Australia's National
Science Agency

Technical Guidance for delivering Reef Trust Landscape Repair

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Preface

This technical guidance document has been developed to support the $200 m Reef Trust Landscape Repair Program (the program). This program has a stronger emphasis on multi-site or reach-scale approaches than previous programs. It uses the Projector Tool for capturing information about the landscape repair projects. The program has specific requirements for landholder agreements and post-project monitoring. Alongside of fine sediment reductions, co-benefits can also be considered in the selection of sites and treatments.

This guidance document describes the required evidence to support gully and stream bank sites submitted to P2R Projector, including site sediment reductions and treatment designs. The guidance updates Sections 2.3 and 2.4 of the Gully and Stream Bank Toolbox 3rd Edition (Wilkinson et al., 2022) and incorporates the scope of the superseded GECAT and SECAT user guides (Humphreys and Wilkinson, 2021a; 2021b). This document should be read in conjunction with the Landscape Repair Guidance document and Monitoring and Evaluation Guidelines. It is primarily written for the Landscape Repair Program but may be relevant for other reef water quality programs.

Proponents are strongly encouraged to become familiar with this document and to follow the guidance to the extent possible for sites of all sizes. This July 2025 update follows changes to program requirements for independent technical review. The Introduction now includes a summary list of site evidence requirements. Minor updates to terminology are also included. The integrated grazing land management (GLM) component will be updated as the program progresses, and in the interim, proponents are directed to the Toolbox 3rd Edition (Wilkinson et al., 2022). There are plans to update and incorporate this guidance into a Toolbox version 4 in 2027, to support later years of the program (2027-2030).

Glossary of terms

ALS: Airborne laser scanning (airborne lidar) used to develop elevation point clouds from a piloted aeroplane.

Cluster: Multiple sites on the same property or within 1 km on adjacent properties are termed a cluster and if the aggregate cost is larger than the defined Tier 2 threshold, they should each have technical review.

DEM: Digital Elevation Model, a spatial grid dataset in which each pixel has an elevation value.

DoD: DEM of Difference, a spatial grid dataset of the difference in elevation between a recent DEM and another DEM representing topography at an earlier time.

Lidar: Light detection and ranging (sometimes LiDAR or lidar scanning). The instrument, method and resultant data used to develop terrain elevation data.

Project: In P2R Projector a Project is what is commonly referred to as a site.

P2R Projector: The online tool used to report land management activities to improve Great Barrier Reef water quality (https://p2rprojector.net.au/).

Site: A gully or a stream bank area to be rehabilitated. In P2R Projector this is termed a Project. Sites (or projects) sit typically within a single property or land parcel.

Tier: Class of site based on cost. Tier 1 sites have direct costs for design and construction materials and labour that are less than $200,000 total cost, or less than $50,000 of structural treatment cost associated with the structural treatments 3–7 and 10 (see Table 2). Tier 2 sites have direct costs greater than these thresholds.

Toolbox: The Gully and Stream Bank Toolbox (Wilkinson et al., 2022) https://www.dcceew.gov.au/parks-heritage/great-barrier-reef/reef-trust/tools-resources#toolbox

1 Introduction

So that landscape repair delivers good value water quality improvements, site selection and treatment design should be guided by a cost-effectiveness ratio defined as the cost to the program divided by the resulting reduction in GBR sediment load. Treatments should be sufficient to reliably control erosion, but not excessively costly. Service providers are responsible for managing services within the agreed average cost-effectiveness for the project, noting that individual sites can vary above and below the average.

It is expected that landscape repair sites or clusters have been identified through regional or Annual Implementation Plans to define priority stream reaches and priority gully hotspots. This process is outlined in Section 2. Sections 3 and 4 provide template structures for reporting concept designs and detailed designs, respectively, and guidance on what to include in each part of these reports. The comprehensiveness of the documentation required varies commensurate with the size of projects.

Documenting erosion control plans is intended to improve the delivery of landscape repair in several ways (Wilkinson et al., 2022):

1. To inform decision-making within the project team.
2. To demonstrate the work is well-targeted and that decisions are based on best available knowledge.
3. To facilitate consultation with landholders.
4. To define the expected outcomes against which monitoring and validation of completed treatments will be compared.
5. To enable landscape repair to be implemented consistent with the design specification.
6. To record the sediment reductions for the Paddock to Reef Monitoring, Modelling and Reporting Program and document the basis of the estimates.
7. To enable independent technical review by the project team, and technical assurance by the program funder.
8. To facilitate project communications to stakeholders (e.g. through fact sheets or field days).

A concept design report and a detailed design report should be prepared for each cluster or site and attached to Projector as evidence supporting the sediment reduction. Projector requires a separate project for each site with different soil properties and treatment effectiveness. Clusters which consequently require multiple projects can still be planned as one cluster with one over-arching concept design and detailed design by attaching the same design documents to each project in the cluster.

For Tier 1 sites (less than $200,000 total cost or $50,000 of structural costs from treatments 3–7, 10) the concept design and detailed design can be combined into one report addressing all components. For larger, more expensive (Tier 2) sites (greater than $200,00 total cost or more than $50,000 structural treatment costs) preparation and independent technical review of a concept design report is generally recommended first, since it can have significant consequences for the detailed design stage.

In summary, the evidence supporting each site/project in Projector is:

1. Justification of site selection, such as an Annual Implementation Plan as described in Section 2.
2. Concept Design report as described in Section 3. The evidence supporting the sediment reduction and the treatment approach may be in separate documents but should together follow the structure of Section 3.
3. Detailed Design report as described in Section 4, and supporting documents such as the Landholder agreement.
4. Site monitoring reports as described in Section 5:
    - As constructed
    - Annually for at least two years after revegetation is completed.

2 Planning a priority area

So that each priority area is cost-effective, it should include at least some sites that have large baseline sediment yields in recent decades. Resources for prioritising catchments and hotspot areas are described in the Gully and Stream Bank Toolbox, Sections 2.1, 2.2.1 and 2.2.2.

Requirements for Annual Implementation Plans are detailed elsewhere including in the Landscape Repair Program Project Design Guidance Document. The priority stream reach or gully hotspot area can be described within the plan as part of the 'prioritisation of sediment reduction sites' and the 'activities and actions to achieve the sediment delivery target' components, including:

- The basis for identifying the priority stream reach and/or gully hotspot area. Reference the catchment priorities described in the Reef 2050 Water Quality Improvement Plan (The State of Queensland, 2018 and published updates) and the regional planning documents relevant to the project and make them available to technical reviewers.
- The range of typical erosion characteristics in the priority area including measured local erosion rates, the gully soil types or the extent of existing riparian vegetation.
- The extent of eroding gully area or stream length which would be treated.
- The intended mix of treatments that are understood to be capable and cost-effective at controlling erosion.
- The approximate magnitudes of the anticipated sediment reduction and on-ground investment.
- The current engagement level with landholders in the priority area and the analysis and engagement activities needed to support implementation.

Also, list and characterise the prospective sites. For example:

- Key locations and properties within the Reach or Cluster hot-spot area (for example, see Table 12 in the Landscape Repair Guidance document). Stream bank sites should preferably sit within priority stream reaches which will be rehabilitated and protected in their entirety as much as landholder engagement will allow and erosion status requires (see Figure 1). Ideally the sediment reduction is calculated within Projector for at least some of the sites identified in the area.
- Maps showing prospective sites relative to sites completed through prior investments.

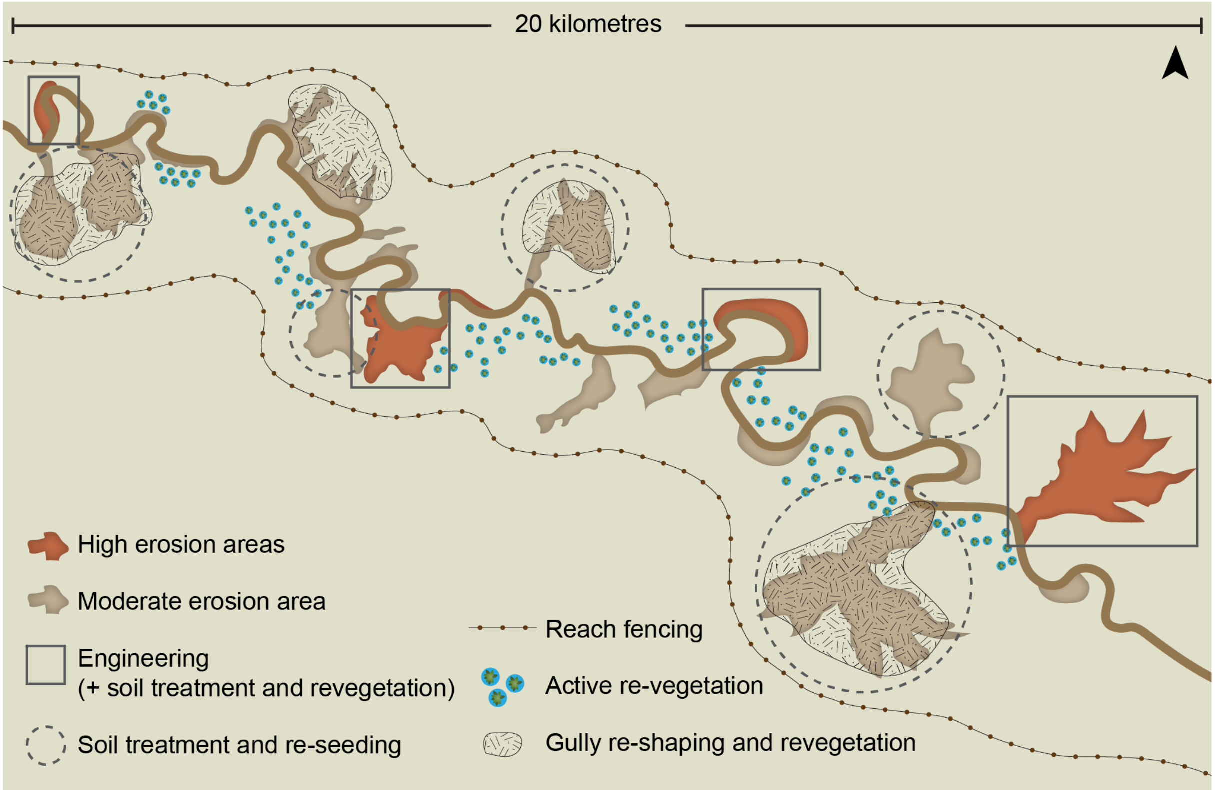

Figure 1: A schematic representation of an idealised landscape repair 'reach'. The reach is made up of several different inter-connected 'individual sites or projects'. This reach may represent a single property or numerous connected properties. [Noting not all reaches or Regions will have both gully and streambank erosion]. The focus is on using structural protection only at very high erosion sites and then using cheaper soil treatment and revegetation options in adjacent areas. All sites should be connected by (native) vegetation corridors. The expectation is that improved or best practice grazing land management (GLM) occurs adjacent to these reaches. This may require additional infrastructure such as internal fencing and water points (not shown) depending on the farming commodity. The graphical production of this figure was provided by Kate Hodge.

