 9 parts water)⁶.

Bentonite is applied to the plot edges to ensure no downward movement of overland flow between the plot edge of the sample frame (Figure 15). This is done to ensure that all overland flow introduced to the plot flows over the plot surface and contributes to the applied bed shear stress.

⁶ Stonewall is a polymer soil stabiliser commonly used to provide rapid stabilisation of soils. Testing of the impacts of Stonewall application to the sample surfaces showed that critical shear rates of the treated surfaces exceeded that of the untreated surfaces. From this it can be concluded that application of the stabiliser effectively stabilised the disturbed edges of the plots, eliminating them as a cause or contributor to scouring or sediment detachment.



Figure 14: Stabiliser applied to the disturbed edges of the plot prior to application of overland flow.



Figure 15: Bentonite (grey material) applied to the plot edge.

7 SAMPLE TESTING

Other properties of the soil sample are collected both in the field and within the sample. These are known as Indirect Tests. They will be used to consider the development of indirect estimates of ETV. The properties assessed include:

- Sample thickness;
- Moisture content;
- pH_w (1:5 water:solid solution) (pH units);
- $\text{EC}_{1:5}$ (1:5 water:solid solution) ($\text{dS}\cdot\text{m}^{-1}$);
- Gravel content ($>2\text{mm}$) (%);
- Particle size distribution of the fine fraction ($<2\text{mm}$) (%);
- Soil texture;
- Exchangeable cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Al^{3+}) ($\text{meq}\cdot 100\text{g}^{-1}$);

- Effective Cation Exchange Capacity (ECEC) (meq.100g^{-1});
- Ca:Mg ratio (unitless);
- Exchangeable Sodium Percent (ESP) (%);
- ECEC to Clay ratio (CCR) (estimate of clay mineralogy);
- Total N and P (mg.kg^{-1});
- Organic C (%);
- Plant available P, K, and S (mg.kg^{-1});
- Dry bulk density (g.cm^{-1});
- Unified Soil Classification System (USCS) classification;
- Revised Universal Soil Loss Equation (RUSLE) erodibility factor (K-factor);
- Shear stress (shear vane) (kPa);
- Surface shear stress (torvane) (kPa);
- Liquid Limit (%) and Plastic Limit (%), also known as the Atterberg Limits;
- Plasticity Index (%);
- Linear Shrinkage (%);
- Direct Cone Penetrometer (blows/100mm);
- Pocket Penetrometer (kPa);
- Relative Density (cohesionless soil); and
- Emerson Class.

7.1 Indirect tests

7.1.1 Sample thickness

Sample thickness will be measured using a ruler. The recorded thickness will be the average value of thicknesses measured at 3 locations on either end of the sample once the end plates are removed (6 measurement in total).

7.1.2 Soil moisture

Soil moisture will be measured using a handheld soil moisture meter (Delta-T SM150T or equivalent). The recorded soil moisture will be the average value of soil moisture measured at 3 locations within the sample area.

7.1.3 pH_w

Testing of pH_w will be completed with method 4A1 in the *Soil Chemical Methods–Australasia* (Rayment and Lyons 2011).

7.1.4 $\text{EC}_{1:5}$

Testing of $\text{EC}_{1:5}$ will be completed with method 3A1 in the *Soil Chemical Methods–Australasia* (Rayment and Lyons 2011).

7.1.5 Gravel content, particle size distribution, and texture

Testing of the gravel content ($>2\text{mm}$) will be completed via dry sieving. Testing of the particle size distribution of the fine fraction ($<2\text{mm}$) will be performed in accordance with the Australian Standard AS 1289.3.6.3 (Standards Australia 2020). When completing the particle distribution testing, the following size classes, expressed as percent passing values, must be determined:

- 19.0mm;
- 13.2mm;
- 9.5mm;
- 6.7mm;
- 4.75mm;
- 2.36mm;
- 1.18mm;
- 0.600mm;
- 0.425mm;
- 0.300mm;
- 0.150mm;
- 0.075mm; and
- 0.002mm.

Texture of the fine fraction ($<2\text{mm}$) use be determined using the laboratory measures of particle size distribution. The texture assigned will be based on the Australian soil texture triangle (NCST 2009).

7.1.6 Exchangeable cations, ECEC, and ESP

Testing of exchangeable cations will be completed in accordance with method 15 in the *Soil Chemical Methods–Australasia* (Rayment and Lyons 2011). The appropriate sub-method will be selected based on material properties such as pH_w and $\text{EC}_{1:5}$.

Effective Cation Exchange Capacity (ECEC) will be calculated as the sum of exchangeable cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Al^{3+}).

The Ca:Mg ratio will be calculated as the ratio of exchangeable Ca^{2+} and Mg^{2+} .

