EROSION & SEDIMENT CONTROL MANAGEMENT PLAN

Document No:	ARMS-0000-H-PLN-N-0012 Rev 1
Project Name:	Nolans Rare Earth Project

REVISION HISTORY

Date	Revision	Description	Prepared	Reviewed	Approved
July 2022	Rev 1	Issued to DITT	S.Binnie NPI Package Lead	M.Robinson ESG Manager	S.Watkins GM Projects
01/11/2021	Rev 0	Issue for Review	S.Binnie NPI Package Lead	M.Robinson ESG Manager	S.Watkins GM Projects

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1.0 INTRODUCTION

This Erosion and Sediment Control Management Plan (ESCMP) is based upon, and provides an update to, the Erosion and Sediment Control Plan (ESCP) developed for the Arafura EIS (2016) and subsequent EIS updates, 2017 and 2019, respectively.

1.1 Purpose

The ESCMP has been prepared around the Project's latest general arrangements and layouts, noting the Project is currently developing through Front-End Engineering Design of the Plant. The Plan provides guidance on:

- strategies for the management and control of erosion and sediment (applicable to all areas and phases of the Project (construction, operation, and closure)); and
- design philosophies for Erosion and Sediment Control (ESC) to guide Contractors and Operators when establishing measures for installation and maintenance activities.
- a consistent approach in developing ESCPs across the Project, that reflects changes in site conditions as construction progresses.

The ESCMP forms part of the Project's Mine Management Plan (MMP – *ARMS-0000-O-PLN-O-0001*) and shall be relied upon for the preparation and implementation of future, detailed, site specific Erosion and Sediment Control Plans (ESCP) by those Contractors (Mining or Construction), or their Engineer, planning to undertake ground disturbance works whereby a permit is deemed required under the Biodiversity Management Plan (BMP - *ARMS-0000-H-PLN-N-0002*). These ESCPs will be drafted/collaborated by Certified Professional in Erosion and Sediment Control (CPESC).

Limitations: This document does not extensively discuss permanent water quality controls proposed for the development (i.e. detailed design) rather focuses on control measures to achieve stabilisation of disturbed areas, nor does it present exhaustive details on the staged, permanent Kerosene Camp Creek diversion, refer ARMS-0000-H-PLN-N-0003 *Diversion Management Plan*.

1.2 Objective

The objective of this ESCMP is to provide an overarching lens to minimise the impacts associated with erosion of disturbed areas and sediment generation during the construction, operational, and closure phases, by:

- Minimising disturbance activities and area;
- Identifying and locating the controls required to divert stormwater runoff away from disturbed areas, effectively managing the upstream catchments;
- Preventing release, and management of sediment laden stormwater runoff from the disturbed areas into downstream catchments and / or the surrounding environment; and
- Encouraging prompt rehabilitation of Project construction, operational and closure areas through appropriate rehabilitation and revegetation.

1.3 Supporting Documentation

This ESCMP is based on the following standards and guidelines:

- Nolans Project Environmental Impact Statement (EIS), Arafura Resources Ltd, May 2016. Including EIS Supplementary Report, October 2017, and Section 14A Notification, June 2019.
- Best Practice Erosion and Sediment Control for Building and Construction Projects, International Erosion Control Association (IECA) Australasia;
- Erosion and Sediment Control Guidelines Built Environment, the former Department of Natural Resources, Environment, the Arts and Sport (NRETAS), Northern Territory Government;
- Northern Territory Minerals Council (Inc.) and the Mines and Petroleum Management Division of the Northern Territory Government, 2004, TEAM NT: Technologies for Environmental Advancement of Mining in the Northern Territory: Toolkit, D.R. Jones and M. Fawcett, principal authors; and
- Erosion and Sediment Control Plans Fact Sheet(s), Land Management Unit, Department of Environment, Parks and Water Security (DEPWS).

2.0 ACRONYMS AND DEFINITIONS

2.1 Acronyms

Abbreviation	Meaning
AA	Access Authority
AEP	Annual Exceedance Probability
Arafura / ARU	Arafura Resources Limited
ASL	Above Sea Level
BMP	Biodiversity Management Plan
BOM	Bureau of Metoerology
CROW	Construction Right of Way
DEPWS	Department of Environment, Parks and Water Security
NRETAS	Department of Natural Resources, Environment, the Arts and Sport
EIS	Environmental Impact Statement
ESC	Erosion and Sediment Control
ESCMP	Erosion and Sediment Control Management Plan
ESCP	Erosion and Sediment Control Plan
IECA	International Erosion Control Association
ITP	Inspection and Test Plans
KP	Knight Piésold Pty Ltd
LOM	Life of Mine
MIA	Mine Infrastructure Area
ML	Mineral Lease
MMP	Mine Management Plan
NWS	Nolans Weather Station
PAF	Potential Acid Forming
ROM	Run-of-Mine
RSF	Residue Storage Facility
RUSLE	Revised Universal Soil Loss Equation
SCD	Sediment Control Dam
TSF	Tailing Storage Facility, refer RSF.
WRD	Waste Rock Dump

2.2 Definitions

Term	Definition
Company	Arafura Resources Ltd.
Contractor	An entity, engaged or approved by the Company enter into an Agreement with the Company, to perform work or cause work to be performed.
Engineer	The party(s) charged with the responsibility of acting for and on behalf of the Principal, in a technical capacity.
Project	Arafura Resources Limited, Nolans Rare Earths Project
Site	The complete Site on and near the Project, including all areas references to the Project.

3.0 PROJECT SITE CONDITIONS

3.1 Project Development

The Nolans Rare Earths Project, for the purposes of erosion and sediment control, is proposing to construct various mine, process and non-process infrastructure across a number of Mineral Leases (MLs) and Access Authorities (AA) on the Aileron and Napperby Stations. This infrastructure is geographically separated from one another and linked by Access Roads / Tracks, and will typically be developed in a sequential fashion as Works progress. The bulk earthworks and civil construction of areas will include:

- Site Access Road including Village Access Road
- Village Pad development including Communications Access Track
- Process Plant Pad development, including:
  - Power Station
  - Residue Storage Facility
- Mine Site, including:
  - Mine Access Road including Explosive Storage Area
  - Mine Infrastructure Area development
  - Mine Surface Water Management development (Creek Diversion)
- Borefield development and Access Tracks

Ground disturbance will be restricted where practical, however, these areas will be cleared, grubbed and topsoil stripped to allow development of the Project Works. Enabling works, or initial minor disturbance activities, are forecast to commence third quarter of 2022, with earthworks continuing in a stage manner from fourth quarter of 2022 through to second quarter of 2024. Stabilisation (temporary if applicable) of the disturbed areas will be carried out as part of the completion of an area's earthworks scope.

Extensive construction works will commence after the earthworks phase, and progressive stabilisation, both temporary and permanent measures, will be executed to maintain control of erosion and sediment throughout the Project's development phase into operation.

3.2 Topography

The mine site lies within the Kerosene Camp Creek catchment on the north facing slopes of an east – west trending ridge of the Reynolds Range. The process plant site is situated on the southern slopes of the same ridge. Topographic elevation is 886 m above sea level (m ASL) at Mt Boothby to the east of the mine site, and 1006 m ASL at Mt Freeling to the west. Most of the Kerosene Camp Creek valley floor at the mine site is typically between 650 and 700 m ASL, and longitudinal gradients along local creeks to the north and south of the ridge line are typically less than 0.5 percent, with steeper gradients of about 10 percent on isolated hills.

3.3 Climate

3.3.1 Rainfall and Evaporation

The mean annual rainfall, as reported in the Site Design Criteria (*NRE-0000-E-DEC-G-0001*) and recorded at the Nolans Weather Station, is approximately 427 mm, with a seasonal pattern of more summer rainfall than winter rainfall. Average monthly rainfall totals range from 4.3 mm in June to 84.1 mm in January. Average three-monthly rainfall totals range from 11.3 mm in May/June/July to 203.4 mm in November/December/January. It must be noted, any month can receive relatively large rainfall totals, or little or no rain at all.

Records from the Nolans Weather Station (NWS) indicate potential evaporation is greatest in October and November, with 270.1 mm and 253.4 mm, respectively, which also coincides with months when rainfall can be highest. Rates of potential evaporation are lower from May to July coinciding with lower mean rainfall and temperatures, according to the onsite Nolans Weather Station, and in contrast to Alice Springs BOM records which indicate significantly lower potential evaporation rates from May to August.

The annual average potential evaporation is approximately 2,600 mm (NWS), which far exceeds the annual average rainfall of 427 mm (NWS).

The rainfall and evaporation rates are provided in Table 3-2.

3.3.1.1 Rainfall Statistics

Rainfall at the Project is generally characterised by infrequent and intense rainfall events, single events can deliver > 50 mm within 24 hour. The Bureau of Meteorology (BOM) Intensity–Frequency–Duration (IFD) indicates 362 mm for a 1 in 100 year, 72 hour rainfall event.

A summary of the IFDs are provided in Table 3-1.

Table 3-1 IFD rainfall depth (mm) [Source: BOM, *Design Rainfall Data System (2016)*]

Storm Duration			Precipitation Depth (mm) for AEP Storm Frequency (%)							
(min)	(h)	(day)	50%	20%	10%	5%	2%	1%	0.5%	0.1%
5			7	11	13	16	19	22	25	33
10			11	17	20	24	30	34	38	51
15			14	21	26	30	37	42	48	64
30	0.5		19	29	35	42	52	59	67	89
60	1		24	37	46	55	68	78	89	118
180	3		34	51	63	76	93	108	123	163
	6		41	61	75	90	111	129	147	195
	12	0.5	50	74	92	109	135	156	178	236
	24	1	62	93	114	135	169	196	230	313
	48	2	76	116	144	172	218	255	300	413

Storm Duration			Precipitation Depth (mm) for AEP Storm Frequency (%)							
(min)	(h)	(day)	50%	20%	10%	5%	2%	1%	0.5%	0.1%
	72	3	84	131	164	198	252	298	347	481
	168	7	95	153	196	242	308	362	427	592

3.3.2 Temperature and Humidity

The Project area experiences hot and arid conditions. The hottest months are November to March, with monthly mean daily maximum temperatures above 35°C, and monthly mean daily minimum temperatures not dropping below 18 °C. The coolest months are May to August, with monthly mean of daily maximum temperatures remaining at or below 25.5 °C, and monthly mean daily minimum temperatures not rising above 9.5°C.

The average humidity at the Project is 40% at 09:00 and 25% at 15:00, consistent across the year with monthly afternoon humidity readings being 15% lower than the morning. The highest levels of humidity are experienced in June at 53%. This coincides with lower temperatures occurring.

The temperature and humidity rates are provided in Table 3-2.

Table 3-2 Summary of Climate Statistics [Source: BOM, *DRDS (2016); Territory Grape Farm NT 1987-2021*]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall (mm)													
Annual Average	84.1	47.8	30.5	19.7	11.8	4.3	17.8	45.9	74.2	15.5	58.3	61	427
Annual Maximum	241.2	172.6	173.6	72.2	53.0	17.4	147.2	484..9	728.4	70.6	274.9	272.4	1628
Highest Daily Rainfall	108.4	78.8	69.8	61.2	18.2	9.0	55.6	246.2	445.0	50.2	254.8	58.2	445
Evaporation (mm)													
Alice Springs	399.9	333.2	322.4	231.0	151.9	111.0	127.1	176.7	246.0	319.3	351.0	378.2	3,139
Site	207.9	175.3	191.6	200.0	197.5	180.8	189.9	218.3	245.3	270.1	253.4	231.5	2,607
Temperature (°C)													
Mean Maximum	37.4	36.5	34.6	30.9	25.7	22.4	22.9	25.4	30.4	33.5	35.9	36.4	31
Mean Minimum	22.2	21.7	19.6	14.5	9.4	6.1	5.1	6.9	11.9	15.7	19	21.3	14.5
Humidity (%)													
Mean 9 am	38	40	37	37	47	53	51	38	32	32	34	37	40
Mean 3 pm	24	28	27	25	27	28	28	22	21	21	22	26	25

Wind (km/h)												
Mean 9 am	17	18.1	19.7	18.9	15.2	12.8	14.3	17.3	18.2	19.6	18.2	18	17.3
Mean 3 pm	15.8	16.7	16.6	14.9	14.2	13.5	14	16	15.5	14.8	14.1	14.5	15

3.3.3 Wind

The winds at the Project, as recorded at the onsite NWS, are predominantly east-south-easterly direction throughout the year, which closely aligns with records sourced from BOM Territory Grape Farm Climate Site. The average wind speeds range from 0.95 to 6.78 m/s (3.4 to 24.4 km/h) with an annual average of 2.93 m/s (10.8 km/h).

The wind roses are provided in Figure 3-1 and speeds are summarised in Figure 3-2.

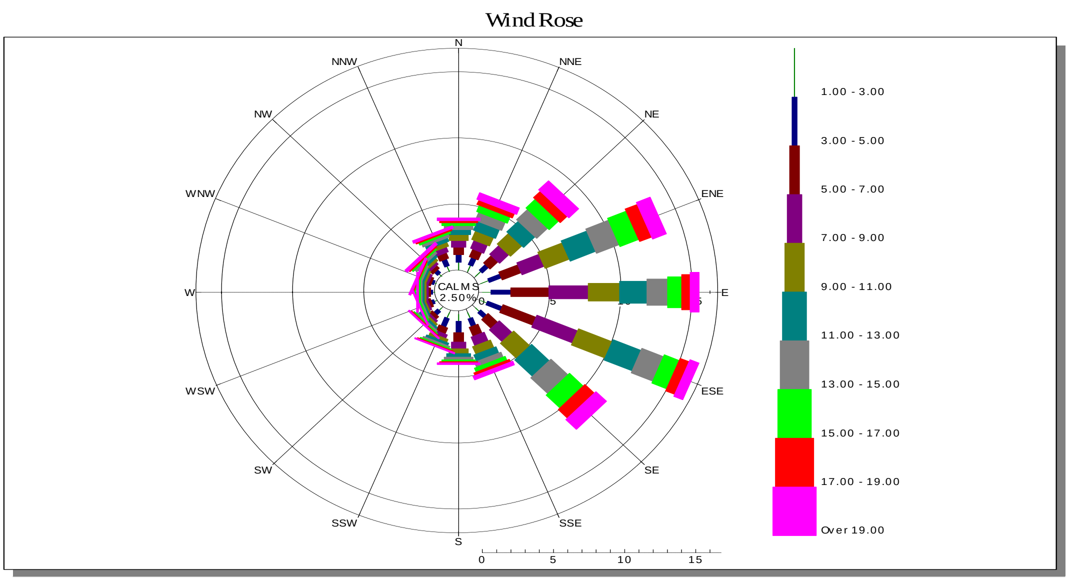


Figure 3-1 Prevailing wind direction

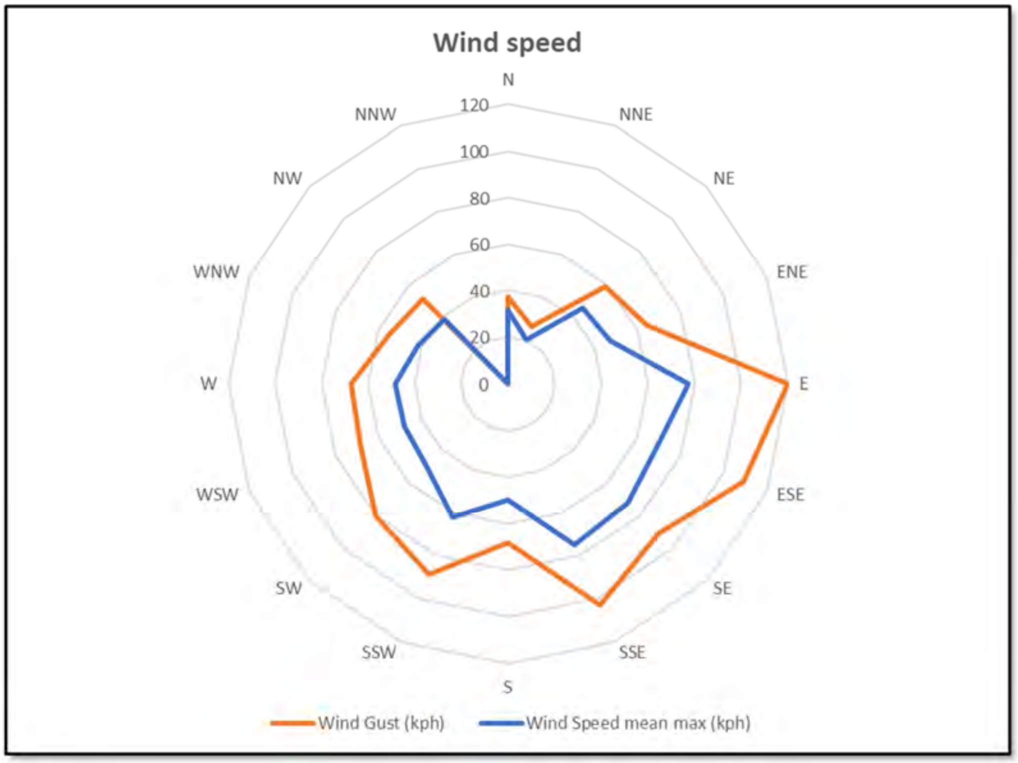


Figure 3-2 Wind Direction vs speed and wind gusts

3.4 Hydrology

Kerosene Camp Creek is an ephemeral creek and flows through the centre of the mine site before joining the Woodforde River 12 km further to the north. Kerosene Camp Creek has a catchment area of approximately 18 km^2 upstream of the mine site.

Nolans Creek is a tributary of Kerosene Camp Creek and has a catchment area of 26 km^2 upstream of the mine site. It flows through the upper north-eastern section of the Mineral Lease where mine infrastructure is not proposed before it joins Kerosene Camp Creek.

Catchments upstream of drainage crossing points along the access road from the Stuart Highway drain towards the Southern Basins and are typically less than 3 km^2, with the exception one (1) catchment of about 10 km^2 between the process plant and village accesses. Areas draining towards the Project are typically less than 1 km^2 in extent and channels are ill-defined with runoff likely to be dispersed across the south facing hillslope.

Semi-arid regions such as the area in which the Project is located are typically characterised by conditions in which actual evaporation during rainfall events closely matches rainfall and virtually all rainfall evaporates, resulting in almost no surface runoff. Therefore, the occurrence of surface runoff and flows within local creeks is infrequent and only occurs during larger rainfall events associated with the occasional southward extension of a tropical monsoon trough or periodic incursion of north-west cloud bands over the interior of the continent.

Local creek beds are mobile with deep sand deposition and banks that show signs of active erosion. Creek channels are typically 1.0 m deep with a base width of 5 m. Intense, short duration rainfall events can be expected to occur over the Project area and the relatively shallow depth of creek channels will lead to out-of-bank flow and possibly temporary and short-term flooding of adjacent areas.

3.5 Groundwater

Groundwater was not encountered during the geotechnical investigation, with boreholes extending to a maximum depth of 25.5 m. Groundwater modelling indicates that groundwater is greater than 30 m deep across the Plant Site and Residue Storage Facility.

3.6 Vegetation

The vegetation types that will be affected by the Project comprise 14 distinct communities and sub-communities, refer to the Biodiversity Management Plan (ARMS-0000-H-PLN-N-0002) and Weed Management Plan (ARMS-0000-H-PLN-N-0009) for further details.

A maximum total of 1,6012 ha may be required to be cleared for the Life of Mine (LOM) Project footprint with the major vegetation units being cleared including:

- Mulga shrubland on sandy red earths over tussock grasses;
- Mulga shrubland on sandy red earths over tussock grasses / Mulga shrubland on sandy red earths over spinifex; and,
- Mixed woodland over tussock grasses

3.7 Soils

Geotechnical investigations of the Nolans Project sites have been carried out in mid-2010, 2011, and most recently in 2018. The assessments determined the ground condition at each Project location, and indicate the sites generally comprise Quaternary alluvium becoming red soil sedimentary deposits overlaying granite and gneiss. The sedimentary plains typically comprise cemented clayey sand (hardpan) with rock head at variable depths but typically beyond 3.0 m, with calcrete being identified in test pits at the residue storage facility (RSF), mine site and are expected to be encountered across the plant site.

Laboratory testing of the geotechnical samples demonstrated the soils are non-dispersive (Class 6).

A topsoil survey (*Baseline Soil Assessment*) of the RSF, process plant, and mine site was conducted in 2021 which established the soil types across the locations presenting more similarly than they are different. All sites are free drained, loamy, non-saline, non-sodic, low fertility, friable earths, and are relatively stable if undisturbed. Due to the characteristics these soils present (i.e., very low surface organic matter, etc.), they are susceptible to being physically degraded, and likely to become powdery and loose if over-worked.

4.0 EROSION AND SEDIMENT CONTROL – DESIGN PHILOSOPHY

4.1 ESC Principles

Water runoff, wind and / or physical disturbance are all processes that can drive soil erosion, causing particles to become mobile, creating sediment. Measures used for controlling erosion differ to mitigations surrounding sediment control and drainage, where the former aims to prevent soil erosion in the first place and the latter aiming to trap and retain sediment produced by erosion processes.

A summary of erosion processes is provided in Table 4-1.

Table 4-1 Erosion Processes (IECA, 2009)

Aspect	Forms of Erosion	Description	Factors Affecting Erosion
Water Erosion	Splash Erosion (raindrop)	The spattering of soil particles caused by the direct impact of precipitation onto an exposed surface. The soil particles are typically moved distances up to 1 m when initially dislodged. These particles may subsequently be transported by surface water runoff. Splash erosion is minimised if soils/tailings/residue storage facilities have a water coverage greater than 2 mm.	The factors which affect water erosion include: • Soil with low surface cover; • Shallow surface soils overlying low permeable subsoils/rock; • Surface soils with high percentage of fine sand or silts; • Surface soils that are hard setting or have a surface crust; • Soils with low levels of organic matter; and • Soil with dispersive properties.
	Sheet Erosion (includes splash erosion)	Uniform removal of soil in thin layers from sloping land. Sheet erosion is minimised through stabilisation of surfaces through practices such as revegetation.	
	Rill Erosion	Rill erosion generally occurs by the removal of soil by water concentrated into small defined channels on sloping land. Rills can be up to 300 mm deep. Rill erosion is minimised through stabilisation of surfaces through practices such as revegetation.	
	Gully Erosion	Gully erosion is similar to rill erosion but produces deeper channels generally greater than 300 mm.	
	Tunnel Erosion	Tunnel erosion is the removal of subsoils in a sub-surface tunnel (i.e. out of sight). It generally occurs near gullies, creek lines or constructed embankments in dispersive soils or where a weak drainage path is already present.	
	Watercourse Erosion	Watercourses naturally transfer sediments downstream. However, a modification of stream banks often leads to instability and erosion.	
Wind Erosion	Surface Creep	Rolling and sliding of large particles (>1 mm) which are too heavy to be lifted in the air. The particle rolls and dislodges other soil particles by hitting into them.	The factors which affect wind erosion include: • Soil with low surface cover; • Dry and High/consistent wind environments; and
	Saltation	Wind directly causing particles generally with a diameter of 0.1 to 0.5 mm to hop and bounce across the surface. The particle then dislodges other particles on impact.	

Aspect	Forms of Erosion	Description	Factors Affecting Erosion
	Suspension	Movement of small dust (<0.1 mm) particles into the air. The particles can rise high above the ground and form severe dust storms.	• Soil characteristics including its binding potential and surface roughness.

The design principles are formulated around the ESCMP's objectives, which hinge upon the protection and mitigation of environmental impacts from the Project. The key objective of the ESCMP is to minimise the erosion and sediment pollution of ground and surface waters resulting from construction, mining, and operational activities. Development and implementation of erosion and sediment management strategies coupled with specific structures and measures aligned with the International Erosion Control Association "Best Practice Erosion and Sediment Control" Guidelines (IECA, 2008) are required to ensure the Project's development achieves compliance with the objective.

The following treatment measure design principles shall be adopted for all areas and all stages of the Project:

1. Site Assessment
2. Minimise ground disturbance
3. Manage clean water (divert, onto and around)
4. Control runoff
5. Rehabilitate and stabilise
6. Monitor

4.1.1 Site Assessment

Staging of construction activities, particularly, the bulk earthworks scopes will permit detailed assessments of the site conditions and characteristics to support development of specific and "progressive" Erosion and Sediment Control Plans (Progressive ESCP). Such plans will be developed on an ongoing basis and tailored in consideration of work activity, location, and season.

4.1.2 Minimise ground disturbance

Ground disturbance activities will be closely managed and monitored during execution of construction activities as to control and restrict the extent and duration of exposed footprints. After bulk earthworks pads are developed and handed over, the construction activities shall still be managed closely to mitigate unnecessary disturbance to hardstands and exposure of erodible surfaces which lead to the generation of sediment.

4.1.3 Manage clean water

Clean water, for the purpose of erosion and sediment control, shall be considered water that either enters the Project site from an adjacent Lot / property / area, and has not been further contaminated by sediment within the site; or water that originates from or on the site (i.e. after sufficient stabilisation or controls are established) and is of such quality that it does not require treatment to achieve compliant water quality standard, nor would it be further improved in quality if passed through a sediment trap.

The primary means of managing clean water receival on the Project Sites from adjacent/upstream catchments will be through the development of perimeter diversion drains and bunds. This infrastructure will direct flows around works areas, where possible, rather than through them, and control any perceived concentrated flows by discharging through re-spreaders to ensure dispersion and mitigate “water shadowing”.

Clean water received directly onto developed Project catchments will be directed through stormwater drainage infrastructure, and where possible, kept separate from potentially disturbed, non-stabilised areas to maintain clean water quality when reporting to stormwater basins. This water can lend itself to stormwater harvesting for re-use across site.

4.1.4 Control runoff

Runoff generated from Project catchments will be managed to prevent uncontrolled release of sediment laden (or otherwise contaminated) water to surrounding and downstream receiving environments. Specific measures and treatments will be employed to control drainage, erosion, sedimentation, and discharge throughout, and off of, the site during all Project phases from temporary to permanent.

4.1.5 Rehabilitate and stabilise

Post-disturbance stabilisation provides the best defence against erosion and sedimentation. Therefore, construction areas will be progressively stabilised following completion and/or suspension of works in a given area. Certain conditions dictate the need, and criteria for temporary stabilisation of such areas like stockpile sites, drainage infrastructure and construction laydowns, these include season, exposure duration, risk of erosion, and final design.

Permanent stabilisation shall be executed as soon as practicable after respective construction activities are completed, including pavements and hardstands, vegetation rehabilitation and drainage structures, and other surface treatments.

4.1.6 Monitor

Monitoring ensures the erosion and sediment control measures and installation of, have been correctly implemented, and promotes maintenance and evaluation of the effectiveness of controls. This practice also lends itself to modification of ESCPs if, and when necessary, where a control’s performances is deemed subpar.

Inspection and test plans (ITP) will be developed for the construction phase, and these will be used to establish monitoring and maintenance programs for Operations.

4.2 Erosion Hazard Risk Assessment

Erosion hazard risk assessments aims to provide guidance around the need, level and type of erosion and sediment control measures, and their associated design standards.

It's envisaged that a detailed erosion risk assessment will be undertaken prior to the finalisation of the Project's detailed engineered designs, which will shore up subsequent detailed progressive ESCPs.

4.2.1 Erosion Hazard

The Revised Universal Soil Loss Equation – RUSLE (IECA 2008) is used to assess a catchments Erosion Hazard. RUSLE provides a basic model for the prediction of long term, average, annual soil loss from sheet and rill erosion for a given catchment with specific measures employed. The RUSLE method and model is a widely accepted technique and allows flexibility that is reflective of stage construction activities across varying work areas.

The RUSLE is represented by the following equation:

$$A = R\ K\ LS\ P\ C$$

Table 4-2 RUSLE variables

Factor	Description	Value	Comment
A	Computed soil loss (tonnes/ha/yr)	19.7	As calculated for the project
R	Rainfall erosivity factor	1000	Average derived from Hua Lu and Bofu Yu (2002)
K	Soil erodibility factor	0.03	Based on information gathered from Topsoil Survey NRE-0000-E-RPT-Y-0001.
LS	Slope length / gradient factor	0.41	Based on catchment characteristics. IECA 2008 – Section E3.3
P	Erosion control practice factor	1.3	Construction phase condition
C	Ground cover and management factor	1.0	Construction phase condition

4.2.2 Erosion Risk Assessment Methodology

Parameters used to illustrate the risks associated with erosion include:

- Slope steepness;
- Soil dispersion;
- Duration of disturbance;
- Estimated soil loss;
- Rainfall depth; and,
- Sensitivity of receiving waters (both surface and hydrogeological)

Table 4-3 shows the erosion risk parameters and rating the Project as a whole, and is non-discriminative for a given catchment area, with respect to, total area, forecast duration of exposure and season of construction.

Table 4-3 Erosion risk parameters

Erosion Risk Rating	Average slope of disturbance	Soil Emerson class number	Duration of soil disturbance	Annual average soil loss (t/ha/yr)	Average monthly rainfall depth (mm)
Very Low	≤ 3	N/A	N/A	0 to 150	0 to 30
Low	> 3 but ≤ 5	Class 4, 6, 7 or 8	≤ 1 month	150 to 225	30+ to 45
Moderate	> 5 but ≤ 10	Class 5	> 1 month but ≤ 4 months	225 to 500	45+ to 100
High	10 but ≤ 15	Class 3	> 4 month but ≤ 6 months	500 to 1500	100+ to 225
Extreme	> 15	Class 1 or 2	> 6 months	> 1500	>225

Adopted from Chapter 4, IECA (2008)

4.2.3 Application of Erosion Risk Assessment

The results presented in Table 4-3 generally illustrate a low erosion risk for the Project activities.

Further characterisation of construction areas within the Mineral Leases for different project scope, will serve to validate this prescribed low erosion risk, and allows clear definition of erosion and sediment measures for specific disturbed catchments, and various stockpiles and infrastructure.

Under the best practice land clearing requirements, IECA (2008) Table 4.4.7, very low-low erosion risk correlates to limit disturbance/clearing activities to eight (8) weeks (or a maximum) of work, if rainfall is reasonably possible.

4.3 Control Measures and Strategies

As established above, controlling drainage, erosion and sediment provides a platform for a successful environmental program where treatment and discharge of compliant water can be achieved. Implementing effective controls at the work site can be a challenge when considering the geographic area large projects tend to occupy, as is the case for Nolans Rare Earths. However, the degree of controls will be dictated by the activity, location, duration, and season, and notably some activities will rely more on sediment and drainage controls (i.e. mine stripping and dumping process) opposed to utilising comprehensive erosion controls.

We learn from IECA (2008), there are three (3) modes associated with stormwater management to mitigate erosion and sediment. The relationship between drainage control, erosion control and sediment control are therefore understood, and are heavily dependent on in-situ site conditions which will be applied to the ESCP for the Project, later in this document. IECA (2008) design fact sheets will be observed in the development of detailed erosion and sediment control techniques and treatments across the site, as they apply to both temporary and permanent infrastructure. Table 4-4 provides a brief insight into some typical controls for various construction activities.

Table 4-4 Typical controls for construction activities around mine and processing facilities

Construction	Erosion and other impacts	Potential / Typical controls
Clear and grubbing, topsoil stripping and stockpiling	Exposure of disturbed areas Loss of topsoil (i.e. wash away) Mobilisation of sediment from stockpile, disturbed area (enters drainage / waterway)	Sediment fencing Breaking up catchments Degree of battering Stabilisation / revegetation
Clearing linear infrastructure (pipelines, powerlines, roads, etc.)	Exposure of disturbed areas Loss of topsoil (i.e. wash away) Mobilisation of sediment from stockpile, disturbed area (enters drainage / waterway)	Vegetation / Mulch windrows Stabilisation of access tracks Revegetation of CROW Whoa-boys and rock check dams
Road (sealed and unsealed) and access track construction	Instability of road formation Mobilisation of sediment Runoff scouring	Drainage channels (lined/unlined), Whoa-boys and rock check dams, batter protection and rock chutes, upstream diversions and/or direction to floodways. Stormwater retention basins
Process pad development	Exposure of disturbed areas Generation of sediment entering drainage infrastructure	Upstream diversion, sediment basins, drainage channels, check dams and chutes, sediment fences, stabilised pavements and hardstands
Construction of Operations Complex and Accommodation camp	Sediment generation reporting to, and potentially blocking stormwater infrastructure and waterway pollution/discolouration	Upstream diversion, sediment basins, drainage channels, sediment fences, level spreaders, stabilised pavements and hardstands
Waste rock dump development and dumping	Exposed stockpiles Mobilisation of sediment from stockpile Scouring and contaminated runoff, leading blocked drainage infrastructure and failure of dump.	Upstream diversion, sediment basins, drainage channels, check dams and chutes, sediment fences
Rehabilitation	Sediment mobilisation leading to blocked drainage systems and contamination of waterways Failure due to application practices, result of concentrating flows, etc. Loss of topsoil and seed bank	Revegetation and stabilisation, contour drains, lined drainage systems, rock check dams and rock chutes/level spreaders/energy dissipaters

4.3.1 Drainage Control

Drainage controls include measures for both the diversion of clean water around and through the site, along with diversion of site runoff to enable treatment of sediment prior to release offsite. These controls serve to minimise rill, gully and scour erosion caused by concentrated flows by effectively managing runoff velocity, volume and location. Management of drainage controls also allows separation of catchments to be maintained between clean water streams (i.e, upslope) and potentially sediment laden project sites and streams.

Implementation of effective drainage control measures attracts long-term benefits in the form of costs and schedule, where maintenance, repair and clean out of deposition sites are observed to be alleviated. Selection of drainage control measures for the project, both temporary and permanent, will be prescribed based on site environmental conditions, execution strategy, season, and work activity (including footprint, available space and catchment size). The following will provide an overview of these drainage control measures (non-exhaustive) and will be used as a guide for the development of future Progressive, and / or, Contractor ESCPs.

4.3.1.1 Flow Diversion Banks

Flow diversion banks are earth embankments/bunds which divert up-slope stormwater runoff from entering the disturbed area. Water collected by a flow diversion bank is transferred to a stable outlet structure (i.e., level spreader). The diversions are capable of containing dispersive subsoil due to the construction methodology not generally requiring the exposure of subsoils. Design considerations include:

- Discharge to a stable outlet.
- Sediment trap if the diverted water is expected to be contaminated.
- Not divert or concentrate flows onto an adjacent property.
- Sides of the bank are to be not steeper than 2:1 (H:V) slope and the completed bank must be at least 500 mm high.

Due to the duration of flow diversion banks at the Project they will be stabilised immediately following initial construction (seeded, mulched and revegetated, where appropriate).

Haul Roads will also be utilised as flow diversion banks across the mine site, specifically surrounding the LOM pit to restrict overland flows entering the mine site.

Specific Areas

Accommodation Village, Process Plant, RSF and Mine Site.

4.3.1.2 Catch Drains

Catch drains are channels excavated to divert flow around disturbed areas, and drain runoff away from erosion prone areas. Catch drains should be at least 300 mm deep and 1000 mm wide. They may be constructed across a slope to convey runoff at a non-erosive velocity. The channel may be combined with an embankment (flow diversion bank) on the downslope side to increase its capacity. The drains intercept the sheet runoff and divert it at a non-scouring velocity to a stabilised outlet.

A typical gradient of a catch drain is 0.5% and may be as low as 0.25% or as high as 0.75%. As a general rule, the deeper the flow, the lower the maximum gradient. Use of rock-check dams can reduce the effective channel gradient of steeper channels by typically 5%.

Specific Areas

Accommodation Village: Village perimeter drain.

Process Plant: Processing plant facilities perimeter drains.

Mine Site: Perimeter drains at Waste Rock Dump(s), ROM Pad and mine lease boundary

4.3.1.3 Table & Diversion (Turnout) Drains

Table drains are constructed adjacent to sealed and unsealed roads to provide a preferential pathway for drainage for sheet flow received from the surrounding environment and the formed road. The drains should be at least 300 mm deep. Table drains will have check dams installed to reduce water velocities and will discharge into a diversion drain.

Diversion, or turnout, drains are constructed drainage channels which receive water from table drains and direct it to a suitable disposal area. The drains are to discharge water via a level spreader or the final grade should be 0.2% for 30 m (i.e. 6 cm fall over 30 m). The positioning of diversion drains is site specific but generally should be at a maximum of 120 m at slopes up to 2% reducing to 15 m for slopes greater than 8%.

Specific Areas

Sealed and unsealed roads across the Project.

4.3.1.4 Check Dams

Check-dams control the flow velocity in channels and are effective at removing coarse sediments from stormwater flow.