3 Site concept design

3.1 Introduction

A concept design describes the basis for undertaking landscape repair at a cluster area or site (Sections 3.2 and 3.3), the planned remediation approach (Section 3.4), demonstration of landholder support (Section 3.5), and the expected sediment reduction and cost-effectiveness (Section 3.6). Where practical, planning should occur concurrently over a cluster of multiple nearby site gully polygons and streamline segments.

The concept design information attached to Projector should be structured around the headings used in this section. The detail of the supporting evidence should be commensurate with the size and complexity of the planned work. A template form for technical review of concept and detailed design plans is in Appendix A.

3.2 Prioritisation process

Briefly describe how the cluster / site was identified, including the priority stream reach or gully hotspot area of which it is a part. Reference the program annual implementation plan, or the equivalent catchment and priority area or reach plan and make them available to technical reviewers (as per Section 2).

3.3 Erosion context

Include the following here:

1. Description of the recent erosion characteristics such as dimensions, processes, soil types, vegetation cover and types.
2. Captioned and representative photos across the cluster or site, supported by a map with photo locations labelled which includes contextual information such as an air photo and existing infrastructure in the area such as fence lines.
3. A broader map and description of the geomorphic setting within the stream reach (stream bank repair) or relative to the stream and surrounding landscape (gully repair).
4. A map of the property or properties including existing fencing and water points (on grazing properties), tracks and other relevant infrastructure (for larger properties this may incorporate the geomorphic map).
5. The history of erosion using a temporal analysis of aerial imagery covering the cluster or site, and a description of the timing of gully initiation and stream bank movement relative to variations in the rainfall record, tree clearing and land use intensification.
6. The historical and current grazing pressure such as the herd sizes and timing of livestock grazing where relevant.

3.4 Remediation approach

Outline the planned treatment approach, including the primary and the supporting treatments (see Table 2 on page 29):

1. Include a map denoting the planned treatments and the existing infrastructure such as fencing, water points and roads.
2. Describe how the approach is suitable to control the erosion issues.
3. Describe how the site will be managed after construction and the specific changes from current management. Describe the immediate and intended ongoing control of livestock access and reference any associated GLM project.
4. Describe the duration and methods for monitoring and maintenance.

3.5 Landholder support

The likelihood of erosion treatments persisting is much higher if livestock grazing pressure is managed to facilitate high ground cover levels in and around sites.

1. Describe how the project integrates with or changes land management and grazing on the properties, and the benefits or issues for property management.
2. Demonstrate that the landholder(s) are supportive of the implementation of the work and that they are prepared to enter a landholder management agreement (LMA) to provide access for construction and monitoring and to protect the legacy of the investment after construction and avoid activities that would threaten it. The form and inclusions of landholder management agreements should be endorsed by DCCEEW. A subset of anticipated elements include:
    a. Duration of at least 3 years post construction but preferably longer,
    b. Scope of landscape repair works agreed,
    c. Site maps,
    d. Access for construction and monitoring,
    e. The ongoing management plan including on grazing properties the control and timing of livestock access, forage management including ground cover and biomass levels that trigger spelling (see e.g., Toolbox sections 3.3, 3.7).
    f. Commitment to activities that improve surrounding grazing practices such as ground cover monitoring and training,
    g. Consent to collect and report relevant data for project management purposes,
    h. The obligations and responsibilities of each party.

3.6 The sediment reduction

Calculating the on-ground cost-effectiveness of project activities at each cluster/site is done within P2R Projector and for gully and stream bank repair it involves 6 steps (Figure 2). The fine sediment reduction (*SR*; step 5) is quantified at the GBR coast. It is estimated as a mean annual value over the 30 years following treatment (e.g. 2020–2050), consistent with the time frame of the Reef 2050 Long-Term Sustainability Plan 2021–2025 (Commonwealth of Australia, 2021), and the associated Reef 2050 Water Quality Improvement Plan (The State of Queensland, 2018). This period is sufficiently long that the climate over the period will contain a typical spread of wet and dry years and can be well-represented by the mean annual historical climate over recent decades.

Cost effectiveness of each cluster/site is the ratio of cost to the fine sediment reduction (*SR* in t/y; Figure 2, final step). The budget cost estimate for the concept design is refined at detailed design stage and should be estimated here as accurately as possible. *SR* is quantified by multiplying a baseline (untreated mean-annual) sediment yield (*BY* in t/y; step 3) by a proportional treatment effectiveness (*TE*; step 4) and by the river sediment delivery ratio describing delivery efficiency from the site to the GBR coast (*RSDR*). *TE* accounts for the time taken for treatments to reach maximum performance following the disturbance and revegetation establishment, and subsequent decline in the average treatment performance associated with treatment failure at a proportion of sites, such as caused by an extreme rainfall event or variable vegetation management (Wilkinson et al., 2022; Appendix A).

BY in t/y (step 3, Figure 2) is determined by multiplying a baseline erosion rate (*BE* in m^3/y; the rate expected in the coming 30 years without treatment from step 2) by soil dry bulk density (*DBD* in t/m^3) and by the proportion of fine sediment (*PF*). *BE* (step 2) is determined by adjusting a historical untreated erosion rate (*HE* in m^3/y; from step 1) to represent the mean-annual value over the 30-year sediment abatement period, by multiplying by factors representing the climate difference between the historical period and long-term average (*HC*), and erosion decay (*ED*). Typically, the parameters requiring the most work at concept design stage are *HE*, *PF* and Cost since these vary the most between sites. The evidence required to support each of these steps is described in the following sub-sections.

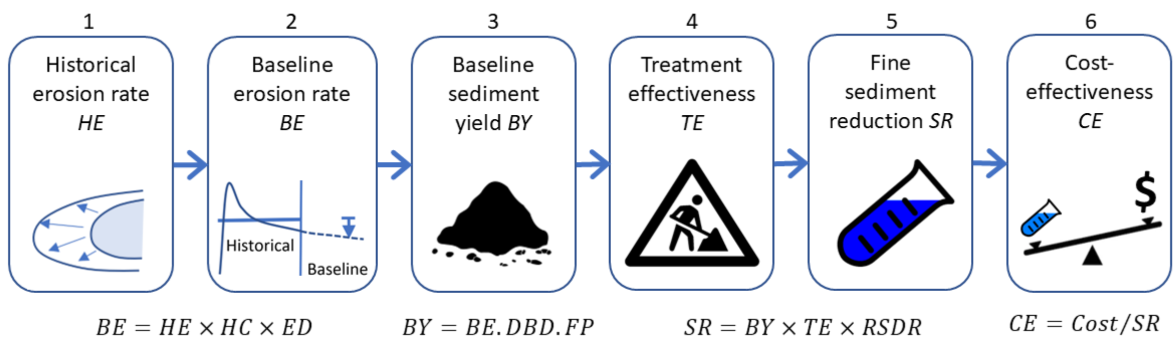

Figure 2. Steps in calculating sediment reductions and cost-effectiveness. Acronyms are defined in the text.

3.6.1 Historical erosion rate

Historical erosion rate should be calculated using the most accurate method provided given the data available. The considerations for selecting the method are described below, followed by guidelines for how to implement and document each method.

A. Selecting the method – Gully erosion

The preferred method to determine the historical erosion rate of gullies is to define the difference in gully volume between the beginning and end of a recent period. This recent period method should be used where sufficient data are available, which are commonly DEMs, air photos and field measurements to define the planform areas and depths. Figure 2 illustrates the most common combinations of these datasets as options. Notes for users:

- Further information is included below on how to use and document the common datasets.
- The option closest to the left of Figure 2 for which data are available will generally give the most accurate estimates and should be used unless those data are of poor quality.
- Where data is limited or of inferior quality, documenting multiple estimates of historical erosion rate can improve the credibility of the chosen option.
- An optional addition to the DEM of Difference method for gullies with internal rain splash and sheetwash erosion is described later in the Baseline erosion rate section.

The Whole Life method estimates the historic erosion rate over the entire life of the gully. It should be used only when no historical air photos or other data on changes in gully volume is available to enable use of the recent period method, and only the current gully volume and gully age can be defined.