Exchangeable Sodium Percentage (ESP) will be calculated as the exchangeable Na^+ concentration divided by the ECEC and expressed as a percent.

7.1.7 CCR

ECEC to Clay ratio (CCR) is an indicator of clay mineralogy (DERM 2011), and will be calculated as the ratio of ECEC ($\text{meq. } 100\text{g}^{-1}$) and clay content (%). Despite having units, it is normally reported without units.

7.1.8 Total N and P

Testing of total N will be completed with method 7A5 in the *Soil Chemical Methods–Australasia* (Rayment and Lyons 2011).

Testing of total P will be completed with ICP.

7.1.9 Organic C

Testing of plant available P will be completed with method 6B3 in the *Soil Chemical Methods–Australasia* (Rayment and Lyons 2011).

7.1.10 Plant available P, K, and S

Testing of plant available P, K, and S will be completed with the following methods in the *Soil Chemical Methods–Australasia* (Rayment and Lyons 2011):

- P – 9B1;
- K – 18A1; and
- S – 10D1.

7.1.11 Dry bulk density

Testing of the dry bulk density will be performed in accordance with method 503.01 in the *Soil Physical Measurement and Interpretation for Land Evaluation* (McKenzie *et al.* (2002).

7.1.12 Unified Soil Classification System (USCS) classification;

The Unified Soil Classification System (USCS) classification will be performed in accordance with the Australian Standard AS 1726 (Standards Australia 2017a).

7.1.13 RUSLE K-factor

The RUSLE K-factor will be calculated using the in accordance with method 528.01 in the *Soil Physical Measurement and Interpretation for Land Evaluation* (McKenzie *et al.* (2002).

7.1.14 Shear stress (shear vane)

The shear stress (shear vane) test will be performed in accordance with the Australian Standard AS 1289.6.2.1 (Standards Australia 2001).

7.1.15 *Surface shear stress (torvane)*

The surface shear stress (torvane) test will be performed in accordance with the ASTM International Standard D8121/D8121M-19 (ASTM 2019).

7.1.16 *Liquid Limit (%), Plastic Limit (%), and Plasticity Index (%):*

The liquid limit test will be performed in accordance with the Australian Standard AS 1289.3.9.1 (Standards Australia 2002). The plastic limit test will be performed in accordance with the Australian Standard AS 1289.3.2.1 (Standards Australia 2009a). These two limits are also known as the Atterberg limits.

The plasticity index will be performed in accordance with the Australian Standard AS 1289.3.3.2 (Standards Australia 2009b).

7.1.17 *Linear Shrinkage*

The linear shrinkage test will be performed in accordance with the Australian Standard AS 1289.3.4.1 (Standards Australia 2008).

7.1.18 *Direct Cone Penetrometer*

The DCP test will be performed in accordance with Australia Standard AS 1289.6.3.2 (Standards Australia 1997). DCP data are reported in the units of 'blows/100mm' to a maximum depth of 500mm (the actual depth depends on the soil). Given the thickness of the sample collected is nominally 200mm, the DCP readings for the surface 200mm are used when assessing relationships between DCP measurements and ETV. That said, measurements for the full depth are still taken in the field for the sake of completeness and to align with the requirements of the standard.

7.1.19 *Pocket Penetrometer*

The pocket penetrometer test evaluates approximate unconfined compressive strength of soils. There is currently no Australian or international standard for this test. Therefore, the measurement is to follow the manufacturers directions. The result reported is to be the average of a minimum of 3 individual tests (preferably more). The size of the foot of the pocket penetrometer used for the test must be recorded.

7.1.20 *Relative density (cohesionless soil)*

Relative density is defined as the ratio of difference of void ratios (denoted with the symbol 'e') of cohesionless soil in its loosest state ($e_{\max}$) and the natural state (e) (difference calculated as $e_{\max} - e$) to the difference between void ratio in its loosest and densest ($e_{\min}$) state (difference calculated as $e_{\max} - e_{\min}$).

This method is valid only for soils that contain up to 5% mass of soil passing a 75 μ m sieve, except that silty sands with non-plastic fines may contain up to 12% passing a

75 μ m sieve. In most cases, this tests will not be performed because the soils assessed have appreciable clay silt and clay contents.

Calculation of void ratios requires the assessment of minimum and maximum dry density of the cohesionless soil, and the dry bulk density in the soil's natural state. Measurement of a soils dry bulk density in its natural state is described in Section 7.1.11. Minimum and maximum dry bulk density will be performed in accordance with the Australian Standard AS 1289.5.5.1 (Standards Australia 1998).

7.1.21 Emerson Class

The Emerson Class evaluates the risk of clay dispersion. The test is done in accordance with AS 1289.3.8.1 (Standards Australia 2017b).