Check-dams are placed at intervals within the channel to create ponding of flow along the channel's length, between the toe of the upstream dam and overflow-invert of the downstream dam. This reduces the flow velocity, decreasing scour of the channel and allows coarse sediments to settle. Design criteria includes:

- Dam centre ("spillway") to be at least 150 mm lower than the edges, and dam height limited in height to around 0.5 m. Greater heights require a larger rock-apron to dissipate energy of the overflow; and
- Maximum spacing between the dams occurs where the toe of the upstream dam is at the same elevation as the crest of the downstream dam

Specific Areas

Situated across the Project within catch drains and table drains

4.3.1.5 Level Spreaders

Level spreaders are typically constructed along the contour line and consist of a level rock protected entry, allowing concentrated flow to spread to a nominated flow width. Level spreaders are used on the outlet of diversion channels and basins to spread flow and convert concentrated flow into sheet flow. Key issues are noted below:

- Level spreader outlet grade must be less than 10% and ideally discharge should occur to areas of undisturbed land
- Typical maintenance, such as periodic checks, should be conducted to ensure that sediment build up and general erosion such as scouring or channel damage upstream and downstream of the spreader, does not occur and
- Protection of the outlet can be achieved using jute mesh, grass turf, rock or other appropriate stabilisers.

Specific Areas

Situated across the Project as outlets to flow diversion banks, diversion drains or rock lined chutes.

4.3.1.6 Rock Lined Chutes

Chutes provide a stable pathway for the transfer of water from elevated surfaces to ground level such as rehabilitated Waste Rock Dumps, Residue Storage Facility, Raw Water Pond, or other infrastructure containing an emergency spillway (ponds or dams, etc.).

Key design details include:

- Surface drainage across an elevated structure to be directed toward chute(s):
- Installation of rock mattress or alternative stable landform at the base to control erosion;
- Chute to be designed with a safety factor of 1.5 (high risk structure); and
- Rock to be geochemically stable, durable and resistant to weathering.

4.3.1.7 Energy Dissipater and Recessed Rock Pad (Outlet Structure)

Energy dissipaters provide outlet control for rock lined chutes to prevent undermining of the chute and control scour immediately downstream. The dissipater itself will be made of coarse riprap or rows of small concrete impact blocks to form as bed roughness and will lead into a recessed rock pad to allow sheet flow to the surrounding environment.

Specific Areas

Situated at the toe of rock lined chutes including the Waste Rock Dumps, Residue Storage Facility and other pond and dams with

4.3.2 Erosion Control

Prevention of erosion is the primary approach in mitigating adverse impacts associated with sedimentation. Construction activities are to be undertaken so as to reduce the duration of soil exposure to erosive forces (wind and water), either by holding the soil in place or by shielding it. The aim of these controls is to prevent or minimise the generation, movement and loss of sediments at their source, typically as a result of raindrop impact or sheet flow.

Typical measures include:

- Minimise the area and duration of disturbance;
- Minimise soil and stockpile erosion caused by wind and rain; and
- Minimise turbidity levels in stormwater runoff by minimising the exposure of soil to rain and stormwater flow.
- Protection of soil surface (i.e. geo-binders, geotextile, jute matting/mesh, etc).
- Progressive stabilisation

Erosion control measures specific to the Project's execution strategy will are outlined as follows and will be used as a guide for the development of detailed and future, Progressive, and / or, Contractor ESCPs.

4.3.2.1 Vegetation/Revegetation

Vegetation or revegetation of a Project is the primary (and long-term) technique for mitigating erosion, and provides:

- Physical protection against raindrop impact;
- Barrier between the earth and flow;
- Increased surface roughness that reduces erosive flow velocities; and
- Increased absorption of rainfall by the soil-profile, reducing the volume of runoff.

Revegetation will be carried out on disturbed soil surface that has the potential to erode and cause sediment movement into the surrounding environment during rain events. Ideally, plants should be native to the area, have good soil binding capability and compete successfully with weed species.

Topsoil collected during the initial ground disturbance will be applied across areas to be revegetated. Vegetation cleared will be stockpiled during the clearing process and stored for use on exposed soil surfaces no longer required (i.e. road easements). The respreading of stockpiled vegetation will provide a protection layer to the seedbank allowing it to grow.

4.3.2.2 Gravelling

Gravelling (gravel sheeting) provides a permanent erosion control from raindrop, wind and potential mud generation impacts. It is ideal for application on areas of broad, low gradient earth surfaces and can be used in high traffic volume areas. In general gravelling will be utilised at site offices/administration buildings, across the accommodation village and dedicated light vehicle parking areas. Similar benefits listed above for revegetation are observed with gravelling, although without the long-term ecological benefits that cultivated land will otherwise yield.

Gravel should be approximately 20 – 75 mm hard, angular, weather resistant and evenly graded. It should be applied to a minimum of 50 mm thickness across the designated area. Reapplication of gravel will be undertaken as required following maintenance inspections.

Note: if gravel continually migrates off dedicated location a Cellular Confinement System (CCS) may be installed to restrict lateral displacement.

4.3.2.3 Dust Control – Water Cart

Ground conditions are generally dry and traffic movements and wind energy has the potential to erode unsealed tracks, access and haul roads, and topsoil stockpiles. Watercarts will be used to suppress dust particles (generally 0.001 to 0.1 mm). Dust suppression from watercarts will be utilised throughout the construction process to facilitate settlement of unsealed and sealed roads, and other pavement hardstands. Stockpiles will be sprayed as required by the watercart to minimise dust emissions on dry windy days.

Specific Areas

Unsealed tracks, access and haulage roads and topsoil stockpiles.

4.3.2.4 Wind Breaks

Natural vegetation will be utilised as a wind break across the Project. Wind breaks act by providing a buffer and reducing wind velocity. Flagging will be used to ensure areas aren't over cleared. Windrowed stockpiles of cleared vegetation from disturbed areas will be used

4.3.2.5 Surface Roughening / Contour Ripping

Surface roughening on exposed or revegetated surfaces increases erosion protection of soil surfaces by increasing water infiltration, delaying the formation of rilling and reducing dust generation. In order to roughen surfaces machinery will be utilised (i.e. rippers).

Ridges will be installed along contours and perpendicular to the predominant wind direction (south easterly wind direction) where possible. In general, and dependent on the natural grades, ridges will be ripped to a depth of up to 600 - 900 mm in pairs approximately 2 to 6 m apart.

The installation will include the diversion of up-gradient stormwater runoff around the roughening areas. Following roughening/ridge installation, the areas will be immediately seeded and mulched to optimise seed germination and growing conditions, whilst promoting infiltration.

Specific Areas

Drill pads, rehabilitation of unsealed tracks, temporary construction areas and laydowns/

4.3.3 Sediment Control

Managing the water quality of received stormwater in accordance with the Project's performance standard will require the implementation of sediment control measures that direct, trap and retain sediment in either form, be it bed load (along drainage surface) or suspended (sediment laden flowing water), thereby promoting sedimentation. Where practical, sediment should be trapped close to its source, reducing break-down of soil particles and the release of dispersive clays (if present, typically not expected at the Project).

Sediment controls have the greatest maintenance requirements of ESC measures. A sediment control structure may not work properly if it does not have regular maintenance (sediment-removal), especially after a storm event.

IECA (2008) explains sediment controls being classified as being Type 1, Type 2 or Type 3 depending upon ability to trap suspended sediments. These controls techniques notionally include:

- Type 1: designed to collect particles smaller than 0.045 mm (i.e., sediment basins);
- Type 2: systems designed to contain / capture particles between 0.045 and 0.14 mm particle size (i.e. sediment traps – rock filter dams, weirs and filtration ponds);
- Type 3: systems designed primarily to trap sediment over 0.14 mm particle size (i.e., sediment fences, buffer zones, etc.); and,
- Supplementary: systems that have limited effectiveness in their application (i.e., grass filter strips, coir logs).

An overview of the sediment control techniques proposed for the project are detailed over the proceeding subsections.

4.3.3.1 Sediment Fences

Sediment fences provide physical filtration of sheet flow passing through filter material and allow settling of suspended sediments by the ponding of water behind the fence. Sediment fences typically:

- Consist of a filter fabric attached to a wire and post fence at a maximum height of 700 mm with an additional 200 mm (min) buried and compacted into an upstream trench;
- Should be constructed along a contour with turn-ups at either end to prevent runoff flowing around the fence;
- Are most effective for coarse-fraction sediments in sheet flows;
- Trap sediment larger than 0.14 mm and have little impact on fine silts;
- May be used in the control of sediment runoff from exposed land, unsealed roads, batters and stockpiles; and
- For large areas on moderate slopes, sediment fences may be placed at intervals down-slope with a catch-drain on its downstream side. This will contain sediments at the source and minimise concentration of flow.

> **Specific Areas**
>
> Topsoil stockpiles, sheet flow on approach to watercourses, and staged construction across large earthwork pads with multiple subplot drainage patterns (i.e. Process Plant).

4.3.3.2 Stormwater Retention Basins (Sediment Trap)

A stormwater retention basin is an effective system to trap and retain a wide range of sediment particle sizes down to 0.045 mm, depending on its hydraulic characteristics (retention time and flow-distribution). It is noted that:

- Stormwater retention basins are usually required when the disturbed area is greater than one hectare, the soils are dispersive and/or there is a need to control runoff turbidity;
- Stormwater retention basins should be located upstream of water bodies, bushland and major stormwater systems;
- Stormwater retention basins are sized to contain and slowly settle fine particles or to slow the flow's velocity allowing settlement of coarser particles during flow-through; and
- Both coarse sediment concentration and turbidity levels can be reduced.

Specific Areas

Accommodation Village, Process Plant, RSF, Mine Site and Access Road, where applicable.

4.3.3.3 Chemical Flocculation

Inducing flocculation and sedimentation to improve water quality between storm events and provide means to mechanically discharge detained stormwater may be required. Chemicals including gypsum, alum, lime or polyelectrolytes will be considered.

Addition of chemical flocculants will only occur 24 hours after the rainfall event has ceased, and more is present on the forecast. Stormwater detained in basins shall be tested to determine the most appropriate chemical flocculant for the project's applications, and even trailed during lesser rainfall events where there is no risk to discharge to receiving environments.

5.0 PROJECT EROSION AND SEDIMENT CONTROL MEASURES

5.1 General Ground Disturbance

Ground disturbances will be undertaken in accordance with the Ground Disturbance Permit System as identified in the Biodiversity Management Plan (*ARMS-0000-H-PLN-N-0002*). Ground disturbance includes all disturbances to natural ground including borrow pits, drill pads and infrastructure construction easements. Disturbances will be staged to reduce the area of exposed surfaces through the construction and operations phases. Clearing and disturbance will be restricted to eight (8) weeks of work, per definition of erosion risk classification (Low).

Future detailed site surveillance, construction scheduling, season, and subsequent evidence-based erosion hazard risk assessments shall allow the re-classification of the erosion risk profile and mitigate the eight (8) week restriction.

5.1.1 Flagging

Flagging will be installed at all locations to be cleared to ensure the areas are not over cleared. The maintenance of vegetation adjacent to clearing assists in reducing any surface water runoff volume and velocity.

5.1.2 Ground Disturbance Process

Disturbances across the project will generally be managed in accordance with the following:

1. Weed Removal

   The area will be surveyed to assess if the vegetation present comprises of any weeds. Weeds will be removed / treated in accordance with the Weed Management Plan prior to ground disturbances occurring. Weed removal is an important part of the process to ensure mulch does not assist in the distribution of weeds across the site.

2. Vegetation Removal

   Vegetation will be cleared in a manner that minimises damage to any retained vegetation, in accordance with the Topsoil Management Plan (ARMS-0000-H-PLN-N-0005). Cleared vegetation will remain in stockpiles. The stockpiled vegetation will either be used during revegetation of the area or transferred to the process plant or mine site for storage/covering topsoil stockpiles.

3. Flow Diversion Bank

   Flow diversion banks will be installed to facilitate the diversion of clean water around the disturbance. The banks will have a level spreader to discharge concentrated flows. The flow diversion will remain in situ until sufficient site drainage has been established.

4. Topsoil Removal

   Following the installation of flow diversion banks, topsoil will be removed and stockpiled adjacent to the disturbance area. The topsoil will be utilised as part of the revegetation process for the disturbance for a given area. Topsoil may be considered for transfer to the Mine Site for storage within the topsoil stockpiles.

5. Sediment Fence

   If the topsoil is intended to be reused at the area of ground disturbance, the stockpile is to be located within the disturbance area and associated flow diversion bank. In addition, a sediment fence is to be installed on the downgradient side of the stockpile.

6. Surface Roughening / Contour Ripping

   The flow diversion bank will be removed / flattened. Roughening will then be undertaken to facilitate vegetation establishment and reduce potential for rill and gully erosion. Following roughening/ridge installation the areas will be immediately seeded and mulched to optimise seed germination and growing conditions.

7. Revegetation

   Where possible, areas will be revegetated immediately following the completion of works with native species. If revegetation is not established sufficiently due to gradient complications, then a cellular confinement system (CCS) may be installed to arrest soil movement and facilitate vegetation establishment.

5.2 Project ESC Design Parameters

The extent and type of erosion control measures depends on the likelihood and intensity of expected rainfall and sheet flow. The treatments and approaches in this ESCP, as outlined above, are divided into three categories of control measures including:

- Erosion Control Measures

  Erosion control design is based on average monthly rainfall ranging from 4.3 mm in June to 84.1 mm in January;

- Drainage Control Measures

  Drainage control design is primarily based on the 1% Annual Exceedance Probability (AEP) for a design storm 72 hour rainfall event for permanent infrastructure and 10% AEP 72 hour rainfall event for temporary drainage works; and,

- Sediment Control Measures

  Sediment control design is based on the 1% AEP design event, 72 hour rainfall event with a rainfall depth of 298 mm, with the exception of the mine surface water management infrastructure.

5.3 Roads and Tracks (Sealed or Unsealed)

Roads and Tracks will be constructed to facilitate effective drainage with a targeted crossfall of 4% (1 in 25). Drainage will be installed adjacent to tracks including:

- Table Drains

  The drain collects drainage from the surrounding environment and road. The drains will be installed with check dams to reduce water velocities; and,

- Diversion Drains

Diversion drains will be installed and pushed out into the surrounding environmental to facilitate the disposal/discharge of flows into the table drains. The drains are to discharge water via a level spreader or the final grade should be 0.2% for 30 m (i.e. 6 cm fall over 30 m).

- Floodways

  Due to the nature of the drainage within the project, floodways will be used where practicable to reduce the interruption of natural sheet flow and to avoid, as much a is practicable, the concentration of water flows across roadways.

5.3.1 Mine Access Road

Small sediment management dams will be built along the road at regular intervals to capture the runoff from the road surface which potentially could contain ore particles (even with controls like washbays to mitigate this risk).

Each sediment dam will be approximately 40 by 40 m and 2 m deep, providing approximately 2,000 m^3 of storage capacity. The exact dimensions will be adjusted to suite the individual dam locations. Placed at 500 m intervals along the haul road this will be sufficient to store the runoff due to a 1% AEP 24 hour storm if empty at the beginning of a storm. Emergency spillways will be installed to safely discharge any water in excess of the storage capacity.

5.4 Accommodation Village

Following the removal of vegetation, construction of the Village earthworks pad will predominantly include a “capping” pavement (subbase, basecourse, FCR, etc) across the areas proposed for modular buildings and light vehicle parking. This provides a stabilised surface and promotes a uniform sheet flow for the surface runoff, preventing pooling/ponding. Revegetation, mulching, or gravelling will be used in other locations within the Village area outside of drainage channels to mitigate raindrop erosion.

Flow diversion banks with level spreader outlets will be installed up gradient to divert “clean” stormwater runoff from the surrounding areas from entering the disturbed / stabilised Village area.

A stormwater basin may be installed to collect overland flow from precipitation falling directly on the Accommodation Village compound/area. Catch- and/or table- drains will be installed throughout the Village footprint, where practical, and down gradient of disturbed areas to transfer runoff to stormwater basin(s). Treatment of channel drains with both drainage and sediment controls will be observed, i.e., rock check dams to stem velocity of concentrated flows, and up-slope sediment fences to manage staged construction efforts.

The stormwater basin will be designed in the detailed design phase.

5.5 Process Plant

5.5.1 Processing Facility

Following the removal of vegetation, the bulk earthworks pad will be constructed through conventional methods using granular pavement (i.e., subbase) and includes a network of table drains that divide the process catchment into a number of subplots directing runoff through the site. This pavement provides a stabilised surface across the Process Plant, mitigating erosion from raindrops and promoting controlled runoff.

A combination of treatments will be used to further control drainage, erosion and sediment during the Plant construction phase, ranging from check dams, armouring (i.e., energy dissipaters), sediment fences and grass filter strips. Gravelling will only be used where suitable rock can be readily made available as a by-product of construction activities or borrow. Revegetation and mulching of construction areas will be progressed as soon as practicable on a phased basis to ensure early rehabilitation.

To remove surface runoff being received from the surrounding areas, flow diversion banks with level spreader outlets will be installed up gradient of the disturbed process areas.

Process plant table drains will direct precipitation falling directly on the Processing Site to stormwater basin(s) (permanent structure(s)). The stormwater basin(s) will be designed to capture a 1% AEP 72 hour storm event of 298 mm (refer to Table 3-1) for the given service catchment.

5.5.2 Power Station

For the purposes of this erosion and sediment control management plan, the Power Station shall be considered as one with the Processing Site. All ESC measure outlined in section 5.5.1 are applicable to the Power Station.

5.5.3 Residue Storage Facility

The Residue Storage Facilities (RSF) will be gradually expanded across the LOM.

Following the removal of vegetation from each staged expansion, construction of the facility will require temporary flow diversion banks be installed up-slope to remove receipt of runoff from surrounding environments. The RSF cells will be constructed below grade, and precipitation received directly on to the footprint will be directed to, and contained within, sedimentation traps. Catch drains, sediment fences and/or mulch berms will be used down-slope to manage surface runoff discharging into the downstream receiving environment.

RSF capacity will be designed to accommodate a 1% AEP extreme wet annual rainfall event. Emergency spillways figure in the facility's constructed layout and include rock chutes and recessed rock pads to control discharge when design storm events are exceeded. The embankment outer face will be revegetated after the final slope is established to prevent gully erosion. Risk of dust generation and wind erosion will be managed through the standard RSF operations whereby the tailings will be maintained at a minimum moisture level.

5.6 Mine Site

Knight Piésold Pty Ltd (KP) was commissioned to undertake a study and design of Surface Water Management for the Mine Site of the Arafura Nolans Project.

The mine surface water management system will provide sediment and flood control for areas disturbed by mining activities from the pre-commissioning construction phase until a stable landform is re-established as part of the closure process. The infrastructure supporting this management systems include:

- Sediment management structures;
- Pit diversion (constructed in stages with development on the Mine); and,
- Mining area flood management.

5.6.1 Sediment Management Structures

The Mine Site's last line of defence against potential discharge of sediment laden waters are a number of large sediment control dams (SCDs) which will be constructed at the downstream extremity of the Mineral Lease to capture all runoff.

During mine surface water management stage 1 development, two (2) SCDs will be constructed at the north-eastern boundary, and will overflow into a polishing pond prior to offsite discharge. These SCDs will collect all runoff from the initial 8 years of mine operation, including ground disturbance, topsoil stockpiles, pit development, and eastern waste rock dump. A third (southern) SCD will be constructed near the Mine Infrastructure Area (MIA) to the south of the pit development, which will service the runoff from the ROM as well the MIA and immediate disturbed surrounds.

The SCDs will be sized to remove particles up to the medium to coarse silt fraction for flows up to 1 % AEP Storms. During the stage 2 development, an additional north-western SCD will be constructed to service the mine expansion and the establishment of the western rock dump.

Other lines of defence combatting erosion and sediment within the Mine Site includes each area/landscape being capable of locally managing sediment source control to mitigate sediment laden runoff. These are briefly discussed across the respective key areas of the mine in the following subsections.

Minor diversion channels will be positioned and excavated at strategic locations across the mine site to promote runoff reporting to respective catchment SCDs for treatment. Check dams will be included where necessary.

5.6.1.1 Open Pit

Haul roads constructed across the mine site will serve as flow diversion banks. The pit perimeter haul road will restrict overland flows entering the pit. The remaining haul roads across the site will have culverts or floodways' installed to facilitate overland flow through the site.

Supplementary flow diversion banks will be constructed, complete with catch drains, directing overland flow to sediment basins, or diversion drains dependent upon the quality of water from the received from surrounding environments.

5.6.1.2 Topsoil Stockpiles

Topsoil storage areas have been identified to facilitate progressive rehabilitation and closure of the Project. The construction phase will be managed such that topsoil is collected from all ground disturbances. The topsoil stored within stockpile areas will be utilised for efficient management and progressive rehabilitation across the Project as required.

Stockpiles will be managed to ensure stability of topsoil is achieved within a minimum timeframe. During the establishment a sediment fence (type 3 control) will be installed surrounding the down gradient area of the stockpile. The sediment fence will be removed following the establishment of vegetation (stability of the landform). Cleared vegetation stockpiles can be used to impede topsoil stockpile toe erosion and can be positioned to act as flow diversion or filtration bunds.

Stormwater discharged through/from the sediment fences will be directed to the SCDs by diversion channels and haul road formations.

5.6.1.3 Waste Rock Dumps

Waste Rock Dumps (WRDs) will be constructed to store waste rock from mining activities. In general, WRDs are positioned in close proximity to Pit entry/egress points to reduce haulage distance and therefore fuel costs.

Geochemistry at the Project indicated the risk of acid, metalliferous or saline drainage is low, and the material can generally be managed as Non Acid Forming waste. However, field testing procedures will be implemented during the operation to identify and appropriately manage any potential (estimate <1%) Potential Acid Forming (PAF) waste.

A low permeability base will be constructed for the WRDs. The construction material will be geochemically stable (inert) and have the ability to be compacted by traffic and track rolling. Catch drains will be constructed adjacent to the WRD bases and act as a perimeter drain collecting surface flows and transferring them to a local stormwater basin (sediment trap). The catch drains will be installed with check dams to reduce flow velocities. A bund will be positioned on the 'outside' of the catch drain to restrict other water sources entering the drain.

5.6.1.4 ROM Pad

The Run-of-Mine (ROM) Pad will be established during the construction period to its LOM extents. The ROM Pad will have a raised compacted base with a target permeability of 5x10-8 m/s. A flow diversion bank will be installed along the perimeter of the ROM Pad to transfer flows to a local stormwater basin and the pad itself will have a gentle gradient to the basin.

The discharge from the ROM pad / basin will be directed through a table drain to the southern SCD.

5.6.1.5 Mine Infrastructure Area

Following the removal of vegetation, the mine infrastructure area (MIA) bulk earthworks pad will be constructed using conventional methods of layers of compacted granular pavement (i.e. subbase/basecourse). This pavement provides a stabilised surface across the MIA. The hardstand pavement will be encompassed by flow diversion bunds / earthen windrows to eliminate runoff being received from surrounding catchments and promote sheet flow of rainfall runoff received directly onto the area until interception by table drains.

Table drains will report to the southern SCD (or local basin) installed to trap all sediment laden runoff from the MIA compound. Bunds will be revegetated promptly post-construction to establish a stabilised surface.

5.6.2 Pit Diversion

The pit diversion channel is intended to divert the natural flow of Kerosene Creek around the open pit and waste dumps and will be constructed in two stages (year 1 and year 8, respectively).

The Kerosene Camp Creek diversion channels (stage 1 & 2) will be designed for a 0.1% AEP rainfall event. Flow diversion bunds complete with cut-off trenches will be built upstream of the pit to divert inflow and outflow from Kerosene Camp Creek into the stage 1 diversion channel.

The diversion channel is expected to be located in rock and constructed with very shallow grade / low flow velocity, and as such drainage and erosion control is not envisaged as being required. Where softer underlying soils are encountered, drainage (check dams) and erosion (gravelling, armouring, etc.) control will be established. The bund embankments will be constructed of low permeability material and have a 500 mm wide layer of (rock pitching) erosion protection on the upstream batter. Revegetation will be promoted as soon as practical after completion of the installation.

The stage 2 diversion channel is excavated considerably deeper into rock compared to stage 1, however, the design and installation methodology will remain consistent, as will be the case for the ESC measures for construction and operation phases.

5.6.3 Mine Area Flood Management

A Flood Protection Bund will be built east of the pit and eastern waste rock dump during the stage 1 pit diversion development to ensure Nolans Creek does not encroach into the nominated mining area, which will be built within the flood plain extents of the river. The bund was sized for flood levels up to 0.1% AEP rainfall events.

A catch drain (or diversion drain) will be installed on the downstream side (mine site side) of the flood protection bund to capture and convey surface water runoff from the mine site landscapes. The runoff will be directed to the north-eastern sediment control dams.

5.7 Borefield

The ESC measures for the Borefield will be managed in accordance with the general ground disturbance process and, roads and tracks measures described in sections 5.1.2 and 5.3, respectively. ESC strategies will also consider those outlined in Appendix P – Land-based Pipeline Construction (IECA 2008 Addendum), specifically P3.

6.0 REHABILITATION AND STABILISATION

It is fundamental to a successful erosion and sediment control philosophy, plan and execution that rehabilitation and stabilisation of the ground disturbance is executed in a timely manner and to a standard that provides a sustainable platform for the long-term.

Stabilisation of newly constructed infrastructure subject to erodible forces, and rehabilitation of areas during and post construction, will be consistent with best practices outlined by IECA (2008), and will be the subject of other Project environmental management plans to be submitted under *ARMS -000-O-PLN-O-0001 – Mine Management Plan*.

Revegetation is considered the primary form of stabilisation for areas outside of the final detailed hardstands / trafficable corridors. Topsoil harvested during the initial ground disturbance process shall respread over roughened (i.e., ripped) surfaces and supplement with seed bank, if necessary. Establishment of revegetation will be continually monitored to ensure the practice is a success or corrected if flawed.

7.0 MAINTENANCE REQUIREMENTS

7.1 Maintenance Philosophy

The ESCP for the proposed development is prepared with the following maintenance philosophy:

- Selection of mitigation measures requiring minimal regular maintenance or simple maintenance procedures; and
- Access must be provided if maintenance is required on any structure.

A maintenance program for the ESC measures is outlined in Table 7-1. A checklist will be developed that records maintenance problems likely to occur for each of the ESC measures adopted by the Project, and identifies the person responsible for implementing, maintaining, inspecting, repairing, and modifying controls.

The inspection frequency will need to be adjusted according to the prevailing weather conditions, i.e., increased during wet periods and reduced during dry periods. Weekly inspections will be sufficient during minor runoff events. An inspection is required after any major runoff event.

Table 7-1 Typical controls for construction activities around mine and processing facilities

Aspect	Forms of Erosion	Description	Factors Affecting Erosion
Erosion Control			
Flagging	As required; or Daily during clearances.	As required.	Identify any damage and re-establish flagging.
Revegetation (Seeds and Stockpiled Vegetation)	As required; or After a major rainfall event	When areas of mulch have been eroded or if vegetation does not establish in the required time.	Re-application of mulch and take action to prevent future damage. Assess if vegetation has established and to identify if any erosion, channelling or weed problems occur. Reseeding and weeding to maintain a dense, vigorous growth of vegetation. Vegetation and mulch will require reestablishment if less than 70% is present. Application of additional mulch as required. Maintenance of any upslope diversion channels or protective fences if installed.
Gravelling	As required; or After a major rainfall event	As required.	Check for continuous even cover and for rilling along the up-gradient slope edges. Replace gravel from the down-gradient location(s).
Cellular Confinement System	As required; or After a major rainfall event	As required.	Removal and reinstallation of system and/or growth media.
Dust Control – Watercart	n/a	n/a	n/a
Wind Breaks – Vegetation	*See revegetation*	n/a	n/a
Surface Roughening / Contour Ripping	As required; or After a major rainfall event	As required.	If rill erosion occurs through ridges the rills are to be filled.

Aspect	Forms of Erosion	Description	Factors Affecting Erosion
Drainage Control			
Flow Diversion Bank	As required; or After a major rainfall event	When slumps, wheel track damage or loss of freeboard has occurred. When litter or sediment has accumulated and filled 30% of the drain depth.	Identify any damaged or eroded areas due to sediment accumulated in the channel, vehicular damage to the banks, settlement of banks and/or scour due to excessive flow velocity. Remove accumulated litter and sediment. Reform bund or channel banks to design grade.
Catch Drain	As required; or After a major rainfall event	Damage of the channel banks has occurred.	Identify any damaged or eroded areas due to sediment accumulated in the channel, vehicular damage to the banks, settlement of banks and/or scour due to excessive flow velocity. Remove accumulated litter and sediment. Reform bund or channel banks to design grade.
Table Drain	Biannual	When litter has accumulated or sediment has filled 30% of the drain depth.	Identify any damaged or eroded areas due to sediment accumulated in the channel, vehicular damage, settlement of banks and/or scour due to excessive flow velocity. Remove accumulated litter and sediment. Reform bund or channel banks to design grade.
Diversion Drain	Biannual	When litter has accumulated or sediment has filled 30% of the drain depth.	Identify any damaged or eroded areas due to sediment accumulated in the channel, vehicular damage, settlement of banks and/or scour due to excessive flow velocity. Remove accumulated litter and sediment. Reform bund or channel banks to design grade.
Check Dam	As required; or After a major rainfall event	When litter has accumulated or sediment has filled 30% of the drain depth.	Identify any damage or sediment build-up. Re-establish dams when sediment begins to flow through the structure. Remove accumulated litter and sediment.
Level Spreader	As required; or After a major rainfall event	When sediment build-up limits the spreader to function effectively Scouring of channel and vegetation damaged.	Identify any damage or sediment build-up causing concentration flow. Reformation of channel banks to design grade. Treat scouring or channel damage upstream of the spreader. Application of additional mulch or vegetation. Remove accumulated litter and sediment.
Temporary Watercourse Crossing: Fords	As required; or After a major rainfall event	When damage of CCS or excessive scour has occurred.	Debris trapped on or upstream of the crossing is removed. Identify and remediate any erosion upstream or downstream scour.
Rock Lined Chute	As required or after a major rainfall event	As required.	Check flow entry condition to ensure no flow is bypassing the chute(s). Check for inlet scour, piping or bank failures. Check whole of structure for rill or gully erosion to ensure chutes are operating efficiently.
Energy Dissipater and Recessed Rock Pad (Outlet Structure)	As required or after a major rainfall event	As required.	Identify any erosion around the edge of the pad and ensure rocks remain adequately recessed into the earth. Check for excessive displacement of rocks and potential for reinstatement.
Sediment Control			
Sediment Fence	As required; or	When sediment accumulates at the base of	Identify any damage caused by on-site Project vehicles or excessive sediment movement.

Aspect	Forms of Erosion	Description	Factors Affecting Erosion
	After a major rainfall event	the control structure or when permeability is excessively reduced.	Remove accumulated litter and sediment. Reform sediment fence, take action to prevent future damage. Where fence is regularly damaged, reassess and reduce the area of inflow, install a second fence at least 1 m downslope of the existing fence.
Sediment Basin	As required; or After a major rainfall event	When litter has accumulated or sediment has filled 10% of the sediment basin volume as indicated by the marker post.	Remove accumulated litter and sediment, spreading it well away from drainage lines. Repair of any scouring damage to inlet and outlet and embankment vegetation. Pump-out of retained water to maintain capacity for subsequent inflow events.

7.2 Monitoring Checklist

A monitoring checklist will be maintained of all erosion and sediment control measures, with entries made as inspections are completed and after rainfall events on:

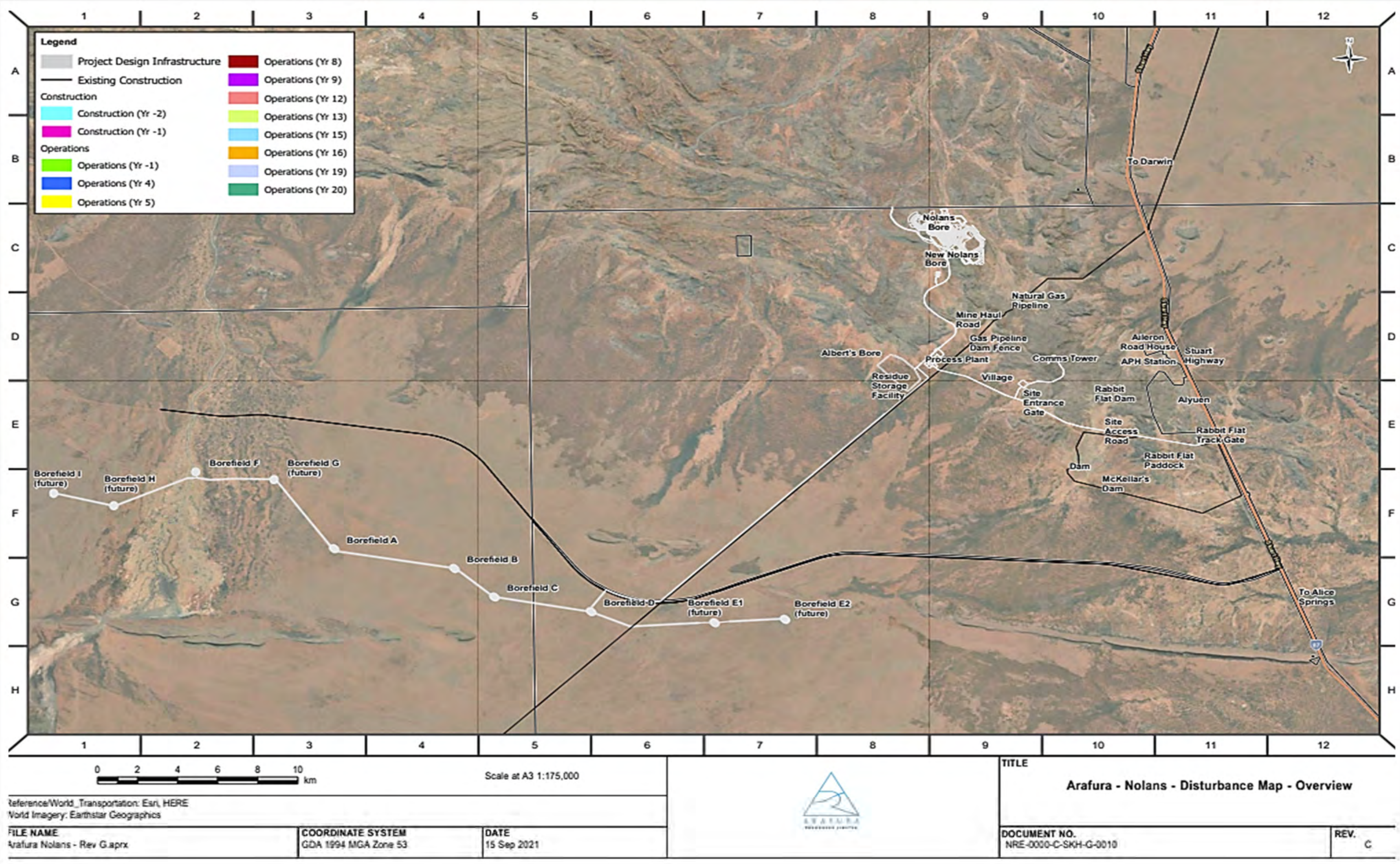
- Condition of ESC structures and stabilised surfaces;
- Repair of any damage to ESC structures; and
- Rainfall, including duration and times.

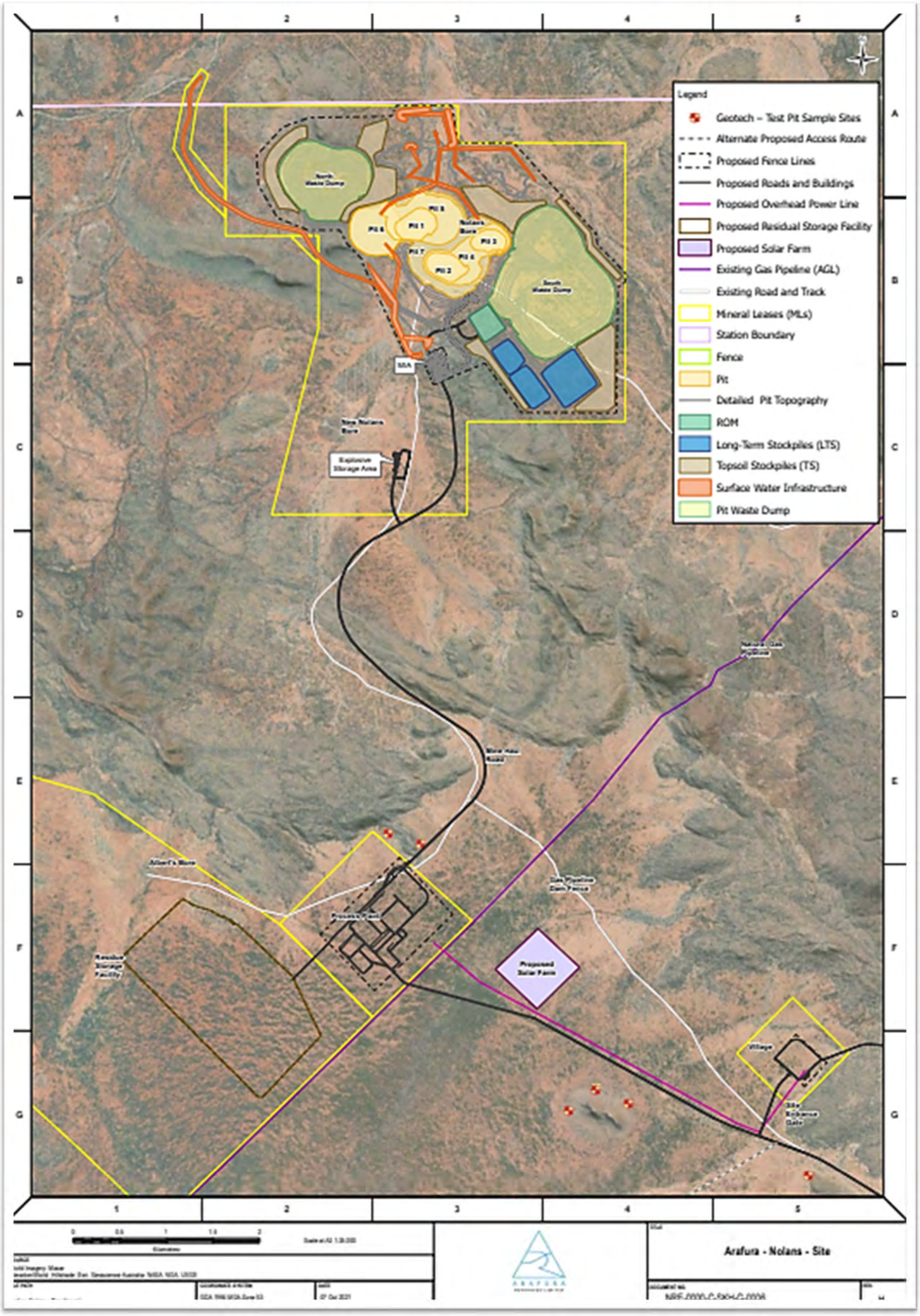
Corrective actions will be investigated and implemented within 24 hours, where practicable, where findings of the ESC monitoring indicate a non-conformance.