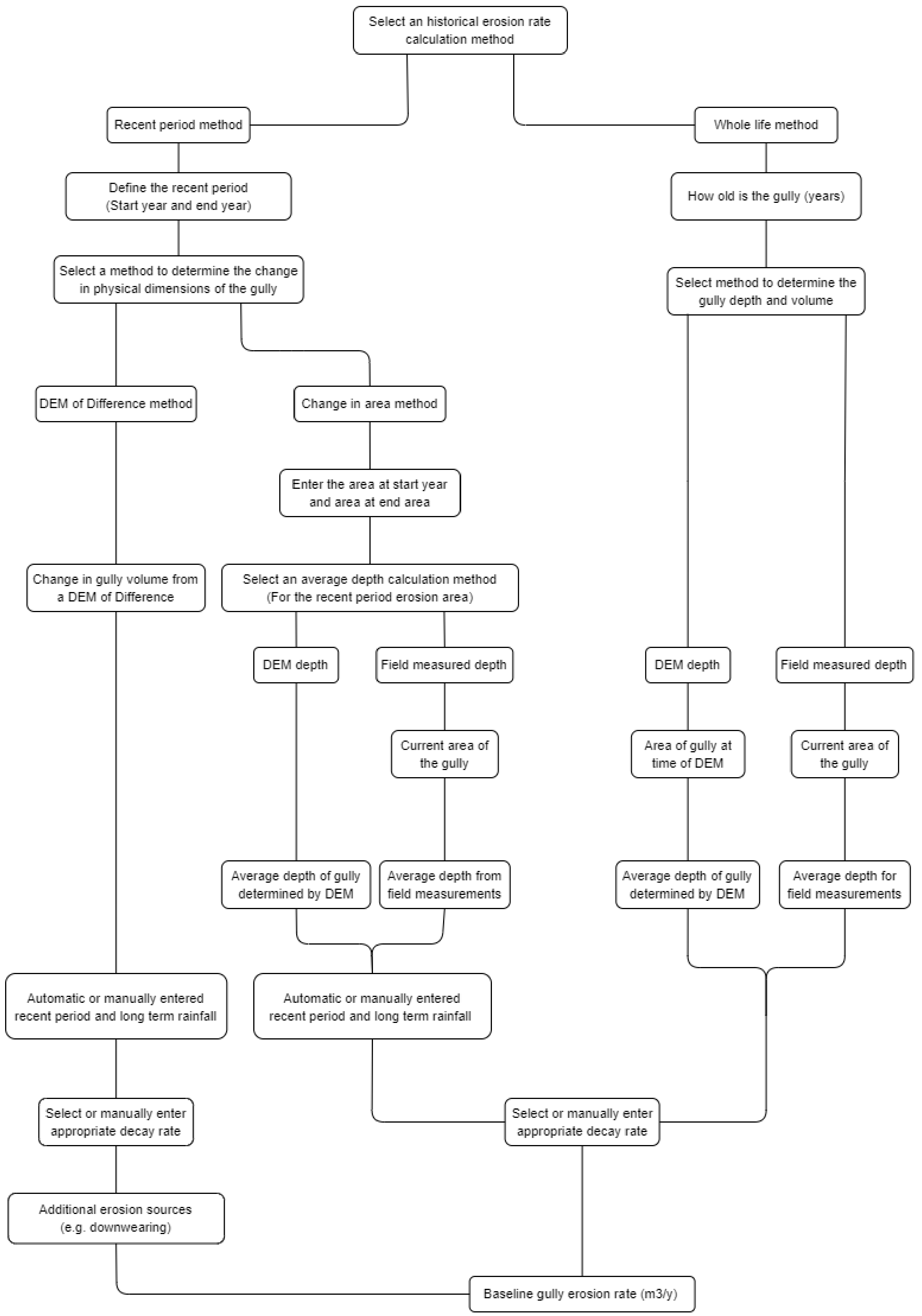

Figure 3. Gully historical erosion rate calculation methods flow chart. The method closest to the left of the chart for which suitable data are available should be used.

B. Selecting the method – Stream bank erosion

The preferred method to determine the historical erosion rate of stream banks is to define the difference in bank position and geometry between the beginning and end of a recent period. This recent period method should be used where sufficient data are available, which are commonly DEMs, air photos and field measurements to define the planform areas and depths. Figure 3 illustrates the most common combinations of these datasets as options. Notes for users:

- Further information is included below on how to use and document the common datasets.
- The option closest to the left of Figure 3 for which data are available will generally give the most accurate estimates and should be used unless those data are of poor quality.
- Where data is limited or of inferior quality, documenting multiple estimates of historical erosion rate can improve the credibility of the chosen option.

The Catchment modelled method utilises Paddock to Reef catchment model predictions of the average long-term erosion rate and sediment contribution from the model sub-catchment within which the cluster or site is located. Technically, this method estimates the baseline sediment yield directly, bypassing the calculation of historical erosion rate and related climate correction. It should be used only when insufficient data on historical bank location is available, and where the planned work extends ideally over a reach of several stream links to account for random error in the predictions for individual links. An extensive riparian fencing and revegetation project would be the most likely use for this method.

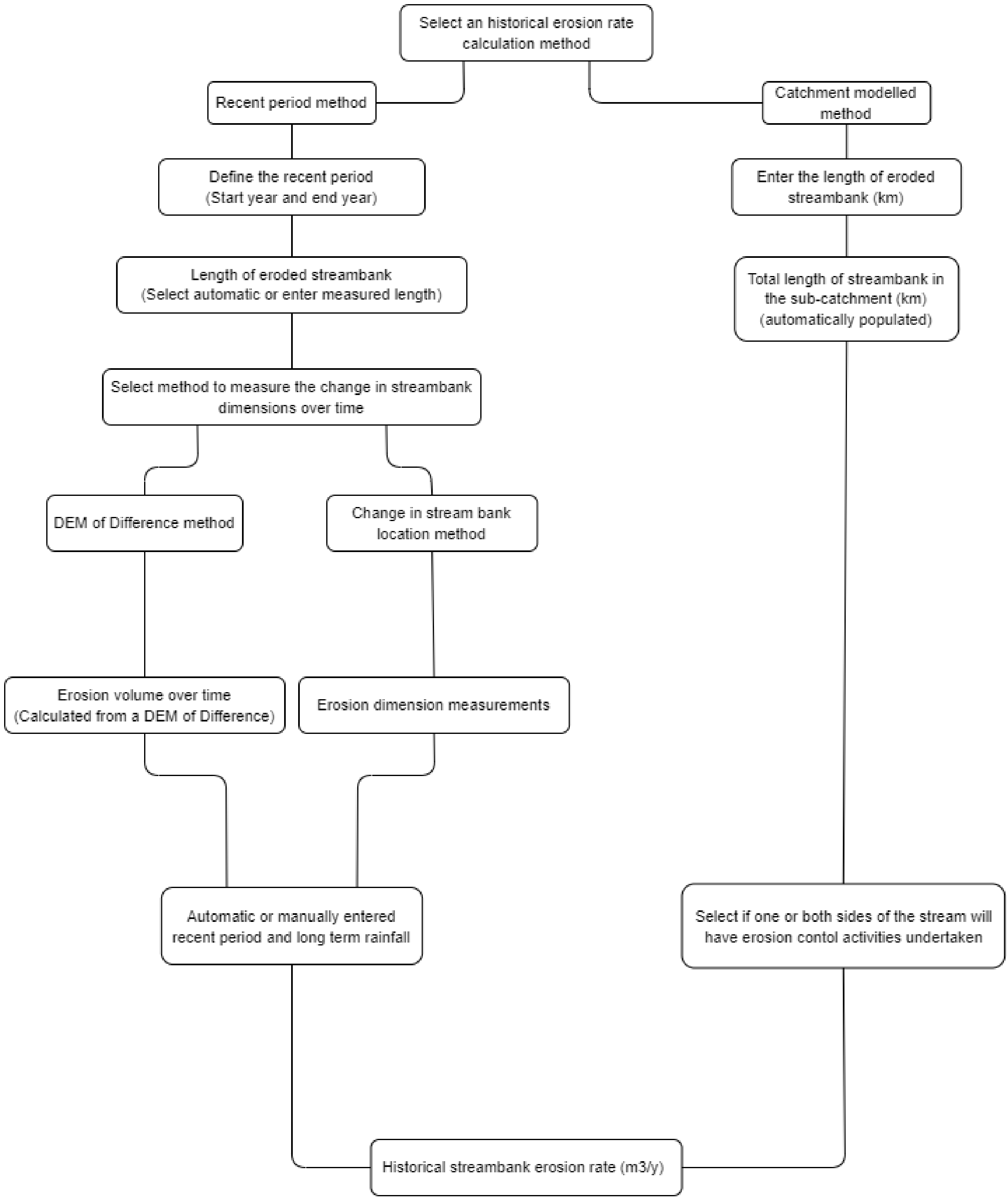

Figure 4. Stream bank historical erosion rate calculation methods flow chart. The method closest to the left of the chart for which suitable data are available should be used. Stream flow climate correction occurs either using stream flow (most common) or rainfall (shown).

C. DEM of Difference method

Use a DEM of Difference (DoD) if two lidar captures are available separated by a sufficiently long recent period to detect erosion. There is no minimum period length but, especially for gullies, periods longer than 5 years are typically better for two reasons:

1. Due to variability in lidar point elevations, DoD has a limit of detection of erosion of typically 0.2–0.5 m that is determined by the terrain, vegetation, and the quality of the lidar datasets related to their point density. Since the erosion magnitude progressively increases with time, the Limit of Detection becomes a smaller proportion of the erosion over longer intervals and so the DoD detects a larger proportion of the actual erosion rate.
2. Longer periods have a climate sequence more representative of the long-term average. While the climate correction factor accounts for variability, uncertainty is smaller when the factor is closer to 1.0.

DoD can be undertaken over shorter intervals such as over a large stream flow event but strong supporting information such as air photos is needed.

The ELVIS repository of publicly available lidar data is available at https://elevation.fsdf.org.au/. Other data may be available locally. Data collected by this program should be made publicly available. Specifications for capturing airborne and UAV lidar data for the purpose of calculating DoDs around gullies and stream banks can be provided by the TAG or by the Queensland Government. The specifications include using overlapping swaths to minimise shadowing.

A DoD can identify deposition as well as erosion. Where the primary erosion process is mass movement such as a riverbank slump, the historical erosion rate should be determined as the net volume change (erosion – deposition). Where deposits contain only coarse material the erosion rate can be determined from the erosion volume alone.

There may be systematic erosion occurring below the limit of detection, for example due to rain splash and sheetwash erosion on gully floors. If additional erosion below the limit of detection has been observed at the site then it can be added as described in the following Section 3.6.2.

The recommended approach for creating a DoD depends on the data point density in points per m^2 (Table 1). The approach should be the one suitable for the lowest point density of the two input DEMs.

Table 1: Recommended geomorphic change approach for different Airborne Lidar (ALS) point densities.

Category	Point density (points/m²)	DEM creation	Approach	DEM resolution	Expected Limit of Detection (LoD) range
Not recommended	< 0.5	N/A	Insufficient data to represent gully and stream bank erosion	N/A	N/A
1	0.5 < 4	Use TIN between ground points to create a DEM	Differencing of regular gridded DEMs (2.5D)	1 m	0.5—2 m
2	4 < 16	Use TIN between ground points to create a DEM	Differencing of regular gridded DEMs (2.5D)	0.5 m	0.2 – 1 m
3	≥ 16	Use classified 'bare ground' LiDAR points OR Use TIN between ground points to create a DEM	Cloud-to-cloud analysis (3D) by CSIRO or others OR Differencing of regular gridded DEMs (2.5D)	≤ 0.5 m analysis resolution ≤ 0.5 m	0.05 – 0.2 m 0.2 – 0.3 m

DEM co-registration (horizontal and vertical alignment)

The first step is to co-register the two DEMs both horizontally and vertically, to minimise systematic error in the DoD. This can be achieved by minimising the sum of squared differences between ground control points (GCPs) common to both DEMs. In most cases, a set of GCPs will need to be defined by the operator. For example, a sealed road surface provides suitable GCPs for vertical co-registration. A building (homestead, water tank etc) would provide suitable GCPs for horizontal co-registration. Visual inspection of an initial DoD (Eq. 1) can be used to identify horizontal or vertical offsets requiring co-registration. Two DEMs that have not been vertically co-registered will often show consistent low-magnitude positive or negative values across the DoD. Two DEMs that have not been horizontally co-registered will often show opposite positive-negative values on the walls of a channel (Figure 5).