7.2 Direct testing of critical shear

The procedure for applying overland flows and determining the initiation of scour is as follows:

1. Prepare the undisturbed sample surface:
 - Remove vegetation if required;
 - Apply stabiliser to the disturbed sample edges; and
 - Apply bentonite to the sample edges.
2. Load the prepared undisturbed sample (still within the sampling frame) into the hydraulic flume frame:
 - Ensure that the gradient measured across the (shorter) plot width is near zero (target $\pm 0.5\%$);
 - Take care that the test surface is at a consistent height with the bottom end of the flume frame; and
 - Seal the gap between the bottom of the sample and the outlet area with bentonite; and
 - Measure soil moisture using a handheld moisture probe.
3. Attach the inlet area:
 - Overlap the inlet channel edge with the top edge of the sample;
 - Take care that the test surface is at a consistent height with the inlet area; and
 - Seal the overlap with bentonite.
4. Connect the water supply to the stilling well via a pump and flow meter.
5. Set the flume frame to the initial gradient. 1% is suggested, but can be altered depending on the soil type and anticipated resistance to scour).
6. Apply overland flow to the surface area at the initial flow rate. 0.1–0.2L.s⁻¹ is suggested but could be altered depending on the soil type and anticipated resistance to scour.
7. Make observations of flow, scour, and sediment:
 - At each flow rate measure flow width in two locations and average flow depth at the same two locations.

- The locations are to remain constant throughout the duration of the test and are to be positioned in a location where flow turbulence is as low as possible, minimising the errors in flow depth measurements.
- Flow depth is recorded at a minimum of three positions across the flow width at each of the two locations where the flow width was recorded. More than three flow depths can be recorded if the flow depth is observed to be variable across the flow width. The average flow depth recorded for each point where flow width is recorded is taken as the average of all flow depths recorded. Flow depth is measured using a steel ruler with a small 'foot' attached to then end at right angles. This is done to assist in ensuring the end of the ruler is in contact with the surface and does not pierce the surface, leading to a recording of a larger depth of flow than actually occurs.
 - Observe whether scour has initiated by:
 - Visual inspection of the surface, or
 - Change in appearance of the generated sediment.
 - Take a runoff sample and derive a measure of sediment concentration.
- 8. If scour was not initiated, increase the flow rate and repeat step 7. Flow rates are typically increased by $\sim 0.3 \text{ L.s}^{-1}$ at each increase in flow rate as this is equal to an increase in applied shear of 1–3Pa over the range of gradients considered (<40%). A maximum flow rate of 4.8 L.s^{-1} is achievable with the pump used, though higher flow rates could be used if a different pump is employed. The size of flow rate increase can be adjusted, but it is critical that the actual applied flow rate is accurately recorded. Continue increasing flow rate until scour is initiated or until the maximum flow rate of the pump is achieved.
- 9. If after the maximum flow rate is achieved and no scour has been initiated, increase the gradient of the hydraulic flume, and repeat steps 6–8.
- 10. Application of overland flow is stopped when scour is initiated or if scour has not initiated and the maximum flow rate on the maximum flume gradient has been applied.
- 11. Measure soil moisture using a handheld moisture probe at the end of the application of overland flow.
- 12. Allow plots to drain under gravity (24 hours), and assess the surface. Assessment of both unscoured and scoured surfaces should be undertaken if scouring occurs and if an unscoured surface remains. Assessments include soil properties listed in Section 6.
- 13. Triplicate plots of each material are tested as outlined in steps 1–12.

For each run, photographs of the test sample prior to application of overland flow and after completion of the flume test should be taken. A video of the application of the overland flow should also be taken and can be used to support observations made during the test run.



Figure 16: Examples of scoured surfaces generated by application of overland flows.

8 DETERMINATION OF CRITICAL SHEAR

Critical flow shear stress is derived from the measures of flow width and depth for the flow rate and gradient at which scour was observed to initiate. Equation 2 can be used, rearranged to solve for τ_c :

$$\tau_c = D\gamma S \quad 6)$$

where τ_c is critical bed shear stress (Pa), D is average flow depth (m) at which the critical bed shear stress was reached, γ is the specific weight of water (N.m^{-3}), and S is slope gradient (m.m^{-1}) at which the critical bed shear stress was reached.

9 DETERMINATION OF ETV

ETV for the sample is determined as the velocity that is required to achieve the critical flow shear stress for a given slope gradient. Flow velocity is determined by solving the flow equation:

$$ETV = \frac{Q}{A} \quad 7)$$

where *ETV* is Erosion Threshold Velocity (m.s^{-1}), *Q* is the flow rate ($\text{m}^3.\text{s}^{-1}$) at which critical bed shear stress was achieved, and *A* is the flow area (m^2) at the point at which critical shear was achieved. Flow area at the point at which critical bed shear stress was achieved is calculated by multiplying the flow width by the average flow depth at the point at which the critical bed shear stress was achieved.