8.0 REFERENCES

Title	Document Number
GHD (2016). Nolans Project Environmental Impact Statement (EIS), Arafura Resources Ltd, May 2016. A report for Arafura Resources Limited. (Specifically, Appendix M, L, W, I).	
GHD (2017). Nolans Project Environmental Impact Statement (EIS) – Supplementary Report, Arafura Resources Ltd, October 2017. A report for Arafura Resources Limited.	
GHD (2019). Nolans Project Section 14A Notification, Arafura Resources Ltd, June 2019. A report for Arafura Resources Limited.	
International Erosion Control Association (IECA) Australasia (November 2008) Best Practice Erosion and Sediment Control for Building and Construction Projects	
International Erosion Control Association (IECA) Australasia (November 2008) Best Practice Erosion and Sediment Control for Building and Construction Projects. Addendum Appendix P: Land-based Pipeline Construction	
Landcom, 2004. Soils & Construction: Vol 1 Managing Urban Stormwater, NSW Government.	
APGA (2017). Code of Environmental Practice – Onshore Pipelines, Rev. 4. September 2017. The Australian Pipelines and Gas Association.	
Knight Piésold (2019). Nolans Project – Residue Storage Facility, Definitive Feasibility Study Design Report, Rev. 0, March 2019. Prepared for Arafura Resources Limited.	PE801-00140/12
Knight Piésold (2019). Nolans Project – Surface Water Management Definitive Feasibility Study - Design Report, Rev. 0, March 2019. Prepared for Arafura Resources Limited.	PE801-00140/13
Knight Piésold (2020). Nolans Project, Definitive Feasibility Study Geotechnical Interpretative Report, Rev. 2. March 2020. Prepared for Arafura Resources Limited.	PE801-00140/14
BoM, 2021. http://www.bom.gov.au/climate/averages/tables/cw_015643_All.shtml, Accessed 15:53, 28/10/2021	
Landloch Baseline Soil Report for Nolans Project	NRE-0000-E-RPT-Y-0001
Air Quality Management Plan	ARMS-0000-H-PLN-N-0001
Biodiversity Management Plan	ARMS-0000-H-PLN-N-0002
Diversion Management Plan	ARMS-0000-H-PLN-N-0003
Topsoil Management Plan	ARMS-0000-H-PLN-N-0005
Waste Rock Management Plan	ARMS-0000-H-PLN-N-0008
Weed Management Plan	ARMS-0000-H-PLN-N-0009
Surface Water Sampling Procedure	ARMS-0000-H-PRO-N-0002
Sediment Sampling Procedure	ARMS-0000-H-PRO-N-0003

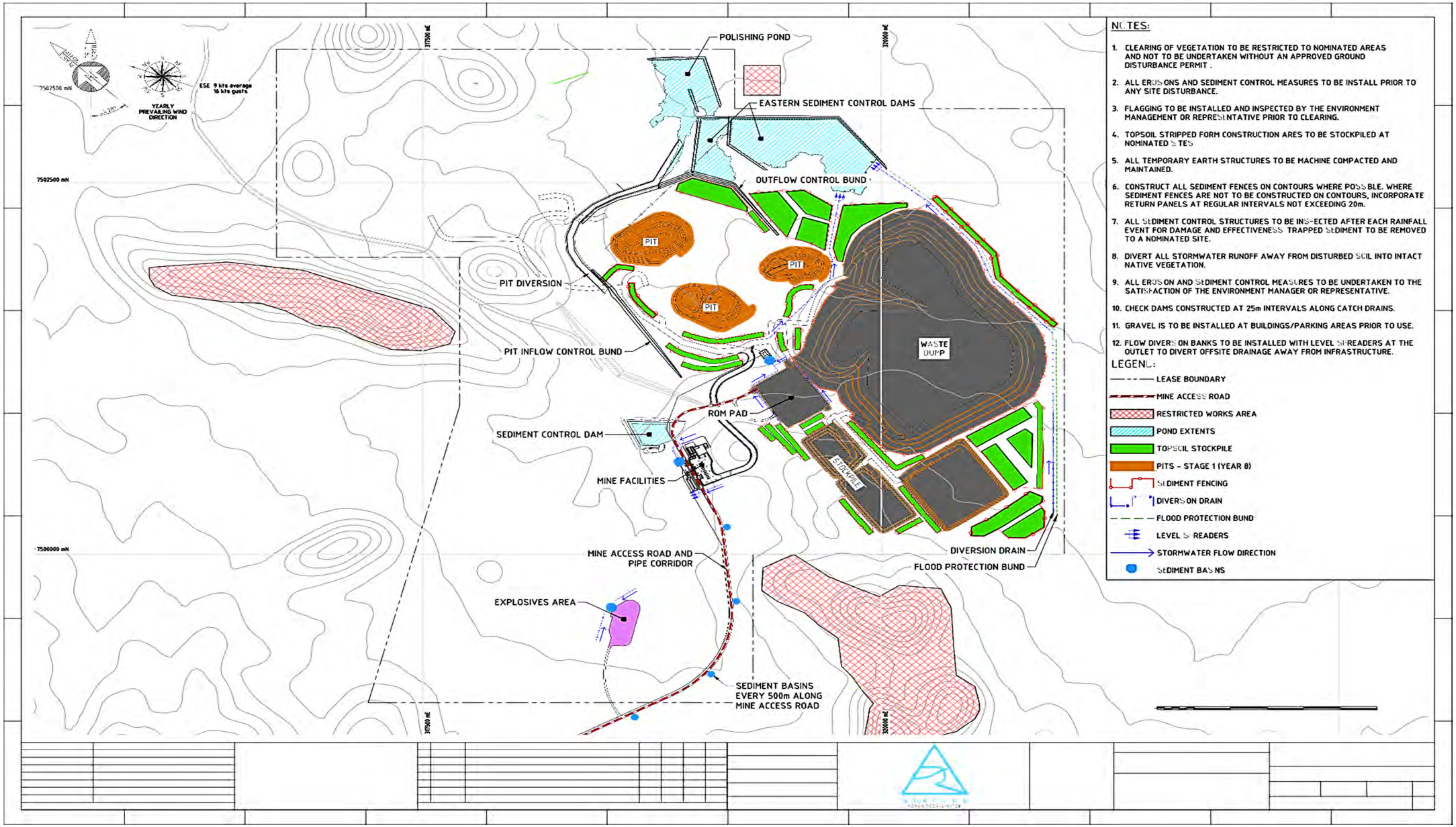
APPENDIX A. PROPOSED DEVELOPMENT

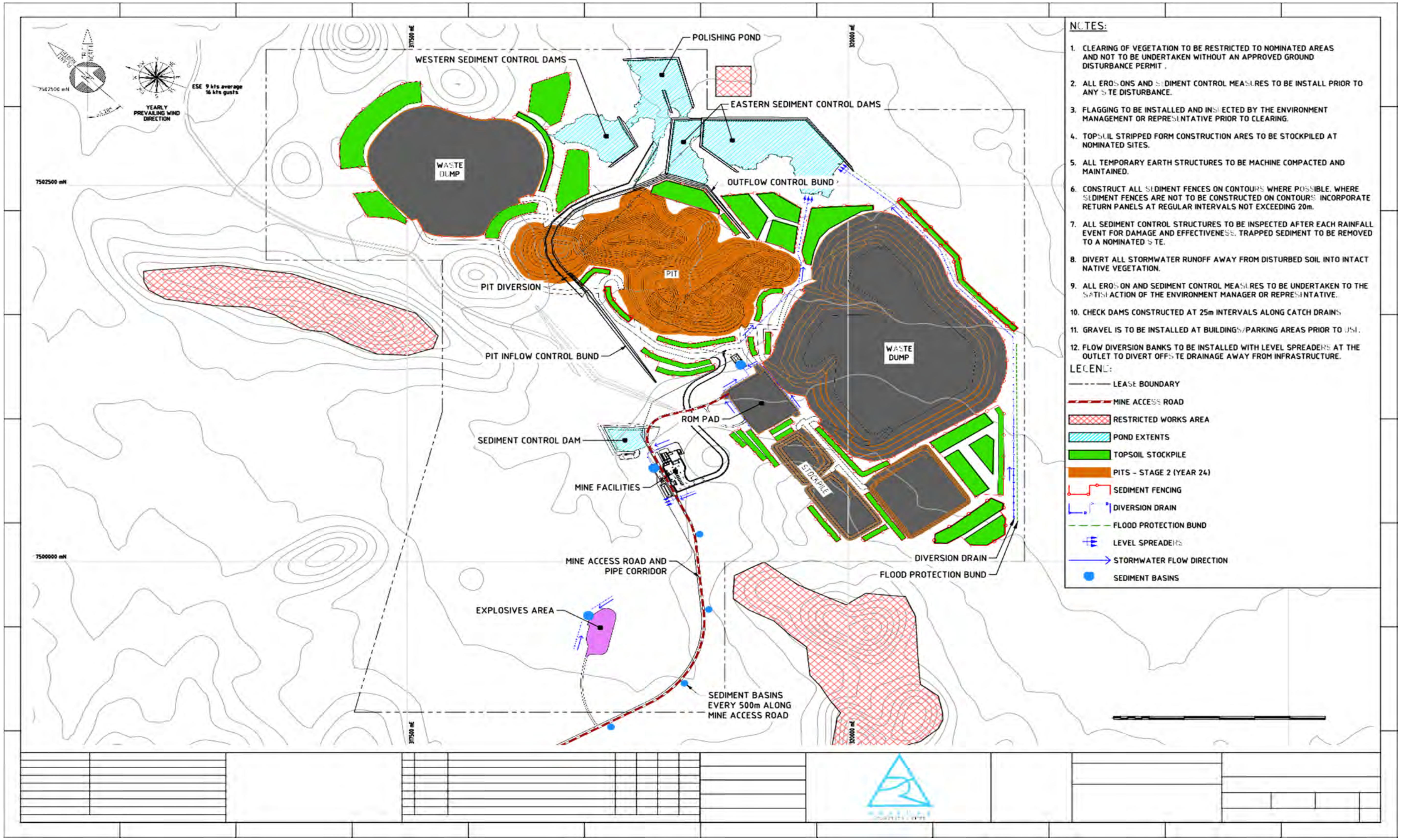


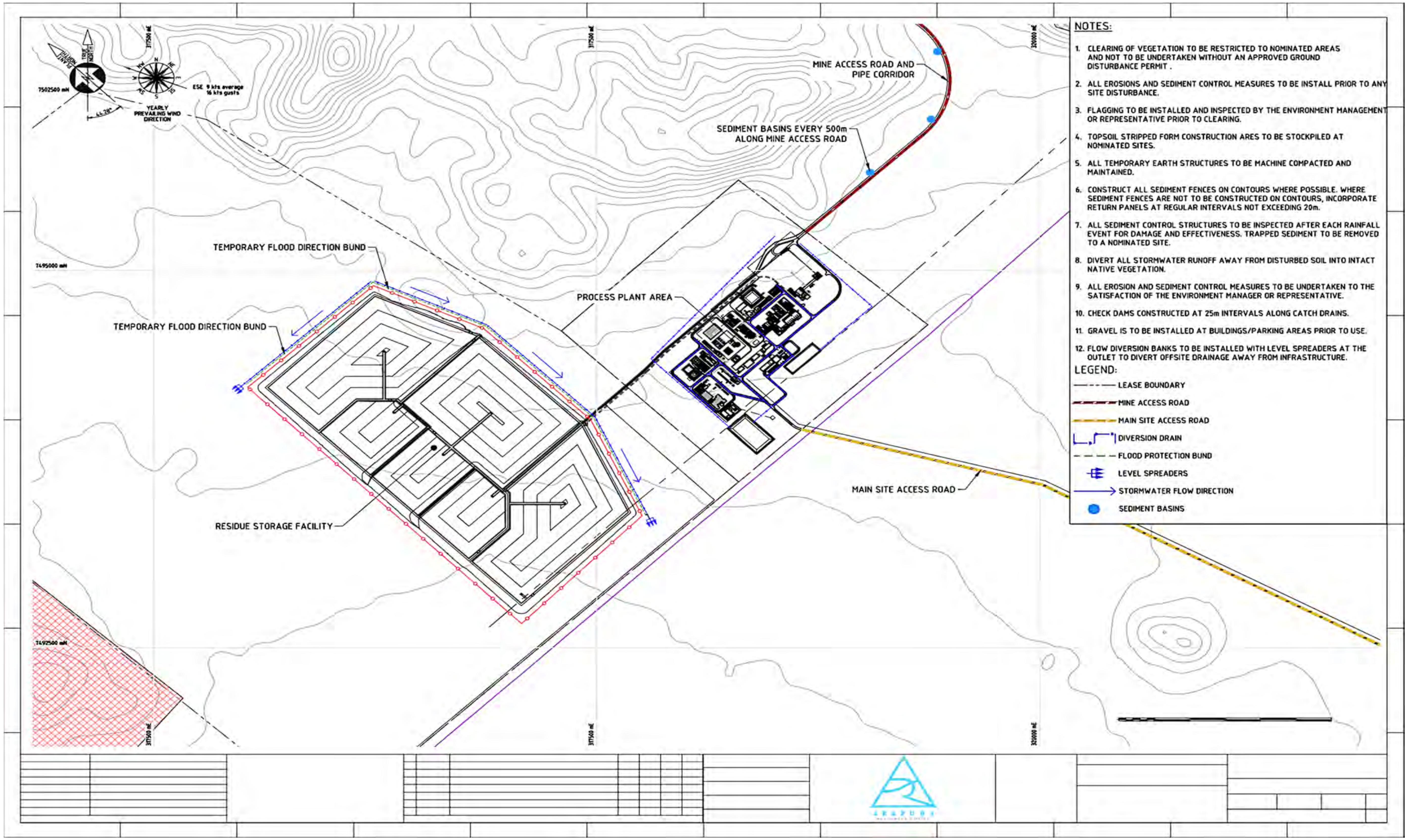


Legend
Geotech – Test Pit Sample Sites
Alternate Proposed Access Route
Proposed Fence Lines
Proposed Roads and Buildings
Proposed Overhead Power Line
Proposed Residual Storage Facility
Proposed Solar Farm
Existing Gas Pipeline (AGL)
Existing Road and Track
Mineral Leases (MLs)
Station Boundary
Fence
Pit
Detailed Pit Topography
ROM
Long-Term Stockpiles (LTS)
Topsoil Stockpiles (TS)
Surface Water Infrastructure
Pit Waste Dump
Proposed Solar Farm
Arafura - Nolans - Site

APPENDIX B. CONCEPT PROJECT ESC PLANS




POLISHING POND
WESTERN SEDIMENT CONTROL DAMS
EASTERN SEDIMENT CONTROL DAMS
YEARLY PREVAILING WIND DIRECTION
ESE 9 kts average 16 kts gusts
7502500 mN
WASTE DUMP
OUTFLOW CONTROL BUND
PIT
PIT DIVERSION
PIT INFLOW CONTROL BUND
WASTE DUMP
ROM PAD
SEDIMENT CONTROL DAM
STOCKPILE
MINE FACILITIES
7500000 mN
MINE ACCESS ROAD AND PIPE CORRIDOR
DIVERSION DRAIN
FLOOD PROTECTION BUND
EXPLOSIVES AREA
SEDIMENT BASINS EVERY 500m ALONG MINE ACCESS ROAD
317500 mE
320000 mE
NOTES:
1. CLEARING OF VEGETATION TO BE RESTRICTED TO NOMINATED AREAS AND NOT TO BE UNDERTAKEN WITHOUT AN APPROVED GROUND DISTURBANCE PERMIT .
2. ALL EROSIONS AND SEDIMENT CONTROL MEASURES TO BE INSTALL PRIOR TO ANY SITE DISTURBANCE.
3. FLAGGING TO BE INSTALLED AND INSPECTED BY THE ENVIRONMENT MANAGEMENT OR REPRESENTATIVE PRIOR TO CLEARING.
4. TOPSOIL STRIPPED FORM CONSTRUCTION ARES TO BE STOCKPILED AT NOMINATED SITES.
5. ALL TEMPORARY EARTH STRUCTURES TO BE MACHINE COMPACTED AND MAINTAINED.
6. CONSTRUCT ALL SEDIMENT FENCES ON CONTOURS WHERE POSSIBLE. WHERE SEDIMENT FENCES ARE NOT TO BE CONSTRUCTED ON CONTOURS INCORPORATE RETURN PANELS AT REGULAR INTERVALS NOT EXCEEDING 20m.
7. ALL SEDIMENT CONTROL STRUCTURES TO BE INSPECTED AFTER EACH RAINFALL EVENT FOR DAMAGE AND EFFECTIVENESS. TRAPPED SEDIMENT TO BE REMOVED TO A NOMINATED SITE.
8. DIVERT ALL STORMWATER RUNOFF AWAY FROM DISTURBED SOIL INTO INTACT NATIVE VEGETATION.
9. ALL EROSION AND SEDIMENT CONTROL MEASURES TO BE UNDERTAKEN TO THE SATISFACTION OF THE ENVIRONMENT MANAGER OR REPRESENTATIVE.
10. CHECK DAMS CONSTRUCTED AT 25m INTERVALS ALONG CATCH DRAINS
11. GRAVEL IS TO BE INSTALLED AT BUILDINGS/PARKING AREAS PRIOR TO USE.
12. FLOW DIVERSION BANKS TO BE INSTALLED WITH LEVEL SPREADERS AT THE OUTLET TO DIVERT OFFSITE DRAINAGE AWAY FROM INFRASTRUCTURE.
LEGEND:
LEASE BOUNDARY
MINE ACCESS ROAD
RESTRICTED WORKS AREA
POND EXTENTS
TOPSOIL STOCKPILE
PITS - STAGE 2 (YEAR 24)
SEDIMENT FENCING
DIVERSION DRAIN
FLOOD PROTECTION BUND
LEVEL SPREADERS
STORMWATER FLOW DIRECTION
SEDIMENT BASINS


MINE ACCESS ROAD AND PIPE CORRIDOR
SEDIMENT BASINS EVERY 500m ALONG MINE ACCESS ROAD
TEMPORARY FLOOD DIRECTION BUND
TEMPORARY FLOOD DIRECTION BUND
PROCESS PLANT AREA
RESIDUE STORAGE FACILITY
MAIN SITE ACCESS ROAD
YEARLY PREVAILING WIND DIRECTION
NOTES:
1. CLEARING OF VEGETATION TO BE RESTRICTED TO NOMINATED AREAS AND NOT TO BE UNDERTAKEN WITHOUT AN APPROVED GROUND DISTURBANCE PERMIT .
2. ALL EROSIONS AND SEDIMENT CONTROL MEASURES TO BE INSTALL PRIOR TO ANY SITE DISTURBANCE.
3. FLAGGING TO BE INSTALLED AND INSPECTED BY THE ENVIRONMENT MANAGEMENT OR REPRESENTATIVE PRIOR TO CLEARING.
4. TOPSOIL STRIPPED FORM CONSTRUCTION ARES TO BE STOCKPILED AT NOMINATED SITES.
5. ALL TEMPORARY EARTH STRUCTURES TO BE MACHINE COMPACTED AND MAINTAINED.
6. CONSTRUCT ALL SEDIMENT FENCES ON CONTOURS WHERE POSSIBLE. WHERE SEDIMENT FENCES ARE NOT TO BE CONSTRUCTED ON CONTOURS, INCORPORATE RETURN PANELS AT REGULAR INTERVALS NOT EXCEEDING 20m.
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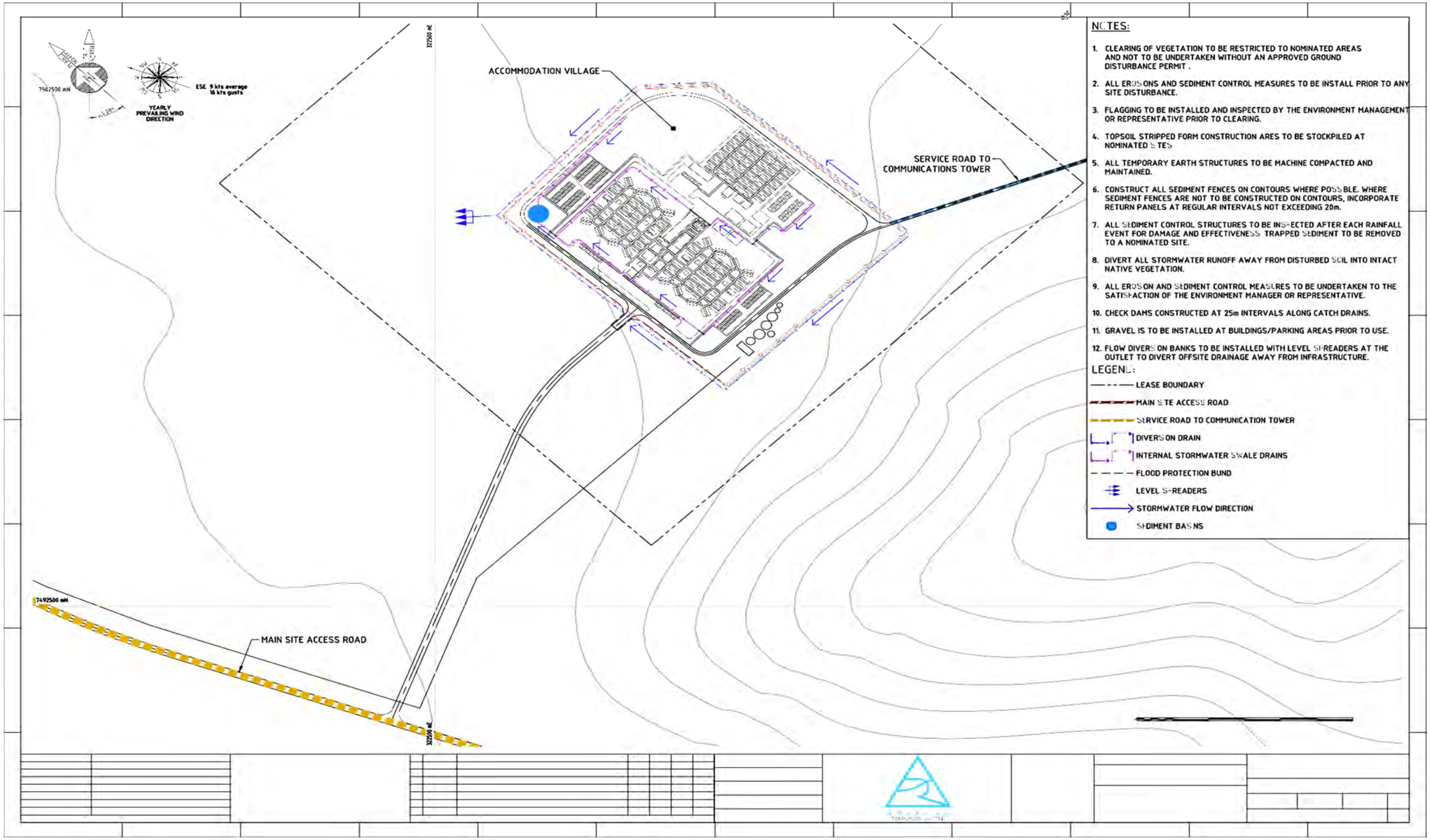
9. ALL EROSION AND SEDIMENT CONTROL MEASURES TO BE UNDERTAKEN TO THE SATISFACTION OF THE ENVIRONMENT MANAGER OR REPRESENTATIVE.
10. CHECK DAMS CONSTRUCTED AT 25m INTERVALS ALONG CATCH DRAINS.
11. GRAVEL IS TO BE INSTALLED AT BUILDINGS/PARKING AREAS PRIOR TO USE.
12. FLOW DIVERSION BANKS TO BE INSTALLED WITH LEVEL SPREADERS AT THE OUTLET TO DIVERT OFFSITE DRAINAGE AWAY FROM INFRASTRUCTURE.
LEGEND:
LEASE BOUNDARY
MINE ACCESS ROAD
MAIN SITE ACCESS ROAD
DIVERSION DRAIN
FLOOD PROTECTION BUND
LEVEL SPREADERS
STORMWATER FLOW DIRECTION
SEDIMENT BASINS


ACCOMMODATION VILLAGE
SERVICE ROAD TO COMMUNICATIONS TOWER
MAIN SITE ACCESS ROAD
YEARLY PREVAILING WIND DIRECTION
ESE 9 kts average 16 kts gusts
7492500 mN
322500 mE
NOTES:
1. CLEARING OF VEGETATION TO BE RESTRICTED TO NOMINATED AREAS AND NOT TO BE UNDERTAKEN WITHOUT AN APPROVED GROUND DISTURBANCE PERMIT .
2. ALL EROSIONS AND SEDIMENT CONTROL MEASURES TO BE INSTALL PRIOR TO ANY SITE DISTURBANCE.
3. FLAGGING TO BE INSTALLED AND INSPECTED BY THE ENVIRONMENT MANAGEMENT OR REPRESENTATIVE PRIOR TO CLEARING.
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10. CHECK DAMS CONSTRUCTED AT 25m INTERVALS ALONG CATCH DRAINS.
11. GRAVEL IS TO BE INSTALLED AT BUILDINGS/PARKING AREAS PRIOR TO USE.
12. FLOW DIVERSION BANKS TO BE INSTALLED WITH LEVEL SPREADERS AT THE OUTLET TO DIVERT OFFSITE DRAINAGE AWAY FROM INFRASTRUCTURE.
LEGEND:
LEASE BOUNDARY
MAIN SITE ACCESS ROAD
SERVICE ROAD TO COMMUNICATION TOWER
DIVERSION DRAIN
INTERNAL STORMWATER SWALE DRAINS
FLOOD PROTECTION BUND
LEVEL SPREADERS
STORMWATER FLOW DIRECTION
SEDIMENT BASINS

APPENDIX C. IECA ESC FACT SHEETS

Drainage Control – General

DRAINAGE CONTROL TECHNIQUES

The temporary drainage control measures placed on construction sites to appropriately manage stormwater runoff are traditionally considered part of the overall *erosion control* process. However, not all aspects of *drainage control* relate solely to the erosion control process. Some drainage control measures function to reduce soil erosion, while others benefit the sediment control process as outlined in Table 1.

Table 1 – Application of drainage control measures

Aspects applicable to erosion control	Aspects applicable to sediment control
• Diversion of up-slope stormwater runoff around soil disturbances. • Division of a site into manageable drainage areas. • Management of sheet runoff to minimise the risk of rill erosion down long slopes. • Control of flow velocity and soil erosion within drainage channels and *Chutes*.	• Diverting up-slope runoff around excavations (benefits sediment control through a reduction in the volume of water required to be de-watered from the pit). • Diversion of 'clean' water around sediment traps, thus improving their sediment-trapping efficiency and reducing the size of major sediment traps, such as *Sediment Basins*.

The proper management of stormwater runoff during the construction phase is critical to the implementation of effective erosion and sediment control. The importance of stormwater management generally increases with increasing rainfall intensity.

The stormwater drainage requirements of a site need to be appropriately incorporated into all stages of construction. Failure to recognise the requirements of such things as the diversion of up-slope 'clean' water, or the efficient delivery of sediment-laden water to sediment traps, can severely limit the overall efficiency of an erosion and sediment control program.

The effective management of stormwater within building and construction sites lies in the appropriate control of runoff velocity, volume and location. This usually requires the establishment of *temporary* drainage control measures, separate to the site's permanent drainage system. The temporary nature of these drainage controls often means that they are designed to a lower drainage standard compared to the permanent drainage system; however, the need for appropriate hydrologic and hydraulic design is just as important.

The primary function of these drainage control measures is to:

- minimise the risk of rill and gully erosion;
- minimise the risk of hydraulic damage to the adopted erosion and sediment control measures;
- control the velocity, volume and location of water flow through the site; and
- appropriately manage the movement of 'clean' and 'dirty' water through the site.

The principles of best practice (2008) construction site drainage control are outlined below.

1. The permanent and temporary drainage requirements of a site need to be appropriately considered during development of the Erosion and Sediment Control Plan.
2. Flow velocities need to be limited to the maximum allowable velocity for each individual drainage system.
3. All drainage channels, temporary or permanent, need to be constructed and maintained with sufficient gradient and surface conditions to maintain their required hydraulic capacity.
4. Wherever reasonable and practicable, up-slope stormwater runoff, whether 'dirty' or 'clean', needs to be diverted around soil disturbances and unstable slopes in a manner that minimises soil erosion, and the saturation of soils within active work areas.

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5. To the maximum degree reasonable and practicable, 'clean' water needs to be diverted around sediment traps in a manner that maximises the sediment trapping efficiency of the sediment trap.
6. On disturbances exceeding 1500m^2, Construction Drainage Plans need to be prepared for each stage of earth works.
7. The construction schedule and ESC installation sequence should allow for the installation of the temporary drainage system, and preferably the permanent stormwater drainage system, as soon as practicable.
8. Long slopes of disturbed or otherwise unstable soil should be divided into small, manageable drainage areas to prevent, or at least minimise, rill erosion.
9. In regions containing dispersive soils, construction details of drainage systems and bank stabilisation works need to demonstrate how these soils are to be stabilised and/or buried under a layer of non-dispersive soil.
10. Appropriate outlet scour protection needs to be placed on all stormwater outlets, *Chutes*, spillways and *Slope Drains* to dissipate flow energy and minimise the risk of soil erosion.
11. Building and construction sites need to employ appropriate short-term drainage control measures to deal with impending storms.
12. Clean, sealed surfaces, such as roofs, should be connected to the permanent underground drainage system (if available) as soon as they are constructed.
13. Adequate drainage controls need to be applied to all permanent and temporary, unsealed roads and tracks to minimise environmental harm caused by runoff from such surfaces.
14. Disturbances to natural watercourses and riparian zones need to be minimised wherever possible, and all temporary watercourse crossings need to employ appropriate drainage, erosion, and sediment controls to minimise sediment inflow into the stream.
15. All drainage systems, whether temporary or permanent, need to be designed to the appropriate drainage standard.

Drainage control techniques include, but are limited to, the following:

- Catch Drains
- Chutes
- Diversion Channels
- Flow Diversion Banks
- Level Spreaders
- Outlet Structures
- Check Dams
- Slope Drains
- Temporary Watercourse Crossings

The design of these drainage control measures are supported by technical guidelines on various chute and channel linings including:

- Cellular Confinement Systems
- Erosion Control Mats
- Geosynthetic Linings
- Grass Linings
- Hard Armouring
- Rock Linings
- Rock Mattresses
- Turf reinforcement Mats

For specific information on the above erosion control techniques, refer to the relevant fact sheets.

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Flow Diversion Banks Part 1: General

DRAINAGE CONTROL TECHNIQUE

Low Gradient	✓	Velocity Control		Short Term	✓
Steep Gradient		Channel Lining		Medium-Long Term	✓
Outlet Control		Soil Treatment		Permanent	[1]

[1] Flow diversion banks are not commonly used as permanent drainage structures.

Symbol → DB →

Photo 1 – Flow diversion bank down-slope of a future pipeline installation

Photo 2 – Flow diversion bank up-slope of a building site

Key Principles

1. Key design parameters are the effective flow capacity of the structure, and the scour resistance of the embankment material.
2. The critical operational issue is usually preventing structural damage to the embankment as a result of high velocity flows or construction traffic.
3. Flow diversion banks are often favoured over *Catch Drains* in areas containing dispersive subsoil because their construction does not require exposure of the subsoils.

Design Information

Dimensional requirements of flow diversion banks and berms vary with the type of embankment. The recommended values are outlined in Table 1.

Table 1 – Recommended dimensional requirements of flow diversion banks/berms

Parameter	Earth banks	Compost berms [1]	Sandbag berms
Height (min)	500mm	300mm (450mm)	N/A
Top width (min)	500mm [2]	100mm (100mm)	N/A
Base width (min)	2500mm [2]	600mm (900mm)	N/A
Side slope (max)	2:1 (H:V)	1:1 (H:V)	N/A
Hydraulic freeboard	150mm (300mm) [3]	100mm	50mm

[1] Values in brackets apply to berms placed across land slopes steeper than 4:1 (H:V).

[2] Top width may be reduced in those non-critical situations in which overtopping will not cause excessive erosion and the banks are unlikely to experience damage from construction equipment.

[3] A minimum freeboard of 300mm applies to non-vegetated earth embankments.

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Free standing earth embankments may be stabilised with rock, vegetation, or *Erosion Control Blankets*; however, unprotected topsoil embankments are also acceptable for short-term applications.

Maximum recommended spacing of flow diversion banks down long continuous slopes is provided in Table 2. The actual spacing specified for a given site may need to be less than that presented in Table 2 if the soils are highly susceptible to erosion, or if intense storm events are expected (i.e. northern parts of Australia during the wet season).

Table 2 – Maximum recommended spacing of flow diversion banks down slopes

Open Earth Slopes						Vegetated Slopes		
Slope	**Horiz.**	**Vert.**	**Slope**	**Horiz.**	**Vert.**	**Slope**	**Horiz.**	**Vert.**
1%	80m	0.9m	15%	19m	2.9m	< 10%	No maximum	
2%	60m	1.2m	20%	16m	3.2m	12%	100m	12m
4%	40m	1.6m	25%	14m	3.5m	15%	80m	12m
6%	32m	1.9m	30%	12m	3.5m	20%	55m	11m
8%	28m	2.2m	35%	10m	3.5m	25%	40m	10m
10%	25m	2.5m	40%	9m	3.5m	30%	30m	9m
12%	22m	2.6m	50%	6m	3.0m	> 36%	Case specific	

Photo 3 – Flow diversion berm used to minimise road runoff flowing down a steep, unstable section of the embankment

Photo 4 – Sandbag flow diversion berm used to minimise surface flow over a recently seeded embankment

Photo 5 – Earth flow diversion bank used to direct runoff towards the entrance of a *Slope Drain*

Photo 6 – Turf-lined flow diversion bank with grass-lined outlet chutes at regular intervals along the embankment

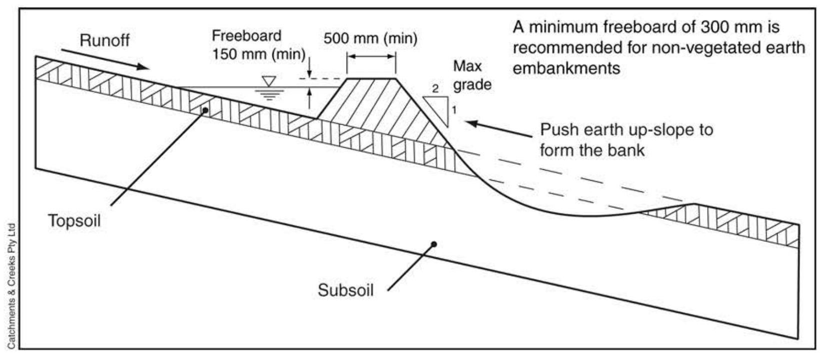
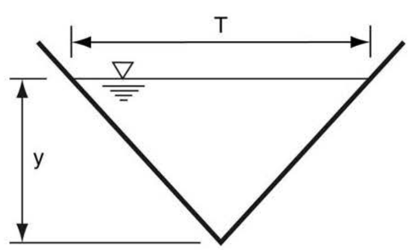
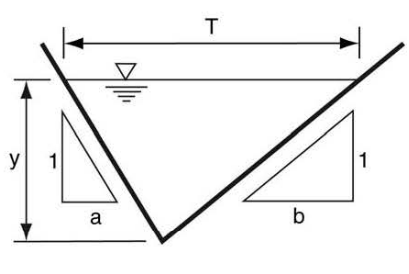


Figure 1 – Profile of 'back-push' bank

The hydraulic capacity of a flow diversion bank normally needs to be assessed on a case-by-case basis; however, the associated fact sheets *"Part 2: On earth slopes"* and *"Part 3: On grassed slopes"* provide the hydraulic capacity for drains with a standard triangular profile established on earth and grassed slopes respectively.