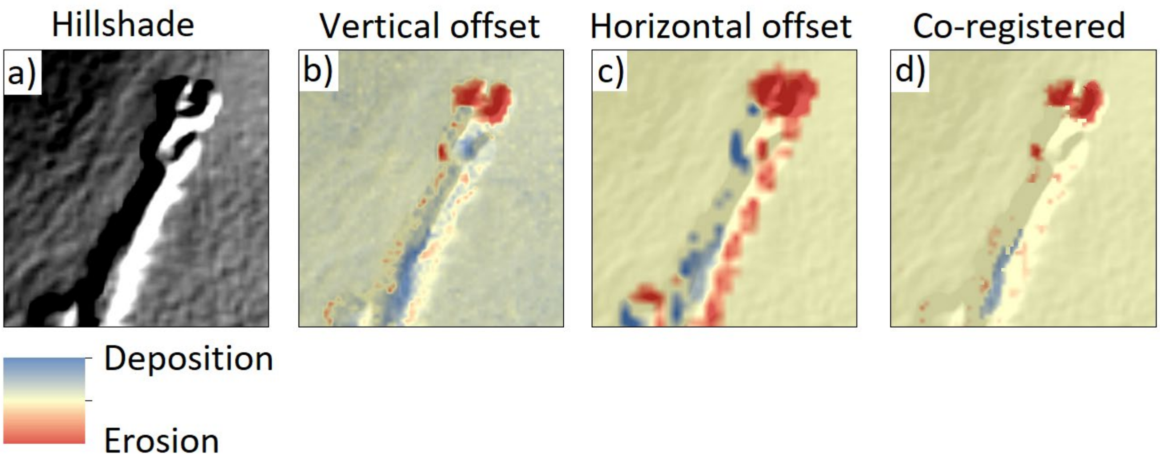

Figure 5: Visual examples of a DEM of difference outputs under different co-registration scenarios. a) Hillshade of DEM. b) A DoD showing faint blue shade across the image (no LOD applied) indicating a vertical offset. c) A DoD showing characteristic opposite positive-negative shading on channel walls indicating a horizontal offset. d) A DoD using two DEMs that have been correctly co-registered.

Limit of detection (LoD) for 2.5D geomorphic change using DEMs

Where possible, it is recommended that creation of DoDs using regular gridded DEMs is done with Prof. Joe Wheaton's freely available software (https://gcd.riverscapes.net/), available as a stand-alone program or as an extension for ArcGIS Desktop. It contains tutorials and guidance for setting the Limit of Detection.

The Limit of Detection (LoD) determines the magnitude of change below which results of a DoD cannot be attributed to 'real' change (i.e., the estimated change may be entirely composed of error). Estimates of change with a magnitude greater than the LoD indicate real land surface change (erosion or deposition) but are still subject to uncertainty. A spatially variable LoD should be used because the error associated with steep and rough surfaces (such as eroding gully walls) is larger than that associated with flat and smooth surfaces. The Wheaton software supports estimation of spatially variable LoD using a fuzzy inference system that incorporates auxiliary datasets to help determine expected error. For gullies, a suitable auxiliary dataset would be a slope raster where high slope values would be associated with larger error.

Limit of detection (LoD) for 3D geomorphic change using cloud-to-cloud analysis

Some recent (since 2018) ALS acquisitions have a point density >16 pts·m^2. This enables cloud-to-cloud change analysis which provides more robust erosion estimates with smaller limits of detection. CSIRO have developed a method for this and can provide a DoD for many of those locations, or otherwise Joe Wheaton's software can be used. CSIRO are developing geomorphic change detection (GCD) maps for areas with two coincident LiDAR point clouds (i.e., sections of the Bowen and Fitzroy) which will be available in 2025.

Volumetric estimation and error equations

The methods described above calculates the annual average geomorphic change estimate (Δ_z) for a given grid cell (x, y) with a magnitude of change (DoD) and estimated error (LoD) as:

$$\Delta_z = (DoD_{xy} \cdot w^2)/yr \ \pm (LoD_{xy} \cdot w^2)/yr \quad (2),$$

where *w* is the resolution of the DEM and *yr* is the number of years between DEM acquisitions. The following is an example annual average geomorphic change estimate for a given grid cell *xy* with the following values:

DEM of difference value	Limit of detection	DEM resolution	Years between DEM acquisitions
DoD_{xy} = 0.7 m	LoD_{xy} = 0.3 m	*w* = 0.5 m	yr = 5

$$\Delta_z = (0.7\ m \cdot 0.25\ m^2)/5 \pm (0.3\ m \cdot 0.25\ m^2)/5 \quad (3)$$

$$\Delta_z = 0.035\ m^3 \pm 0.015\ m^3 \quad (4)$$

For this example, the upper estimate of annual average change is 0.05 m^3 per year and the lower estimate is 0.02 m^3 per year.

Guidelines for reporting DEM of Difference

Document the following points:

1. Average point density for each lidar dataset and the derived DEM resolution.
2. The co-registration method.
3. Demonstrate the accuracy of results with (i) maps of DoD erosion and deposition across and around the gully or stream bank, and (ii) several cross sections across different parts of the erosion feature showing coincidence in elevation outside of the gully or streambank.
4. Describe how the limit of detection was determined.
5. Map the estimated erosion and deposition depth over a hillshade DEM or air photo (e.g., see the stream bank and gully erosion examples below).

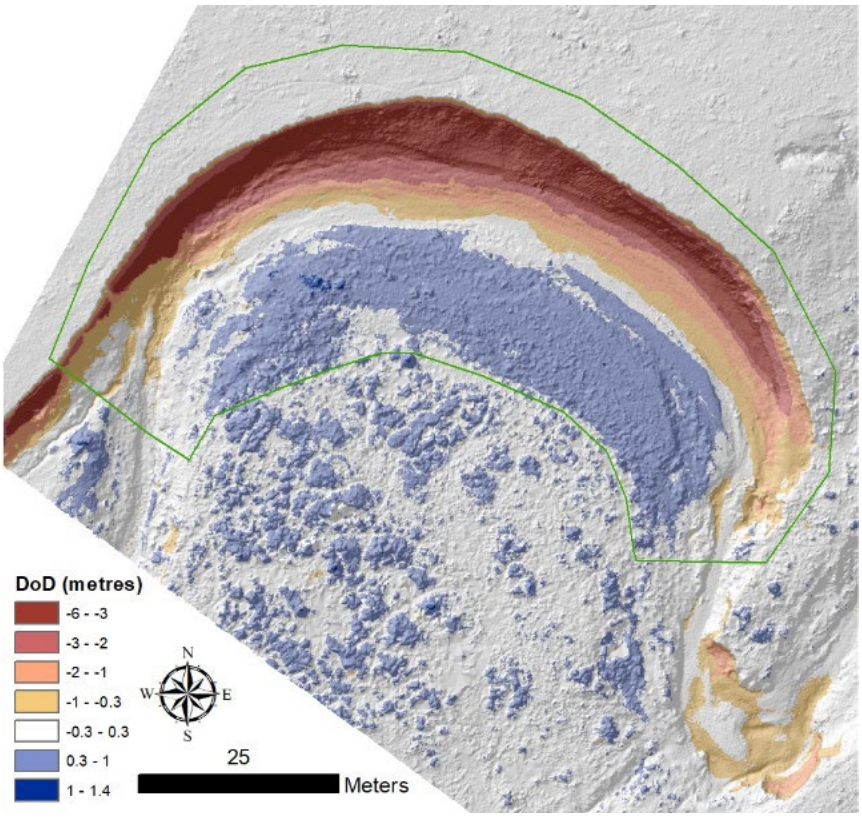

Figure 6: A DEM of Difference with a hillshade DEM behind for a stream bank site. Reproduced from Daley et al. (2020). Note that only erosion within the green polygon was included in the site sediment yield estimate in this case, excluding any erosion which was not to be repaired.

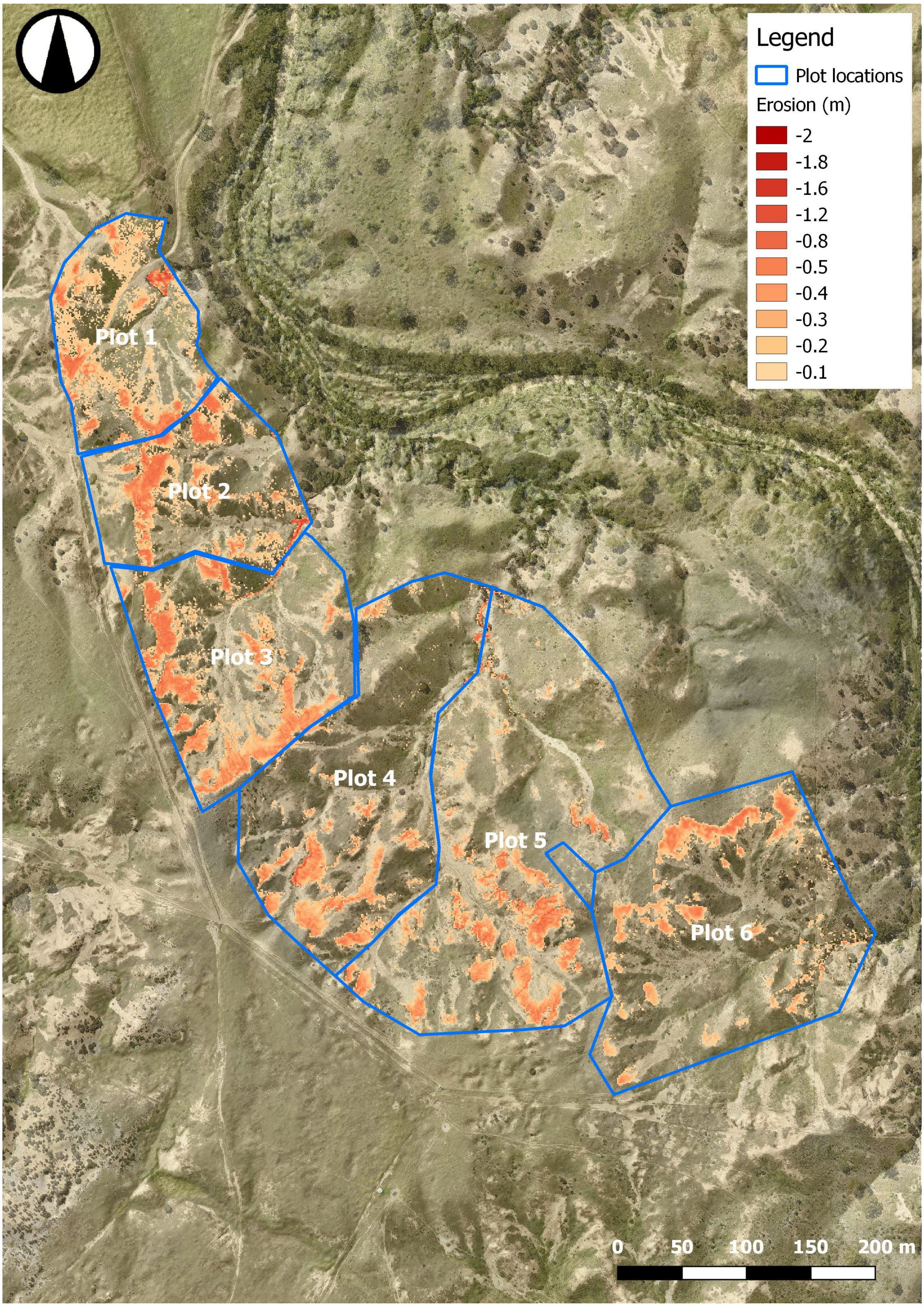

Figure 7. DEM of Difference map for a large gully site. Reproduced from Neilly Group Engineering (2019). Note the bare ground in lower parts of the gullies that is associated with sediment deposition. Calculating a spatially variable limit of detection using the Wheaton software is now required wherever possible (see text).