The Manning's coefficient (*n*) can be calculated by solving the Mannings equation (equation 3) for said coefficient. By doing this, the ETV for a range of slope gradients can then be calculated using equations 3 and 7.

10 REPORTING RESULTS

Values for ETV are calculated for triplicate samples of the same soil, and the average ETV of the three samples will be reported. The ETV value for a soil must be reported along with its associated slope gradient. This may be usefully achieved through the use of a graph showing ETV versus slope gradient.

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APPENDIX A: INDEPENDENT REVIEWS

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Synthesis of Reviews on Methods for Determining Erosion Threshold Velocity

William Elliot, PhD

21 January 2025

Client: Evan Howard, Landloch Pty Ltd

Background

Inland Rail Pty Ltd (IRPL) is building a new freight rail line to connect Melbourne to Brisbane. The proposed Inland Rail corridor will cross inland areas of Victoria, New South Wales and Queensland following ~1,000 km of existing lines and constructing about ~600 km of new line (Landloch 2024a). To support the design of railway channel crossings, IRPL has asked Landloch Pty Ltd to develop erosion threshold velocities (ETVs) for a range of soils. Landloch's approach is to collect large undisturbed trays of soil from along the proposed route (Landloch 2023a), and measure soil detachment critical shear (τ_{auc}) using simulated surface runoff. From τ_{auc} and channel gradient, ETV values can be calculated. The laboratory testing procedure is described in a technical report *Methods for Testing Erosion Threshold Velocity Method 2 – Direct Laboratory-based ETV Testing Rev 3* (Landloch 2023b).

As part of measuring critical shear, Landloch asked two independent scientists to review the Methods for Testing Documents (Landloch, 2023b) and to visit the Landloch Laboratory in Toowoomba, QLD, to evaluate the testing equipment and observe one of the tests. Review reports were submitted to Landloch by both reviewers (Elliot, 2024; Gillies, 2024). Additional feedback was obtained from Evan Howard, Principal Consultant with Landloch in correspondence and from other Landloch staff during a site visit. Feedback was also provided by Mr. Howard during the drafting of the initial reviews. This document is a synthesis of the two independent reviews provided by Elliot (2024) and Gillies (2024). This is the second review of the Methods Report by Elliot. The first review was submitted in August 2023 (Elliot, 2023). It was apparent that most of the suggestions for improvement in the first Methods document were incorporated into the 2023 revision 3 Methods Document (Landloch, 2023b).

In addition to the site visit, Dr. Gillies was provided with two reports: *Methods for Testing Erosion Threshold Velocity (ETV) Method 2 – Direct Laboratory-Based ETV Testing* (Landloch 2023b) and the *"Erosion Threshold Velocities Report, Illabo to Stockinbingal Inland Rail Project"* (Landloch 2024b). The scope of this review is limited to the Methods Report and onsite observations of the testing procedure only and does not consider the wider use of this information in any design or planning by ARTC.

Background of Reviewers

Dr. William Elliot has a PhD in Agricultural Engineering with a minor in Soil Management. He has taught in agriculture colleges in Kenya, Liberia, and England, and in Universities in Scotland, and Iowa, Ohio, and Idaho USA. He has more than 100 peer-reviewed publications and book chapters. He was a Research Engineer for the USDA Forest Service Rocky Mountain Research Station in Moscow, Idaho for 26 years, managing research teams of up to a dozen specialists and scientists. His area of expertise is forest soil erosion processes and prediction. He has carried out erosion field studies associated with natural rainfall and snowmelt, as well as erosion associated with simulated rainfall and runoff on croplands, rangelands, and forests.

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Dr. Malcolm Gillies is a Senior Lecturer (Water Engineering) at the University of South Queensland, Toowoomba. Dr. Gillies has taught courses in agricultural science, water hydraulics and soil and water engineering for more than 14 years. His research interests are in field irrigation science and management where he has authored or coauthored more than 50 articles. Dr. Gillies was accompanied on his site visit by Dr. Joseph Foley, Associate Professor in Water Engineering and Irrigation at the same university.

General Comments

The Inland Rail corridor spans a large geographical area and therefore encompasses a wide range of challenges due to varied hydrological factors and soil conditions. Inland Rail are to be applauded for any attempts to improve upon design and subsequent channel crossing infrastructure expenditure costs with actual measurements of erosion threshold velocities.

The procedures described in the methods report are reasonable and widely used by the scientific community. The report is well written with only minor editorial or grammatical concerns as noted below.