The geometric properties of triangular drainage channels formed by the construction of a flow diversion bank are provided in Table 3.

Table 3 – Geometric properties of triangular drainage profiles

Symmetrical or asymmetric V-drain: 	**Area (A):** $A = 0.5\,T\,y$
	Wetted perimeter (P): $P = \sqrt{T^2 + 4y^2}$
	Hydraulics radius (R): $R = \frac{Ty}{2\sqrt{T^2 + 4y^2}}$
Asymmetric V-drain: **where flow top width, T = y(a + b)** 	**Area (A):** $A = \left(\frac{a+b}{2}\right)y^2$
	Wetted perimeter (P): $P = y\left[\sqrt{(1+a^2)} + \sqrt{(1+b^2)}\right]$
	Hydraulics radius (R): $R = \frac{0.5(a+b)y}{\sqrt{(1+a^2)} + \sqrt{(1+b^2)}}$

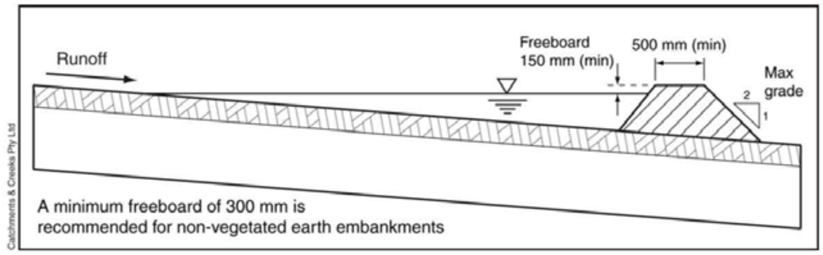


Figure 2 – Flow diversion bank formed from earth

Photo 7 – Flow diversion banks placed each side of drainage line passing through road construction site

Types of flow diversion banks:

The following provides a brief description of some of the flow diversion banks used within rural and construction land management.

Absorption bank	A level bank turned up at each end to promote water infiltration.
Back-push bank	A bank formed by moving in-situ earth up a slope.
Conventional bank	A bank formed by moving in-situ earth down thus forming an excavated drain up-slope of the bank. Also known as a 'catch bank'.
Diversion bank	A graded bank used to collect and divert water away from a soil disturbance, or to a dam, drainage channel, or sediment trap.
Graded bank	A bank constructed with a positive gradient to promote water movement.
Level bank	A bank constructed along a contour. Discharge usually occurs at each end of the bank.
Perimeter bank	A bank located along the upper or lower perimeter of a well-defined area, such as a building site, or along the top edge of a batter.
Trainer bank	A bank used to divert water away from unstable land.
Water-spreading bank	Banks used to collect and distribute surface runoff over an increased flow width. Typically used on low-gradient, marginal arable land.

Description

Flow diversion banks typically consist of a raised earth embankment normally placed along level or near level ground. Minor flow diversion berms can also be formed from tightly packed sandbags, or compost.

Short-term flow diversion banks can also be constructed from tightly packed straw bales. Such banks are often constructed prior to an impending storm.

The term *perimeter bank* is often used to describe an embankment constructed around the 'perimeter' of a work site. These are used to either prevent clean water entering the site, or to prevent the uncontrolled release of dirty water from a site.

The term *back-push bank* is used to describe an embankment formed by pushing in-situ soils up a slope to from an earth embankment.

Purpose

Flow diversion banks and berms are used as temporary drainage systems to:

- collect sheet runoff (clean or dirty) from slopes and transport it across the slope to a stable outlet (Photo 1);
- divert up-slope runoff around a stockpile or soil disturbance (Photo 2);
- divert stormwater away from an unstable slope (Photos 3 & 4);
- direct water to the inlet of a *Chute* or *Slope Drain* (Photos 5 & 6);
- control the depth of ponding around a sediment trap such as a stormwater drop (field) inlet.

Flow diversion banks can also act as a form of topsoil stockpile. Topsoil can be stripped from a site and used to form flow diversion banks either up-slope and/or down-slope of the soil disturbance (Photo 1). Such a practice can be very space effective when conducting 'strip' construction such as roadways and pipeline installation.

Limitations

Catchment area is limited by the allowable flow capacity of the diversion bank and the allowable flow velocity of the surface material.

Not used on slopes steeper than 10% (10:1).

Advantages

Quick to establish or re-establish if disturbed.

Generally inexpensive to construct and remove.

Allows for the management of stormwater flow without the need to excavate a drainage channel. This can be a significant advantage in areas that have highly erosive or dispersive subsoils.

Disadvantages

Can cause sediment problems and flow concentration if overtopped during a severe storm.

Can restrict the movement of equipment around the site.

Can be highly susceptible to damage by construction equipment.

Common Problems

Damaged by construction traffic.

Scour along the base of the embankment caused by excessive flow velocity or an unstable outlet.

Overtopping flows caused by the deposition of sediment up-slope of the bank.

Special Requirements

All flow diversion banks must have a stable outlet.

Flow diversion banks should be seeded and mulched if their working life is expected to exceed 30 days, or as required by the erosion control standard.

Banks should **not** be constructed of unstable, non-cohesive, or dispersive soil.

Location

When flow diversion banks are required and their locations are not shown on the approved plans, their location on the ground should be determined after taking into consideration the following:

- the bank must discharge to a stabilised outlet;
- the bank should drain to a sediment trap if the diverted water is expected to be contaminated with sediment;
- stormwater must not be unnaturally diverted or concentrated onto an adjacent property.

Site Inspection

Check for slumps, wheel track damage, or loss of freeboard.

Check for excessive sediment deposition.

Check for erosion along the bank.

Installation

1. Refer to approved plans for location, extent, and construction details. If there are questions or problems with the location, extent, or method of installation, contact the engineer or responsible on-site officer for assistance.
2. Clear the location for the bank, clearing only the area that is needed to provide access for personnel and equipment.
3. Remove roots, stumps, and other debris and dispose of them properly. Do not use debris to build the bank.
4. Form the bank from the material, and to the dimension specified in the approved plans.
5. If earth is used, then ensure the sides of the bank are no steeper than a 2:1 (H:V) slope, and the completed bank must be at least 500mm high.
6. If formed from sandbags, then ensure the bags are tightly packed such that water leakage through the bags is minimised.
7. Check the bank alignment to ensure positive drainage in the desired direction.
8. The bank should be vegetated (turfed, seeded and mulched), or otherwise stabilised immediately, unless it will operate for less than 30 days or if significant rainfall is not expected during the life of the bank.
9. Ensure the embankment drains to a stable outlet, and does not discharge to an unstable fill slope.

Maintenance

1. Inspect flow diversion banks at least weekly and after runoff-producing rainfall.
2. Inspect the bank for any slumps, wheel track damage or loss of freeboard. Make repairs as necessary.
3. Check that fill material or sediment has not partially blocked the drainage path up-slope of the embankment. Where necessary, remove any deposited material to allow free drainage.
4. Dispose of any collected sediment or fill in a manner that will not create an erosion or pollution hazard.
5. Repair any places in the bank that are weakened or in risk of failure.

Removal

1. When the soil disturbance above the bank is finished and the area is stabilised, the flow diversion bank should be removed, unless it is to remain as a permanent drainage feature.
2. Dispose of any sediment or earth in a manner that will not create an erosion or pollution hazard.
3. Grade the area and smooth it out in preparation for stabilisation.
4. Stabilise the area by grassing or as specified in the approved plan.

Catch Drains Part 1: General Information

DRAINAGE CONTROL TECHNIQUE

Low Gradient	✓	Velocity Control		Short Term	✓
Steep Gradient		Channel Lining		Medium-Long Term	✓
Outlet Control		Soil Treatment		Permanent	[1]

[1] The design of permanent catch drains requires consideration of issues not discussed within this fact sheet, such as maintenance requirements. This fact sheet should not be used for the design of permanent drains.

Symbol → CD →

Photo 1 – Unlined catch drain

Photo 2 – Large rural catch drain (channel-bank)

Key Principles

1. Catch drains typically have standardised cross-sectional dimensions. Rather than uniquely sizing each catch drain to a given catchment, standard-sized drains are used based on a maximum allowable catchment area for a given rainfall intensity.
2. The **maximum** recommended spacing of catch drains down a slope (Table 3) is based on the aim of avoiding rill erosion within the up-slope drainage slope. It should be noted that the **actual** spacing of catch drains down a given slope may need to be less than the specified maximum spacing if the soils are highly erosive soils, or if rilling begins to occur between two existing drains.
3. The critical design parameters are the spacing of the drains down a slope, the maximum allowable catchment area, the choice of lining material (e.g. earth, turf, rock or erosion control mats), and the required channel gradient.

Design Information

Catch drains are drainage structures, as such, their design (i.e. maximum catchment area and horizontal spacing) must be based on local hydrologic and soil conditions.

Catch drains must have sufficient cross-sectional dimensions to fully contain the design flow with a minimum freeboard of 0.15m. This fact sheet provides design information on three standard parabolic-profile catch drains referred to as Type-A, Type-B and Type-C, and three triangular-profile V-drains; Type-AV, Type-BV and Type-CV.

The minimum dimensions of these catch drains are provided in Tables 1 and 2.

The cross-sectional profile can be parabolic (U-shape), trapezoidal, or triangular (V-drain). Cut slopes (channel banks) should be no steeper than 1.5:1(H:V) and fill slopes (typically associated with a down-slope embankment) no steeper than 2:1 (H:V).

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Table 1 – Dimensions of standard parabolic catch drains (Figures 1 & 3)

Catch drain type	Max top width of flow (T)	Maximum flow depth (y)	Top width of formed drain [1]	Depth of formed drain	Hyd. rad. (R) at max flow depth	Area (A) at max flow depth
Type-A	1.0m	0.15m	1.6m	0.30m	0.094m	0.100m^2
Type-B	1.8m	0.30m	2.4m	0.45m	0.186m	0.360m^2
Type-C	3.0m	0.50m	3.6m	0.65m	0.310m	1.000m^2

[1] Top width of the formed drain assumes the upper bank slope is limited to a maximum of 2:1.

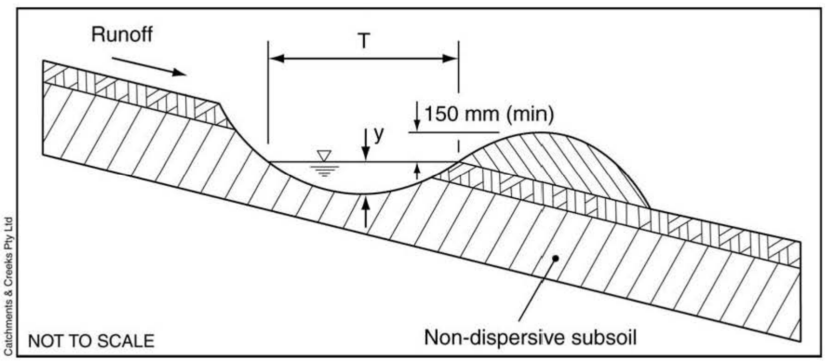

Figure 1 – Parabolic catch drain with bank

Table 2 – Dimensions of standard triangular V-drains (Figure 2)

Catch drain type	Max top width of flow (T)	Maximum flow depth (y)	Top width of formed drain	Depth of formed drain	Hyd. rad. (R) at max flow depth	Area (A) at max flow depth
Type-AV	1.0m	0.15m	2.0m	0.30m	0.072m	0.075m^2
Type-BV	1.8m	0.30m	2.7m	0.45m	0.142m	0.270m^2
Type-CV	3.0m	0.50m	3.9m	0.65m	0.237m	0.750m^2

Maximum spacing of catch drains:

Maximum recommended spacing of catch drains down slopes is presented in Table 3. The actual spacing specified for a given site may need to be less than that presented in Table 3 if the soils are highly susceptible to erosion, or if intense storm events are expected (i.e. northern parts of Australia during the wet season).

Table 3 – Maximum recommended spacing of catch drains down slopes

Open Earth Slopes						Vegetated Slopes		
Slope	Horiz.	Vert.	Slope	Horiz.	Vert.	Slope	Horiz.	Vert.
1%	80m	0.9m	15%	19m	2.9m	< 10%	No maximum	
2%	60m	1.2m	20%	16m	3.2m	12%	100m	12m
4%	40m	1.6m	25%	14m	3.5m	15%	80m	12m
6%	32m	1.9m	30%	12m	3.5m	20%	55m	11m
8%	28m	2.2m	35%	10m	3.5m	25%	40m	10m
10%	25m	2.5m	40%	9m	3.5m	30%	30m	9m
12%	22m	2.6m	50%	6m	3.0m	> 36%	Case specific	

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Table 4 – Drain profile parameters for catch drains

Parabolic: $y = C_1.T^2$	C_1	V-drain: $y = C_2.T$	C_2
Type-A	0.1500	**Type-AV**	0.1500
Type-B	0.0926	**Type-BV**	0.1667
Type-C	0.0556	**Type-CV**	0.1667

Channel lining:

If high flow velocities are expected, then the drain must be appropriately stabilised with geotextile fabric, *Erosion Control Mats/Mesh*, grass or rock. Alternatively, *Check Dams* can be placed at appropriate intervals to control the flow velocity; however, the impact of these *Check Dams* on the hydraulic capacity of the drain **must** be considered.

Photo 3 – Rock lined catch drain

Photo 4 – Permanent catch drain

Gradient:

The longitudinal gradient of catch drains primarily depends on the allowable flow velocity and Manning's roughness of the drainage channel. Excess channel gradient can initiate undesirable erosion (Photos 5 & 6).

Photo 5 – Upper limit of erosion within a catch drain

Photo 6 – Velocity-induced bed scour within a catch drain

Outlet Structures:

Catch drains must discharge to a stabilised outlet, such as a road, permanent drainage channel, *Chute*, *Slope Drain*, or *Level Spreader*. *Level Spreaders* are used when the flow is to be released as 'sheet' flow.

At the immediate outlet of the catch drain it may be necessary to construct an energy dissipater or rock pad to control soil scour (refer to the Fact Sheet on *Outlet Structures*).

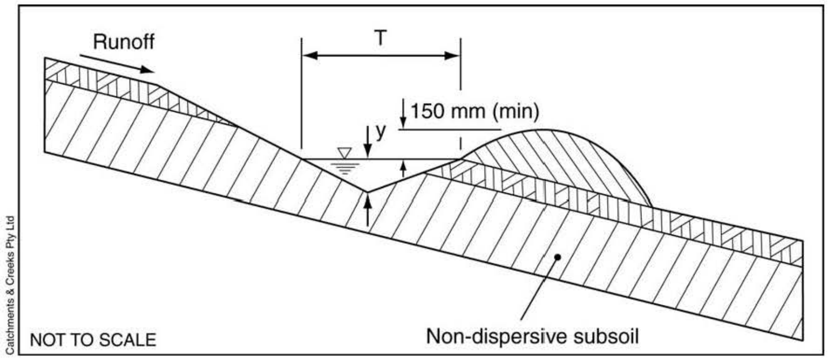

Figure 2 – Triangular V-drain with down-slope bank

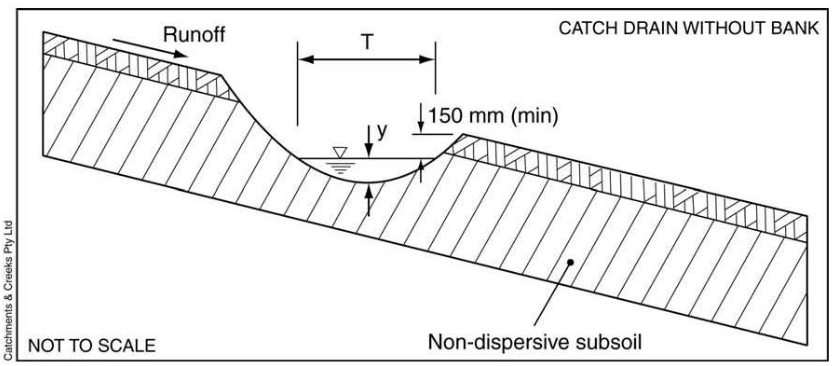

Figure 3 – Parabolic catch drain without bank

Types of drains:

The following provides a brief description of some of the drains used within rural and construction land management.

Berm drain:	A drain formed by a berm located between the top and bottom of a batter.
Catch drain:	A drain adjacent to a batter or embankment.
	Also, the generic term used for all temporary drains on construction sites.
Contour drain:	A drain formed along the contour (zero fall). Such drains act as infiltration trenches, similar (but not the same) as contour furrowing or deep ripping.
Cross drain:	A drain directing surface runoff across a road or track.
Diversion drain:	A drain used to collect and divert water from an adjacent catchment.
Mitre drain:	A drain used to direct road runoff away from the road alignment.
Spoon drain:	A minor drain of semi-circular cross-section and no associated embankment.
Table drain:	A drain that has one bank consisting of the shoulder of a roadway.
Windrow drain:	A drain formed by an earth windrow located along the edge of a road or trail.
Rubble drain:	A sub-surface drain formed by a gravel-filled trench.

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Description

Catch drains are small open channels formed at regular intervals down a slope, or immediately up-slope or down-slope of a soil disturbance. They are usually excavated with a grader blade, or U-shaped cutting/excavation tools.

Catch drains can be formed with or without an associated down-slope bank. The inclusion of a down-slope bank significantly increases the hydraulic capacity of the drain; however, these banks are susceptible to damage by vehicles resulting in hydraulic failure of the drain.

Channel-banks (push-down) catch drains are formed by pushing the excavated material down-slope of the drain. These drains should only be used in areas that have good, erosion-resistant subsoils.

'Back-Push' banks are formed by pushing the excavated material up-slope to form a *Flow Diversion Bank*. In such cases the diverted water flows up-slope of the embankment instead of within the excavated trench (refer to the fact sheet on *Flow Diversion Banks*).

Back-push banks are used in preference to catch drains in areas that have highly erosive or dispersible subsoils.

Catch drains are usually significantly smaller than formally designed *Diversion Channels*.

The term 'catch drain' is also used in the stormwater industry to refer to permanent drainage channels placed above cut batters to prevent uncontrolled discharge down the batter.

Purpose

Catch drains can be used to:

- direct stormwater runoff around a soil disturbance, or an unstable slope;
- collect sheet-flow runoff from an unstable slope before it is allowed to concentrate and cause rill erosion;
- collect sediment laden runoff down-slope of a disturbance and direct it to a sediment trap;
- collect and divert up-slope water around stockpiles and excavations.

Limitations

Catch drains are only suitable for relatively small flow rates. For the management of high flow rates a formally designed *Diversion Channel* may be required.

The maximum catchment area depends on the type of drain (i.e. Type A/AV, B/BV or C/CV), and the local hydrologic conditions.

Advantages

Quick and inexpensive to establish, or re-establish if disturbed.

Usually do not require complex formal design if based on standard design tables.

If constructed at appropriate gradients, flow velocities are usually small enough to avoid the need for special channel linings.

Disadvantages

Can cause significant erosion problems and flow concentration if overtopped during heavy storms.

Can restrict the movement of earthmoving equipment around the site, including access to stockpiles. Thus, catch drains may have limited use within active construction areas until earthworks are completed.

Common Problems

Installed at incorrect gradient. If the gradient is too shallow, it causes a reduction in the hydraulic capacity, if too steep it causes an increase in flow velocity.

Damage to associated flow diversion bank (rutting) caused by vehicles.

Catch drains that do not discharge to a stable outlet, causing downstream erosion, or initiating scour within the drain (Photo 5).

Special Requirements

The erosion-resistance of the local subsoils should be investigated before planning or designing any excavated drains.

Straw bales or other sediment traps should **not** be placed within these drains due to the risk of causing surcharging of the drain.

Catch drains need to be appropriately stabilised (e.g. compacted and/or lined with a suitable channel lining) within a specified period from the time of construction.

Catch drain should drain to a suitable sediment trap if the diverted water is expected to contain sediment. 'Clean' water should divert around sediment traps.

The drain must have positive gradient along its full length to allow free drainage.

Sufficient space must be provided to allow maintenance access.

Location

Typically used up-slope of cut batters, intermittently down long, exposed slopes, and up-slope of those stockpiles located within overland flow paths.

Catch drains are generally required up-slope of all cut and fill batters with a height greater than 2 metres and where run-on water is expected.

Site Inspection

Check that the drain has a stable, positive grade along its length.

Check for a stable drain outlet.

Check if the associated embankment is free of damage (e.g. damage caused by construction traffic).

Check that the drain has adequate hydraulic capacity given the catchment area (general observations based on past experience).

Check if rill erosion is occurring within the catchment area up-slope of the drain. If rilling is occurring, then the lateral spacing of the drains will need to be reduced. However, some degree of rill erosion should be expected if recent storms exceeded the intensity of the nominated design storm.

Inspect for evidence of water spilling out (overtopping) of the drain, or erosion down-slope of the drain.

Inspect for erosion along the bed (invert) of the drain. Investigate the reasons for any erosion before recommending solutions. Bed erosion can result from either excessive channel velocities, or an unstable outlet, which causes bed erosion (head-cut) to migrate up the channel.

Possible solutions to channel erosion include:

- reduce effective catchment area;
- increase channel width;
- increase channel roughness;
- stabilise bed with mats or mesh;
- stabilise bed with turf or rock;
- stabilise the outlet.

Check the channel lining (if any) for damage or displacement. If *Erosion Control Mats* have been used, check that they are correctly overlapped in direction of flow.

If the drain is lined with rock, check that the rock is not reducing the drain's required hydraulic capacity.

Diversion Channels

DRAINAGE CONTROL TECHNIQUE

Low Gradient	✓	Velocity Control		Short Term	✓
Steep Gradient		Channel Lining		Medium-Long Term	✓
Outlet Control		Soil Treatment		Permanent	[1]

[1] The design of permanent diversion channels requires consideration of issues not discussed within this fact sheet, such as safety and maintenance requirements.

Symbol → DC →

Photo 1 – Temporary diversion channel collecting 'dirty' water down-slope of a soil disturbance

Photo 2 – Permanent diversion channel collecting stormwater runoff up-slope of a subdivision

Key Principles

1. Diversion channels are sized for a specific design flow rate based on the catchment area, topography, soil and hydrologic conditions.
2. Critical design parameters are the choice of surface lining, hydraulic capacity and stability of the discharge point.
3. Critical operation issues are usually related to controlling sediment, vegetation and debris collection within the channel, and maintaining a stable outlet.

Design Information

Diversion channels are usually major hydraulic structures requiring design input from an experienced hydraulics specialist. This fact sheet does **not** provide sufficient information to allow diversion channels to be designed by inexperienced persons.

The design of permanent drainage channels requires consideration of issues not discussed within this fact sheet, such as safety and maintenance requirements.

The design discharge (Q) must reflect the specified drainage control standard of the site. Refer to the relevant regulating authority for relevant design standards. Where such standards do not exist, then refer to IECA (2008) Chapter 4 – *Design standards and technique selection*.

Typical design standards are presented in Table 1.

Refer to the various fact sheets under the sub-heading *Channel Linings* for velocity calculations and guidelines on the design of rock, grass or mat lining of the channel.

Recommended maximum bank slopes are provided in Table 2.

Table 1 – Typical design standards for temporary diversion channels

Parameter	Design standard
Design discharge	• Refer to IECA (2008) Table 4.3.1, Chapter 4 – *Design standards and technique selection*
Channel depth	• Minimum channel depth of 300mm
Freeboard	• Minimum freeboard being the greater of 150mm, 10% of channel depth, or the velocity head ($V^2/2g$) • Allow embankment settlement of 10% of fill height (in addition to freeboard) if the embankment's design life exceeds 1 year
Embankment	• Optional embankment formed down-slope of the channel (Figure 1). • Minimum crest width of 600mm, and down-slope bank gradient of 2:1 for reasons of stability against overtopping flows
Safety	• Safety requirements, such as the depth*velocity product (d.V), generally do not apply to drainage channels • Safety considerations generally focus on allowing good egress from the channel, and ensuring safety risks are obvious
Maintenance berm	• Desirable 1.5m wide (min) maintenance berm on at least one side of the channel (not always practicable in short-term projects)

Table 2 – Typical maximum bank slopes [1]

Site conditions	Max bank slope (H:V)
Highly compacted clay (hard, pick required)	1:1 to 1.25:1
Medium compact sandy clay	1.2:1 to 1.5:1
Slightly compact silty clay or sandy clay (soft, spade required)	1.5:1 to 2:1
Non-cohesive fine sandy soil or soils with humus or peat content	2:1 to 3:1
Non mowable vegetated slopes	3:1
Permanent, mowable, grass slopes (maximum grade)	4:1
Permanent, mowable grass slopes (recommended grade)	6:1
Rock lined channels	1.5:1 [2]

[1] Bank slopes provided as a guide only. Actual bank slope should be based on geotechnical and landscaping advice wherever practicable.

[2] Desirable maximum bank slope is 2:1 for dumped rock; however, with increased placement effort and skills, rock may be placed on bank slopes up to 1.5:1 in low velocity channels.

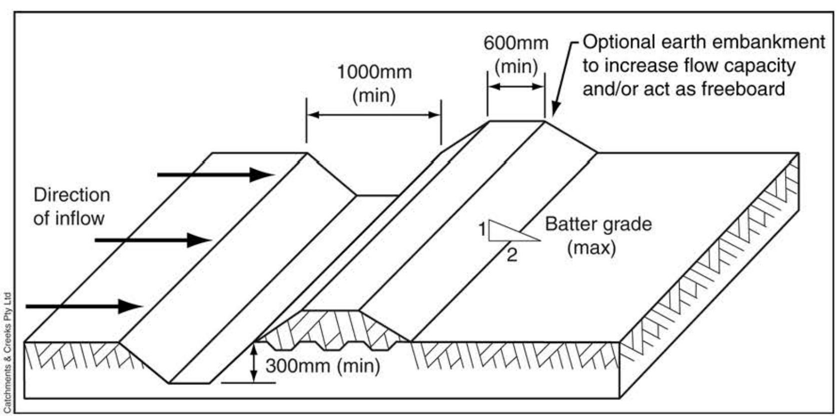

Figure 1 – Typical profile of temporary diversion channels

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Hydraulic design of diversion channels:

Step 1 Determine the required design discharge (Q).

If the channel gradient varies significantly along its length, then it may be desirable to split the channel into individual sections and determine an appropriate design discharge at the downstream end of each of these sections.

Step 2 Nominate the channel profile: parabolic or triangular (V-drain). Parabolic channel are generally less susceptible to invert erosion.

Step 3 Choose the preferred surface condition of the channel (e.g. earth, grass, rock).

The design information provided in the *Catch Drain* fact sheets can be used as a guide in selecting a surface lining and trial channel size.

Step 4 Select a bank slope (m) using Table 2 as a guide. Do **not** necessarily select the maximum bank slope, but consider such issues as safety and maintenance access.

Step 5 Determine the Manning's roughness (n) and allowable flow velocity (V_{allow}) using the relevant fact sheet (refer to channel linings) or Tables A17 to A20, and Tables A23 to A28 in IECA 2008, Appendix A – *Construction site hydrology and hydraulics*.

For grass and rock-lined channels it may be necessary to estimate a channel depth, and hydraulic radius (Steps 6 to 8) before determining Manning's roughness.

Step 6 Determine the minimum required flow area ($A = Q/V_{allow}$).

The design flow area does not have to be equal to this minimum flow area, but of course it must not be less than this area. It depends on how confident the designer is in the determination of the design discharge and the allowable flow velocity.

Step 7 Choose a trial channel size (depth, y; bed width, b; and flow top width, T) and the required freeboard (refer to Table 1).

Ultimately this may require an iterative process where various channel profiles are tested for hydraulic capacity.

Step 8 Determine the hydraulic radius (R) of the channel (based on flow area, **not** the overall channel dimension, which would include freeboard). Refer to Table A30 in IECA (2008) Appendix A.

Step 9a **If the channel gradient is <u>not</u> set by site conditions, then:**

Determine the channel gradient (S) using Manning's equation.

$$S = (n.V)^2/(R)^{4/3} \qquad \text{(S has units of m/m)}$$

Step 9b **If the channel gradient is set by site conditions, then:**

Determine the actual flow velocity (V) and compare this with the allowable flow velocity (V_{allow}).

$$V = (1/n)\,R^{2/3}\,S^{1/2}$$

If $V < V_{allow}$, then accept the design, or repeat Steps 7 & 9 for a smaller channel.

If $V > V_{allow}$, then repeat Steps 7 & 9 selecting a larger channel.

Step 10 Confirm final freeboard requirements given final depth and velocity head (Table 1).

Step 11 Ensure suitable conditions exist (e.g. machinery access) to construct and maintain the channel, otherwise a narrower channel width may be required.

Step 12 Given the final channel depth and velocity, check the required freeboard.

Specify the overall dimensions of the diversion channel, including freeboard.

Step 13 Ensure appropriate, non-erosive, flow conditions exist at the points of flow entry into the channel.

Step 14 Ensure the channel discharges to an appropriate, stable outlet structure.

Step 15 Appropriately consider all likely safety issues, and modify the channel design and/or surrounding environment where required.

Design example:

Design an earth-lined channel of trapezoidal cross-section to carry $0.5m^3/s$ located within a moderately erodible soil.

Step 1 The required design discharge is given as, $Q = 0.5m^3/s$.

Step 2 The question specifies a trapezoidal channel profile.

Step 3 The surface condition has been specified as earth-lined.

Step 4 For a slightly compacted soil (typical for a temporary drain), the maximum bank slope is likely to be around 1.5:1 or 2:1 (from Table 2).

If the drain was going to be deep (say, y > 0.5m) a flatter slope of 3:1 would be desirable for reasons of safety; however, this drain is likely to be relatively shallow, so choose a bank slope of 2:1 (i.e. m = 2).

Warning: 'm' is the term used for both bank slope, and the metric unit of metres!

Step 5 Select a Manning's "n" for an earth lined channel, n = 0.02 from Table A17 of IECA (2008) Appendix A – *Construction site hydrology and hydraulics*.

For a moderately erodible soil, choose a maximum allowable velocity, $V_{allow} = 0.6m/s$ from Table A23 of Appendix A.

Step 6 The minimum required flow area, $A_{min} = Q/V_{allow} = 0.5/0.6 = 0.833m^2$.

Step 7 For this example it will be assumed that the designer has confidence in the determination of the design discharge and the selection of an allowable flow velocity for the given soil conditions. Therefore, a design flow area of $0.84m^2$ is chosen (only slightly greater than the minimum value determined in Step 6).

Choose: $A = 0.84m^2$

Trial flow depth and bed width: Given that maximum depth of the excavated channel may be limited by existing site conditions, a first guess of the channel dimensions can be obtained by adopting one of the following options:

(i) try a flow depth, y = maximum allowable channel depth - 150mm; or

(ii) try a bed width, $b = (A/(1 + m))^{1/2}$

If we choose the latter option, then: $b = \sqrt{\frac{A}{(1+m)}} = \sqrt{\frac{0.84}{(1+2)}} = 0.53m$

For small channels it is good practice to select a bed width equal to the width of a typical excavator bucket. The most common bucket widths are 450, 600 and 900mm. So, for this example a bed width, b = 0.6m will be chosen.

If a flow depth (y) is chosen, then $b = \frac{A}{y} - y(m)$

If a bed width (b) is chosen, then: $y = \frac{\sqrt{(b^2 + 4(m)A)} - b}{2m}$

Thus for this example: $y = \frac{\sqrt{(0.6^2 + 4(2)0.84)} - 0.6}{2(2)} = 0.515m$

Step 8 From Table A30 of Appendix A, the hydraulic radius (R) is given by:

$$R = \frac{y(b + my)}{b + 2y\sqrt{(1+m^2)}} = \frac{0.515(0.6 + (2)0.515)}{0.6 + 2(0.515)\sqrt{(1+2^2)}} = 0.289m$$

Step 9a If its assumed that the channel slope is not governed by existing site conditions (i.e. the designer is free to determine a preferred channel slope), then the desired channel slope can be determined from Manning's equation:

Desired channel slope: $$S = \frac{n^2.V^2}{R^{4/3}} = \frac{(0.02)^2.(0.6)^2}{(0.289)^{4/3}} = 0.00075$$

The above equation provides slope in units or [m/m], thus the channel slope is equivalent to, S = 0.075%.

Step 10 Freeboard requirements will be defined by the greater of:

(i) 150mm

(ii) 10% of channel depth, = 0.1(0.515 + 0.15) = 0.067m, or

(iii) the velocity head ($V^2/2g$) = $(0.6)^2/19.6$ = 0.018m

Therefore, choose a freeboard of 150mm.

Final channel dimension:

Discharge, Q = 0.5m^3/s

Channel slope, S = 0.075%

Bank slope, m = 2 or (2:1) (H:V)

Maximum design flow depth, y = 0.515m

Freeboard = 0.15m

Excavated channel depth = 0.515 + 0.15 = 0.665m

Bed width, b = 0.6m

Top width of excavated channel = 0.6 + 2(2)(0.515 + 0.15) = 3.26m

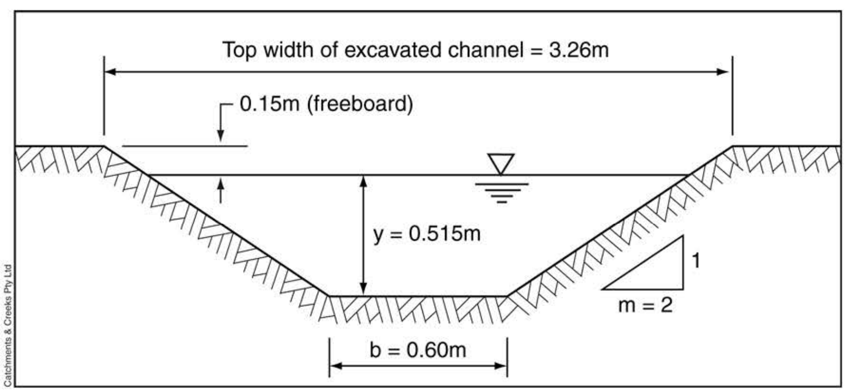

Figure 2 – Final channel dimensions

Description

Diversion channels are formally designed temporary or permanent excavated drainage channels usually with well-defined bed and banks.

Diversion channels are normally stabilised with a healthy and complete coverage of vegetation, primarily consisting of grasses. However, this should not prevent the use of alternative channel lining as appropriate for the site conditions.

Diversion channels can be formed with or without an associated down-slope flow diversion bank. The inclusion of a down-slope bank can significantly increase the hydraulic capacity of the channel.

Purpose

Diversion channels are used to:

- collect and transport stormwater runoff around or through a work site;
- collect sediment laden runoff down-slope of a disturbance and direct it to a sediment trap;
- temporarily divert a existing drainage channel while construction activities are occurring.

Limitations

Channel size and gradient are governed by the allowable flow velocity of the surface material.

Advantages

Low maintenance requirements.

On larger catchments, the cost savings resulting from the diversion of uncontaminated 'clean' flow around a soil disturbance and/or sediment trap can be significant.

Disadvantages

May restrict vehicular movements around the site, possibly requiring the construction of *Temporary Watercourse Crossings* over the channel.

Can cause significant erosion problems and flow concentration if overtopped during heavy storms.

Common Problems

The low channel gradient can cause long-term ponding and mosquito breeding.

Soil erosion at points of water inflow and at the channel outlet.

Special Requirements

The erosion-resistance of the local subsoils should be investigated before planning or designing any drainage channels.

Diversion channels should be vegetated if the expected working life exceeds 30 days. Exception may apply in arid and semi-arid regions.

If the channel is to be vegetated using grass seeding, then the channel should be established well before high flows are expected within the channel.

All diversion channels **must** have a stable outlet.

The channel must have positive gradient along its full length to allow free drainage.

Sufficient space must be provided to allow construction and maintenance access.

Site Inspection

Check that the drain has a stable, positive grade along its length.

Check for a stable drain outlet.

Check if the associated embankment is free of damage (e.g. damage caused by construction traffic).

Check that the drain has adequate hydraulic capacity given the catchment area (general observations based on past experience).

Check for sediment accumulation within the channel.

Check for excessive settlement of any associated fill embankments.

Check the channel lining (if any) for damage or displacement. If *Erosion Control Mats* have been used, check that they are correctly overlapped in direction of flow.

If the channel is lined with rock, check that the rock is not reducing the channel's required hydraulic capacity.

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Check that the drain has a stable, positive grade along its length.

Check for a stable drain outlet.

Check if the associated embankment is free of damage (e.g. damage caused by construction traffic).