D. Change in area method

The change in area method requires defining the gully or stream bank extents in the start year and end year, using geo-referenced air photographs. Great care should be taken to accurately digitise the edge of the incised area of the gully from air photos. Preferably a lidar DEM is available for at least the end year and the planform extent can be determined from that (e.g., Figure 8).

Sources of historical air photos include Google Earth, QldGlobe (https://qldglobe.information.qld.gov.au/) and Qimagery (https://qimagery.information.qld.gov.au/). The planform extent of some gullies has been mapped from lidar DEMs in priority areas using a semi-automated method, including synoptic estimates of gully sediment yields (https://maps.eatlas.org.au/). The planform extent of all incised channels is also mapped using a different method which includes the potential of each gully to expand (https://data.csiro.au/collection/csiro:52249).

The erosion depth within the change in area should be determined based on the difference in elevation between a reconstructed prior surface and the end-year DEM. The prior surface must reconstruct the gradient of the surface as realistically as possible considering the topography and pre-existing drainage lines evident in the start year air photo. A planar 'lid' may be appropriate for a gully or stream bank where the surrounding terrain is demonstrated to be very flat based on cross sections and historical air photos. If a lidar DEM is not available, the average depth should be determined using measured cross sections at representative locations.

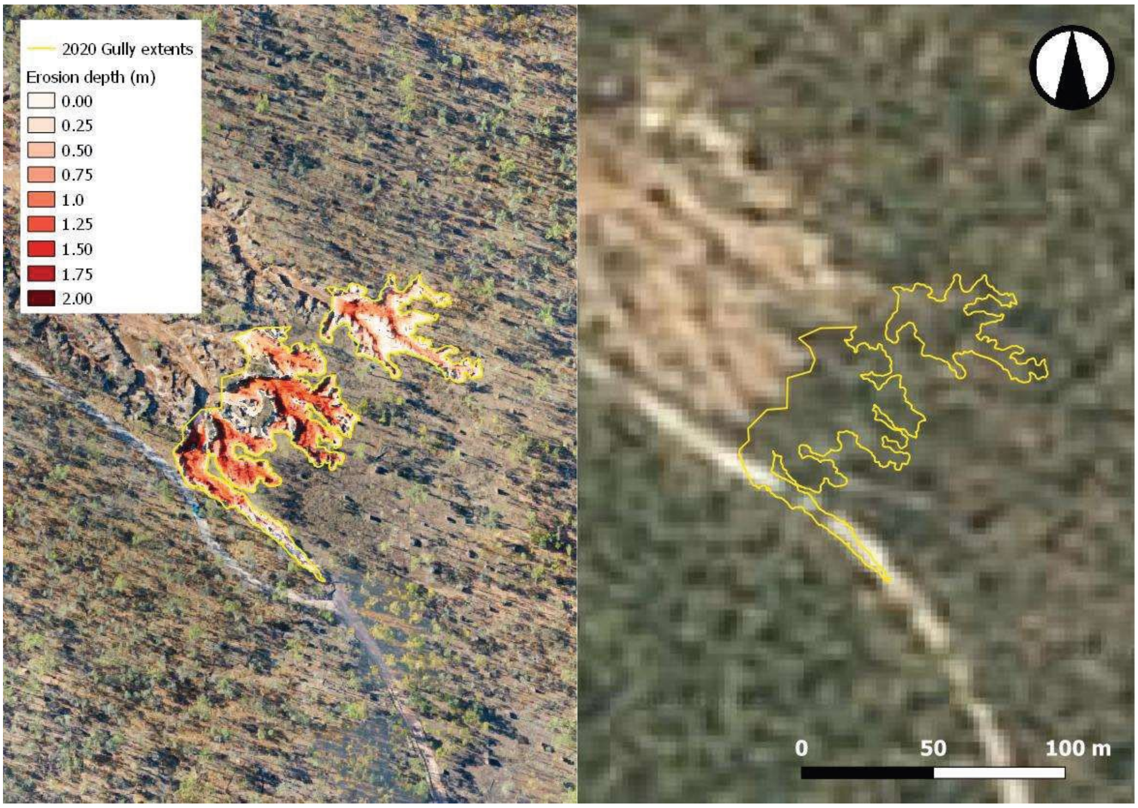

Figure 8. Change in area method for a gully with only one good air photo and a single DEM. Left: 2020 air photo showing the end-year gully extent overlain with erosion depth between the DEM and a prior surface. Right: 2012 air photo overlaid with 2020 gully extent. The use of a planar 'lid' to represent the ground surface prior to erosion was justified by accompanying cross sections. Reproduced with permission from Neilly Group Engineering.

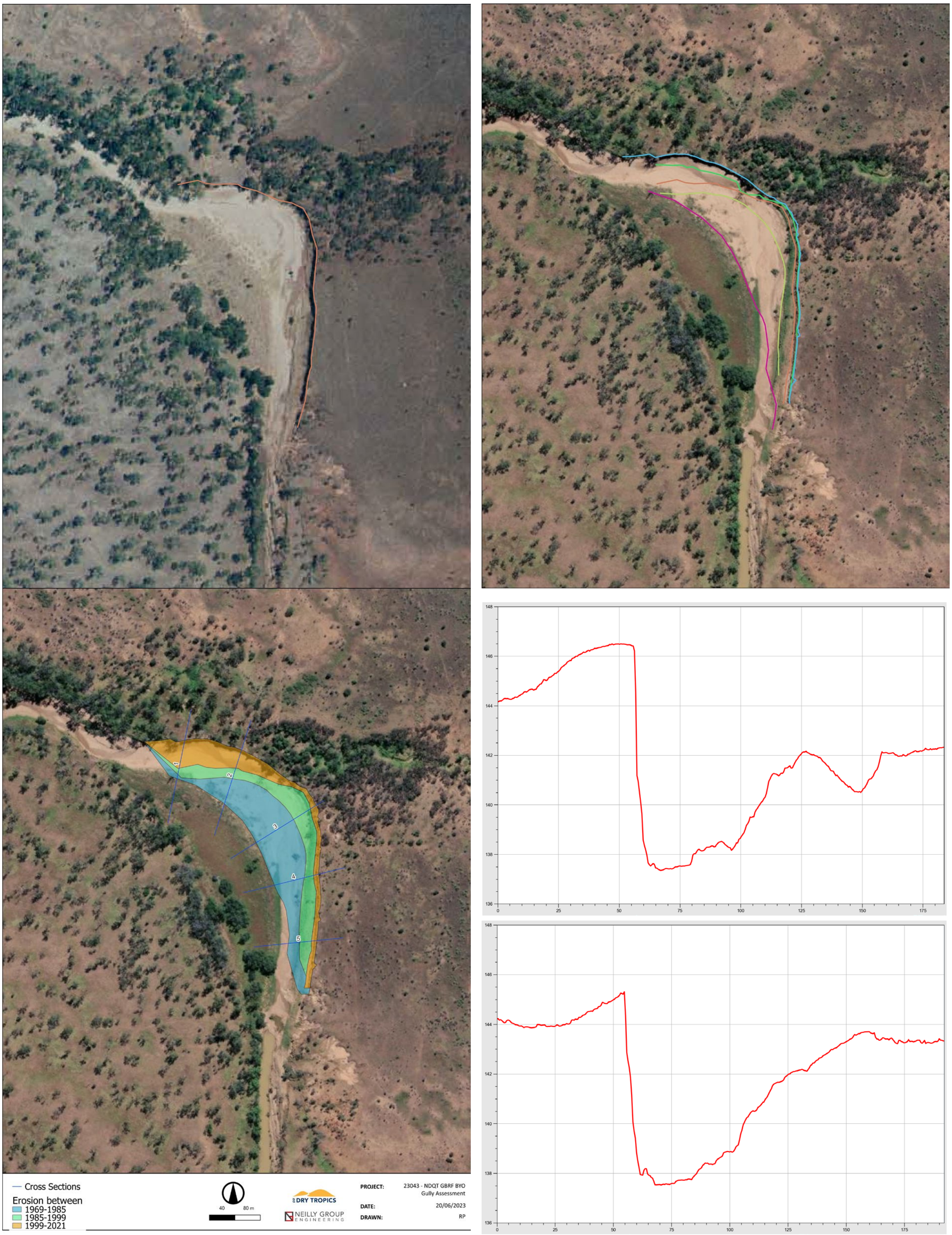

Figure 9. Example of images to include in reporting the change in area method (at reduced size here for the purposes of the example. Each image should be reported at *full page size and high resolution*. Top left: air photo and riverbank position at the start of the recent period (1999). Top right: air photo overlaid with bank positions from 1969, 1985, 1999, 2010 and 2021, to illustrate the ongoing nature of erosion. Bottom left: Erosion extents, with the location of cross sections used to estimate bank height. Bottom right: Two of the five cross sections used to determine bank height. Reproduced with permission from Neilly Group Engineering and NQ Dry Tropics.

Requirements for reporting the change in area method:

1. Include air photographs from the start and end years, overlain by lines showing the planform extent at each date.
2. Include a map of the calculated erosion depth if a DEM and prior surface was used.
3. Include the location of cross sections if they are used to determine the average erosion depth, and photos of erosion cross sections.
4. Report the key dimensions of the erosion cross sections such as gully top and bottom widths and depths, and stream bank erosion depths.

All imagery should be provided at high resolution, over several report pages. A subset of the data used to calculate erosion volume at a stream bank site from change in bank position and cross sections extracted from a lidar DEM is given in Figure 9. These images are compiled onto one page here but were each provided at full page size. Air photos from each year analysed were also provided.

E. Gully whole life

The whole life method is analogous to the change in area method and the reporting requirements are comparable. The only difference is that the erosion area is now the whole gully. The gully age should be supported by air photos before and after the estimated year of initiation, or if initiation occurred prior to the first available air photo then it should be estimated based on historical records, such as the introduction of cattle grazing to the area.