The method of on-site soil sampling described to Gillies and Foley, and the soil sampling apparatus are robust, and the novelty is to be applauded. The method is a technically sound process that will capture representative large samples of the soil surface conditions from many sites; except for very stony soils and soils immediately following tillage. These two particular exceptions are well understood by the Landloch team, and they have verbally indicated that they carefully locate sample sites or choose alternative sites when such conditions are encountered.

As reported in Landloch (2023b) the size of the soil sample is larger than most other laboratory testing apparatus in published literature. The large size of the flume is one of the strong features of this study. This permits the testing procedure to more accurately account for the ground surface conditions present on site including microtopography, plant roots and surface roughness. The larger flume will better address variability within a soil sample, a problem associated with all erosion studies. The disadvantage is the difficulty in obtaining such large undisturbed samples for testing. The authors should report the depth of these samples as depth influences soil wetting and may limit some soil property testing protocols, like the cone penetrometer test. The document should also note the materials used on the bottom of the flume and whether the flume is solid or porous (page 16 in report). In a subsequent email, Howard stated that the bottom of the flume was solid.

Gillies and Foley were generally impressed by the testing apparatus in which the soil sample is placed and were comfortable with the efforts to address the transition between the metal flume and the soil surface. Water is applied to the top end of the sample via a wide stilling well and passes over a region surfaced with sandpaper with a similar surface roughness to bare soil, ensuring that the flow transition is as smooth as possible. The edges of the soil sample,

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including the upstream transition are sealed with bentonite which appears to function as designed. Care should be taken to ensure that the soil surface is at a consistent height with respect to the entry manifold. The application of a soil stabilizer to the sides of the flume is a good practice to minimize edge effects and support the assumption that the hydraulic radius is equal to the depth.

One concern we have with the preparation of the samples is the variance in antecedent moisture content. For cohesive sediments, i.e. clay and loam soils, the structural strength and therefore susceptibility to erosion is potentially influenced by the moisture content. The sampling procedure includes a measurement of moisture content in the field prior to extracting the sample and again at the completion of the flowing water tests in the lab. The procedure also attempts to preserve the moisture content between the time of field sampling and beginning of laboratory testing. While this process is sound the concern is that there will be a range of possible moisture levels in the samples at the time of laboratory testing. This concern may be addressed by either conducting a sensitivity analysis of ETV results to antecedent moisture content and/or using a standardised moisture content for testing. Howard indicated that LandLoch have already investigated the impact of wetting the surface prior to the testing procedure and that this had a relatively small impact on the ETV. Formally documenting this investigation should improve our trust in this method¹.

The ability to retain in situ bulk densities and water contents in the soil samples as shown in figs. 7 and 8 in the Methods Report improves the confidence that the results of the study will be reasonable. Many similar studies use disturbed soil samples and repack them to a field bulk density, but such a practice fails to retain inherent mechanical, chemical and biological bonds between soil particles.

The testing method is based on established theory to determine shear stress from water depth and bed slope. This theory requires a normal flow regime, a condition that normally occurs after a sufficient distance of flow in open channel of uniform cross section. The distance to establish normal flow may exceed hundreds of metres for deeper water depths. The use of shallow flows in the testing apparatus appears to be an attempt to induce normal flow over a short distance. The error induced by flow regimes other than normal flow is likely to be within the current measurement error for water depth.

Rainwater, i.e. with low salinity, is used for the testing procedure to ensure the water chemistry does not influence the soil detachability (Landloch 2023b). This is a positive feature of this study as it will more nearly mimic field conditions. Higher salinity water, i.e. bore water, may reduce the susceptibility to slaking and dispersion and lead to erroneous results. Use of rainwater means that the adopted methodology is repeatable and will yield lower erosive threshold velocities than if other water sources were used.

¹ Although beyond the scope of this review, in the Landloch (2024c) Correlation Report, the correlation coefficient r between τ_{auc} and soil water content for 19 soils was -0.27 (P value = 0.26, N.S.).

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The approach to measure and control flowrates is sound and should lead to accurate results. The inline turbine meters are of acceptable quality and installed correctly. The use of two separate meters and the associated pipework permits accuracy at both low and high flows.

The greatest concern with the testing procedure is in regard to the accuracy and repeatability of the flow depth and width as water flows over the soil surface. The depth is measured manually with a steel rule by an experienced operator, while attempting to contact the saturated soil surface underwater in the turbulent water flow in which significant distortion in the fluid surface exists. The shallow depths being measured, and the quick measurement process required, undermines the accuracy of water depth data. The accuracy of the velocity is directly related to the accuracy of this measured water depth. Water depth has an inverse relationship with the slope of the soil surface in the testing apparatus, hence potential errors in water depth will be greater at higher grades. Whilst not clearly stated in the current testing procedure from Landloch (2023b) each sample is tested first at low slopes and only progresses to steeper grades if the threshold of erosion is not met. Although not explicitly stated this method inherently utilises greater water depths where possible, thus minimising the impact of shallow water induced measurement error. The impact of potential errors in water depth are also reduced by measuring the depth at a minimum of six locations and taking an average to produce the final depth.