Check that the drain has adequate hydraulic capacity given the catchment area (general observations based on past experience).

Check for sediment accumulation within the channel.

Check for excessive settlement of any associated fill embankments.

Check the channel lining (if any) for damage or displacement. If *Erosion Control Mats* have been used, check that they are correctly overlapped in direction of flow.

If the channel is lined with rock, check that the rock is not reducing the channel's required hydraulic capacity.

Installation

1. Refer to approved plans for location, extent, and construction details. If there are questions or problems with the location, extent, or method of installation, contact the engineer or responsible on-site officer for assistance.
2. Ensure all necessary soil testing (e.g. soil pH, nutrient levels) and analysis has been completed, and required soil adjustments performed prior to planting.
3. Clear the location for the channel, clearing only what is needed to provide access for personnel and construction equipment.
4. Remove roots, stumps, and other debris and dispose of them properly. Do not use debris to build any associated embankments.
5. Excavate the diversion channel to the specified shape, elevation and gradient. The sides of the channel should be no steeper than a 2:1 (H:V) if constructed in earth, unless specifically directed within the approved plans.
6. Stabilise the channel and banks immediately unless it will operate for less than 30 days. In either case, temporary erosion protection (matting, rock, etc.) will be required as specified within the approved plans or as directed.
7. Ensure the channel discharges to a stable area.

Additional requirements for turf placement:

1. Turf should be used within 12 hours of delivery, otherwise ensure the turf is stored in conditions appropriate for the weather conditions (e.g. a shaded area).
2. Moistening the turf after it is unrolled will help maintain its viability.
3. Turf should be laid on a minimum 75mm bed of adequately fertilised topsoil. Rake the soil surface to break the crust just before laying the turf.
4. During the warmer months, lightly irrigate the soil immediately before laying the turf.
5. Ensure the turf is not laid on gravel, heavily compacted soils, or soils that have been recently treated with herbicides.
6. Ensure the turf extends up the sides of the drain at least 100mm above the elevation of the channel invert, or at least to a sufficient elevation to fully contain expected channel flow.
7. On channel gradients of 3:1(H:V) or steeper, or in situations where high flow velocities (i.e. velocity >1.5m/s) are likely within the first two week following placement, secure the individual turf strips with wooden or plastic pegs.
8. Ensure that intimate contact is achieved and maintained between the turf and the soil such that seepage flow beneath the turf is avoided.
9. Water until the soil is wet 100mm below the turf. Thereafter, watering should be sufficient to maintain and promote healthy growth

Maintenance

1. During the site's construction period, inspect the diversion channel weekly and after any increase in flows within the channel. Repair any slumps, wheel track damage or loss of freeboard.
2. Ensure fill material or sediment is not partially blocking the channel. Where necessary, remove any deposited material to allow free drainage.
3. Dispose of any collected sediment or fill in a manner that will not create an erosion or pollution hazard.

Removal

1. When the construction work above a temporary diversion channel is finished and the area is stabilised, the area should be appropriately rehabilitated.
2. Dispose of any collected sediment or fill in a manner that will not create an erosion or pollution hazard.
3. Grade the area and smooth it out in preparation for stabilisation.
4. Stabilise the area as specified in the approved plan.

Check Dams

DRAINAGE CONTROL TECHNIQUE

Low Gradient	✓	Velocity Control	✓	Short Term	✓
Steep Gradient		Channel Lining		Medium-Long Term	✓
Outlet Control		Soil Treatment		Permanent	[1]

[1] Though not generally considered as permanent structures within drainage channels, rock check dams have been used in stormwater treatment swales to improve retention time and increase sedimentation. Permanent rock check dams can also be used to form a stable, terraced invert within mild-sloping (<10%) table drains. Permanent checks dams, however, can cause mowing problems.

Symbol (refer to Table 2)

Photo 1 – Sandbag check dams

Photo 2 – Rock check dam

Key Principles

1. The primary function of check dams is to control flow velocities within unlined drains. Most check dams, however, will also trap small quantities of sediment, thus allowing these structures to act as both *drainage* and *sediment* control devices.
2. Sediment control does **not** have to be considered a performance objective in all cases.
3. Hydraulic performance is governed by the height and spacing of the dams. The spacing of check dams down a drain varies with the slope of the drain and the height of each dam.
4. It is critical to ensure the check dams do not cause flow to unnecessarily spill out of the drain possibly resulting in flooding or erosion problems.
5. The crest of the check should be curved such that flow first spills over the centre of the dam. Use of a flat crest profile can cause erosion (rilling) down the banks of the drain.

Design Information

Table 2 provides guidance on the attributes and typical usage of various types of check dams, it is summarised in Table 1.

Table 1 – Summary of technique selection

Type of check dam	Typical conditions of use
Fibre rolls, Triangular & Sandbag check dam	• Drains less than 500mm deep
Rock check dam	• Drains more than 500mm deep
Compost-filled bags	• Situations where velocity control and enhanced stormwater treatment (filtration and adsorption) is required

Table 2 – Typical use of the various types of check dams

Technique	Code	Symbol [1]	Attributes and typical usage
Fibre rolls	FCD	→ FCD →	• Biodegradable (jute/coir) logs. • Used in wide, shallow drains where the logs can be successfully anchored down. • Used in locations where it is desirable to allow the fibre roll to integrate into the vegetation, such as vegetated channels. • Can be used as a minor sediment trap.
Rock check dams	RCD	→ RCD →	• Constructed from 150 to 300mm rock. • Best used **only** in drains at least 500mm deep, with a gradient less than 10%. • Should only be used in locations where it is known that they will be removed once a suitable grass cover has been established. • Can also be used as a minor sediment trap.
Recessed rock check dams	RRC	→ RRC →	• Constructed from minimum 200mm rock. • Used in wide, shallow, high velocity channels to prevent uncontrolled gully erosion during the revegetation period. • These are specialist hydraulic structures requiring specialist knowledge for their proper usage.
Sandbag check dams (including compost-filled bags)	SBC	→ SBC →	• Sandbags are typically filled with sand, aggregate, gravel, or compost. • Compost filled bags are considered to provide improved water treatment through filtration and adsorption. This system included compost-filled *Filter Socks*. • Typically used in drains less than 500mm deep, with a gradient less than 10%. • These check dams are typically small (in height) and therefore less likely to divert water out of the drain. • Can be used as a minor sediment trap.
Stiff grass barriers	SGB	■■ SGB ■■	• Requires long establishment times. • Typically used as a component of long-term gully stabilisation in rural areas. • Most suited to sandy soils. • Can be used as a minor sediment trap.
Triangular ditch checks	TDC	→ TDC →	• Manufactured from re-useable, porous, solid frame, PVC mesh. • Commonly used to stabilise newly formed, wide, shallow drains. • Used in drains with less than 10% gradient. • Can be used as a minor sediment trap.

[1] The check dam symbol is usually not used on ESC plans; instead the use of check dams is normally specified within technical notes listed on the plans. A table may be included within the ESCP to provide details on the type of check dam used at specific locations within the site.

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Typical maximum channel gradient of 10% (1 in 10). Preference should be given to the use of a suitable channel lining if the drain or chute is steeper than 10%.

Check dams are spaced down the drain such that the crest of the check dam is level with the toe of the immediate upstream check dam (as shown in Figures 1).

Maximum recommended crest height of around 500mm. Check dams with a height exceeding 500mm should be checked for hydraulic stability.

Maximum slope of the face of rock check dams is 2:1 (H:V). For check dams higher than 500mm, the slope of the **downstream** face may need to be significantly flatter than a 2:1.

The crest of the check dam should be curved such that flow first spills over the centre of the dam. Ideally, the crest of each dam should be at least 150mm lower than the bank elevation at the outer edges of the structure.

The purpose of a curved crest profile is to:

- minimise the quantity of water bypassing around the edge of the check dam; and
- to concentrate flow into the centre of the channel.

Use of a flat crest profile can cause erosion (rilling) down the banks of the drain.

For sandbag check dams placed in shallow profile drainage channels, such as some table drains, it may be necessary to remove one or two sandbags from the centre of the structure (refer to Photo 3) to promote flow at the centre of the drain. The sandbags may also need to be placed in a curved (concave) horizontal profile to minimise flow bypassing around the ends of the dam (this can also be seen in Photo 3).

Check dams should not be used to control erosion within drains formed from dispersive soil (Photos 9 & 10). In such cases, the exposed dispersive soil should be covered with non-dispersive soil, then stabilised with an appropriate channel liner.

In circumstance where the use of check dams could cause such a significant reduction in the drain's hydraulic capacity to force water out of the drain resulting in either traffic safety issues (table drains) or flooding of adjacent properties, then the design options are:

- select an appropriate channel lining such that the use of check dams within the drain will no longer be required;
- perform an appropriate hydraulic analysis on the check dams to ensure that adequate hydraulic performance of the drain is maintained (refer over-page for guidance on such hydraulic analysis).

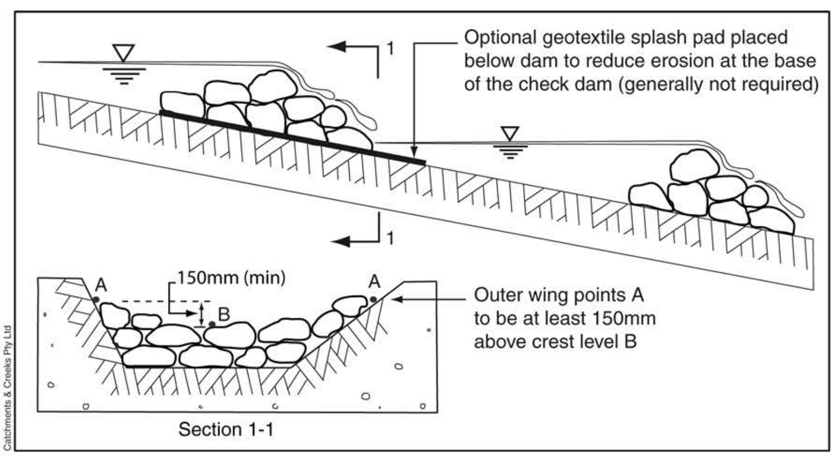

Figure 1 – Profile of temporary check dams

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Photo 3 – Sandbag check dam

Photo 4 – Fibre rolls

Photo 5 – Triangular ditch checks

Photo 6 – Stiff grass barrier (background)

Photo 7 – Poor placement of rocks, note rocks are higher in centre of check dam

Photo 8 – Retained rock check dams can interfere with ongoing mowing

Photo 9 – Typical erosion problem when placed in dispersive soil

Photo 10 – Typical erosion problem when placed in dispersive soil

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Erosion control at toe of check dams:

Erosion downstream of each check dam will be minimised if the dams are correctly spaced such that the crest of each dam is level with the toe of the nearest upstream dam.

Where necessary, the risk of erosion at the toe of each check dam may reduced by constructing each check dam on a sheet of geotextile fabric (e.g. filter cloth or woven fabric) that extends downstream of the dam a distance at least equal to the height of the dam (Figure 1).

Hydraulic design:

In general, a hydraulic analysis is not normally performed on check dams as their use should be restricted to those locations where they are unlikely to cause hydraulic problems. However, in circumstance where use of check dams could cause either traffic safety issues (table drains) or flooding of adjacent properties, then a hydraulic analysis will be required.

As a quick check, Table 3 can be used to assess the hydraulic capacity of a proposed check dam. Table 3 provides the maximum discharge for a given maximum water level (H) and check dam width (W). The table is based on a check dam with a **flat crested**, trapezoidal weir profile with side slopes of 1 in 2 (Figure 2) using Equation 1.

$$Q = 1.7\, W H^{1.5} + 2.5\, H^{2.5} \qquad \text{(Eqn 1)}$$

Table 3 – Assumed hydraulic capacity of check dam [1] (m^3/s)

Allowable upstream head (H) metres	Check dam flat crest width (W) metres				
	1.0	**1.5**	**2.0**	**2.5**	**3.0**
0.1	0.06	0.09	0.12	0.14	0.17
0.2	0.20	0.27	0.35	0.43	0.50
0.3	0.40	0.54	0.68	0.82	0.96
0.4	0.69	0.90	1.12	1.33	1.55
0.5	1.05	1.35	1.65	1.95	2.25
0.6	1.49	1.89	2.28	2.68	3.07
0.7	2.03	2.53	3.02	3.52	4.02
0.8	2.66	3.27	3.88	4.48	5.09
0.9	3.39	4.11	4.84	5.57	6.29
1.0	4.22	5.07	5.92	6.77	7.62

[1] Hydraulics is based on a flat crested, trapezoidal weir profile with a side slope of 2:1 (H:V).

If the side slopes of the drainage channel is not 2:1 (H:V), then the appropriate weir equation is:

$$Q = 1.7\, W H^{1.5} + 1.26\, m\, H^{2.5} \qquad \text{(Eqn 2)}$$

where:

- Q = Discharge passing over the check dam (m^3/s)
- W = Crest width of the check dam crest (m)
- H = Upstream water head relative to the crest of the check dam (m)
- m = Channel side slope, m:1 (H:V)

Both Equations 1 and 2 assume a flat crested weir profile; however, it is a requirement that check dams must have a curved crest with a minimum 150mm depression (Figure 1). Thus, Equations 1 and 2, and Table 3, all overestimate the hydraulic capacity of check dams. Therefore, a conservative design approach is required.

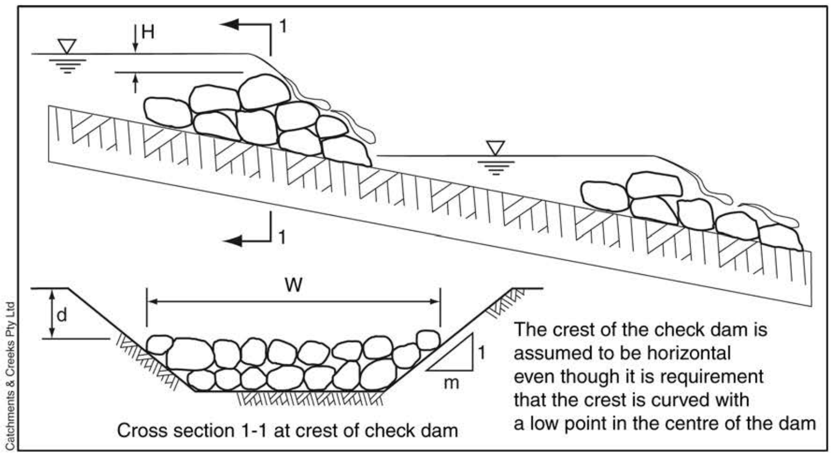

Figure 2 – Assumed check dam profile for Equations 1 and 2

Design example 1:

Determine the maximum allowable height of rock check dams placed along a channel that has a base width of 1.0m and side slopes of 3:1 (m:1). The total depth of channel is 0.7m and the required flow rate is $0.4m^3/s$. (note; this is the required allowable flow rate during the operational phase of the check dams, which may be different from that specified for design of the drain, especially if the drain is a permanent structure).

Solution:

The difficulty here is that the crest width of the check dam (W) will vary with the height of the dam, which is the variable that we are trying to determine. Therefore we will need to answer this question using a trial and error process.

As a first guess, try the maximum recommended check dam height of 0.5m. This means the maximum allowable upstream head (H) is 0.7 - 0.5 = 0.2m.

Thus the check dam crest width is:

$$W = \text{(bed width of channel)} + 2.\text{(side slope, m)}.\text{(height of check dam)}$$

$$W = 1.0 + 2(3)(0.5) = 4m$$

Using Equation 2, the maximum allowable discharge (i.e when H = 0.2m) is:

$$Q = 1.7\,W\,H^{1.5} + 1.26\,m\,H^{2.5} = 1.7(4)(0.2)^{1.5} + 1.26(3)(0.2)^{2.5} = 0.68m^3/s > 0.4m^3/s$$

Therefore the available hydraulic capacity of $0.68m^3/s$ is greater than the required hydraulic capacity of only $0.4m^3/s$, thus the check dam height will be limited to the maximum recommended height of 0.5m.

Design example 2:

Determine the maximum allowable flow rate (Q) for a check dam in a drainage channel with side slopes of 2:1; check dam crest width, W = 2m; and maximum allowable upstream hydraulic head, H = 0.4m.

Solution:

Given the side slope is 2:1 (H:V), we can use Table 3 to answer this question. From Table 3 it can be seen that the maximum allowable flow rate is around, $Q = 1.12m^3/s$ (note, Table 3 overestimates the available hydraulic capacity if the check dam has a curved, U-shaped crest).

Stiff grass barriers:

Stiff grass barriers (Figure 3) are typically used as a component of long-term gully stabilisation in rural areas. The most common grass species is the sterile form of vetiver zizanoides.

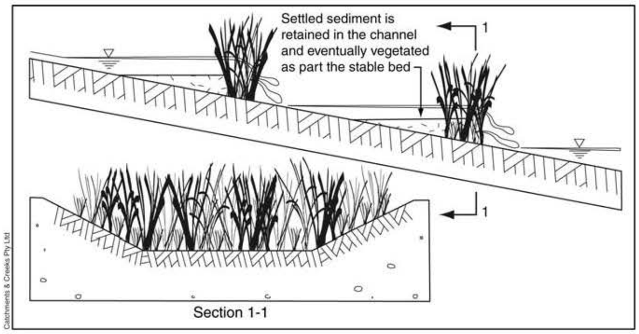

Figure 3 – Stiff grass barriers

Recessed rock check dams:

Recessed rock check dams can be used to:

- Control flow velocities in wide, shallow channels (typically less than 500mm deep) where other types of check dams, such as sandbags, are expected to wash away. In such cases the check dams are partially recessed into the channel bed.
- Control flow velocities and erosion in high velocity channels where a large rock size (greater than 300mm) is required, but the channel is too shallow to accommodate such rocks being placed directly on the channel bed. In such cases the check dams are partially recessed into the channel bed.
- Limit potential future gully erosion within constructed waterways and vegetated drainage channels. In such cases the rocks are recessed into the bed of the channel so that the top of each check dam is just below the bed of the channel (Figure 4).

In this latter case, the recessed rock checks (these are technically not 'dams') are used as an 'insurance policy' against possible future channel erosion, especially during the vegetation establishment phase when the channel roughness is significantly less than the assumed ultimate condition. The intension is to limit the extent and depth of any channel erosion between each recessed check structure. If erosion does not occur, then the check dams remain buried and incorporated into the stable channel profile.

Following installation of the recessed rock checks, the rocks are covered with soil (including the filling of all voids) and vegetated to fully incorporate the rock into the channel.

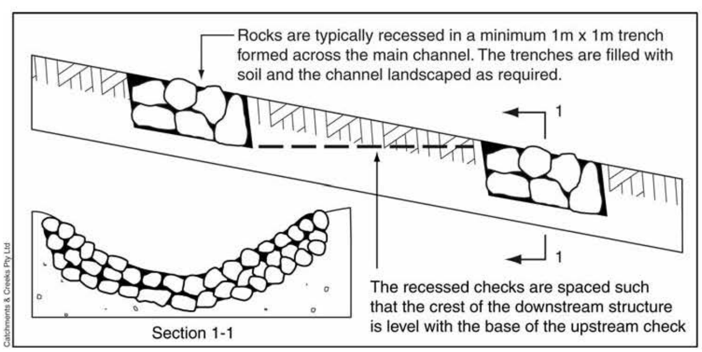

Figure 4 – Fully recessed rock check dams

Description

Check dams can be constructed from semipervious or impervious materials, typically rock or sandbags filled with a variety of porous materials.

Check dams should **not** be constructed from straw bales.

Rock check dams may be recessed into the channel bed to allow the use of larger sized rock, and/or to limit the crest height of the dams.

Purpose

Used to reduce flow velocity and the resulting erosion within:

- temporary, open earth channels;
- permanent vegetated channels during the plant establishment phase.

Check dam can also provide limited sediment trapping ability, but usually as a secondary function.

Limitations

Check dams are normally limited to mild sloping channels less than 10% grade.

Typical maximum height of 500mm.

Generally not used in watercourses. Instead, consider the used on *Sediment Weirs, Rock Filter Dams*, or formally designed rock weirs or drop structures.

Should not be placed directly on dispersive soils, or within drains cut into dispersive soils.

Advantages

Quick and inexpensive to install.

Low maintenance.

Disadvantages

Rock check dams can cause damage to grass cutting equipment if not removed from the channel after vegetation has been established (Photo 8).

Common Problems

Hydraulic problems often occur when rock check dams are specified in shallow drains.

Erosion can occur around the edges of the check dams, especially if installed with a flat crest.

Inappropriate spacing of the dams. This usually results from inadequate installation information supplied on the ESCPs.

Special Requirements

If soils are highly erosive (but not dispersive), then consider the use of an underlying geotextile skirt placed under each check dam (Figure 1).

Appropriate care must be taken to prevent failure caused by water undermining or bypassing round the dams.

Site Inspection

Check for invert erosion within the channel being stabilised with check dams.

Ensure the type of check dam is appropriate for the flow conditions and type of drainage channel.

Ensure the crest is below the height of the outer wings of the dams (refer to Figure 1).

Ensure the dams are appropriately spaced.

Materials

- Rock: 150 to 300mm nominal diameter, hard, erosion resistant rock. Smaller rock may be used if suitable large rock is not available.
- Sandbags: geotextile bags (woven synthetic, or non-woven biodegradable) filled with clean coarse sand, clean aggregate, straw or compost.

Installation

1. Refer to approved plans for location and installation details. If there are questions or problems with the location or method of installation, contact the engineer or responsible on-site officer for assistance.
2. Prior to placement of the check dams, ensure the type and size of each check dams will not cause a safety hazard or cause water to spill out of the drain.
3. Locate the first check dam at the downstream end of the section of channel being protected. Locate each successive check dam such that the crest of the immediate downstream dam is level with the toe of the check dam being installed.
4. Ensure the channel slope is no steeper than 10:1 (H:V). Otherwise consider the use of a suitable channel liner instead of the check dams.
5. Construct the check dam to the dimensions and profile shown within the approved plan.

6. Where specified, the check dams shall be constructed on a sheet of geotextile fabric used as a downstream splash pad.
7. Each check dam shall be extended up the channel bank (where practicable) to an elevation at least 150mm above the crest level of the dam.

Maintenance

1. Inspect each check dam and the drainage channel at least weekly and after runoff-producing rainfall.
2. Correct all damage immediately. If significant erosion occurs between any of the check dams, then check the spacing of dams and where necessary install intermediate check dams or a suitable channel liner.
3. Check for displacement of the check dams
4. Check for soil scour around the ends of each check dam. If such erosion is occurring, consider extending the width of the check dam to avoid such problems.
5. If severe soil erosion occurs either under or around the check dams, then seek expert advice on an alternative treatment measure.
6. Remove any sediment accumulated by the check dams, unless it is intended that this sediment will remain within the channel.
7. Dispose of collected sediment in a suitable manner that will not cause an erosion or pollution hazard.

Removal

1. When construction work within the drainage area above the check dams has been completed, and the disturbed areas and the drainage channel are sufficiently stabilised to restrain erosion, all temporary check dams must be removed.
2. Remove the check dams and associated sediment and dispose of in a suitable manner that will not cause an erosion or pollution hazard.

Level Spreaders

DRAINAGE CONTROL TECHNIQUE

Low Gradient	✓	Velocity Control		Short Term	✓
Steep Gradient	[1]	Channel Lining		Medium-Long Term	✓
Outlet Control	✓	Soil Treatment		Permanent	✓

[1] Level spreaders can release sheet flow down steep slopes, but the level spreader itself must be constructed across a level gradient.

Symbol

Photo 1 – Diversion drains (centre) collect stormwater from roadside table drains, then releases the water as sheet flow via a level spreader

Photo 2 – Level spreader established to discharge stormwater from a diversion drain into the roadside property

Key Principles

1. Flow must be released from the level spreader as *sheet flow*.
2. Flow must be released over a stable, well-grassed surface that will maintain suitable flow conditions down the slope.
3. Critical design parameter is the length of the outlet sill.
4. Critical operational parameter is the level construction of the outlet sill.

Design Information

The length of the outlet sill (weir) of the level spreader is governed by the design discharge, and the allowable flow velocity of the down-slope area.

Allowable flow velocity for grassed surfaces can be determined from Table 1.

Minimum dimension can be determined from Tables 2 and 3.

Minimum sill length is 4m.

Maximum sill length is 25m. If a longer sill length is required, then the inflow must be spilt and released through more than one level spreader.

Up-slope channel grade should not exceed 1% for the last 6m before entering the level spreader.

Discharge must release evenly along a level surface (sill) of 0% cross gradient.

Caution the use of a design discharge exceeding $0.85m^3/s$.

Caution the release of water onto grass slopes steeper than 10%.

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Table 1 – Allowable flow velocity (m/s) for grassed surfaces [1]

Percentage grass cover	Gradient of grass surface (%)									
	1	2	3	4	5	6	8	10	15	20
70% [2]	2.0	1.8	1.7	1.6	1.6	1.5	1.5	1.4	1.3	1.3
100% [3]	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.9	1.8	1.7
Poor soils [3]	1.5	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.0	0.9

[1] Maximum allowable flow velocity limited to 2.0m/s due to shallow water flow and resulting high shear stress. High flow velocities are allowable on reinforced grass.

[2] 70% cover would be typical for most grasses recently established by seed, but only when there is sufficient plant establishment time.

[3] 'Poor soils' refers to the soil's high erosion potential, such as dispersive clays (Emerson Class 1 and 2) such as sodic, yellow and red soils. Unstable, dispersible clayey sands and sandy clays, such as yellow and grey massive earths formed on sandstones and some granites. Highly erodible soils may include: lithosols, alluvials, podzols, siliceous sands, soloths, solodized solonetz, grey podzolics, some black earths, fine surface texture-contrast soils, and Soil Groups ML and CL.

Table 2 – Level spreader sill length – metres per unit discharge (m per m^3/s) [1]

Land slope (%)	Allowable down-slope velocity over well grassed surface (m/s)						
	1.0	1.2	1.5	1.8	2.0	2.2	2.5
1.0	3.5*	2.5*	1.6*	1.1*	0.9*	0.8*	0.6*
2.0	5.2	3.8*	2.5*	1.8*	1.4*	1.2*	0.9*
3.0	6.6	4.8	3.2*	2.3*	1.8*	1.5*	1.2*
4.0	7.7	5.6	3.8*	2.7*	2.2*	1.8*	1.4*
5.0	8.7	6.3	4.3*	3.1*	2.5*	2.1*	1.6*
6.0	9.5	7.0	4.7	3.4*	2.8*	2.3*	1.8*
7.0	10.3	7.6	5.2	3.7*	3.1*	2.6*	2.0*
8.0	11.0	8.2	5.6	4.0*	3.3*	2.8*	2.2*
9.0	11.8	8.7	6.0	4.3*	3.5*	3.0*	2.4*
10.0	12.4	9.2	6.3	4.6*	3.8*	3.2*	2.5*
Caution the release of water onto grass slopes steeper than 10%.							
15.0	15.2	11.3	7.8	5.7	4.8	4.0*	3.2*
20.0	17.4	13.1	9.1	6.7	5.6	4.7	3.7*
25.0	19.4	14.6	10.3	7.6	6.3	5.3	4.3*
33.3	22.1	16.8	11.9	8.8	7.4	6.2	5.0
50.0	26.6	20.3	14.5	10.8	9.1	7.8	6.3

* Sill length limited to minimum 4m for discharges less than $0.85m^3/s$.

Design example:

Design a level spreader to release a flow rate of $0.5m^3/s$ down a 10% slope containing a good (70%) grass cover on moderately erodible soil.

Solution:

From Table 1, choose a maximum flow velocity of 1.4m/s as best representative of a good grass cover on a moderately erodible soil.

From Table 2, select a sill width per unit flow rate of $7.3m/m^3/s$.

Therefore, the sill length would need to be 0.5 x 7.3 = 3.65m < 4m (minimum).

Conclusion, specify a sill length of 4m.

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The minimum sill lengths presented in Table 2 have been determined assuming a Manning's roughness for 50-150mm (Class D) grassed surfaces based on Equation 1. The sill length is sensitive to the selection of Manning's roughness. Variations between Table 2 and other published design tables for is due to variations in the assumed Manning's roughness, which is highly variable depending on the type and length of grass, and local growing conditions.

Class D roughness:

$$n = \frac{R^{1/6}}{51.24 + 20.77\log_{10}(R^{1.4}.S^{0.4})} \quad \text{(Eqn 1)}$$

Table 3 – Minimum dimension of level spreader

Discharge (m^3/s)	Entrance width (m)	Depth (m)	End width (m)
0 to 0.28	3.0	0.15	0.9
0.29 to 0.57	4.9	0.18	0.9
0.58 to 0.85	7.3	0.21	0.9

Construction of a level spreader may require formation of flow control banks as shown in Figures 1 to 3.

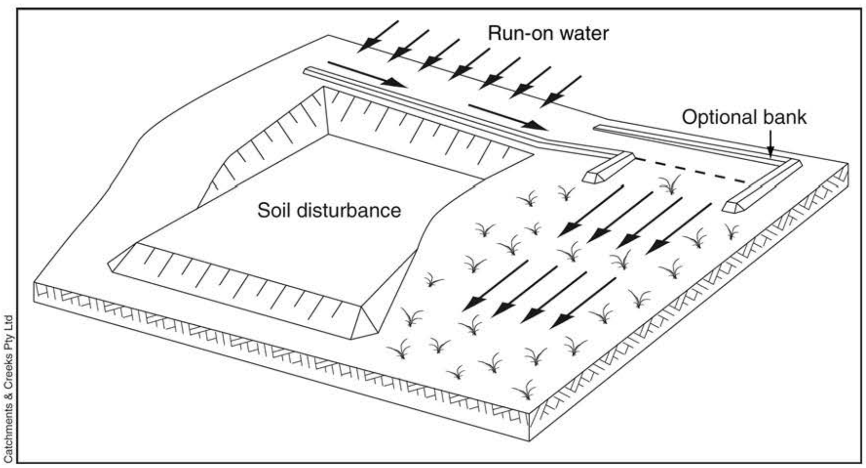

Figure 1 – Example of a level spreader used for flow diversion around a soil disturbance

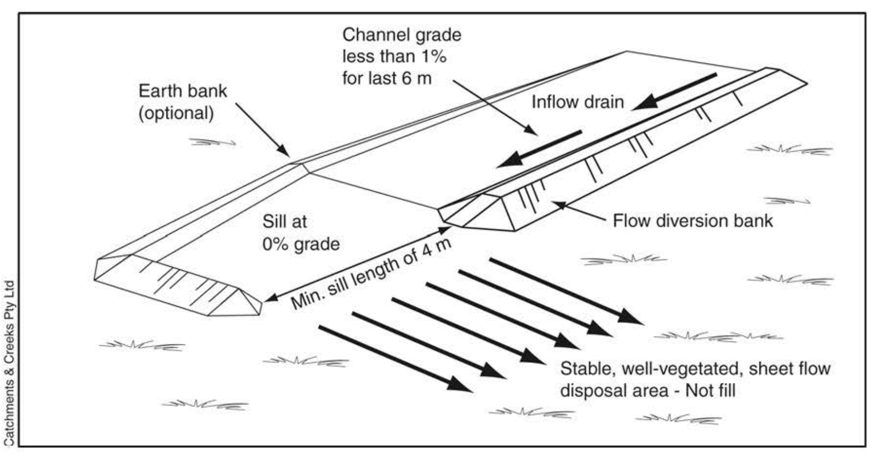

Figure 2 – Typical layout of level spreader

Description

Level spreaders consist of a level, grassed, side-flow weir (i.e. water discharges at 90 degrees to the inflow direction) constructed along the contour.

Purpose

Used to allow concentrated inflow to be released as *sheet flow* down a stable, vegetated slope.

Can be used as an outlet for *Catch Drains* and *Flow Diversion Banks*.

Level spreaders are commonly used in rural areas to discharge stormwater from roadside table drains into an adjacent property (Photos 1 & 2).

Limitations

Minimum sill length of 4m.

Maximum sill length of 25m.

Maximum discharge of around 0.85m^3/s.

Must only be used where the outflow can be discharged to an undisturbed, stable, grassed surface.

Construction traffic should be prohibited from the area of the level spreader.

Not suitable for highly erosive soils, dispersive soils, or soils with poor vegetation cover.

Advantages

Inexpensive to construct and maintain.

Disadvantages

Can be difficult to construct the outlet sill to the required precision.

May require a considerable width of undisturbed land.

May require the land to be free of trees, shrubs and other surface irregularities to avoid local erosion problems.

Common Problems

The most common problems result from damage to the outlet sill either from erosion, sedimentation, or stock.

Other problems can result from water flow concentrating below the level spreader due to the existence of a concave surface, vehicular tracks, or uneven vegetation cover.

Special Requirements

Outlet area must be free of depressions that may concentrate the outflow.

Extra erosion protection using jute mesh, *Erosion Control Mats*, turf, rock etc. may be required at the sill (Figure 4).

Generally constructed by dozers no larger than D5 or equivalent.

Extreme caution must be exercised when attempting to discharge *sheet flow* down a steep gradient (>10%) to ensure that the sedimentation or damage to the outlet sill does not concentrate the outflow.

Site Inspection

Check for sediment build-up on the sill, or the concentration of outflow.

Check for erosion down-slope of the sill.

Installation

1. Refer to approved plans for location, dimensions and construction details. If there are questions or problems with the location, dimensions, or method of installation contact the engineer or responsible on-site officer for assistance.
2. Wherever practical, locate the level spreader on undisturbed, stable soil.
3. Ensure flow discharging from the level spreader will disperse across a properly stabilised slope not exceeding 10:1 (H:V) and sufficiently even in grade across the slope to avoid concentrating the outflow.
4. The outlet sill of the spreader should be protected with erosion control matting to prevent erosion during the establishment of vegetation. The matting should be a minimum of 1200mm wide extending at least 300mm upstream of the edge of the outlet crest and buried at least 150mm in a vertical trench. The downstream edge should be securely held in place with closely spaced heavy-duty wire staples at least 150mm long.
5. Ensure that the outlet sill (crest) is level for the specified length.
6. Immediately after construction, turf, or seed and mulch where appropriate, the level spreader.

Maintenance

1. Inspect the level spreader after every rainfall event until vegetation is established.
2. After establishment of vegetation over the level spreader, inspections should be made on a regular basis and after runoff-producing rainfall.
3. Ensure that there is no soil erosion and that sediment deposition is not causing the concentration of flow.
4. Ensure that there is no soil erosion or channel damage upstream of the level spreader, or soil erosion or vegetation damage downstream of the level spreader.
5. Investigate the source of any excessive sedimentation.
6. Maintain grass in a health condition with no less than 90% cover unless current weather conditions require otherwise.
7. Grass height should be maintained at a minimum 50mm blade length within the level spreader and downstream discharge area, and a maximum blade length no greater than adjacent grasses.

Removal

1. Temporary level spreaders should be decommissioned only after an alternative stable outlet is operational, or when the inflow channel is decommissioned.
2. Remove collected sediment and dispose of in a suitable manner that will not cause an erosion or pollution hazard.
3. Remove and appropriately dispose of any exposed geotextile.
4. Grade the area and smooth it out in preparation for stabilisation.
5. Stabilise the area as specified on the approved plan.

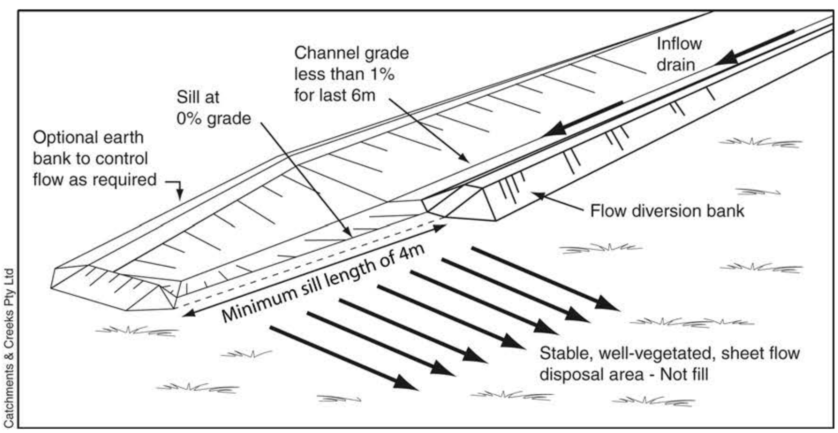

Figure 3 – Alternative level spreader layout

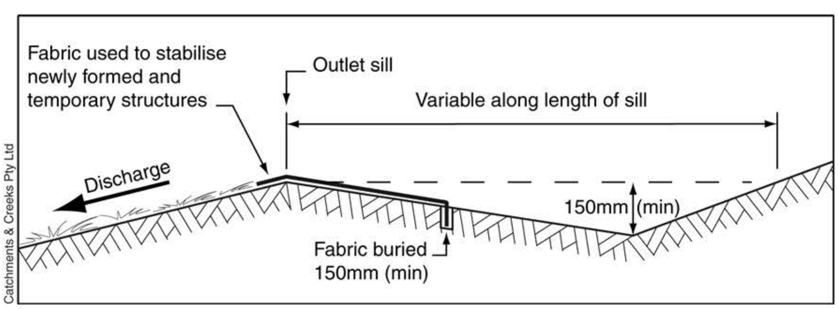

Figure 4 – Cross-sectional profile of end sill

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Chutes Part 1: General information

DRAINAGE CONTROL TECHNIQUE

Low Gradient		Velocity Control		Short Term	✓
Steep Gradient	✓	Channel Lining		Medium-Long Term	✓
Outlet Control	[1]	Soil Treatment		Permanent	[2]

[1] Chutes can act as stable outlet structures for *Catch Drains* and *Flow Diversion Banks*.