If the gully depth is estimated using a DEM and reconstructed prior surface, it is important that the prior surface should represent the cross section of drainage lines which predated the gully within the current gully area, especially if drainage lines are evident in the historical air photography such as by hill shading or contrasting vegetation.

3.6.2 Baseline erosion rate

A. Historical climate factor (climate correction)

A climate correction factor is applied to the recent period historical erosion rate to account for the recent period being drier or wetter than the long-term average climate, which is the best assumption for the 30-year post construction sediment abatement period. For example, if the recent period was wetter than average then the historical erosion rate would be greater than the longer-term average rate.

For gullies, use the automatic calculation in Projector which is based on the ratio of rainfall between the measurement period and long-term average. Stream bank clusters or sites in first order sub-catchment streams can also use the default rainfall ratio if no stream gauge is present.

For larger streams the climate correction should be calculated manually based on stream discharge. Report the location ID number of the recording station used, the data ranges used (e.g. long-term average 1960 - 2018, recent period average 2000 - 2018), the erosivity measure used as described below, and the value calculated:

- The ratio of mean-annual streamflow in the long term (at least 30 years) divided by mean-annual stream flow during the recent period.
- Rate of events in events per year above a threshold discharge (typically 1:5 years). Count the number of events above threshold in the long-term record and divide by the number of years of record (e.g., 10 events above threshold in 50 years = 0.20 events per year). Secondly, count the number of events above the same threshold in the recent period and divide by the duration of the recent period (e.g., 3 events in 10 years = 0.33). The climate correction factor = long-term / recent period = 0.20 / 0.33 = 0.61
- If the stream bank erosion volume in a short recent period (< 5 years) occurred primarily in a single large flood, then an alternative is to enter the period over which erosion occurred as equal to the recurrence interval of that flood peak/duration (e.g., 20 years), rather than the period length between the DEMs or air photos, and then apply a climate correction factor of 1.0.

B. Gully erosion decay factor

The baseline erosion rate is defined as the erosion rate over the 30 year post-construction sediment abatement period in the absence of erosion control treatment. To predict this, recent historical gully erosion rates are multiplied by a decay factor recognising that erosion rates typically decay exponentially once a gully is more than several decades old.

The decay factor is determined considering the gully age relative to the length of the recent period of measurement. If the recent period duration is a small proportion of total gully life, then the recent rate is a good indicator of the baseline rate. For example, if the recent period is short (e.g., 5–20 years) and the gully age is more than 50 years then the decay factor is close to 1. However, if the recent period is a large proportion of the total gully life, or the whole of life method is used, the baseline rate will differ by a larger amount from the average over the historical period.

For example, if the period is approximately half of the gully age or more or if the whole life method is used then the decay factor default values are 0.5–0.7 depending on gully age (see the Projector interface).

C. Additional sediment sources

In most gullies, most of the sediment is supplied by wall erosion which can be quantified by DEM of difference (DoD) or change in area methods. However, within gullies in erodible soil areas that are denuded of vegetation can undergo rain-splash and sheetwash erosion (downwearing), which in gullies of large area can contribute significantly to the overall sediment yield (Daley et al., 2023). This process is often indicated by erosion-resistant material such as rocks or cattle dung becoming perched on pedestals, around which downwearing has occurred. Note that it is not essential to include downwearing in gully baseline sediment yield estimates, and in many gullies it is unlikely to be a significant contributor, particularly those without extensive areas that are permanently denuded of vegetation.

Where the historical gully erosion rate is determined by DEM of Difference (DoD) analysis, downwearing can occur at rates smaller than the limit of detection. Therefore, downwearing within the permanently denuded area where erosion is less than the DoD limit of detection can be added to the erosion rate (m^3/y) calculated from DoD. Where the Change in Area method is used, downwearing can add to the erosion rate estimated from the lateral expansion if the gully area is large and includes denuded areas.

Preferably, the erosion rate (mm/yr) should be estimated based on erosion pin measurements from the relevant parts of the gully to be treated, from monitoring over at least 1–2 years. Alternatively, a conservative estimate of the rate of downwearing can be based on monitoring and reporting of the process in nearby gullies at locations with comparable soil and gully form. This estimate will be typically in the range of 5–10 mm/y, and the data source should be referenced, or the data reported as described below.

Gully floor downwearing measurements should be reported as follows:

1. Define the area (m^2) of downwearing erosion occurring, which is the area having (i) erosion less than the DoD limit of detection (i.e. excluding where the DoD is used to detect change), and (ii) that is permanently bare of vegetation. Downwearing can also be added as a source in the change in area method but should cover only the part of the gully within the area that is chronically bare and has physical evidence of erosion.

2. Include a map of the area of downwearing, showing the ground cover and the locations of rain splash and sheetwash measurement.

3. Include several photos of erosion pedestals and/or erosion pins across this area, with a scale reference such as a ruler or tape measure.

4. Measure erosion rate over at least one wet season at >10 representative locations per hectare for small gullies, up to 30 locations for very large gullies. Report a boxplot of the measured erosion rates, the mean and median values, and map the spatial variability in the measured rates.

5. Describe the start and end times of measurement and the rainfall in the measurement period relative to the long-term average. Apply a climate correction to the downwearing erosion rate if the measurement period was wetter or drier than average, acknowledging that the relationship between rainfall and gully floor erosion is poorly understood (Daley et al., 2023).

D. Gully sediment delivery ratio

Typically, all fine sediment from gullies is delivered to the stream network. In rare occurrences of discontinuous gullies, or gullies upstream of farm dams or a hillslope flood-out without a defined channel, Projector provides delivery ratio options ranging from 0.4–0.8 depending on the drainage line length without a defined channel and the surface vegetation:

1.0: Standard: A continuous defined (incised) drainage channel connecting the gully to the stream network

0.8: Non-channelised distance from gully to stream is between zero and 50 m

0.6: Non-channelised distance from gully to stream is 50 – 200 m, degraded landscape

0.4: Non-channelised distance from gully to stream is more than 200 m, natural landscape.

3.6.3 Baseline sediment yield

The baseline (untreated) fine sediment yield (t/y) is the baseline erosion rate determined above, multiplied by the proportion of soil <20 microns in particle diameter and by the soil dry bulk density (t/m^3).

Tier 1 sites

Soil properties for tier 1 sites (< $200,000 total or <$50,000 structural treatment cost) can be based on soil sampling at other sites in the cluster with apparently similar soil texture. The default value provided in P2R Projector can be used if these are unavailable. Other alternative soil data sources are the P2R dropbox (best), or ANSIS (https://portal.ansis.net) or the Soil and Landscape Grid of Australia (https://esoil.io/TERNLandscapes/Public/Pages/SLGA/index.html).

Tier 2 sites

Existing soil mapping datasets often poorly represent the properties of stream bank and gully soil. Detailed soil information can accurately quantify the proportion of soil that is <20 microns and also inform soil amelioration needs. Therefore, for large erosion control clusters or sites (e.g., >$200,000 or >$50,000 structural treatment cost) it is good practice to undertake soil sampling and laboratory analysis where practical. The safety risk posed by crocodiles may curtail the feasible spatial extent of stream bank sampling.

In general, bulk density values are much less sensitive than particle size and soil chemistry (based on unpublished data from GBRF projects), so default bulk density values can be applied.

In general soil cores are not needed and representative samples can be collected as follows:

1. Prepare and report a map of the major contrasting soil units across the site (e.g., major differences in texture and colour).
2. Sample each soil unit separately at locations that are representative of the active erosion; e.g. from the gully or stream bank erosion face. Multiple sample locations will be needed for extensive units (e.g., 3 for a unit up to 1 ha in area).

3. At each location, scrape off weathered or leached material from the exposed soil surface to a depth of at least 10 cm.
4. Sample the depth profile of each soil unit by taking a uniform amount of material from the surface down to the full depth of erosion. For high banks, several sub-samples can be collected down the depth profile and combined in proportions that are representative of the depth profile.
5. Determine the proportion of each total sample that is < 20 micron by weight by laboratory analysis (sieve partitioning of coarse fractions and then hydrometer method).
6. Estimate the average properties for each site based on the estimated proportion of eroding volume that each sample represents.
7. Analyse the requirements for chemical amelioration (if relevant) based on standard agricultural testing of Electrical Conductivity, Exchangeable Sodium Percentage, pH, Cation Exchange Capacity. For further information and advice on soil sampling and analysis contact soils@qld.gov.au.
8. Provide the data to the Department of Environment and Science soils@qld.gov.au if requested.

For more information see the Australian soil and land survey field handbook (The National Committee on Soil and Terrain, 2009) or McKenzie et al., (2008) or Queensland Soil Conservation Guidelines (https://www.qld.gov.au/environment/land/management/soil/erosion/guidelines)

Report soil properties from site sampling as follows:

- Include a map and photos showing the sample locations and profile depths.
- Photograph the sampling locations and methods.
- Laboratory analysis results by sample.
- Calculate the weighted average properties across each site based on the length and depth of each unit sampled relative to the length and depth of the site area of active erosion. If there is significant difference in soil properties between sites they should be entered separately into Projector.

3.6.4 Sediment reduction

A. Treatment effectiveness

The suitability of the planned bundle of primary and supporting treatments for controlling the erosion problems described earlier should be justified (capable but not excessively costly).

Select the minimum-cost techniques suitable to control the erosion: Guidance on the objectives and suitable locations for each erosion control technique is summarised in Table 2 (3rd column) and detailed in Section 3 of the Gully and Stream Bank Toolbox (Wilkinson et al., 2022). Design to minimise the risk of failure, such as by ensuring hydraulic structures can withstand a one in 50-

year runoff event, and that known limitations are followed. Based on experience in Reef Trust Phase IV, cost-effective treatment of sites with a range of erosion rates (for example, t/ha/year of gully area or stream bank length) can be achieved, provided that the intensity and unit costs of the treatment are adjusted to suit the site.

Adapt the design of the techniques to suit the site conditions: The techniques must be designed to be fit-for-purpose at the scale and context of the erosion processes at the site. Ensure consistency with restoring ecosystem health and resilience.