Operators using steel rulers will face some difficulty in correctly positioning the base of the ruler at the wet soil surface and may inadvertently push the ruler into the soil altering the water depth measurement. LandLoch have already identified this problem and are now using a small foot at the base of the ruler to assist the operator in correctly identifying the soil surface.

Similarly, the flow width is captured quickly by measuring the top width by hand with a steel ruler. Calculations for flow velocity would require average width, while the use of top width would tend to skew results, particularly as the flow width becomes narrower. There is also some concern here with the highly subjective selection of measurement positions, and implications on repeatability. This has been partly addressed by using the same experienced and competent operator for each test. The potential errors caused by difficulty in measuring flow width are also minimised by commencing tests using shallower slopes as this would tend to increase the width of flow and reduce error.

Despite these concerns with measuring flow width and water depth, the method adopted is likely the only practical and feasible manner to capture this information in the rapid timeframe required in this testing. Similar measurement methods have been employed in U.S. erosion studies in forests (Robichaud et al., 2010) and rangelands (Pierson et al., 2009). Gillies and Foley are not aware of alternative means to capture these data that would be appropriate for this type of testing. Elliot et al. (1997) measured widths of rills for a range of flow rates on high resolution photographs projected on a screen taken from an overhead camera, but did not directly measure flow depths in that study.

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The sediment samples at the end of the flume were collected by taking several short grab samples. Instead, it would be advised to capture the entire width of flow over a single standardised time period, possibly employing a sampling mechanism downstream of the flume. This suggestion may be impractical at higher discharges than our observations during our visit. It is noted that these sediment samples are merely used to detect the threshold of entrainment and thus the quantity of sediment captured is not important.

The authors should note when and where the soil strength measurements will be made. Will they be measured on field sites when collecting samples, in the tray before runoff simulation, in the tray sometime after the runoff simulation, or on sample collected at the same time and from the same place as the trays.

The direct cone penetrometer test may not be useful for this study. The standard that was cited describes the method as requiring a soil depth of 450 mm. If this study is going to use a variation of this test, like less cone penetration, the modified method should be described. If this test is found to be useful for estimating ETV then others will be able to apply the same test.

The size of the foot on the pocket penetrometer should be noted. Typically, this tool is equipped with the shaft of the penetrometer for use on compacted soils 6.4 mm diameter and attaching a 25 mm diameter foot for less compacted soils. In the USDA WEPP cropland field studies (Elliot et al., 1989), the researchers found it necessary to fabricate a 50 mm diameter foot to test the strength of the weak saturated soils following their rainfall/runoff erosion studies. The timing of this test, and whether done in the field or the lab should be reported.

One additional property the authors may wish to consider is the slope of the site where the soil sample was collected. Elliot and Flanagan (2023) reported a correlation coefficient (r) of 0.6 between critical shear and slope of the research site for 36 cropland soils in the U.S., greater than any other property in their study.

No mention is made of the statistical analyses that will be carried out to relate soil properties to ETV. This will likely be covered in reports presenting the results of the study. I assume that the authors will do correlation analyses for all properties, and then some sort of stepwise regression to develop predictive equations.

On page 15, the report states that the initial gradient is 1% in step 5, but in step 8 it states that the gradients considered are 10—30%. I suggest the authors state the purpose of the 1% run. Is it to measure a potential low critical shear, or to prewet the sample before starting the test at 5%; or should step 8 state that gradients ranged from 1—30%?

On the bottom of page 15, the document suggests that a graph may be used to show the relationship between ETV and slope gradient. Once the testing is complete and there is a sufficiently large data set, it might be useful to develop a multiple regression equation to

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estimate ETV from ETV for a standard slope, channel roughness, slope steepness and maybe even channel shape (flat, parabolic or rectangular) and vegetation. Such information would a great improvement on current information on ETV and how it varies with channel gradient (<https://www.agric.wa.gov.au/water-management/suggested-maximum-velocities-surface-water-flow>).

Several references are listed that are not cited in the text. The authors may wish to delete those references. Although not cited, they are good references for this study. Retaining or deleting those references is left to the authors' discretion.