[2] The design of permanent chutes may require consideration of issues not discussed here.

Symbol → CH →

Photo 1 – Permanent, grouted-stone batter chute

Photo 2 – Temporary batter chute lined with filter cloth

Key Principles

1. The critical design components of a chute are the flow entry into the chute, the maximum allowable flow velocity down the face of the chute, and the dissipation of energy at the base of the chute.
2. The critical operational issues are ensuring unrestricted flow entry into the chute, ensuring flow does not undermine or spill out of the chute, and ensuring soil erosion is controlled at the base of the chute.
3. Most chutes fail as a result of water failing to enter the chutes properly. It is critical to control potential leaks and flow bypassing, especially at the chute entrance.

Design Information

The material contained within this fact sheet has been supplied for use by persons experienced in hydraulic design.

Drainage chutes are hydraulic structures that need to be designed for a specified design storm using standard hydrologic and hydraulic equations. The hydraulic design can be broken down into three components:

- **Inlet design:** flow conditions may be determined using an appropriate **weir equation**. It is important to ensure that the water level upstream of the chute's inlet will be fully contained by the associated *Flow Diversion Banks*.
- **Chute lining:** selection of an appropriate chute lining is governed by the estimated flow velocity, which can be determined on long chutes through use of **Manning's equation**.
- **Outlet design:** a suitable energy dissipater or outlet structure is required at the base of the chute. The design of these structures is usually based on the use of standard design charts.

Inlet design:

A basin spillway is just one type of chute. If the length of the approach channel is short, then friction loss upstream of the chute crest can be ignored and the upstream water level (relative to the crest invert) can be determined directly from the appropriate weir equation. Figure 1 shows the flow profile of a typical emergency spillway chute. It is noted that flow conditions approaching a roadway batter chute may be significantly different from that shown below.

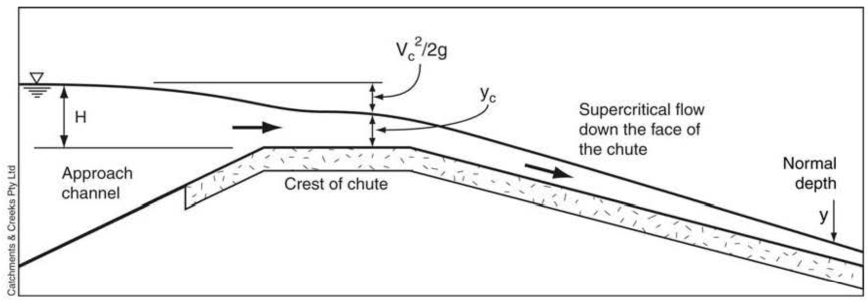

Figure 1 – Hydraulic profile for spillway crest where only minor friction loss occurs within the approach channel

In cases where the approach channel is short, the upstream water level (H) relative to the chute crest can be determined from an appropriate weir equation presented in Table 1.

Table 1 – Weir equations for short spillway crest length where only minor friction loss occurs within the approach channel

Weir cross sectional profile	Side slope (H:V)	Weir equation
Rectangular (b = base width)	vertical sides	$Q = 1.7\,b\,H^{1.5}$
Triangular	m:1	$Q = 1.26\,m\,H^{2.5}$
Parabolic ($T = 3.3(Y)^{0.5}$)	N/A	$Q = 2.06\,H^{1.5}$
Trapezoidal where : b = base width and m = side slope	1:1	$Q = 1.7\,b\,H^{1.5} + 1.26\,H^{2.5}$
	2:1	$Q = 1.7\,b\,H^{1.5} + 2.5\,H^{2.5}$
	3:1	$Q = 1.7\,b\,H^{1.5} + 3.8\,H^{2.5}$
	4:1	$Q = 1.7\,b\,H^{1.5} + 5.0\,H^{2.5}$
	m:1	$Q = 1.7\,b\,H^{1.5} + 1.26\,m\,H^{2.5}$

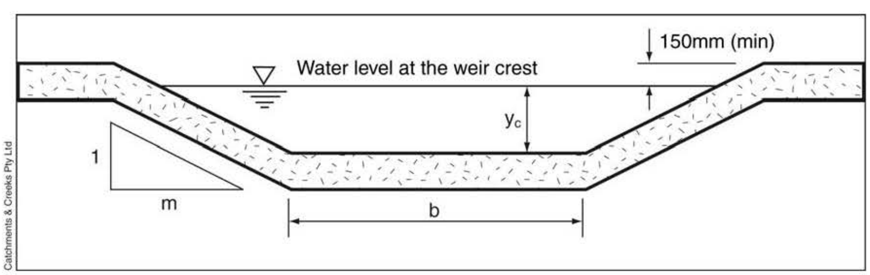

Figure 2 – Inlet profile of a trapezoidal chute

Tables 2 and 3 provides the *Head–Discharge* relationship for a parabolic weir ($T = 3.286(Y)^{0.5}$), and a trapezoidal weir with 2:1 (H:V) side slopes and base width (b).

Table 2 – Inlet weir capacity for various parabolic and trapezoidal chutes [m³/s]

Head (H) upstream of the chute inlet (m)	Parabolic top width = $3.3(y)^{0.5}$	Crest width (b) of a trapezoidal chute [1] (m)				
		0.3	0.5	1.0	1.5	2.0
0.1	0.065	0.024	0.035	0.062	0.089	0.115
0.2	0.184	0.091	0.121	0.197	0.273	0.349
0.3	0.338	0.208	0.264	0.404	0.543	0.683
0.4	0.521	0.384	0.470	0.685	0.900	1.115
0.5	—	0.626	0.746	1.047	1.347	1.648
0.6	—	0.940	1.098	1.493	1.888	2.283
0.7	—	1.332	1.531	2.029	2.527	3.024
0.8	—	1.807	2.051	2.659	3.267	3.875
0.9	—	2.372	2.662	3.388	4.114	4.839
1.0	—	3.030	3.370	4.220	5.070	5.920

[1] Flat crested, trapezoidal weir profile with 2:1 (H:V) side slopes (m = 2).

Table 3 – Trapezoidal chute inlet weir capacity [1] [m³/s]

Head (H) required upstream of the chute entrance (m)	Crest width (b) of a rectangular chute (m)				
	2.5	3.0	4.0	5.0	6.0
0.1	0.14	0.17	0.22	0.28	0.33
0.2	0.43	0.50	0.65	0.81	0.96
0.3	0.82	0.96	1.24	1.52	1.80
0.4	1.33	1.55	1.98	2.41	2.84
0.5	1.95	2.25	2.85	3.45	4.05
0.6	2.68	3.07	3.86	4.65	5.44
0.7	3.52	4.02	5.02	6.01	7.01
0.8	4.48	5.09	6.31	7.52	8.74
0.9	5.57	6.29	7.74	9.19	10.65
1.0	6.77	7.62	9.32	11.02	12.72

[1] Flat crested, trapezoidal weir profile with 2:1 (H:V) side slopes (m = 2).

Table 4 provides the head–discharge relationship for a rectangular weir with base width (b).

Table 4 – Rectangular chute inlet weir capacity [m³/s]

Head (H) required upstream of the chute entrance (m)	Crest width (b) of a rectangular chute (m)				
	1.0	2.0	3.0	4.0	5.0
0.1	0.054	0.108	0.161	0.215	0.269
0.2	0.152	0.304	0.456	0.608	0.760
0.3	0.279	0.559	0.838	1.117	1.397
0.4	0.430	0.860	1.290	1.720	2.150
0.5	0.601	1.202	1.803	2.404	3.005
0.6	0.790	1.580	2.370	3.160	3.950
0.7	0.996	1.991	2.987	3.983	4.978
0.8	1.216	2.433	3.649	4.866	6.082
0.9	1.451	2.903	4.354	5.806	7.257
1.0	1.700	3.400	5.100	6.800	8.500

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If the flow path upstream of the chute consists of erodible material, then it is important to ensure adequate scour protection exists. Such scour protection should extend upstream of the chute's crest a distance of at least 5 times the depth of approaching flow (Figure 3). This scour protection should be suitably recessed into the ground to allow the free flow of water.

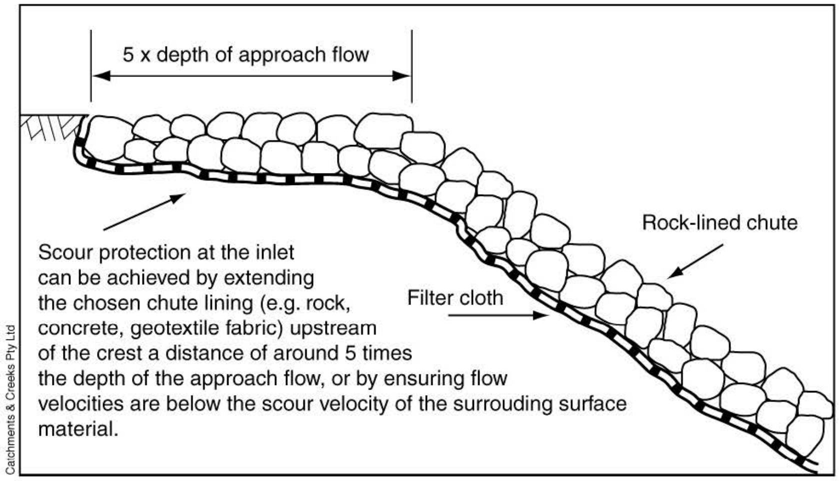

Figure 3 – One option for controlling scour at the chute entrance

A *Flow Diversion Bank* may be required adjacent the inlet to control flow entry. If a raised bank is used, then the height of the bank should allow for a minimum freeboard of 0.15m.

Dimensions and geometry:

- Minimum recommended chute depth of 300mm. Shallower depths may be appropriate for smooth chutes (i.e. minimal splash) with very low flow depths.
- Freeboard of 150mm, or the equivalent of the flow depth, whichever is smaller. A greater freeboard may be required if it is necessary to contain any splash.
- The chute must be straight from inlet to outlet (i.e. no bends or curves).

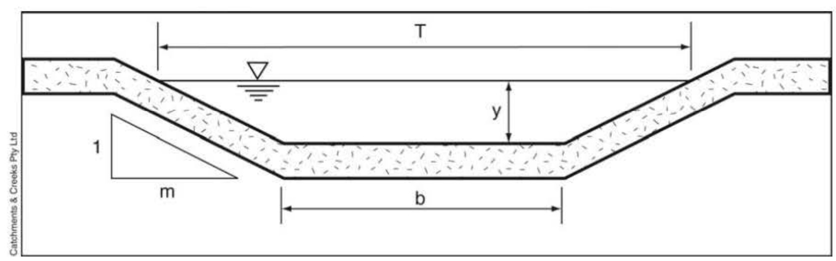

Figure 4 – Typical profile of the face of the chute

Chute linings:

Refer to the Parts 2 to 5 of this fact sheet for relevant design information.

Warning: it is essential that rock-lined chutes have a gradient significantly less than the natural angle of repose of the rock, usually around 38 degrees (1 in 1.3) for smooth round rock, to 41 degrees (1 in 1.2) for angular rock.

Flexible chute linings should be adequately anchored to the foundations to avoid slippage. A maximum spacing of 3 metres is recommended between anchor points down the chute.

If splash is expected down the chute, then the sides of the chute should be lined with suitable scour protection such as 300mm wide turf strips.

Outlet structures for temporary drainage chutes:

The following design procedure is <u>not</u> appropriate for the design of energy dissipaters at the base of Sediment Basin spillways.

Recommended mean (d_{50}) rock sizes and length (L) of rock protection for minor chute are presented in Tables 5 and 6. These rock sizes are based on information presented within ASCE (1992) rounded up to the next 100mm increment, with a minimum rock size set as 100mm.

Table 5 – Mean rock size, d_{50} (mm) for batter chute outlet protection [1]

Depth of approach flow (mm) [2]	Flow velocity at base of *Chute* (m/s)						
	2.0	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
50	100	100	100	200	200	200	300
100	100	100	200	200	300	300	400
200	100	200	300	300	400	[3]	[3]
300	200	200	300	400	[3]	[3]	[3]

[1] For exit flow velocities not exceeding 1.5m/s, and where growing conditions allow, loose 100mm rock may be replaced with 75mm rock stabilised with a good cover of grass.

[2] This is the flow depth at the base of the chute as it approaches the outlet structure. The flow depth is based on the maximum depth, not the average flow depth.

[3] Consider using 400mm grouted rock pad, or a rock-filled mattress outlet.

The pad lengths provided in Table 6 are suitable for temporary, rock-lined outlet structures only. These rock pad length will not necessarily fully contain all energy dissipation and flow turbulence; therefore, some degree of scour may still occur downstream of the outlet structure.

Table 6 – Recommended length, L (m) of rock pad for batter chute outlet protection

Depth of approach flow (mm)	Flow velocity at base of *Chute* (m/s)						
	2.0	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
50	1.0	1.5	2.1	2.6	3.1	3.6	4.2
100	1.3	2.0	2.7	3.4	4.1	4.8	5.5
200	2.1	2.7	3.4	4.3	5.2	6.1	7.0
300	2.7	3.6	4.3	4.8	5.8	6.8	7.9

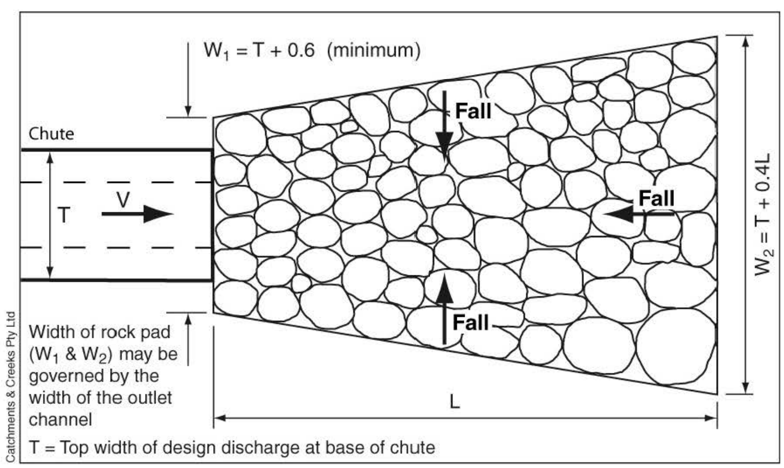

Figure 5 – Typical layout of a recessed rock pad for a chute (plan view)

As indicated in Figures 5, 6 and 7, outlet structures for minor chutes should be recessed below the surrounding ground level to promote effective energy dissipation. The recommended recess depth (Z) can be determined from Table 7.

Table 7 – Recommended recess depth, Z (m) for batter *Chute* outlet protection

Depth of approach flow (mm)	Flow velocity at base of *Chute* (m/s)						
	2.0	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
50	0.13	0.20	0.28	0.36	0.43	0.50	0.60
100	0.14	0.23	0.32	0.42	0.50	0.60	0.70
200	0.12	0.21	0.31	0.42	0.50	0.60	0.70
300	0.07	0.16	0.25	0.35	0.44	0.55	0.65

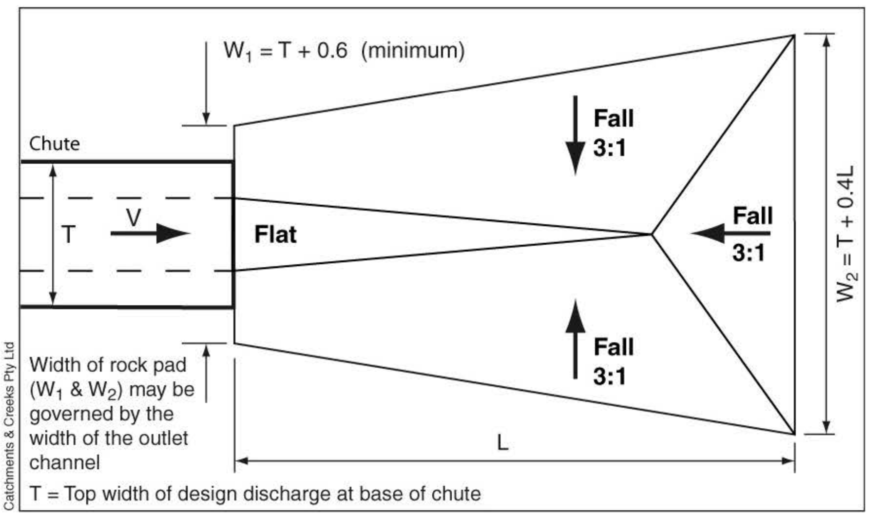

Figure 6 – Typical arrangement of recessed outlet structure for chutes

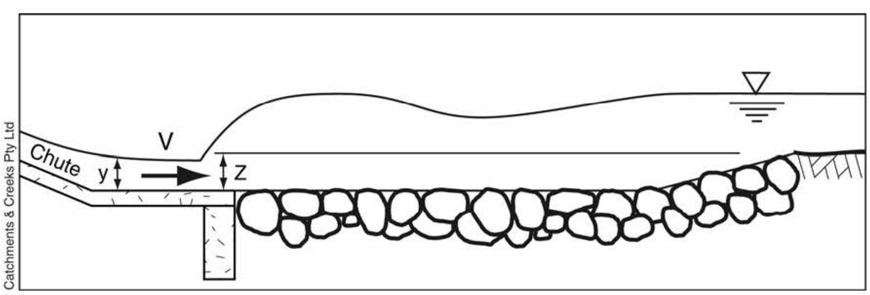

Figure 7 – Typical profile of recessed outlet structure for chutes

Note: *In circumstances where the outlet structure is located downstream of a smooth surface chute, e.g. concrete-lined, then the rocks should be grouted in place to avoid displacement.*

Reference:

ASCE 1992, *Design and construction of urban stormwater management systems*. ASCE Manuals and Reports of Engineering Practice No. 77, and Water Environment Federation Manual of Practice FD-20, American Society of Civil Engineers, New York.

It is important to ensure enters the chute properly (Photos 3 and 4), and in a manner that does not cause water to bypass along or around the edge of the chute.

Photo 3 – Sandbags (temporary) used to control flow entry into grass chute

Photo 4 – Geotextile socks used to control flow entry into temporary batter chute

To ensure appropriate flow entry into a chute, the chute must have a well-defined profile (either rectangular or trapezoidal) with adequate depth to fully contain the design discharge.

Photo 5 – Spillway chute with well-defined inlet profile

Photo 6 – Turf chute with poorly-defined inlet profile causing flow bypass

The chute must also have sufficient depth and/or scour controls to prevent any erosion resulting from splash.

Photo 7 – Severe erosion along edge of chute caused by water spilling out of the chute

Photo 8 – Erosion caused by inadequate rock size and water bypassing around the poorly located boulders

Design example – Chute outlet structure:

Design the outlet protection for a temporary, trapezoidal chute lined with filter cloth on a 3:1 batter slope with a base width of 1.0m, side slopes of 2:1, and design discharge of 600L/s.

Solution

Adopting a Manning's roughness of, n = 0.022 for the filter cloth, the flow conditions at the base of the chute can be determined from Manning's equation as:

Discharge, $Q = 0.6m^3/s$

Manning's roughness, n = 0.022 (based on an expected flow depth > 0.1m)

Channel slope, S = 0.333 (m/m)

Bed width, b = 1.0m

Channel side slope, m = 2:1

Flow depth, y = 0.1m

Flow top width, B = b + 2my = 1.8m

Hydraulic radius, R = 0.083m

Velocity, $$V = \frac{1}{n} R^{2/3} S^{1/2} = \frac{1}{0.022}(0.083)^{2/3}(0.333)^{1/2} = 5.0m/s$$

From Table 5 the mean rock size, d_{50} = 200mm

From Table 6 the length of the rock pad, L = 2.0m

From Table 7 the recommended recess depth, Z = 0.42m

From Figure 6 the upstream width of the rock pad, W1 = B + 0.6 = 2.4m

From Figure 6 the downstream width of the rock pad, W2 = B + 0.4L = 2.6m

If it is assumed that the largest rock is likely to be around 1.5 times the size of the average rock size, i.e. d50/d90 approximately equals 0.67, then we can estimate the required depth of rock protection as, T = 1.8(d50) = 0.36m. In any case, a minimum of two layers of rock should be specified on the construction plans.

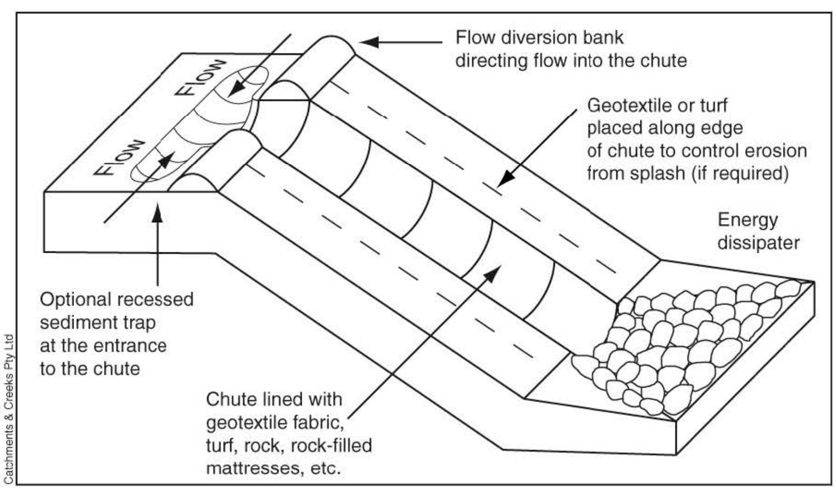

Figure 8 – Typical components of a temporary drainage chute

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Description

A steep, open channel passing down a slope. The channel gradient is usually steeper than 10%.

Temporary chutes are usually lined with fabrics such as filter cloth. Permanent chutes can be constructed from materials such as turf, rock, rock-filled mattresses or concrete.

Purpose

Chutes are used to transport concentrated flow down steep slopes. They are most commonly used on constructed slopes such as road batters.

The emergency spillways of a *Sediment Basin* is a special form of chute.

Limitations

Local topography must allow safe collection and passage of water into the chute.

Bitumen or asphalt is generally not suitable as a permanent chute liner.

Advantages

Temporary chutes can be both quick and cheep to construct.

Chutes typically have a flow capacity significantly greater than most *Slope Drains*.

Disadvantages

Some chute linings have a short service life.

Significant damage can result from overtopping flows.

The chute lining may be subject to slippage caused by poor foundations.

Common Problems

Inappropriate inlet geometry can cause inflow to bypass or undermine the chute.

Severe rilling along the sides of the chute can be caused by splash or lateral inflows being deflected by the edge of the chute.

Erosion at the base of the chute caused by inadequate energy dissipation.

Special Requirements

Flow Diversion Banks are often required to control inflows.

Good subsoil drainage and foundations are required to stabilise the chute lining.

Site Inspection

Check flow entry conditions to ensure no bypassing, undermining, sedimentation or erosion.

Ensure the chute is straight.

Check for erosion around the edges of the chute (top and sides).

Ensure the outlet is appropriately stabilised.

General specifications for chutes:

Installation

1. Refer to approved plans for location and construction details. If there are questions or problems with the location or method of installation, contact the engineer or responsible on-site officer for assistance.
2. Construct the subgrade to the elevations shown on the plans. Remove all unsuitable material and replace with stable material to achieve the desired foundations.
3. If the chute is temporary, then compact the subgrade to a firm consistency. If the chute is intended to be permanent, then compact and finish the subgrade as specified within the design plans.
4. If the chute is to be lined with rock, then avoid compacting the subgrade to a condition that would prevent the rock lining from adequately bedding into the subgrade.
5. Ensure the subgrade is firm enough to minimise water seepage.
6. On fill slopes, ensure that the soil is adequately compacted for a width of at least one metre each side of the chute to minimise the risk of soil erosion, otherwise protect the soil with suitable scour protection measures such as turf or erosion control mats.
7. Place and secure the chute lining as directed.
8. If concrete is used as a lining, then keep the subgrade moist at the time concrete is placed. Form, cut-off walls and anchor blocks as directed in the approved plans.
9. Install an appropriate outlet structure (energy dissipater) at the base of the chute (refer to separate specifications).
10. Ensure water leaving the chute and the outlet structure will flow freely without causing undesirable ponding or scour.
11. Appropriately stabilise all disturbed areas immediately after construction.

Maintenance

1. During the construction period, inspect all chutes prior to forecast rainfall, daily during extended periods of rainfall, after significant runoff producing storm events, or otherwise on a weekly basis. Make repairs as necessary.
2. Check for movement of, or damage to, the chute lining, including surface cracking.
3. Check for soil scour adjacent the chute. Investigate the cause of any scour, and repair as necessary.
4. When making repairs, always restore the chute to its original configuration unless an amended layout is required.

Removal

1. Temporary chutes should be removed when an alternative, stable, drainage system is available.
2. Remove all materials and deposited sediment, and dispose of in a suitable manner that will not cause an erosion or pollution hazard.
3. Grade the area in preparation for stabilisation, then stabilise the area as specified in the approved plan.

Specifications for rock pad outlet structure:

Materials (Rock outlet pads)

- Rock: hard, angular, durable, weather resistant and evenly graded with 50% by weight larger than the specified nominal rock size and sufficient small rock to fill the voids between the larger rock. The diameter of the largest rock size should be no larger than 1.5 times the nominal rock size. Specific gravity to be at least 2.5.
- Geotextile fabric: heavy-duty, needle-punched, non-woven filter cloth, minimum bidim A24 or equivalent.

Installation (Rock outlet pads)

1. Refer to approved plans for location and construction details. If there are questions or problems with the location, dimensions or method of installation contact the engineer or responsible on-site officer for assistance.
2. The dimensions of the outlet structure must align with the dominant flow direction.
3. Excavate the outlet pad footprint to the specified dimension such the when the rock is placed in the excavated pit the top of the rocks will be level with the surrounding ground, unless otherwise directed.
4. If the excavated soils are dispersive, over-excavated the rock pad by at least 300mm and backfill with stable, non-dispersive material.
5. Line the excavated pit with geotextile filter cloth, preferably using a single sheet. If joints are required, overlap the fabric at least 300mm.
6. Ensure the filter cloth is protected from punching or tearing during installation of the fabric and the rock. Repair any damage by removing the rock and placing with another piece of filter cloth over the damaged area overlapping the existing fabric a minimum of 300mm.
7. Ensure there are at least two layers of rocks. Where necessary, reposition the larger rocks to ensure two layers of rocks are achieved without elevating the upper surface above the pipe invert.
8. Ensure the rock is placed in a manner that will allow water to discharge freely from the pipe.
9. Ensure the upper surface of the rock pad does not cause water to be deflected around the edge of the rock pad.
10. Immediately after construction, appropriately stabilise all disturbed areas.

Maintenance

1. While construction works continue on the site, inspect the outlet structure prior to forecast rainfall, daily during extended periods of rainfall, after significant runoff producing rainfall, and on at least a weekly basis.
2. Replace any displaced rock with rock of a significantly (minimum 110%) larger size than the displaced rock.

Removal

1. Temporary outlet structures should be completely removed, or where appropriate, rehabilitated so as not to cause ongoing environmental nuisance or harm.
2. Following removal of the device, the disturbed area must be appropriately rehabilitated so as not to cause ongoing environmental nuisance or harm.
3. Remove materials and collected sediment and dispose of in a suitable manner that will not cause an erosion or pollution hazard.

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Energy Dissipaters

DRAINAGE CONTROL TECHNIQUE

Low Gradient		Velocity Control	✓	Short Term	✓
Steep Gradient		Channel Lining		Medium-Long Term	✓
Outlet Control	✓	Soil Treatment		Permanent	[1]

[1] The design of permanent energy dissipaters may require consideration of issues not discussed within this fact sheet. Obtaining expert hydraulic advice is always recommended.

Symbol (not applicable)

Photo 1 – Rock mattress lined basin spillway and energy dissipater

Photo 2 – Rock lined basin spillway and energy dissipater

Key Principles

1. Energy dissipation must be contained within a suitably stabilised area, therefore it is essential for the designer to be able to control the **location** of the hydraulic jump.
2. The key performance objectives are to control soil erosion associated with the energy dissipater, and present structural damage to the chute, culvert or spillway.

Design Information

Energy dissipation is usually required to achieve one or more of the following:

- prevent the undermining of the outlet, chute or spillway;
- control of bed scour immediately downstream of the energy dissipater;
- control of bank erosion well downstream of the structure caused by an 'outlet jet', if such jetting is possible at the structure.

Bank erosion downstream of pipe outlet is likely to result from the effects of an outlet jet if:

- tailwater levels are above the centre of a pipe outlet (which causes the jet to float); and
- the flow velocity at the outlet exceeds the scour velocity of the bank material; and
- the distance between the outlet and the opposing bank is less than approximately 10 times the equivalent pipe diameter for a single outlet, or 13 times the equivalent pipe diameter for a multi-cell outlet.

The control of *bed scour* is usually achieved by the development of a thick, low velocity, boundary layer usually through the introduction of erosion resistant bed roughness (e.g. rock).

Downstream bank erosion is usually controlled by breaking-up the outlet jet through the energy dissipating effects of a hydraulic jump, plunge pool, or impact structure.

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Bed friction outlets

These energy dissipaters use coarse riprap or rows of small concrete impact blocks as a form of bed roughness to retard the outlet flow. This bed roughness can help spread the flow and develop an effective boundary layer thus reducing the potential for downstream bed scour. If favourable tailwater conditions exist, these outlets can also induce a hydraulic jump to aid in energy dissipation.

Bed friction outlet structures exhibit only minimal control over 'floating' outlet jets. They are therefore most effective when operating under low tailwater conditions.

For design guidelines, refer to the separate fact sheet on *Outlet Structures*.

Photo 3 – Rock pad outlet structure

Photo 4 – Rock pad outlet structure

Hydraulic jump energy dissipaters

These energy dissipaters that rely of the formation of a hydraulic jump and are usually best used to control high velocity flows confined within rectangular or near-rectangular channels. These structures usually require well-regulated tailwater conditions to prevent the hydraulic jump from being swept downstream of the stabilised energy dissipation zone.

To control the location of the hydraulic jump, the outlet pond can be recessed into the bed of the channel forming a recessed energy dissipation pool. Generally these dissipation pools need to be designed to be free draining to avoid permanent ponding and prevent mosquito breeding.

If a hydraulic jump is required to be formed downstream of a chute, then the crest of the chute must be flat, and the chute's cross-section must be as close to *rectangular* as is possible to produce near-uniform, 1-dimentsional flow conditions. Trapezoidal chutes with flat side slopes can cause highly 3D flow conditions resulting in the formation of an ineffective hydraulic jump.

Hydraulic jump energy dissipaters are usually **not** effective downstream of piped outlets because jetting from the pipe can prevent an effective hydraulic jump from forming.

Photo 5 – Hydraulic jump type energy dissipater on sediment basin spillway

Photo 6 – Hydraulic jump dissipater downstream of detention basin outlet

Plunge pool energy dissipaters

Plunge pools can be an effective way of dissipating energy and controlling bed scour. However, in order to be effective the outlet jet **must** be allowed to free fall into the pool. Therefore, low tailwater conditions are required. Under high tailwater conditions (i.e. when a floating outlet jet is formed) plunge pool designs are relatively ineffective. Though distinguished from hydraulic jump dissipaters, most plunge pool dissipaters effectively act as 'confined' hydraulic jumps.

Concrete or other hard-lined plunge pool dissipaters should be free draining to avoid the formation of stagnant water. Many standardised plunge pool dissipater designs can be successfully modified to avoid long-term ponding by introducing a narrow, open notch within the end sill.

Plunge pool dissipaters can be highly dangerous hydraulic structures resulting in severe head injuries to persons being swept through the structure.

Photo 7 – Rock-lined plunge pool energy dissipater

Photo 8 – Note use of impact blocks to stabilise the location of the hydraulic jump

Stepped spillways

Stepped spillways dissipate energy as the flow passes down the face of the spillway (chute), as well as allowing the formation of a hydraulic jump at the base of the spillway. Each step can operate under conditions of either a plunging jet (nappe flow regime), or as a fully or partially formed hydraulic jump.

Under high flow conditions, the water can begin to skim over the individual steps (skimming flow regime) greatly reducing energy dissipation down the face of the spillway. Once skimming flow conditions are fully developed, the spillway begins to behave like an unstepped spillway.

For design guidelines, refer to *Hydraulic design of stepped channels and spillways*, H. Chanson, Report CH43/94, February 1994, Department of Civil Engineering, The University of Queensland, Brisbane.

Photo 9 – Gabion lined stepped spillway on a stormwater detention basin

Photo 10 – Stepped chute acting as an outlet structure for a table drain

Impact structures

These structures contain impact walls, blocks or columns to break-up the jet and induce highly turbulent flow. They are generally very effective at dissipating flow energy from medium to high velocity outlets where control of the outlet jet is required. The control of bed scour immediately downstream of the outlet structure usually requires the use of additional riprap protection.

The height of impact blocks is usually set equal to the height of the incoming jet. In the case of culverts and stormwater outlets, this means a height equal to the height of the culvert or pipe.

These are some of the most dangerous of all the hydraulic structures. Their design and use must only be managed under the supervision of suitably trained experts.

Photo 11 – Baffled spillway

Photo 12 – Impact block energy dissipater

Design Information

Warning, energy dissipater can represent a significant safety risk to persons swept into the flow. In circumstance where a person could be swept into such danger, safety issues <u>must</u> be given appropriate consideration.

Energy dissipaters are usually major hydraulic structures requiring design input from experienced hydraulics specialists. This fact sheet does not provide sufficient information to allow energy dissipaters to be designed by inexperienced persons.

Photo 13 – Spillways <u>must</u> have a well-defined profile to fully contain the flow

Photo 14 – A suitable energy dissipater <u>must</u> be constructed at the base of the spillway

Design of rock mattress or concrete-lined energy dissipation pools:

The following design procedure and tables are provided as a guide only. This design information requires interpretation and application by experienced hydraulic design professionals.

Hydraulic design requires the estimation of flow depth, velocity, and Froude number at the base of the chute or spillway.

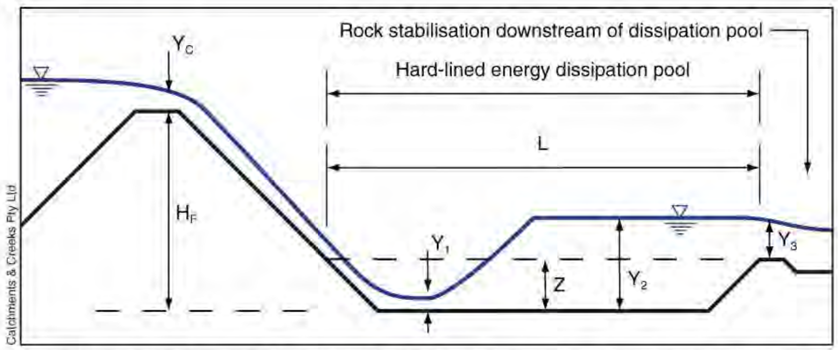

Figure 1 – typical profile of recessed, hard-lined energy dissipation pool located at the base of chute or spillway

Design steps:

1. Determine the flow depth (y_1), velocity (V_1) and Froude number (F_1) at the base of the chute for the design discharge.

$$F_1 = \frac{V_1}{\sqrt{g.y_1}} \qquad \text{(Eqn 1)}$$

2. For flow conditions where $F_1 > 1$ (i.e. supercritical flow) and where the resulting hydraulic jump can be represented by 1-dimensional hydraulic analysis (i.e. a regular hydraulic jump contained within a rectangular channel), calculate the sequent depth (y_2) associated with the hydraulic jump.

$$y_2 = \frac{y_1}{2}\left(\sqrt{(1+8F_1^{\,2})} - 1\right) \qquad \text{(Eqn 2)}$$

3. Determine the probable tailwater conditions including water level and flow depth (y_3) downstream of the recessed energy dissipation pool. This downstream flow depth should not be less than the critical flow depth (y_c).

4. Determine the recess depth of the energy dissipation pool.

$$Z = y_2 - y_3 \qquad \text{(Eqn 3)}$$

5. Calculate the desired length of the energy dissipation pool (L). Two equations can be used to determine this pool length, these equations are presented below as Equations 4 and 5.

$$L = 6y_2 \qquad \text{(Eqn 4)}$$

$$L = 6.9(y_2 - y_1) \qquad \text{(Eqn 5)}$$

An **approximate** length of the dissipation pool can be determined from Table 1 for an energy dissipation pool containing a standard, rectangular hydraulic jump. It is noted that hydraulic jumps formed within trapezoidal channels can be unpredictable in their shape and stability, potentially resulting in an increased length of the required energy dissipation basin.