Treatment identification and effectiveness should be determined as described in Section 2.2.4, and Table 1 in the Gully and Stream Bank Toolbox which is reproduced overleaf. The overall effectiveness of the bundle Treatment effectiveness is assigned based on the primary treatment. This is the treatment which primarily determines the effectiveness of treatment over the whole site; it may be the treatment with the highest effectiveness value but is not necessarily so if an intensive treatment (e.g., a rock chute) is implemented in a small portion of a site in which most erosion receives less-intensive treatments (e.g., fencing and revegetation). The values assigned by Projector for the primary treatment assume that at this stage only initial maintenance is funded for the post-treatment years. Applying the stated effectiveness values requires that:

1. **The primary erosion control technique must cover the full spatial extent over which baseline sediment yield is calculated**. Do not use baseline sediment yields of whole features where only a subsection is treated. If different primary treatments will be applied in different subsections of the site, then either assess the sediment reduction from each subsection separately or justify an intermediate effectiveness value and review this independently.
2. **Implement all supporting activities fully** (Table 1, 4th column).
3. **Design and construct erosion control using best-quality industry practice.** Guidance on design and construction procedures is provided in Section 3 for each technique. To minimise risk of failure it is recommended that engineered hydraulic structures be designed to withstand at least a one in 50-year runoff event. Minimise the area of vegetation disturbed by construction.
4. **Control risks of failure by using an independent technical review of planned designs and site monitoring.**
5. **Plan and implement monitoring and maintenance**, as described in Section 4 of the Toolbox.

The stated effectiveness values are appropriate to typical site conditions. Effectiveness can be increased or decreased if appropriate to the site conditions. For example, stream bank fencing and weed control may be more effective on small streams with low banks.

Table 2. Erosion control treatments, arranged in order of increasing complexity (unit area cost), for gully erosion (1–7) and for stream bank erosion (8–10). Each primary treatment has defined conditions for when to apply it, which are further detailed in the Toolbox Section 3. Implement each primary treatment as a bundle with the relevant supporting treatments listed. The estimates of erosion control effectiveness are defined for 2 maintenance regimes as described in Section 3, based on documented local and global studies (see Appendix A). Refer to footnotes. Reproduced from Wilkinson et al., (2022).

Erosion control treatment (darker colours denote foundational activities, which should also support more intensive activities shown in lighter colours)	**Relative unit area cost/ technical complexity**	**Conditions when to consider applying the treatment**	**Recommended supporting treatments** (those in brackets apply in some cases)	**Estimated effectiveness** (assuming recommended supporting treatments are undertaken if required)[D] **Initial** maintenance	**Ongoing** maintenance	**Specification** (see Toolbox section)
1. Improving grazing management in gully catchments[A]	$	On properties with land in poor condition, and on which other erosion control activities are also implemented.	2	0.1	0.2	3.2
2. Fence to control livestock access to gully sites	$$	Essential prerequisite for all activities where livestock are present (may result in additional watering point being required).	1	0.1	0.2	3.3
3. Porous check dams	$$$	To revegetate floors of gullies with small catchment areas <6 ha. Requires gully wall protection in highly dispersive soils. Also used as a supporting activity to maintain floor stability in intensively treated gullies.	1, 2	0.2	0.3	3.4
4. Gully runoff diversion banks and drainage management[B]	$$$	Where overland flow or road runoff is contributing to erosion and diversion can be safely implemented. Contour ripping only under limited conditions.	1, 2, (3)	0.4	0.5	3.5
5. Gully head rock chute	$$$$	At rapidly moving gully headcuts (e.g. >1 m/year over last 10+ years).	1, 2, 3, 4	0.6 0.8[E]	0.7 0.9[E]	3.6
6. Gully reshaping and revegetation	$$$$	Large rapidly eroding gullies with dispersive/slaking soils – EAT[C] class 1 & 2.	1, 2, 3, 4, (5)	0.6	0.7	3.7
7. Gully reshaping and rock capping	$$$$	Large, rapidly eroding alluvial gullies with dispersive/slaking soils – EAT[C] class 1 and 2, or with poor control of livestock access.	1, 2, 3, (4, 5)	0.8	0.9	3.8
8. Stream bank fencing and weed control	$$	Essential wherever livestock present (may cause additional watering point to be required). Suitability depends on having local seed sources and effective weed and livestock management.	1	0.1	0.2	3.9
9. Stream bank revegetation (planting)	$$$	Where existing woody vegetation cover is <25% foliage projected cover, weed problem is manageable with active planting, and/or where more immediate reduction of erosion rate is required.	1, 8, (10)	0.2	0.3	3.10
10. Structural stream bank protection and revegetation, or bed protection and revegetation	$$$$	Only if extensive section of bank erosion with rates >1 m/year – requires consultation and approval from technical team.	1, 8, (9)	0.6	0.7	3.11

A Apply to the sediment yield of gullies directly affected. Not additional to effectiveness of other gully erosion control activities. Effects on hillslope erosion can be estimated using the Paddock to Reef Projector tool.
B If the drainage work reduces runoff into the gully by a large proportion (>0.5) then the effectiveness can alternatively be 0.2 in addition to the effectiveness of in-channel techniques
C Emerson aggregate test (EAT)
D The technical information used to set effectiveness values is described in Toolbox Appendix A. The Landscape Repair Program is implementing initial maintenance. Ongoing maintenance runs for 30 years.
E Apply only if gully is a linear gully with length <50 m. Only applies to the headward extension component of the erosion directly associated with the chute.

If treatment of a gully or stream bank is planned that has been previously treated, then the effectiveness of the new project should be calculated as the difference between the planned and previous treatments. For example:

- If diversion banks were previously installed above a gully and now it is planned to reshape and revegetate the gully, then the additional effectiveness is 0.6 – 0.4 = 0.2.
- If half of a site is already revegetated and the new treatment is infill planting of the other half of the site then the effectiveness is half of the default effectiveness for that treatment.

If work has occurred at the site previously then the baseline sediment yield should be calculated only for the area that is now being treated.

Describe how the site will be managed after construction including duration of maintenance and monitoring.

B. River sediment delivery ratio

The river sediment delivery ratio (RSDR) is provided in Projector from Paddock to Reef catchment modelling and is determined by modelled sediment deposition in reservoirs and floodplains downstream of the site. Floodplain deposition can occur either during overbank flows or within the channel margins.

3.6.5 Cost-effectiveness

So that the approximate site cost-effectiveness can be calculated and reviewed, list estimates for all direct costs, including:

- site design,
- construction supervision,
- labour and materials for each treatment.

Other costs can typically be covered by project planning resources, such as site identification, communication, monitoring, reporting and project administration. A more detailed costing should be specified in the detailed design stage.

4 Detailed design reporting

The detailed design report should describe the objectives to be achieved by the primary and each supporting treatment and all the information communicating how to construct the treatments. If a site proceeds directly to a detailed design report without technical review, then all components of the concept design report should be included within the detailed design report.

The length and detail of a detailed design report is commensurate with the size and complexity of the planned work.

The detailed design report should include resolution of any issues not resolved at the concept design stage.

4.1 Updated sediment reduction

Update the sediment reduction, including:

1. Refined erosion rate estimates if new data are available or the planned extent of work has changed.
2. If default soil properties were used for convenience at concept design stage, then now ensure that the soil properties data follows the recommendations of Section 3.6.3 to refine the sediment reduction.
3. Refine the treatment effectiveness if planned erosion control techniques or details have changed since concept design stage.

The PSC and DCCEEW should be notified of changes to sediment reductions after endorsement of a cluster or site concept design.

4.2 Treatment design method and specifications

Detail the planned erosion control techniques, including:

1. Maps of the extent of each technique relative to the erosion and existing infrastructure.
2. Describe how the design objectives and the suitability of the treatment for the site was determined, and how considerations for design and construction in Section 3 of the Toolbox have been addressed, for the primary and supporting treatments. The design should be comprehensively reported commensurate with the size of the planned work.
3. It is expected that hydraulic structures will be designed for at least a 50-year Annual Recurrence Interval event magnitude and duration (or 2% Annual Exceedance Probability). Include hydraulic modelling outputs for stream bank structural treatments, gully reshaping and diversion banks, and CHUTE (Keller, 2003) or equivalent outputs for rock chutes. Report both the existing and as-built conditions. Some important design details to include are listed in Section 3 of the Toolbox.

4. Support earthworks surface treatments by soil chemistry analysis and amelioration if required (e.g., Toolbox section 3.7).
5. Revegetation reference ecosystem, species mix, planting density and establishment methods.
6. Fencing and livestock watering design.
7. The revegetation plan for the site including species selection and establishment methods.
8. A schedule of quantities and the budget on-ground cost for each primary and supporting erosion treatment.

Design should be undertaken by qualified and experienced specialists, such as those listed in the skills needs box in Section 2.2.1 of the Toolbox. Structural designs should be RPEQ certified if failure poses risk to public safety.

4.3 Construction plan

Include a construction step by step plan and technical specifications and methods to demonstrate that the design can be implemented as specified. This should include:

- Specify hold points for inspection by experienced supervisors of consistency with design specifications.
- Assess the health and safety risks and describe controls.
- Include a construction schedule that minimises risk of structural or revegetation failure considering expected seasonal climate.
- Confirm that regulatory permits such as vegetation management have been applied for and that construction will not occur prior to approvals being received.

4.4 Landholder agreement

The written agreement should be attached for all sites and include the elements listed in Section 3.5.

4.5 Construction and implementation

Ensure the construction of all structural and revegetation treatments follows the specifications given in the endorsed detailed design. Confirm any deviations that may influence the effectiveness with the technical reviewer and funder.

Ensure that the considerations for construction and implementation in Section 3 of the Gully and Stream Bank Toolbox (Wilkinson et al., 2023) are followed. Schedule sufficient time for ordering materials and to check that they meet the specification.

Ensure that the appropriate skills are on hand during construction (see skills needs box in the Toolbox Section 2.2.1). This includes the skills to inspect the construction thoroughly at specified hold points for consistency with design dimensions and specifications and to determine the action required to correct any deviations from the specification.

4.6 Site monitoring and maintenance plans

Site monitoring demonstrates the completion of the erosion control treatments, their full establishment, and identifies any teething issues that require corrective actions. The Landscape Repair Program Monitoring and Evaluation Guidelines describe requirements in detail. The monitoring and maintenance sections of the Detailed Design Report should include:

Monitoring plan:

1. A report on pre-treatment monitoring.
2. Define the monitoring frequency (sufficient to respond to maintenance needs based on climate) and duration (at least 3 years wherever possible).
3. Include a layout map of the monitoring locations on an air photo, relative to the treatments and existing property infrastructure. The monitoring locations should include all hydraulic structures and coverage of revegetation treatments.
4. Describe the protocol for site monitoring according to Toolbox Section 4 and the Landscape Repair Program Monitoring and Evaluation Guidelines, including:
    - 3-6 photo points,
    - Treatment intactness including livestock integrity of fences, vegetation cover and composition, the integrity of erosion control structures, control of livestock access, stocking rate during grazing periods,
    - Landholder perspectives including demonstrated on-going commitment to the maintenance of the site as per the land management agreement,
    - P2R perception of Practice change survey
    - Commentary on First Nations participation
    - The main apparent threats to the success of the treatments,
    - The maintenance needs identified.