This review has the following suggestions on possible improvements to the testing procedure:

- Objectivity (less subjectivity) determine locations for measuring channel widths and depths, both along the length of the sample, and across the width of soil sample.
- Strengthen the existing focus on capturing measurements at lower surface slopes to reduce possible errors in water depth.
- Further investigation on the sensitivity of ETV results to antecedent moisture content of the sample.
- Add further details in the Methods report describing the sampling tray design if this is not covered in other reports.
- Provide more detail about the soil strength measurement methods and proposed statistical analyses.

These are recommendations only and are not required for our favourable views on the adequacy of the current method to assess the ETV currently employed by Landloch.

In conclusion, the testing methodology used by Landloch to establish the erosion threshold velocities for soils along the Inland Rail Corridor is generally sound and robust. The methodology is scientifically defensible for determining critical shears and erosion threshold velocities. The approach tends to err towards the worst-case scenario for erosion, i.e. bare soil, water with low salinity, and relatively rapid increases in water velocity over unsaturated samples. We have confidence in the ability of Landloch to conduct this testing in a robust and repeatable manner and to respond to the challenges posed by this task over the Inland Rail corridor.

Editorial Suggestions

Cover page, update the date to the latest revision.

Page 1, first line under scope change "method" to "document"

Page 2, line 2 change "*b* is" to "*b* are"

Footnote on the bottom is too long for the footer and was carried over to the bottom of page 3.

Consider increasing the size of the footer or moving this footnote into the main text.

Page 3, second paragraph below equation 5, line 5, change "modified" to "increased"

Page 4, 8 lines from the bottom, change "flumes" to "flume gradients"

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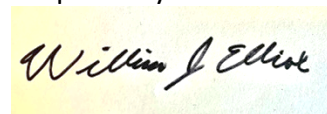
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Page 17, line before “11 INTERPRETING RESULTS”, suggest changing “equation 3” to “equations 3 and 8”

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Respectfully Submitted



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25th November, 2024

To whom this may concern,

The purpose of this letter is to provide a brief technical review of the testing methodology for threshold erosion velocities developed by and undertaken by LandLoch. This testing is being conducted to determine erosion risk and inform engineering designs along the Inland Rail corridor. The review was informed by one visit to the LandLoch Site by Dr Malcolm Gillies and A/Prof. Joseph Foley to view the hydraulic testing of two soil samples. We were also provided two reports: "Methods for Testing Erosion Threshold Velocity (ETV) Method 2 – Direct Laboratory-Based ETV Testing" (LandLoch 2023) and the "Erosion Threshold Velocities Report, Illabo to Stockinbingal Inland Rail Project" (LandLoch 2024). The scope of this review is limited to this testing procedure only and does not consider the wider use of this information in any design or planning by ARTC.

The Centre for Engineering in Agriculture (CAE) at the University of Southern Queensland (UniSQ) were invited to conduct this review by Inland Rail/ARTC. We would prefer if UniSQ was contracted by Inland Rail/ARTC or Bill Elliot rather than through LandLoch in order to remove any perceived impropriety and/or conflict of interest between CAE and LandLoch. Moving forward we are comfortable acting as the local reviewer for the US based discipline expert, Dr Bill Elliott.

The Inland Rail corridor spans a large geographical area and therefore also encompasses a wide range of challenges due to varied hydrological factors and soil conditions. ARTC/Inland Rail are to be applauded for any attempts to improve upon design and subsequent crossing infrastructure expenditure costs with actual measurements of erosion threshold velocities.

The method of on-site soil sampling described to us, and the soil sampling apparatus is robust, and its novelty is to be applauded. It is a technically sound process that will capture representative large samples of the soil surface conditions from many sites; except for very stony soils and soils immediately following tillage. These two particular exceptions are well understood by the Landloch team, and they have verbally indicated that they carefully locate the sample or choose new sample sites when such conditions are encountered. As mentioned in LandLoch (2023) the size of the soil sample is larger than other laboratory testing apparatus in any published literature. This permits the testing procedure to more accurately account for the ground surface conditions present on site including microtopography, plant roots and surface roughness.

We are generally impressed by the testing apparatus in which the soil sample is placed and are comfortable with the efforts to address the transition between the metal flume and the soil surface. Water is applied to the top end of the sample via a wide stilling well and passes over a region surfaced with sandpaper with a similar surface roughness to bare soil, ensuring that the flow transition is as smooth as possible. The edges of the soil sample, including the upstream transition are sealed with

bentonite which appears to function as designed. Care should be taken to ensure that the soil surface is at a consistent height with respect to the entry manifold.