Table 2 provides an **estimate** of the recess depth (Z) based on a downstream flow depth (y_3) equal to the critical flow depth (y_c). **Tables 1 and 2 should be used for preliminary design purposes only.**

Table 1 – Approximate length, L (m) of an energy dissipation pool containing a standard, rectangular hydraulic jump [1]

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	**0.3**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**
0.01	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.8	0.9	0.9
0.02	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.1	1.2	1.3
0.05	0.8	1.0	1.1	1.3	1.5	1.6	1.7	1.8	1.9	2.0
0.10	1.2	1.3	1.5	1.9	2.1	2.2	2.4	2.5	2.7	2.9
0.15	1.4	1.6	1.9	2.3	2.5	2.7	2.9	3.0	3.3	3.5
0.20	1.6	1.8	2.1	2.6	2.9	3.1	3.3	3.5	3.8	4.0
0.25	1.8	2.1	2.4	2.9	3.2	3.5	3.7	3.9	4.2	4.5
0.30	2.0	2.2	2.6	3.2	3.5	3.8	4.1	4.3	4.6	4.9
0.35	2.2	2.4	2.8	3.4	3.8	4.1	4.4	4.6	5.0	5.3
0.40	2.3	2.6	3.0	3.6	4.1	4.4	4.7	4.9	5.3	5.6
0.45	2.4	2.7	3.1	3.8	4.3	4.7	4.9	5.2	5.6	6.0
0.50	2.6	2.9	3.3	4.0	4.5	4.9	5.2	5.5	5.9	6.3
1.00	3.6	4.0	4.6	5.6	6.3	6.8	7.3	7.6	8.3	8.8
1.50	4.4	4.9	5.6	6.8	7.6	8.3	8.8	9.3	10.0	11.0

[1] Length of energy dissipation pool is based on an average of $6y_2$ and $6.9(y_2 - y_1)$, with y_1 based on a smooth chute (i.e. minimal friction loss), and y_2 determined from Table 5. Data is presented for preliminary design purposes only.

Table 2 – Approximate recess depth, Z (m) for an energy dissipation pool containing a standard, rectangular hydraulic jump [1]

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	**0.3**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**
0.01	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.12
0.02	0.06	0.06	0.08	0.10	0.11	0.12	0.13	0.14	0.16	0.17
0.05	0.08	0.09	0.11	0.15	0.17	0.19	0.20	0.22	0.24	0.25
0.10	0.10	0.12	0.15	0.20	0.23	0.26	0.28	0.29	0.32	0.35
0.15	0.12	0.14	0.18	0.24	0.27	0.30	0.33	0.35	0.39	0.42
0.20	0.14	0.16	0.20	0.26	0.31	0.34	0.37	0.40	0.44	0.47
0.25	0.15	0.18	0.22	0.29	0.34	0.38	0.41	0.44	0.48	0.52
0.30	0.16	0.19	0.23	0.31	0.37	0.41	0.44	0.47	0.52	0.57
0.35	0.17	0.20	0.25	0.33	0.39	0.43	0.47	0.50	0.56	0.60
0.40	0.17	0.21	0.26	0.35	0.41	0.46	0.50	0.53	0.59	0.64
0.45	0.18	0.22	0.27	0.37	0.43	0.48	0.52	0.56	0.62	0.67
0.50	0.19	0.23	0.29	0.38	0.45	0.50	0.55	0.59	0.65	0.71
1.00	0.24	0.29	0.37	0.50	0.59	0.67	0.73	0.78	0.87	0.95
1.50	0.28	0.34	0.43	0.58	0.69	0.78	0.86	0.92	1.03	1.12

[1] Recess depth is based on a downstream flow depth (y_3) equal to the critical flow depth, and y_1 based on a smooth chute (i.e. minimal friction loss). Data is presented for preliminary design purposes only.

Design of rock protection downstream of hydraulic jump energy dissipaters:

Equation 6 is the recommended equation for sizing rock placed within the zone of highly turbulent water immediately **downstream** of the end sill of an **energy dissipater** (i.e. not within the main energy dissipation zone).

$$d_{50} = \frac{(0.081).V^{2.23}}{(s_r - 1)} \qquad \text{(Eqn 6)}$$

where: d_{50} = nominal rock size (diameter) of which 10% of the rocks are smaller (m)
V = local, depth-average flow velocity immediately downstream of the end sill (m/s)

Design of rock-lined energy dissipation pools:

The following design procedure and tables are provided as a guide only. This design information requires interpretation and application by experienced hydraulic design professionals.

An **estimation** of the recess depth (relative to the downstream water level) of a rock-lined energy dissipation pool can be determined from Equation 7.

$$Z + y_3 = 4.75 \frac{(H_F)^{0.2} q^{0.57}}{(d_{90})^{0.32}} \qquad \text{(Eqn 7)}$$

where: Z = Recess of energy dissipation pool relative to downstream ground level (m)
y_3 = depth of flow downstream of the energy dissipation pool at design flow (m)
H_F = fall in chute or spillway upstream of the energy dissipater (m)
q = design unit flow rate (m^2/s)
d_{90} = rock size, lining the dissipation pool, of which 90% of rocks are smaller (m)

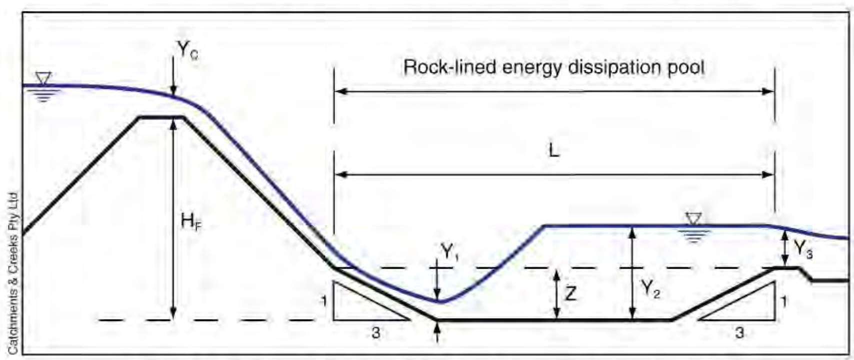

Figure 2 – Typical profile of rock-lined energy dissipation pool

The length of the dissipation pool (L) may be based on the same design procedures presented for a rock mattress or concrete-lined dissipation pool presented in the previous section.

Tables 3 to 5 provide an estimation of the recess depth (Z) for a mean rock size (d_{50}) of 200, 300 and 500mm, based on a rock size distribution, $d_{50}/d_{90} = 0.5$.

In circumstances where the energy dissipater is located downstream of a smooth channel surface (e.g. a concrete-lined chute or spillway), then the rocks located within the first quarter (minimum) of the dissipater basin should be grouted in place to avoid displacement. The displacement of loose rocks located immediately downstream of a smooth channel surface is partially caused by the changing boundary layer conditions from the smooth upstream channel to the rough, rock-lined basin.

Caution: trapezoidal chutes can result in the formation unstable, three-dimensional hydraulic jumps that may not dissipate energy as efficiently as rectangular chutes.

Table 3 – Approximate operating water depth within an energy dissipation pool ($Z + y_3$) lined with mean (d_{50}) 200mm rock, with rock size distribution, d_{50}/d_{90} = 0.5

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	0.3	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0
0.005	0.23	0.24	0.27	0.31	0.34	0.36	0.37	0.39	0.41	0.43
0.01	0.33	0.36	0.40	0.46	0.50	0.53	0.55	0.57	0.61	0.64
0.02	0.50	0.54	0.60	0.68	0.74	0.79	0.82	0.85	0.90	0.94
0.04	0.74	0.80	0.89	1.02	1.10	1.17	1.22	1.27	1.34	1.40
0.06	0.93	1.01	1.12	1.28	1.39	1.47	1.54			
0.08	1.09	1.19	1.31	1.51						
0.10	1.24	1.35	1.49							
0.15	1.57									

Table 4 – Approximate operating water depth within an energy dissipation pool ($Z + y_3$) lined with mean (d_{50}) 300mm rock, with rock size distribution, d_{50}/d_{90} = 0.5

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	0.3	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0
0.005	0.20	0.21	0.24	0.27	0.30	0.31	0.33	0.34	0.36	0.38
0.01	0.29	0.32	0.35	0.41	0.44	0.47	0.49	0.50	0.53	0.56
0.02	0.44	0.47	0.52	0.60	0.65	0.69	0.72	0.75	0.79	0.83
0.04	0.65	0.70	0.78	0.89	0.97	1.03	1.07	1.11	1.18	1.23
0.06	0.82	0.88	0.98	1.13	1.22	1.29	1.35	1.40	1.48	1.55
0.08	0.96	1.04	1.15	1.33	1.44	1.52				
0.10	1.09	1.18	1.31	1.51						
0.15	1.37	1.49								

Table 5 – Approximate operating water depth within an energy dissipation pool ($Z + y_3$) lined with mean (d_{50}) 500mm rock, with rock size distribution, d_{50}/d_{90} = 0.5

Unit flow (m^2/s)	Chute fall upstream of energy dissipater, H_F (m)									
	0.2	0.3	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0
0.005	0.17	0.18	0.20	0.23	0.25	0.27	0.28	0.29	0.31	0.32
0.01	0.25	0.27	0.30	0.34	0.37	0.40	0.41	0.43	0.45	0.47
0.02	0.37	0.40	0.44	0.51	0.55	0.59	0.61	0.64	0.67	0.70
0.04	0.55	0.60	0.66	0.76	0.82	0.87	0.91	0.94	1.00	1.05
0.06	0.69	0.75	0.83	0.96	1.04	1.10	1.15	1.19	1.26	1.32
0.08	0.82	0.88	0.98	1.13	1.22	1.29	1.35	1.40	1.49	1.55
0.10	0.93	1.00	1.11	1.28	1.39	1.47	1.54			
0.15	1.17	1.27	1.40	1.61						
0.20	1.38	1.49								
0.25	1.56									

Emergency Spillways (Sediment basins)

DRAINAGE CONTROL TECHNIQUE

Low Gradient		Velocity Control		Short-Term	✓
Steep Gradient	✓	Channel Lining		Medium-Long Term	✓
Outlet Control		Soil Treatment		Permanent	[1]

[1] The design of permanent spillways may require consideration of issues not discussed here.

Symbol ⟶ ES ⟶

Photo 1 – Rock-lined sediment basin spillway with low-flow pipe outlet

Photo 2 – Rock mattress-lined sediment basin emergency spillway

Key Principles

1. The critical design components of a spillway are the flow entry into the spillway, the maximum allowable flow velocity down the face of the spillway, and the dissipation of energy at the base of the spillway.
2. The critical operational issues are ensuring unrestricted flow entry into the spillway, ensuring flow does not undermine or spill over the edge of the spillway, and ensuring soil erosion is controlled at the base of the spillway.
3. Failure of a spillway is likely to result from one or more of the following issues: inadequate rock size (if used), inadequate depth of the spillway chute, piping erosion caused by dispersive and/or poorly compacted soils, or failure of the energy dissipater.

Design Information

The material contained within this fact sheet has been supplied for use by persons experienced in hydraulic design.

This fact sheet addresses issues associated with the design of open channel spillways used in association with temporary sediment basins.

Design procedures and guidelines on the design of the spillway's chute can be obtained from the separate fact sheets presented for drainage *Chutes*. However, all references to the design of *Outlet structures* within these fact sheets do **not** apply to the design of spillway energy dissipaters. In addition, the recommended freeboard on spillway chutes is 300mm.

Design procedures and guidelines for energy dissipater located at the base of the temporary sediment basin spillways can be obtained from the separate fact sheet on *Energy dissipaters*.

Warning, sediment basin spillways and their associated energy dissipaters are usually major hydraulic structures requiring design input from experienced hydraulics specialists. This fact sheet does **not** provide sufficient information to allow these structures to be designed by inexperienced persons.

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The recommended minimum design storm for sizing the emergency spillway is defined in Table 1. Designers should confirm the design standard with the appropriate regulatory authority.

Table 1 – Recommended design standard for emergency spillways on temporary sediment basins [1]

Design life	Minimum design storm ARI
Less than 3 months operation	1 in 10 year
3 to 12 months operation	1 in 20 year
Greater than 12 months	1 in 50 year
If failure is expected to result in loss of life	Probable maximum flood (PMF)

[1] Alternative design requirements may apply to Referable Dams in accordance with State legislation, or as recommended by the Dam Safety Committee (ANCOLD 2000a & 2000b)

The crest of the emergency spillway should be in accordance with the following (default values), unless otherwise supported by appropriate investigation, risk assessment, and design:

- 300mm above the primary outlet (if included);
- 300mm below a basin embankment formed in virgin soil;
- 450mm below a basin embankment formed from fill.

In addition to the above, design of the emergency spillway must ensure that the maximum water level within the basin during the design storm specified in Table 1 is at least:

- 300mm below a basin embankment formed from fill;
- 150mm plus expected wave height for large basins with significant fetch length.

Recommended freeboard for the spillway chute is 300mm (note; this is an increase from the 150mm freeboard recommended for drainage chutes).

Anticipated wave heights generated within the settling pond can be determined from the procedures presented in the *Shore Protection Manual* (Department of the Army, 1984).

The hydraulic design of the spillway chute (Figure 1) is outlined within the separate fact sheets for *Chutes*.

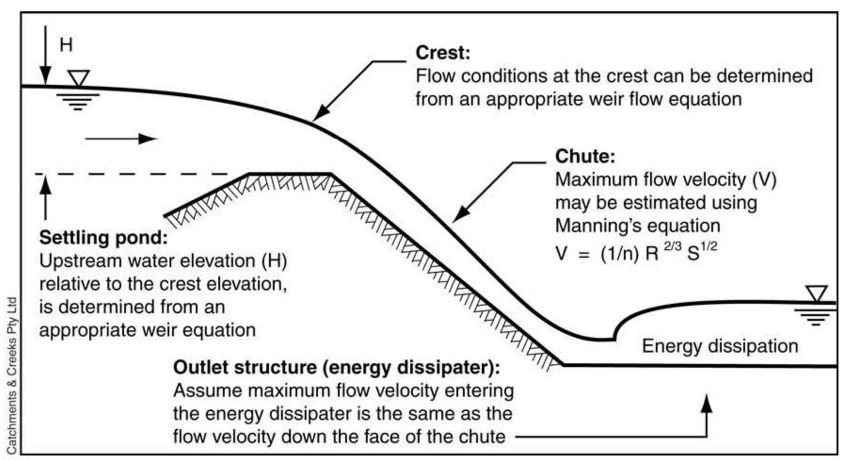

Figure 1 – Hydraulic components of a sediment basin spillway

Design of the flow entry conditions into the spillway:

All reasonable and practicable efforts must be taken to construct the spillway in virgin soil, (Photo 4 & Figure 2) rather than within a fill embankment (Photos 1, 2, 7 & 8). Placement of an emergency spillway within a fill embankment can significantly increase the risk of failure of the embankment.

The approach channel can be curved upstream of the spillway crest, but must be straight from the crest to the energy dissipater as shown in Figure 2. The approach channel should have a back-slope towards the impoundment area of not less than 2% and should be flared at its entrance, gradually reducing to the design width at the spillway crest.

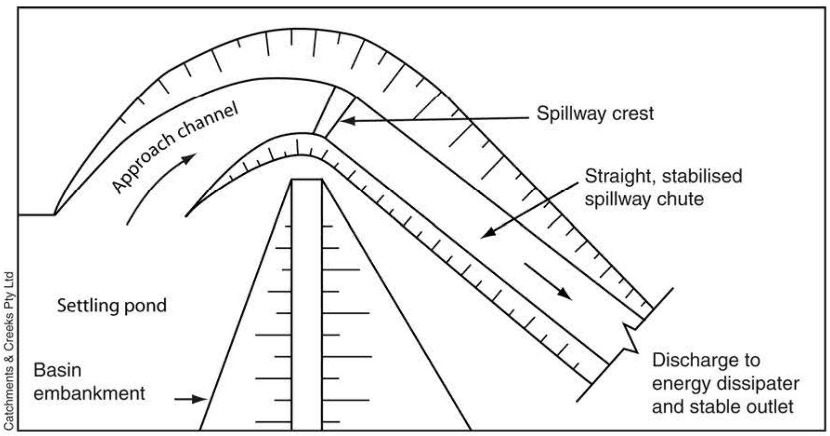

Figure 2 – Emergency spillway (plan view)

If the spillway crest length (L) and its approach channel are short, then friction loss upstream of the spillway crest can be ignored and the water level within the sediment basin 'H' (relative to the spillway crest) can be determined directly from the appropriate weir equation. Figure 3 shows flow approaching a spillway crest along a short approach channel.

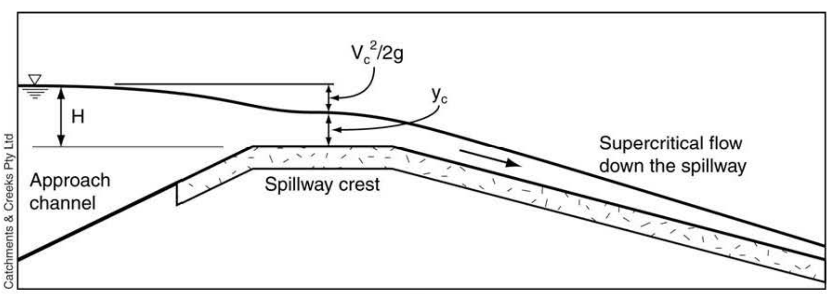

Figure 3 – Hydraulic profile for spillway crest where friction loss within the approach channel is insignificant

In those circumstances where the approach channel is short, the upstream water level (H) relative to the weir crest can be determined from the equations presented in Table 2.

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Table 2 – Weir equations for short spillway crest length where friction loss in the approach channel is negligible

Weir cross sectional profile	Side slope (H:V)	Weir equation
Rectangular (b = base width)	vertical sides	$Q = 1.7\,b\,H^{1.5}$
Triangular	m:1	$Q = 1.26\,m\,H^{2.5}$
Trapezoidal	1:1	$Q = 1.7\,b\,H^{1.5} + 1.26\,H^{2.5}$
where : b = base width	2:1	$Q = 1.7\,b\,H^{1.5} + 2.5\,H^{2.5}$
and m = side slope	3:1	$Q = 1.7\,b\,H^{1.5} + 3.8\,H^{2.5}$
(see Figure 4)	4:1	$Q = 1.7\,b\,H^{1.5} + 5.0\,H^{2.5}$
	m:1	$Q = 1.7\,b\,H^{1.5} + 1.26\,m\,H^{2.5}$

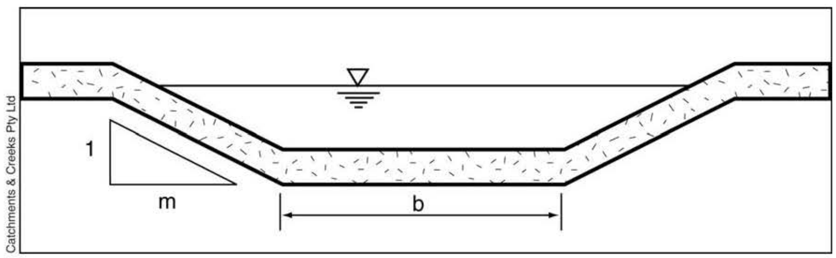

Figure 4 – Trapezoidal spillway (weir) crest

For some sediment basin spillways, however, friction loss within the approach channel is significant and cannot be ignored. In such cases an allowance must be made for this friction loss when determining the relationship between basin water level and spillway discharge. Figure 5 shows flow approaching a spillway crest where friction loss within the approach channel is significant.

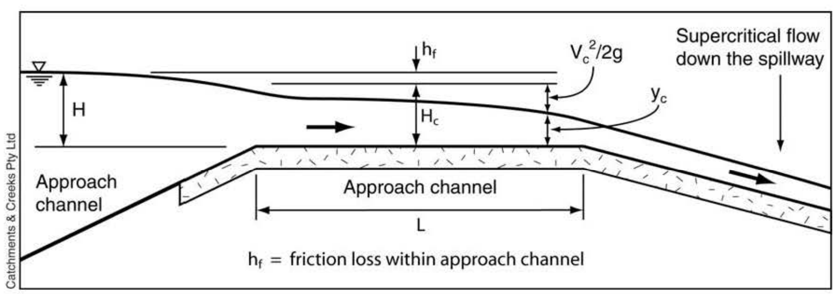

Figure 5 – Hydraulic profile for a spillway where friction loss within the approach channel is significant

A numerical backwater model (e.g. HecRas) should be used to determine the water level profile along the length of the approach channel and thus the anticipated maximum water level within a sediment basin. Such models can also be used to determine flow velocities down the face of the spillway chute. Alternatively, water levels within the basin (H) relative to the spillway crest can be determined from Equation 1.

$$H = H_c + h_f \qquad \text{(Eqn 1)}$$

where:

- H = water level within *Sediment Basin* relative to spillway crest [m]
- H_c = total head (energy level) at the spillway crest = $y_c + V_c^2/2g$ [m]
- y_c = critical depth at spillway crest [m]
- V_c = critical flow velocity at spillway crest [m/s]
- g = acceleration due to gravity = 9.8m/s^2
- h_f = friction loss within the approach channel and across the crest width [m]

Friction loss (h_f) within the approach channel can be estimated using Equation 2.

$$h_f = \frac{V^2 n^2 L}{R^{4/3}} \qquad \text{(Eqn 2)}$$

where:

- V = average flow velocity within the approach channel (if unknown, then assume a velocity of half the critical flow velocity (V_c) [m/s]
- n = Manning's roughness of the approach channel
- L = length of the approach channel upstream of the spillway crest [m]
- R = average hydraulic radius of the approach channel [m]

In circumstances where friction within the approach channel is significant, but the determination of peak water level within the sediment basin is **not** critical, the total upstream head (H) can be estimated from the equations presented in Table 3.

Table 3 – Approximate weir equations for spillways with a long approach channel where friction loss is significant

Weir cross sectional profile	Side slope (H:V)	Weir equation
Rectangular (b = base width)	N/A	$Q = 1.6\,b\,H^{1.5}$
Triangular	m:1	$Q = 1.2\,m\,H^{2.5}$
Trapezoidal (b = base width)	m:1	$Q = 1.6\,b\,H^{1.5} + 1.2\,m\,H^{2.5}$

To maintain the desired maximum allowable water level within the settling pond, concrete capping (sealing) of the spillway crest (Figure 6) is usually required if porous materials, such as loose rock or rock-filled mattresses, are used to line the spillway crest.

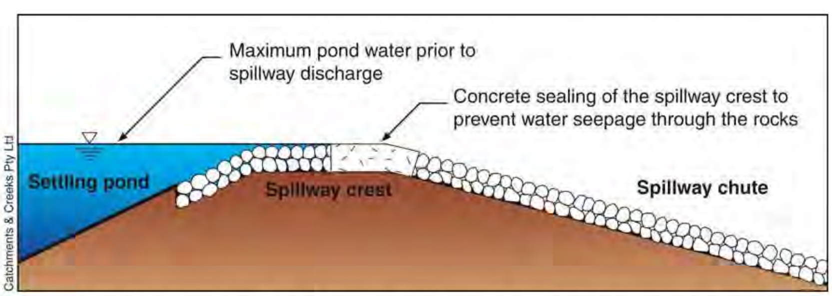

Figure 6 – Concrete sealing of the spillway crest to control seepage through the rock lining

Wherever practical, the spillway should be cut into virgin soil away from any fill embankment as shown in Photo 4.

Photo 3 – Permanent, gabion-lined stepped spillway located on a detention basin

Photo 4 – Rock-lined spillway cut into virgin soil (note the spillway is curved up to the crest, after which it remains straight)

Recessing the entire basin into the natural soil (Photo 5) will avoid the need to construct an expensive spillway structure.

Photo 5 – Recessing the basin into the ground allows the natural ground level to become the spillway

Photo 6 – Spillways lined with loose rock generally have a high risk of failure compared to concrete and rock mattress linings

Spillways must have a well-defined cross-section that can fully contain the expected discharge.

Photo 7 – Spillways <u>must</u> have a well-defined profile to fully contain the flow

Photo 8 – A suitable energy dissipater <u>must</u> exist at the base of the spillway

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Description

An open channel either passing over or around a sediment basin embankment.

If the basin is fully recessed below natural ground level, the spillway may consist of the natural ground surface.

Spillways are typically lined with materials such as rock, rock-filled mattresses, and concrete.

Purpose

Spillways are used to discharge excess flows from a sediment basin.

The term 'emergency spillway' implies that a primary spillway is incorporated into the low-flow (riser pipe) outlet structure.

Limitations

Bitumen or asphalt is generally not suitable for lining the spillway.

Grass-lined spillways are generally only suitable when the spillway is formed directly on a low-gradient, natural surface.

Common Problems

Inappropriate inlet geometry can cause flow to bypass and/or undermine the spillway.

Severe rilling along the sides of the spillway can be caused by splash. It is noted that spillways generally have a minimum freeboard of 300mm instead of the 150mm applied to minor drainage chutes.

Erosion at the base of the spillway caused by inadequate energy dissipation. Energy dissipation at the base of spillways generally involves complex 3-dimensional hydraulic design.

Common Problems (rock-linings)

Severe erosion problems if rocks are placed directly on dispersive soil. To reduce the potential for such problems, dispersive soils should be covered with a minimum 200mm layer of non-dispersive soil before rock placement.

Failure of rock-lined chutes due to the absence of a suitable filter cloth or aggregate filter layer beneath the primary armour rock layer.

Special Requirements

The spillway and associated energy dissipater must be fully contained within the related property.

An underlying geotextile or rock filter layer is generally required unless all voids are filled with soil and pocket planted (thus preventing the disturbance and release of underlying sediments through these voids).

The upper rock surface should blend with surrounding land to allow water to freely enter the channel.

Site Inspection

Check flow entry conditions to ensure no bypassing, undermining, sedimentation or erosion.

Ensure the spillway chute downstream of the crest is straight.

Check for erosion around the edges of the spillway (top and sides).

Ensure the energy dissipater and the channel downstream of the dissipater are appropriately stabilised.

Ensure the rock size and shape agrees with approved plan.

Check the thickness of rock application and the existence of underlying filter layer.

Check for excessive vegetation growth that may restrict the channel capacity.

Construction

1. The spillway must be excavated as shown on the plans, and the excavated material if classified as suitable, must be used in the embankment, and if not suitable it must be disposed of into spoil heaps.
2. Ensure excavated dimensions allow adequate boxing-out such that the specified elevations, grades, chute width, and entrance and exit slopes for the emergency spillway will be achieved after placement of the rock or other scour protection measures as specified in the plans.
3. Place specified scour protection measures on the emergency spillway. Ensure the finished grade blends with the surrounding area to allow a smooth flow transition from spillway to downstream channel.
4. If a synthetic filter fabric underlay is specified, place the filter fabric directly on the prepared foundation. If more than 1 sheet of filter fabric is required, overlap the edges by at least 300mm and place anchor pins at minimum 1m spacing along the overlap. Bury the upstream end of the fabric a minimum 300mm below ground and where necessary, bury the lower end of the fabric or overlap a minimum 300mm over the next downstream section as required. Ensure the filter fabric extends at least 1000mm upstream of the spillway crest.
5. Take care not to damage the fabric during or after placement. If damage occurs, remove the rock and repair the sheet by adding another layer of fabric with a minimum overlap of 300mm around the damaged area. If extensive damage is suspected, remove and replace the entire sheet.
6. Where large rock is used, or machine placement is difficult, a minimum 100mm layer of fine gravel, aggregate, or sand may be needed to protect the fabric.
7. Placement of rock should follow immediately after placement of the filter fabric. Place rock so that it forms a dense, well-graded mass of rock with a minimum of voids. The desired distribution of rock throughout the mass may be obtained by selective loading at the quarry and controlled dumping during final placement.
8. The finished slope should be free of pockets of small rock or clusters of large rocks. Hand placing may be necessary to achieve the proper distribution of rock sizes to produce a relatively smooth, uniform surface. The finished grade of the rock should blend with the surrounding area. No overfall or protrusion of rock should be apparent.
9. Ensure that the final arrangement of the spillway crest will not promote excessive flow through the rock such that the water can be retained within the settling basin an elevation no less than 50mm above or below the nominated spillway crest elevation.

Maintenance

1. During the construction period, inspect the spillway prior to forecast rainfall, daily during extended periods of rainfall, after significant runoff producing storm events, or otherwise on a weekly basis. Make repairs as necessary.
2. Check for movement of, or damage to, the spillway's lining, including surface cracking.
3. Check for soil scour adjacent the spillway. Investigate the cause of any scour, and repair as necessary.
4. When making repairs, always restore the spillway to its original configuration unless an amended layout is required.

Removal

1. Temporary spillways should be removed when an alternative, stable, drainage system is available.
2. Remove all materials and deposited sediment, and dispose of in a suitable manner that will not cause an erosion or pollution hazard.
3. Grade the area in preparation for stabilisation, then stabilise the area as specified in the approved plan.

Erosion Control – General

EROSION CONTROL TECHNIQUES

Photo 1 – Application of erosion control blankets and mats

Photo 2 – Straw mulching

Soil erosion is the process through which the effects of wind, water, or physical action displace soil particles, causing them to be transported. The main factors affecting surface erosion are rainfall erosivity, soil erodibility, slope length, slope steepness, soil cover, and the surface flow conditions (i.e. flow type, velocity, duration, and frequency).

In this context, the term *soil erosion* includes the displacement of soil, earth, gravel, sand, silt, clay, mud, sediment, cement, and contaminated liquid wash-off resulting from such activities as equipment cleaning and material-cutting activities (e.g. concrete cutting).

Controlling the initial erosion of soils is often the only feasible strategy for minimising environmental impacts resulting from disturbances of soils with a high clay or fine silt content.

It should be noted that complying with an agreed sediment control standard does **not** guarantee that environmental harm will be avoided, or that sediment-laden water will not be released from the site during severe storms. Therefore, taking all reasonable and practicable measures to minimise soil erosion is essential if environmental harm is to be minimised.

Erosion control measures concentrate on preventing, or at least minimising, soil erosion, especially erosion resulting from raindrop impact (Photo 3). Technically, erosion control refers to the control of soil erosion caused by both sheet and concentrated flow. As such, those temporary drainage control measures placed on a construction site to appropriately manage stormwater runoff are considered a subset of the overall erosion control process.

The principles of best practice (2008) construction site erosion control are outlined below.

1. Wherever reasonable and practicable, priority needs to be given to preventing, or at least minimising soil erosion (i.e. drainage and erosion control measures), rather than allowing the erosion to occur and trying to trap the resulting sediment. Where this is not practicable, then all reasonable and practicable measures need to be taken to minimise soil erosion even if the adopted sediment control measures comply with the required treatment standard.
2. The standard of erosion control needs to be appropriate for the given soil properties, expected weather conditions, and susceptibility of the receiving waters to environmental harm resulting from turbid runoff.
3. Appropriate erosion control measures need to be incorporated into all stages of a soil disturbance.
4. The timing and degree of erosion control specified in the Erosion and Sediment Control Plan(s) needs to be appropriate for the given soil properties, expected weather conditions, and susceptibility of the receiving waters to environmental harm resulting from turbid runoff.

5. If tree clearing is required well in advance of future earthworks, then tree clearing methods that will minimise potential soil erosion need to be employed, especially in areas of unstable or highly erodible soil.
6. Erosion and Sediment Control Plans (ESCPs) need to specify the required application rates for mulching and revegetation measures.
7. Erosion control measures need to be appropriate for the slope of the land and the expected wind and surface flow conditions.
8. Wherever reasonable and practicable, the use of synthetic reinforced *Erosion Control Mats* and *Erosion Control Blankets* needs to be avoided within bushland and other areas where they could endanger wildlife such as ground-dwelling animals.
9. Wherever reasonable and practicable, measures need to be taken to apply appropriate erosion control practices around the site office area and on temporary access roads to minimise raindrop impact erosion and the generation of mud.
10. Finished soil surfaces need to be left in an appropriate roughened state and quality to encourage revegetation where required.
11. Where appropriate, Erosion and Sediment Control Plans (ESCPs) need to incorporate technical notes on suitable dust control measures.
12. The construction schedule or ESC installation sequence needs to ensure that soil stabilisation procedures, including site preparation and revegetation, are commenced as soon as practicable after each stage of earthworks is completed.
13. Topsoil needs to be appropriately managed to preserve its long-term value.
14. Plant species need to be appropriate for the site conditions, including compatibility with local environmental values, and anticipated erosive forces.

Erosion control techniques include, but are limited to, the following:

- Bonded Fibre Matrix
- Cellular Confinement System
- Compost Blanket
- Dust Control
- Erosion Control Blanket
- Gravelling
- Heavy Mulching (including heavy brush, bark, and woodchip mulching)
- Light Mulching (including brush and straw mulching, and hydromulching)
- Revegetation (permanent and temporary revegetation, including turf, and dead and dormant grass cover)
- Rock Mulching
- Soil Binders (including Polyacrylamide)
- Surface Roughening

For specific information on the above erosion control techniques, refer to the relevant fact sheets.

Photo 3 – Raindrop impact erosion

Photo 4 – Sheet erosion

Photo 5 – Rill erosion

Photo 6 – Gully erosion

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Table 1 – Summary of erosion control techniques

Technique	Code	Symbol	Typical use
Bonded Fibre Matrix	BFM	BFM	• Grass establishment and protection of newly seeded areas.
Cellular Confinement System	CCS	CCS	• Containment of topsoil or rock mulch on medium to steep slopes. • Control erosion on non-vegetated medium to steep slopes such as bridge abutments and heavily shaded areas.
Compost Blanket	CBT	CBT	• Used during the revegetation of steep slopes either incorporating grasses or other plants. • Particularly useful when the slope is too steep for the placement of topsoil, or when sufficient topsoil is absent from the slope.
Erosion Control Blanket	ECB	ECB	• Temporary erosion control on exposed soils not subjected to concentrated flow. • Temporary control of raindrop impact erosion on earth embankments before and during the revegetation phase.
Gravelling	Gravel	GRAVEL	• Protection of non-vegetated soils from raindrop impact erosion. • Stabilisation of site office area, temporary car parks and access roads.
Heavy Mulching	MH	MH	• Stabilisation of soil surfaces that are expected to remain non-vegetated for medium to long periods. • Suppression of weed growth on non-grassed areas. • Stabilisation of existing and proposed garden beds.
Light Mulching	M	M	• Control of raindrop impact erosion on flat and mild slopes. May be placed on steeper slopes with appropriate anchoring. • Control water loss and assist seed germination on newly seeded soil.
Revegetation	R	R	• Temporary and permanent stabilisation of soil. • Stabilisation of long-term stockpiles. • Includes *Turfing* and temporary seeding.
Rock Mulching	MR	MR	• Stabilisation of long-term, non-vegetated banks and minor drainage channels. • Stabilisation of those areas of a garden bed subject to concentrated overland flow.
Soil Binders	SBS	SBS	• Dust control. • Stabilisation of unsealed roads.

Photo 7 – Bonded fibre matrix

Photo 8 – Cellular confinement system

Photo 9 – Compost blanket

Photo 10 – Erosion control blanket

Photo 11 – Gravelling

Photo 12 – Heavy mulching

Photo 13 – Light mulching

Photo 14 – Rock mulching

Revegetation

EROSION CONTROL TECHNIQUE

Revegetation	✓	Temperate Climates	✓	Short-term	[1]
Non Vegetation		Wet Tropics	✓	Long-term	
Weed Control		Semi-Arid Zones	✓	Permanent	✓

[1] Temporary revegetation can be an effective form of erosion control, but it usually needs to incorporate *Light Mulching* in order to provide sufficient protection from raindrop impact erosion.

Symbol R

Photo 1 – Turfing

Photo 2 – Fertiliser spreader and chisel plough

Key principles

1. Test the soils, and where required, adjust the soils before planting
2. The primary function of "temporary" vegetation, in association with mulching, is to achieve effective short-term erosion control through coverage of the soil surface, thus the effective percentage surface cover is the key performance measure.
3. Vegetative-based erosion control is primarily achieved through coverage of the soil. Root stabilisation of the soil structure is generally of secondary importance. However, the function of the roots becomes increasingly important as the surface slope increases.
4. The initial coverage of annual grasses in the weeks following seeding may not provide adequate erosion protection against raindrop impact because these grasses primarily grow vertically, thus providing only limited coverage of the soil surface. In such cases, mowing can increase the effective soil cover.

Design Information

Selecting the most suitable plant establishment techniques, appropriate species, seeding rates, planting densities, fertiliser types, watering rates, and maintenance techniques, requires the guidance of experts such as soil scientists, revegetation specialists, local bushland groups, and government extension officers.

Each of the various forms of soil erosion, whether initiated by wind, rain, or flowing water, are best controlled by different forms and/or combinations of vegetation. Table 1 outlines the types of vegetation most likely to be effective in the control of the various forms of soil erosion. Of course there are always exceptions to such generalisation.