Maintenance plan (Section 2.6 and Section 4 of the Toolbox). The maintenance plan should be tailored to the planned treatments including, for example:

- Plant establishment watering
- Weed control
- Repairing structural intactness,
- Reseeding or tree replacement
- Remediating surface drainage to prevent damage from runoff concentration on batter slopes.
- Digging out, fill and compacting tunnel erosion
- Excluding livestock from treatment areas for as long as possible to ensure vegetation establishment.

5 Site monitoring

Requirements for LRP site monitoring are described in the Reef Trust Landscape Repair Program Monitoring and Evaluation Guidelines. Monitoring stages are reported as follows:

Pre-construction monitoring

Attach a report on pre-construction monitoring to the project (site) in Projector at Detailed Design stage.

Try to select monitoring locations that are representative of the site and that can be continued after construction and in following years. However, it is fine to include pre-construction photos from additional locations that don't end up as monitoring locations and this will assist technical review of the concept and detailed design reports.

Any modifications to the standard monitoring methods for the project should be described.

Post-construction monitoring

The initial post-construction monitoring report for each site (or multiple reports for a cluster) are attached to Projector to demonstrate completion of implementation.

The purpose of the initial post-construction monitoring is to demonstrate the construction has occurred consistent with the detailed design and the revegetation treatments are initially established. This report should include:

1. An 'As Constructed Report' including
   a. Demonstration that construction was aligned with the detailed design specifications, for example;
      - UAV photos showing the extent of the treatments,
      - DEM of difference before-after construction (if available),
      - photos of rock chute cross sections and rock size mixture,
      - the height of structures relative to the gully or stream bed,
      - the extent of the revegetation area including the fencing setback from the bank top
      - The revegetation completion noting that complete ground cover may not be realistic depending on the time since grass seeding.
   b. Include photos taken at construction hold points, such as of the grubbed foundation for diversion banks, geofabric placement underneath rock chutes and reshaped surfaces before mulch application.
   c. Describe any construction surprises or issues and how they were addressed.
   d. A statement of conformance from the works supervisor (RPEQ or otherwise) that the construction was completed consistent with the design specifications for materials,

dimensions and construction methods. If the construction deviated from the endorsed design, then detail the changes and their impact on treatment effectiveness.

2. Annual monitoring report following each wet season for at least two years after all construction and revegetation is completed. Monitoring should continue annually until the end of the project. The standard monitoring protocol for the site should be informed by the Toolbox and the Monitoring and Evaluation Guidelines for the program, tracking revegetation establishment and the intactness of structures. Reports should be attached to Projector or MERIT to be confirmed.

Longer-term ongoing monitoring and maintenance may be addressed by a separate project.

6 Acknowledgements

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7 References

Commonwealth of Australia. 2018. Reef 2050 Long-Term Sustainability Plan. Commonwealth of Australia. 16 pp.

Daley JS, Stout JC, Curwen G, Brooks A, Thwaites R, Spencer J. 2020. An assessment of gully sediment yields on Bonnie Doon Creek, Strathalbyn Station. Precision Erosion & Sediment Management Research Group Griffith University. 99 pp.

Daley JS, Spencer JR, Brooks AP, Stout JC, Thwaites R. 2023. Direct rain splash and downwearing of internal surfaces as an important erosion process in alluvial gully development. CATENA, 221: 106760. https://doi.org/10.1016/j.catena.2022.106760.

Keller RJ. 2003. Guidelines for the Design of Rock Chutes using CHUTE. CRC for Catchment Hydrology. https://toolkit.ewater.org.au/Tools/CHUTE/documentation

Humphreys P, Wilkinson S. 2021. Stream bank Erosion Control Assessment Tool (SECAT) Survey User Guide, Paddock to Reef Integrated Monitoring, Modelling and Reporting Program. State of Queensland.

Humphreys P, Wilkinson S. 2021. Gully Erosion Control Assessment Tool (GECAT) Survey User Guide, Paddock to Reef Integrated Monitoring, Modelling and Reporting Program. State of Queensland.

McKenzie, N.J., Grundy, M.J., Webster, R., Ringrose-Voase, A.J., 2008. Guidelines for surveying soil and land resources. CSIRO Publishing.

Neilly Group Engineering (2019). Sediment loss assessment DTM of Difference analysis.

The National Committee on Soil and Terrain, 2009. Australian soil and land survey field handbook. CSIRO Publishing, Collingwood, Australia.

The State of Queensland. 2018. Reef 2050 Water quality improvement plan 2017-2022. https://www.reefplan.qld.gov.au/about/

Wilkinson S, Hairsine P, Bartley R, Brooks A, Pietsch T, Hawdon A, Shepherd B. 2022. Gully and Stream Bank Toolbox. A technical guide for the Gully and Stream Bank Erosion Control Programs in Great Barrier Reef catchments. 3rd Edition. Commonwealth of Australia. 104 pp. https://www.dcceew.gov.au/parks-heritage/great-barrier-reef/reef-trust/tools-resources#toolbox

Appendix A: Template for technical review of site documentation

Technical review of site documentation in the Landscape Repair Program

Form version 1, July 2025

Site name:

Reviewer:

Date:

Review comments:

Review checklist (extended comments above):

Planning and implementation item	**Reviewer comment**
Documents are well organised and comprehensive commensurate with the size and complexity of the planned work	
Site selection	
Site is within a Water Quality Improvement Plan priority catchment.	
Stream bank erosion control sites are set within a reach plan.	
Basis of the site selection is described/referenced and is based on the best available knowledge of local patterns of erosion	
River sediment delivery ratio at sites as high as possible and above 0.4 for intensive treatments	
Site or cluster has sufficient baseline sediment yield to deliver an efficient water quality improvement project	
Landholder(s) willing to engage with the project and to agree in writing to provide access to the site and control of livestock over at least several years.	
The erosion processes are described, supported by several captioned representative photos across the site and a map of erosion extent	
History of erosion over at least 20 years is documented or referenced using temporal analysis of aerial imagery and recent climate variability. Possible changes in coming decades are considered.	
Description of site soils and vegetation relevant to rehabilitation such as presence of dispersible soils or ecologically significant vegetation which may trigger approvals for works.	
Site context is well described including map of existing infrastructure and site management practices	
Other comments	

Baseline sediment yield assessment	
Sediment yield is calculated and presented using the Projector tool. Historical erosion rate is calculated using the most accurate method given the data available.	
Historical erosion rate is justified including: • Limit of detection is justified referencing the spatial resolution and lidar point density per square metre, demonstration that DEMs are spatially registered to each other by cross section plots. • Map of erosion and deposition depths greater than the limit of detection (air photo showing over the area where change is smaller than the limit of detection). • If down-wearing erosion smaller than the limit of detection is added (optional) the rate is justified as being representative of the area applied (number and method of measurements, map of measurement locations over air photo, measurement start and end dates, mean rainfall during measurement period and long term). • Historical air photos are included and annotated if used to determine the change in erosion area (and also if other methods are used). • Ground photos of erosion cross sections are included. • Prior surface reconstruction considers the prior existence of drainage features rather than assuming a flat 'lid'.	
Untreated erosion rate is corrected from historical considering the deviation of the climate during the measurement period from the long-term average.	
Data sources for soil bulk density and proportion fines and nutrient content are appropriate based on the stage of planning (concept or detailed design) and the cost of the site (Toolbox P21, P27). Soil sample locations are shown on a map and are demonstrated to be representative of depth profiles.	
Other comments	
Concept design	
The treatments have clear and achievable objectives for the future condition of the site	
Description and map of the planned treatments	
The suitability of the planned bundle of primary and supporting treatments for controlling the erosion is justified (capable and not excessive)	
The planned treatments are consistent with their objectives and locations as described in the Toolbox Section 3, including supporting treatments listed in Table 1. Consider the extent of riparian vegetation (if relevant), vegetation establishment, control of livestock access and planned forage management in and around the site.	
Landholder perspective including how the project integrates with, adds to, benefits or changes land management and why they support the project.	
Description of how the site will be managed after construction including duration of maintenance and monitoring.	

Written landholder agreement in place or will be before site selection is confirmed.	
Other comments	
Cost-effectiveness	
Effectiveness values are as recommended for the primary treatment in the Toolbox Table 1 or deviations are strongly justified relative to site conditions	
On-ground costs are within expected range considering site and treatment characteristics	
Cost-effectiveness is within project guideline if applicable	
Other comments	
Detailed design	
Resolution of issues identified in earlier reviews (if any)	
Design specialists are qualified and experienced; RPEQ certification if failure poses risk to public safety.	
Map of the extent of each treatment relative to the erosion and the existing infrastructure	
The design objectives, locations, design and construction considerations and supporting treatment details are consistent with the Toolbox Section 3. Design undertaken by qualified and experienced specialists and comprehensively reported commensurate with the size of the planned work, e.g. hydraulic modelling outputs for stream bank structures, gully reshaping and diversion banks; CHUTE outputs for rock chutes; hydraulic structures designed for 50y ARI; revegetation reference ecosystem, species mix and density, revegetation establishment methods.	
Schedule of quantities is included and reasonable	
Budget itemises each erosion control treatment, and all aspects of project delivery and implementation, costs appear reasonable and are justified.	
Earthworks are supported by appropriate soil chemistry analysis and amelioration if required (e.g., Toolbox section 3.7).	
Construction methods are consistent with considerations in Toolbox section 3 and demonstrate that the design can be implemented as specified. Hold points are planned for inspection by experienced supervisors for consistency with design specifications.	
Construction schedule minimises risk of structural or revegetation failure considering expected seasonal climate.	
Regulatory permits are approved or will be prior to construction	
Health and safety risks have been assessed and are being managed.	
Other comments	
Maintenance	
Duration of a written landholder management agreement and the obligations and responsibilities of each party are described that demonstrate vegetation cover (trees/grass as relevant) will be maintained, or preferably the signed agreement is attached.	

Post-construction site management plan includes timing of livestock access if any, ground cover and biomass levels that trigger spelling. See e.g., Toolbox sections 3.3, 3.7.	
Commitment to maintain treatments based on the local conditions, including weed control, remediating drainage, structural intactness, tunnel erosion repair, reseeding, tree replacement, watering.	
Other comments	
Monitoring	
Monitoring method is consistent with Toolbox Section 4; photo points, treatment intactness, vegetation cover and composition, grazing practice, landholder perspectives, documented changes and maintenance needs.	
Monitoring duration is at least 2 years preferably 3. Frequency is sufficient to respond to maintenance needs based on climate.	
Monitoring reports are available. Includes pre-construction, as constructed, and annually post-construction (constructed sites only).	
Monitoring reports are consistent with the program monitoring requirements and Technical Guidance document (constructed sites only).	
Construction was consistent with plans, or modifications were reasonable and documented (constructed sites only).	
Monitoring identifies and plans required maintenance (constructed sites only).	
Other comments	

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