One concern we have with the preparation of the samples is the variance in antecedent moisture content. For cohesive sediments, i.e. clay and loam soils, the structural strength and therefore susceptibility to erosion is potentially influenced by the moisture content. The sampling procedure includes a measurement of moisture content in the field prior to extracting the sample and again at the completion of the flowing water tests in the lab. The procedure also attempts to preserve the moisture content between the time of field sampling and beginning of laboratory testing. While this process is sound the concern is that there will be a range of possible moisture levels in the samples at the time of laboratory testing. This concern may be addressed by either conducting a sensitivity analysis of ETV results to antecedent moisture content and/or using a standardised moisture content for testing. Evan Howard indicated that LandLoch have already investigated the impact of wetting the surface prior to the testing procedure and that this has relatively small impact on the ETV. Formally documenting this investigation should improve our trust in this method.

The testing method is based on established theory to determine shear stress from water depth and bed slope. This theory requires a normal flow regime, a condition that normally occurs after a sufficient distance of flow in open channel of uniform cross section. The distance to establish normal flow may exceed hundreds of metres for deeper water depths. The use of shallow flows in the testing apparatus appears to be an attempt to induce normal flow over a short distance. The error induced by flow regimes other than normal flow is likely to be within the current measurement error for water depth.

Rainwater, i.e. with low salinity, is used for the testing procedure to ensure the water chemistry does not influence the soil detachability (LandLoch 2023). Higher salinity water, i.e. bore water, may reduce the susceptibility to slaking and dispersion and lead to erroneous results. Use of rainwater means that the adopted methodology is repeatable and will yield lower erosive threshold velocities than if other water sources were used.

The approach to measure and control flowrates is sound and should lead to accurate results. The inline turbine meters are of acceptable quality and installed correctly. The use of two separate meters and the associated pipework permits accuracy at both low and high flows.

The greatest concern with the testing procedure is in regard to the accuracy and repeatability of the flow depth and width as water flows over the soil surface. The depth is measured manually with a steel rule by an experienced operator, while attempting to contact the saturated soil surface underwater in the turbulent water flow in which significant distortion in the fluid surface exists. The shallow depths being measured, and the quick measurement process required, undermines the accuracy of water depth data. The accuracy of the velocity is directly related to the accuracy of this measured water depth. Water depth has an inverse relationship with the slope of the soil surface in the testing apparatus, hence potential errors in water depth will be greater at higher grades. Whilst not clearly stated in the current testing procedure from LandLoch each sample is tested first at low slopes and only progresses to steeper grades if the threshold of erosion is not met. Although not explicitly stated this method inherently utilises greater water depths where possible, thus minimising the impact of shallow water induced measurement error. The impact of potential errors in water depth are also reduced by measuring the depth at a minimum of six locations, and taking an average to produce the final depth.

Operators using steel rulers will face some difficulty in correctly positioning the base of the ruler at the wet soil surface and may inadvertently push the ruler into the soil altering the water depth

measurement. LandLoch have already identified this problem and are now using a small foot at the base of the ruler to assist the operator in correctly identifying the soil surface.

Similarly, the flow width is captured quickly by measuring the top width by hand with a steel ruler. Calculations for flow velocity would require average width, while the use of top width would tend to skew results, particularly as the flow width becomes narrower. There is also some concern here with the highly subjective selection of measurement positions, and implications on repeatability. This has been partly addressed by using the same experienced and competent operator for each test. The potential errors caused by difficulty in measuring flow width are also minimised by commencing tests using shallower slopes as this would tend to increase the width of flow and reduce error.

Despite these concerns with measuring flow width and water depth, the method adopted is likely the only practical and feasible manner to capture this information in the rapid timeframe required in this testing. We are not aware of alternative means to capture this data that would be appropriate for this type of testing.

The sediment samples at the end of the flume were collected by taking several short grab samples. Instead it would be advised to capture the entire width of flow over a single standardised time period, possibly employing a sampling mechanism downstream of the flume. This suggestion may be impractical at higher discharges than our observations during our visit. It is noted that these sediment samples are merely used to detect the threshold of entrainment and thus the quantity of sediment captured is not important.

This review has the following suggestions on possible improvements to the testing procedure:

- Objectivity (less subjectivity) of on-surface flow measurement position selections, both along the length of the sample, and across the width of soil sample.
- Strengthen the existing focus on capturing measurements at lower surface slopes to reduce possible errors in water depth.
- Further investigation on the sensitivity of ETV results to antecedent moisture content of the sample.

These are recommendations only and are not required for our favourable views on the adequacy of the current method to assess the ETV currently employed by LandLoch.

In conclusion, the testing methodology used by LandLoch to establish the erosion threshold velocities for soils along the Inland Rail Corridor is generally sound and robust. The approach tends to err towards the worst-case scenario for erosion, i.e. bare soil, water with low salinity, and relatively rapid increases in water velocity over unsaturated samples. We have confidence in the ability of LandLoch to conduct this testing in a robust and repeatable manner and to respond to the challenges posed by this task over the Inland Rail corridor.

Sincerely,



Malcolm Gillies

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