Table 1 – Plant selection for the control of soil erosion

Erosion form	Primary vegetation	Secondary vegetation	Comments
Water induced:			
Raindrop impact	Ground covers, grasses, and living or dead organic matter	Trees, shrubs	• Ground covers need to quickly cover the soil surface (i.e. not just straight, vertical shoots—which is often the early growth characteristic of many annuals). • In this context, "grasses" includes living, dormant and dead grasses. • Trees contribute by suppling leaf and bark litter (mulch).
Sheet erosion	Ground covers, grasses		• Non-clumping, continuous ground cover is required.
Rill erosion	Ground covers, grasses		• Non-clumping, continuous ground cover is required.
Gully erosion	Ground covers, vetiver grass	Trees, shrubs, woody debris	• Vetiver grass can be used to form a vegetative sediment barrier. • Trees and shrubs may be required for bank stability.
Tunnel erosion			• Stabilisation of soil and control of water pathways are of primary importance. • Avoid deep-rooted or short-lived plants on water impoundment embankments.
Wave erosion	Reeds	Mangroves	• Critical locations include coastlines, rivers, lakes and dams. • Mangroves can struggle to deal with significant wave attack.
Gravity induced:			
Mass movement	Trees, vetiver grass	Shrubs	• Use of deep-rooted plants is critical.
Wind induced:			
Wind erosion	Ground covers	Tree, shrubs, mulches	• Trees can form windbreaks. • Aided by increased surface roughness.
Watercourse erosion:			
Refer to the *Instream Erosion Control* fact sheet, and Tables I14 to I15 (p. I.32 to I.34) in Appendix I – *Instream works.*			

ESTIMATING GROUND COVER

(i) Quadrat method

Materials:

- 50m tape measure
- 1m^2 quadrat (a "quadrat" for these purposes being a 1m x 1m rectangular viewing grid)
- visual cover estimation template (Figure 1, otherwise refer to McDonald et al., 1990)
- notebook and pens

Procedure:

1. Locate sampling points at four evenly spaced points along a 50m transect.
2. Place the 1m^2 quadrat on the ground with the nominated point at the centre. Identify all species rooted **within** the quadrat (if required), and estimate and record the percentage cover. Where required, record the percentage cover of each plant species. For the purpose of species identification, do not record plants rooted outside, but branching across, the quadrat. For purposes of total cover estimation, record all matter, plant (living or dead) and mulch, whether rooted inside or outside the quadrat.

(McDonald, R.C., Isbell, R.F., Speight, J.C., Walker, J. and Hopkins, M.S. 1990, *Australian Soils and Land Survey Field Handbook*, Inkata press, Melbourne)

(ii) Ellenbank Pasture Meter

The Ellenbank Pasture Meter consists of a weighted plate that compresses pasture, then measures the height of the compressed vegetation. Even though this procedure provides a good estimate of pasture density (for stock feed), it does **not** necessarily provide a good estimate of cover. It is noted that the bulk of the pasture may consist of tall, near-vertical stalks that provide limited protection against raindrop impact in comparison to shorter, near-horizontal dead or living stalks.

ESTIMATION OF TREE AND SHRUB DENSITY

Materials:

- 2 x 50m tape measures
- star pickets
- notebook and pens

Procedure:

At each sample site, mark the western end of a 50m transect with a star picket. Measure the tree and shrub densities using the Point-Centred Quarter method (Barbour et al. 1987), as described below.

1. Locate sampling points at the 0m, 25m and 50m points on the transect.
2. At each sample point, align two axes centred on the sample point. The axes follow the line of the transect, and a line perpendicular to the transect.
3. Within each quadrant formed by the axes, identify the closest tree and shrub. If the tree or shrub exceeds a distance of 50m, do not record it.
4. Measure the distance in metres to the closest tree, and to the closest shrub.
5. Record the species and estimate its height.
6. For each transect, average the distance measurements for trees (D_{ave}).
7. Calculate the average tree density (stems per hectare), $T_d = 10{,}000 / (2 \times (D_{ave})^2)$
8. Calculate the relative density of species, X =

   (Number trees of species, X) / (Total number of trees x average tree density)
9. Repeat Steps 6 to 8 for shrub species. Record the adopted classification of shrubs (e.g. all woody plants less than 6m tall, including tree saplings).

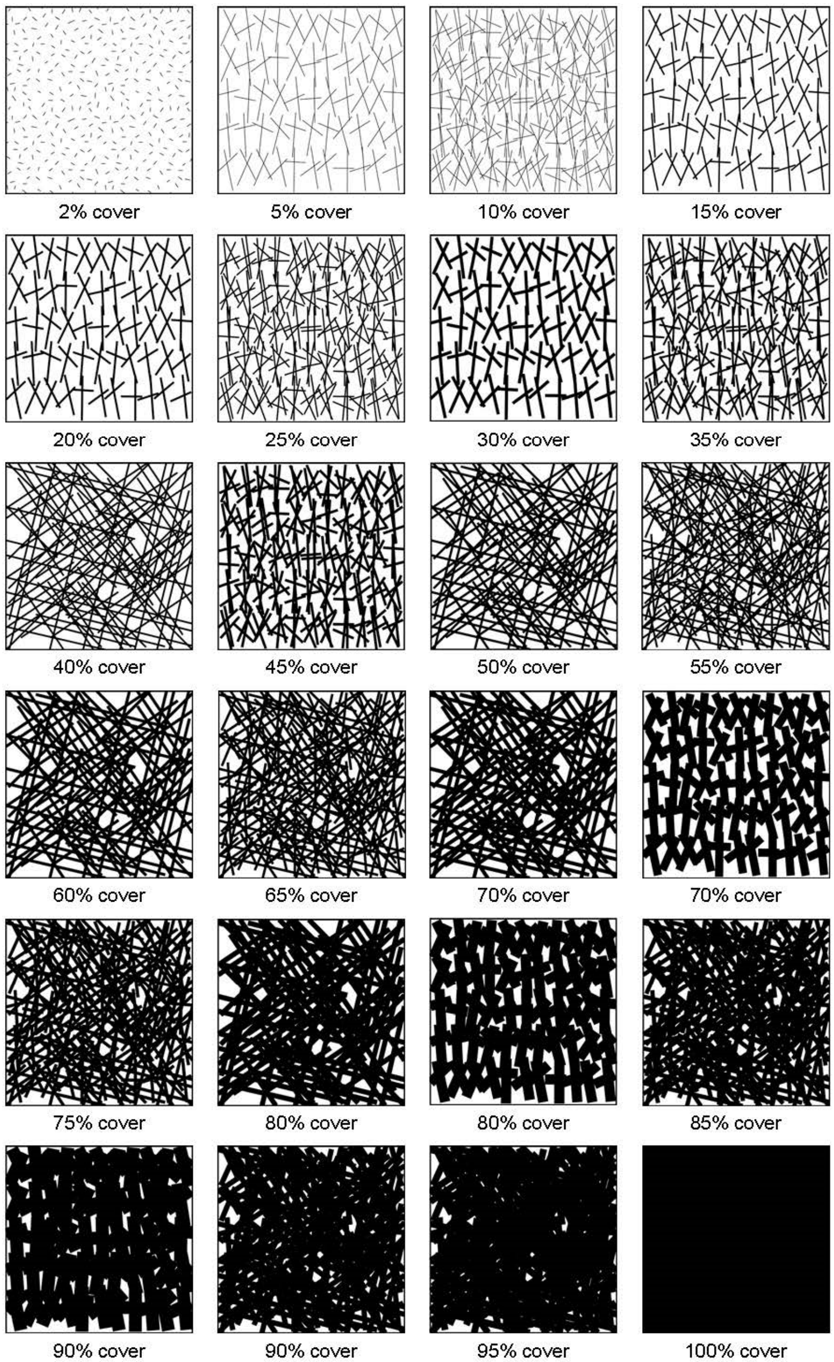

Figure 1 – Visual cover estimation template

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Description

Establishment of temporary or permanent vegetation over exposed soil surfaces.

"Temporary seeding" is a process of providing a temporary grass cover during construction delays, or when final further soil disturbance is expected within a given area and short-term erosion control measures are deemed necessary.

Purpose

Site revegetation is performed for a number of reasons, including:

- Improve aesthetics
- Erosion control
- General ecological reasons including habitat, food source & shelter
- Stabilisation of shallow land slips
- Increase stormwater infiltration and reduce the volume of runoff
- Reduce rainfall impact energy
- Increase organic content of the soil
- Established vegetated buffer zones
- Reduce dust problems
- Filter sediment from sheet flow

Limitations

There are limits to the role vegetation alone can play in controlling erosion. Both soil strength and vegetation cover (including root system) can take years to develop to the required condition.

Usually not suitable in heavy traffic areas or on long slopes steeper than 2:1(H:V).

Advantages

In terms of ecologically sustainable soil protection, vegetation is the best long-term solution to wind and water induced erosion.

Most forms of vegetation are self-regenerating and to some degree, self maintaining.

Well-landscaped works are aesthetic and usually well received by the public.

Disadvantages

Long establishment time for most forms of vegetation, except turfing.

Subject to damage in heavy traffic areas.

Conflicts can exist between the choice of native and exotic species.

In some rural and semi-arid areas, watering costs can be high.

Usually requires a long maintenance period.

Common Problems

Poor site drainage can damage plant seeds and remove mulch cover.

Poor soil preparation can significantly limit the establishment, growth and erosion benefits of vegetation.

Many problems can initiate from inadequate soil testing and soil amendment.

Special Requirements

Usually requires guidance from local experts, such as local agronomists.

At least 70% ground cover (combined plant and mulch) is considered necessary to provide a satisfactory level of erosion control.

A mulch cover layer is usually required to control short-term erosion and provide good growing conditions. The mulching of exposed soils is generally recommended on all seeded areas, especially when the area contains: high clay content soils, dispersive soils, exposed subsoils, or during hot, dry weather (to limit soil moisture loss).

Requires suitable soil and soil conditioning.

Plant establishment requires a reliable water supply.

On some open grassed areas, slashing is recommended to reduce the excessive growth of the primary cover and also to remove immature seed heads. This is particularly important for summer plantings as regrowth can compete strongly for light and water with the secondary and tertiary cover species.

Long-term maintenance needs are usually inversely proportional to the degree of planning and quality of site preparation.

Site Inspection

Check effective percentage cover.

Check for damage to protective fencing.

Seed, seedlings and mulch may need re-application if the vegetation does not establish in the required time.

Look for displacement of mulch by wind or water.

Specifications for site revegetation vary considerably from site to site. Site supervisors should obtain site specific planting specifications.

Installation

1. Refer to approved plans for location, extent, and application details. If there are questions or problems with the location, extent, or method of application contact the engineer, landscape architect or responsible on-site officer for assistance.
2. Apply soil conditioners and fertiliser as specified on the approved plans. Rip the soil to a depth of 100 to 150mm to mix the components into the soil and to loosen and roughen the soil surface before seeding.
3. There should be sufficient soil depth to provide an adequate root zone. The depth to rock or impermeable layers such as hardpans should be 300mm or more, except on slopes steeper than 2:1(H:V) where such soil depth may not be feasible.
4. Ensure the soil pH is within the specified range.
5. Apply seed uniformly by hand or with a fertiliser spreader, drill-seeder, hydro-seeder, or other suitable equipment as specified.
6. When using broadcast-seeding methods, subdivide the area into workable sections and apply one-half the specified quantity of seed while moving back and forth across the area, making a uniform pattern. Then apply the second half in the same way, but moving at right angles to the first pass. Cover broadcast seed by raking or chain dragging; then firm the surface with a roller to provide good seed to soil contact.
7. Apply seed at the recommended rate, and disc or otherwise mechanically treat the surface to bring the seed into contact with the soil.
8. The seeded area should be mulched as specified in the approved plan.

Maintenance

1. During the construction phase, inspect the treated area fortnightly and after runoff-producing rainfall. Make repairs as needed.
2. Watering the vegetation periodically is essential, especially in the first 7 days after establishment. Use low-pressure sprays because high-pressure jets can wash away the seed and mulch cover.
3. Watering should start immediately after planting. Watering should comply with specifications provided with the approved plans. Generally watering should vary according to weather and soil conditions. A typical watering schedule may consist of the following:
   - 25 mm every second day for the first three waterings;
   - 25 mm twice a week for the next three weeks; and
   - 25 mm once weekly for a further two weeks.
4. Monitor site revegetation, particularly after rainfall, and appropriate maintenance and/or amendment to ensure that the revegetation is controlling erosion and stabilising soil slopes as required.
5. Where practicable, fill in, or level out, any rill erosion between plants. If excessive erosion occurs, then consider increasing the planting density, applying appropriate erosion control measures, or introducing alternative, non-clumping plant species.
6. Areas must be re-seeded and mulched if the vegetation fails to establish or is damaged by runoff or construction activities.
7. If the temporary vegetation cover or erosion control measure (e.g. mulch cover) should fail for any reason before establishment of the permanent vegetation cover, then it must be replaced with an appropriate type of cover sufficient to control soil erosion.
8. If the permanent vegetation should fail to establish or to adequately restrain erosion for any reason during the construction or maintenance period, the area should be revegetated or protected with other erosion control measures as appropriate.
9. In areas where the obtained vegetation cover is considered inadequate for erosion control, the affected area should be over-seeded and fertilised using half the originally specified rates, or as directed.

10. Maintain grass blade length at a minimum 50mm height within medium to high velocity drainage areas, and 20 to 50mm within low velocity flow paths.
11. Where necessary, or as directed by the site supervisor, slash the temporary crop/grass cover to allow the successful growth of the underlying permanent vegetation cover.
12. Control weed growth within 1m of immature trees for 6 to 12 months for fast growing species, and 18 to 20 months for slower growing species, or until the end of the specified maintenance period.
13. Where mulch is used to control weed growth, inspect and where necessary, renew at maintenance periods not exceeding 4 to 6 months.
14. Apply additional seed, mulch and/or soil conditioning as required. Mulches usually need to be maintained or renewed (as necessary) 2 to 3 times a year.
15. Inspect and where necessary repair protective fencing at maintenance periods not exceeding 1 month.
16. Re-firm plants loosened by wind-rock, livestock or wildlife.
17. Replace dead or severely retarded plants.
18. Prune any plants of dead or diseased parts. Cut off all damaged tree limbs above the tree collar at the trunk or main branch. Use several cuts including undercutting to avoid peeling bark from the healthy areas of the tree.
19. Dispose of cleared vegetation in an appropriate manner such as chipping or mulching, on-site burial, or off-site disposal. Cleared vegetation should not be dumped near a watercourse or on a floodplain where is could be removed by floodwaters. Vegetation should not be burnt on-site without specific approval from the local authority.
20. Repair damaged tree roots by cutting off the damaged areas and sealing them with an approved product. Spread moist topsoil over exposed roots.

Gravelling

EROSION CONTROL TECHNIQUE

Revegetation		Temperate Climates	✓	Short-Term	[2]
Non Vegetation	✓	Wet Tropics	✓	Long-Term	✓
Weed Control	[1]	Semi-Arid Zones	✓	Permanent	✓

[1] Refer to *Rock Mulching* fact sheet for weed control application.

[2] Can be used for short-term erosion control around the construction office area and car park.

Symbol

Photo 1 – Gravelling of construction access road

Photo 2 – Gravelling of construction site car park

Key Principles

1. Primarily used to control raindrop impact and mud generation, therefore the depth of cover, and percentage of fines (particles finer than 1mm) are critical.
2. Operational performance is governed by the control of raindrop impact erosion, dust and surface mud on trafficable areas.
3. Gravel is **not** a suitable material for the stabilisation of construction site entry/exit points; however it may be suitable for the formation of rock entry pads on some small building sites (e.g. those building sites with little or no soil/earth import or removal).

Design Information

Minimum 100% coverage of the soil surface.

Nominal aggregate (rock) size of 20 to 75mm.

Apply at a minimum thickness of 50mm, or at least twice the nominal aggregate size.

Allowable flow velocities for rock with a specific gravity of 2.6 are presented in Table 1.

The equivalent allowable shear stress, based on a critical Shield's parameter of 0.07 and a safety factor of 1.5, is provided in Table 2.

The assumed Manning's roughness for the gravel (used to determine the allowable flow velocity from the allowable shear stress) is presented in Table 3. This Manning's roughness is based on a d_{50}/d_{90} = 0.8 (i.e. a relatively uniform rock size). Note; d_{50} is the nominal rock size of which 50% of the rocks are smaller.

Hydraulic design of gravelled surface is only required if the surface is likely to be subjected to significant overland flow that could displace the gravel or otherwise cause erosion.

Table 1 – Allowable flow velocity (m/s) for various rock sizes [1,2]

Hydraulic radius (mm)	Nominal mean (d_{50}) rock size (mm)					
	20	30	40	50	60	75
50	0.86	0.85	0.83	0.81	0.80	0.80
75	1.02	1.05	1.05	1.03	1.02	0.99
100	1.14	1.19	1.21	1.21	1.20	1.18
150	1.29	1.40	1.45	1.47	1.48	1.48
200	1.39	1.53	1.61	1.66	1.69	1.71
300	1.51	1.70	1.83	1.91	1.98	2.03
500	1.65	1.89	2.06	2.19	2.30	2.42

[1] Based on a relative density of 2.6 (i.e. rock mass of 2.6 tonne/m^3)

[2] Applicable to slopes less than 5%. Caution if applied to slopes of 5 to 10%.

Table 2 – Allowable shear stress (N/m^2) for various rock sizes [1]

Hydraulic radius (mm)	Nominal mean (d_{50}) rock size (mm)					
	20	30	40	50	60	75
N/A	14.6	22.0	29.3	36.6	43.9	54.9

[1] Based on a critical Shield's parameter of 0.07 and a safety factor of 1.5.

Table 3 – Assumed Manning's roughness (n) of gravel [1]

Hydraulic radius (mm)	Nominal mean (d_{50}) rock size (mm)					
	20	30	40	50	60	75
50	0.027	0.034	0.040	0.046	0.052	0.060
75	0.025	0.029	0.034	0.038	0.043	0.049
100	0.023	0.027	0.031	0.034	0.038	0.043
150	0.022	0.025	0.028	0.030	0.033	0.037
200	0.021	0.024	0.026	0.028	0.030	0.033
300	0.021	0.023	0.024	0.026	0.028	0.030
500	0.021	0.022	0.024	0.025	0.026	0.028

[1] Based on a rock size distribution of d_{50}/d_{90} = 0.8.

Description

The stabilisation of broad, low gradient, earth surfaces using a mixture of relatively small size rock approximately 20 to 75mm in diameter.

The term *gravelling* normally refers to the application of a layer of gravel or aggregate on roads or car parks. It is generally not used to describe the use of small rocks as garden mulch (see *Rock Mulching*).

Purpose

Primarily used in high traffic areas to reduce soil compaction and control raindrop impact and wind erosion.

Limitations

The small rock size limits its scour resistance resulting in a relatively low allowable shear stress.

Gravel should **not** be placed directly onto dispersible soils. Instead dispersive soil should be covered with a minimum 200mm layer of non-dispersive soil before placement of gravel.

Advantages

Produces a low cost, trafficable surface.

Gravelling the general construction office area and car park can significantly reduce the generation of mud during extended periods of wet weather.

Gravel roads generally experience less environmentally-damaging sediment runoff than dirt roads.

Disadvantages

Effective service life of a single application of gravel can be short, especially during wet weather and/or when placed on wet clayey soils.

The cost may not be easy to justify if recommended for placement over short-term construction access tracks.

Common Problems

Compression of the gravel into soft, clayey soils.

Special Requirements

Placement of the gravel on an appropriate geotextile can improve the service life of the gravelled surface.

Location

Light traffic access roads, car parks and general construction office area.

Site Inspection

Check even, continuous (100%) cover of earth.

Check if reapplication is required.

Check for rilling along the up-slope edges of the treated area, and the free passage of stormwater runoff across the gravel.

Performance Indicators

Application depth measured at random test locations.

Aggregate size, and particle size range measured using conventional particle size test procedures (if required).

Installation

1. Refer to approved plans for location, extent, and application details. If there are questions or problems with the location, extent, or method of application contact the engineer or responsible on-site officer for assistance.
2. Spread enough gravel to completely cover the surface of the soil at the density or thickness specified in the approved plans. If the application density is not supplied, then apply at a thickness of at least twice the mean rock size.
3. Make all necessary adjustments to ensure any run-on stormwater flow is allowed to pass freely across the treated area following its natural drainage path.

Maintenance

1. Inspect all treated surfaces fortnightly and after runoff-producing rainfall.
2. Check for rill erosion, or dislodgment of the gravel.
3. Replace any displaced gravel to maintain the required coverage.
4. If wash-outs occur, repair the slope and reinstall surface cover.
5. If the gravelling is not effective in containing the soil erosion it should be replaced, or an alternative erosion control procedure adopted.

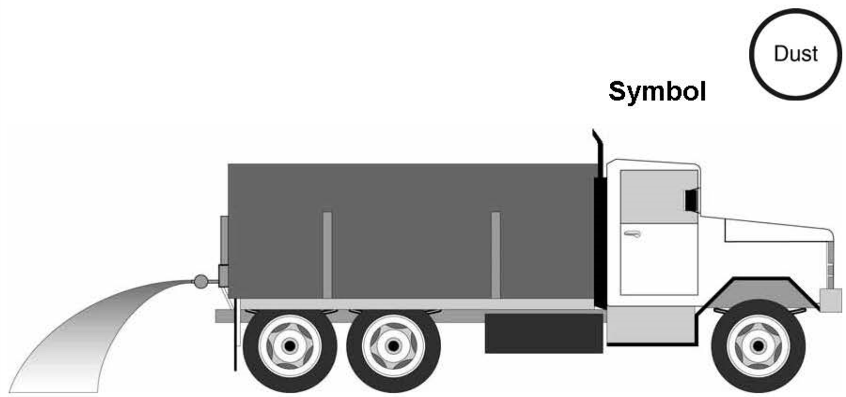
Dust Control

EROSION CONTROL TECHNIQUE

Revegetation	[1]	Temperate Climates	✓	Short-term	✓
Non Vegetation	[1]	Wet Tropics	✓	Long-term	[2]
Weed Control		Semi-Arid Zones	✓	Permanent	

[1] Treatment options can include temporary vegetation and non-vegetated treatment options.

[2] Most treatment options, excluding permanent revegetation, provide only short-term benefits.



Key Principles

1. Potential adverse impacts of dust control products/chemicals on the environment (both short- and long-term) **must** not exceed the potential benefits achieved by their use, or any locally adopted measures of unacceptable environmental risk.
2. Critical design parameters include ability to control dust generation, suitability of the product to the work place conditions and the soil type.
3. Effectiveness and durability of most treatment measures depends on soil type, weather conditions, and frequency of disturbance (e.g. traffic movement).

Design Information

Dust control involves the suppression of dust particles generally in the range 0.001 to 0.1mm (1 to 100 microns). Much of the dust generated on construction sites is likely to be greater than 10 microns. Non-visible dust particles (less than 5 microns) are potentially the most harmful to human health.

Dust generation associated with wind erosion is normally controlled using one or more of the following techniques:

(i) Maintaining moist soil conditions (water trucks and sprinkler systems)
(ii) Chemical sealants placed over the soil surface (refer to *Soil Binders* fact sheet)
(iii) Surface roughening (refer to *Surface Roughening* fact sheet)
(iv) Revegetation (short- and long-term ground cover options)
(v) Wind breaks (e.g. retention of existing vegetation, or 60:40 fabric:opening shade cloth).

Dust problems can also be reduced by the following activities:

- Limiting the area of soil disturbance at any given time.
- Promptly replacing topsoil after completion of earthworks
- Programming works to minimise the life of soil stockpiles.
- Temporarily stabilising (e.g. vegetation or mulching) long-term stockpiles.
- Gravelling unsealed access and haul roads.
- Minimising traffic movements on exposed surfaces.
- Limiting vehicular traffic to 25kph.
- Retaining existing vegetation as wind breaks.

International Erosion Control Association (IECA, 1993) reports that:

- 30% soil cover will reduce soil losses by 80%.
- Roughening the soil to produce 150mm high ridges perpendicular to the prevailing wind can reduce soil losses by 80%.
- A small decrease in velocity can have a major impact in reducing wind erosion given that the erosive power of wind is proportional to the cube of the velocity.
- For wind barriers perpendicular to the wind, the width of the [protected] zone leeward of the barriers is around 8 to 10 times the height of the barrier.

Possible treatment options for dust are summarised in Table 1. A summary of dust suppressant agents is provided in Table 2. Discussion on the use of soil binders for dust control is provided in the *Soil Binders* fact sheet.

Table 1 – Dust control practices [1]

Site condition	Treatment options							
	Permanent vegetation	Mulching	Watering	Chemical surface stabiliser [2]	Gravel road [3]	Stabilised entry/exit pad	Haul truck covers	Minimise site disturbance
Areas not subject to traffic	✓	✓	✓	✓	✓			✓
Areas subject to traffic			✓	✓	✓	✓		✓
Material stockpiles			✓	✓				✓
Demolition areas			✓			✓	✓	
Clearing & excavation			✓	✓				✓
Unpaved roads			✓	✓	✓	✓	✓	
Earth transport					✓	✓		

[1] Sourced from: California Stormwater BMP Handbook – Construction (2003).

[2] Oil or oil-treated subgrade should not be used for dust control as this may migrate into downstream water bodies. It is also noted that surface stabilising chemicals (soil binder) may make the soil water repellent, possibly resulting in long-term revegetation problems.

[3] On long-term access and haul roads, the sealing of road with an application of 10mm single-coat bitumen seal can be more effective than the application of dust suppressants.

The following materials must not be used for dust suppression purposes:

- oil;
- landfill gas condensate;
- any contaminated leachate or stormwater when the use of such material is likely to cause unlawful environmental harm.

Table 2 – Summary of dust suppressant attributes [1]

Suppressant type	Typical attributes
Soil binders	• Refer to *Soil Binders* fact sheet
Chlorides: Calcium chloride ($CaCl_2$) Magnesium chloride ($MgCl_2$)	• Chloride compounds attract moisture from the air (hygroscopic) and attach themselves to soil particles if they are applied to wet soils • Less effective in dry climates • Ease of application, with 0 to 4 hours curing time • Can be applied when temperatures drop below freezing • Most suited to temperate and semi-humid conditions • Lose effectiveness in continual dry periods • Less effective than polymers during periods of heavy rainfall • Susceptible to leaching • Suitable for use on moderate surface fines (10–20%) • Not suitable on materials with a low-fines content • High fines content surfaces may become slippery in wet weather • Corrosive impacts associated with calcium chloride
Organic, non-bituminous: Calcium ligno-sulfonate Sodium ligno-sulfonate Ammonium ligno-sulfonate	• Ligno-sulfonate (lignin) is a by-product of the pulp-and-paper industry • React with negatively charged clay particles to agglomerate the soil • Perform well under arid conditions and in dry climates • Failures occur following rains • Susceptible to leaching by heavy rains • Suitable on high fines content (10–30%) in a dense graded material with nil loose gravel • Less effective on igneous, medium to low fines content materials and crushed gravels • High fines content surfaces may become slippery in wet weather • It is best to grade haul road to remove surface material, potholes, and corrugations before application of agent • Curing takes 4 to 8 hours
Petroleum-based products: Bitumen emulsion (slow-breaking non-ionic)	• Generally effective regardless of climate • Will pothole in wet weather and high traffic conditions • Suitable on materials with a low-fines content (<10%) • Non suitable where runoff could contaminate receiving waters
Electrochemical stabilisers: Sulfonated petroleum Enzymes	• Work over a wide range of climates • Suitable for clay materials but depends on clay mineralogy • Iron rich soils generally respond well • Least susceptible to leaching • Ineffective if surface is low in fines and contains loose gravel

[1] After UMA Engineering Ltd 1987, *Guidelines for Cost Effective use and Application of Dust Palliatives.* UMA Engineering Ltd, Ontario, Canada.

Water trucks and sprinkler systems

Water trucks have traditionally been used to control dust within construction sites, particularly on haul roads and for highway construction. The maintenance of moist soil conditions through watering remains a viable dust control measure.

The addition of wetting agents and polymer binders (refer to *Soil Binders* fact sheet) to the water can decrease both the water requirements and the required application frequency. Wetting agents can improve the depth and uniformity of the soil wetting process. Polymer binders improve the binding of individual soil particles, thus reducing dust generation even after drying of the soil surface. Dust suppressing agents can be applied by both water trucks and sprinkler systems.

Dust-suppressing fog and mist generators

High volume mist generating machines can be used to suppress airborne dust resulting from blasting operations. Large cannon-like systems can throw a mist some 250m to blanket the treatment area. On small sites, hydraulic atomising misting nozzles can be attached to sprinkler-like distribution system.

An ionic wetting agent can be added to the water to improve the performance of misting dust suppression systems.

Foaming agents

Foaming agent additives can be added to directional dust-suppressing sprinkler systems to apply a foam to the surface of conveyor belt materials to reduce dust resulting from crusher and material handling plants.

Vegetable oil based soil binders

Biodegradable vegetable oil based soil binders can be applied as a water-based emulsion to provide up to 3 months service life in heavy vehicular traffic areas.

Polymer based soil binders (refer to *Soil Binders* fact sheet)

Polymeric emulsion soil binders include: acrylic copolymers and polymers; liquid polymers of methacrylates and acrylates; copolymers of sodium acrylates and acrylamides; poly-acrylamide and copolymer of acrylamide; and hydro-colloid polymers.

In general terms, polymers can provide around 9 to 18 months service life if the treated area remain free of disturbance and traffic movement. On haul roads and permanent unsealed roads, polymer soil binders can be incorporated into road maintenance (grading and rolling) to improve surface stability and compaction.

Photo 1 – Dust generation on a construction site

Photo 2 – Dust control using a water truck

Surface Roughening

EROSION CONTROL TECHNIQUE

Revegetation		Temperate Climates	✓	Short-Term	✓
Non Vegetation	✓	Wet Tropics	✓	Long-Term	
Weed Control		Semi-Arid Zones	✓	Permanent	

SR

Symbol

Photo 1 – Tracked vehicle walking up and down slope

Photo 2 – Corrugated (roughened) surface

Key Principles

1. Surface roughening is an erosion control technique of which the benefits can vary significantly from region to region, soil to soil, and climate to climate.
2. The appropriate application of surface roughening is possibly best resolved on a site by site basis. However, in most cases exposed soil surfaces should be left in a suitably roughened state, even if they are about to be vegetated or topped with another layer of soil.
3. In general, clayey soils should **not** be finished with a glassy smooth surface, especially if they are to be revegetated using such techniques as hydroseeding or hydromulching, or any of the hydraulically applied erosion control blankets.

Design Information

On exposed or recently vegetated surfaces, erosion protection can be increased by roughening the soil surface to increase water infiltration, delay the formation of rilling, and reduce dust generation. Surface roughening can be applied to both subsoils and topsoils, either before and/or after seeding.

A roughened soil surface is, however, not always desirable. In some cases it may be undesirable to promote the infiltration of water into the soil, such as stockpiled soil immediately prior it being used as embankment fill. Also, on steep slopes, loose surface soil can present an increased risk of sediment runoff, especially during periods of high rainfall intensity.

Table 1 provides general guidelines on the application of surface roughening to cut and fill slopes. This information must be applied in association with site specific geotechnical advice.

Table 1 – Typical application of surface roughening on slopes

Slope condition	Treatment
Cut slope steeper than 3:1(H:V)	• Stair-stepping with a vertical cut of 50 to 100mm can be used to aid in the anchorage of topsoil on steep slopes. • In situations where the stair-stepping is to be a permanent feature of the slope, the vertical cut should be less than 600mm high in soft material, or 1000mm high in rocky material. The width of each step should be greater than the cut height. Such stepping usually does not involve the subsequent placement of topsoil, and thus is only done on good, fertile subsoils, and rocky slopes that are not intended to be seeded. • The horizontal surface of each step should slope inwards towards the vertical face.
	• Grooving is generally limited to slopes less than 2:1. • Grooves should be at least 75mm deep, and not more than 400mm apart.
Fill slope steeper than 3:1(H:V)	• On slopes to be vegetated, ensure the face of the fill slope consists of firm, but not hard, fill 100 to 150mm deep; otherwise use grooving as described above. • On non-vegetated slopes (e.g. arid and semi-arid areas) achieve a soil compaction similar to natural slopes in the region.
Cut and fill slopes no steeper than 3:1(H:V)	• Application of shallow grooves/ploughing (along the contour) using normal tilling, discing, harrowing, or other suitable means. • Grooves should be spaced no less than 250mm, and not less than 25mm deep. • On slopes intended to be mown, ensure surface roughening is appropriate for the intended mowing procedures.
Sandy soils no steeper than 2:1(H:V)	• Roughen using tracked machinery (track walking).

(a) Stair-stepping:

Stair-stepping is achieved during the formation of cut slopes. It involves cutting the slope to form a series of steps formed along the contour. Each step slopes inward towards the slope to aid in the capture and pooling of water and seed.

Stair-stepping can be applied to very steep slopes to reduce the risk of topsoil slippage (Photo 6).

Photo 3 – Stair-stepping

Photo 4 – Slippage of topsoil from steep cut batter

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(b) Track walking:

This is achieved by walking a tracked vehicle up and down the slope.

- Generally limited to a maximum 2:1 (H:V) slope.
- Best used on sandy soils that are not likely to compact under the weight of the vehicle.
- When used on some clayey soils, recessed track marks (similar to Photo 5) can be left in the soil resulting in the concentration of stormwater runoff.

Photo 5 – Wheel track marks down a slope potentially causing concentrated runoff

Photo 6 – Rilling down newly vegetated slope cutting through surface roughening

(c) Contour ploughing:

Contour ploughing involves the ripping of mild slopes using a chisel plough or similar tined implement.

- Plough depth of around 200mm is typical, but 300 to 350mm can be achieved with heavy duty tines.
- Typically used to prepare land surfaces prior to revegetation.
- Generally limited to slopes of less than about 10:1 (10% or approximately 6 degrees).

Photo 7 – Contour ploughing

Photo 8 – Contour ploughing

(d) Grooving:

Grooving involves the formation of a series of minor surface grooves aligned with the contour of a slope. These grooves can be formed using disks, tillers, spring harrows, chisel ploughs, scarifiers, rippers, or by attaching a serrated edge to a grader blade (commercially available attachment), the latter being useful when trimming road batters.

Grooves can also be formed by walking modified drum rollers up and down a slope. The drum rollers are modified by welding triangular sections to the drum (known also as "land imprinters").

(e) Contour furrowing:

Contour furrowing involves the construction of a series of small, level channels (furrows) designed to capture and hold rainwater on moderately steep land, thereby reducing runoff and the potential erosion hazard. The distance between the furrows depends on the soil type and slope. Contour furrowing is typically applied to moderately steep grazing land.

- The furrows generally penetrate at least 300mm, spaced 1 to 10m apart. It is usually carried out on hard packed soils to improve water infiltration, or on overburden immediately prior to topsoiling to assist bonding between the two soil layers.
- Contour furrowing should be employed only with extreme caution on dispersive soils. Always seek expert (soil science) advice.

Contour furrowing is generally not considered a part of *surface roughening*, instead it is a land management technique typically used in rural areas.

(f) Contour ripping:

Contour ripping is the formation of 600 to 900mm deep furrows along the contour of slopes. The deep furrows capture and infiltrate stormwater thus making best use of limited rainfall. In semi-arid areas subject to occasional heavy rainfall (e.g. parts of northern Australia), soil saturation following such heavy rain can lead to concentrated runoff down the slope damaging the rip lines, and potentially resulting in high sediment runoff (similar to Photo 6).

- Formed using machinery such as single or multi-tine ripper (600–900mm deep) attached to a heavy tractor or bulldozer.
- Typical ripping with two tines spaced about 1m apart. Each twin-furrow being spaced 2 to 6m apart depending on the slope grade.
- Generally limited to slopes of less than 6:1 (10 degrees).
- Generally limited to a maximum 3:1 (H:V) slope.
- Contour ripping should be employed only with extreme caution on dispersive soils. If soils are dispersive, then contour ripping may increase the erosion risk.

Contour ripping is generally not considered a part of *surface roughening*, instead it is a land management technique typically used in rural areas, and for mine site rehabilitation within arid and semi-arid areas.

Description

The roughening of exposed soil slopes with horizontal groves running across the slope. It is different from 'contour furrowing' and 'contour ripping', which are often used as a land management tools in rural areas.

Surface roughening can be achieved by a number of methods including walking a tracked vehicle up and down the slope.

It can also be produced by attaching a serrated edge to a grader blade (especially when trimming road batters), or by using a chisel plough, scarifier or ripper.

Purpose

Surface roughening can be used on exposed and recently seeded surfaces to:

- increase stormwater infiltration;
- delay the formation of rilling;
- reduce wind-induced soil erosion;
- promote faster seed germination within the dozer cleat marks by trapping and holding small pools of water, as well as seed and fertiliser.
- reduce runoff velocity (up to a given rainfall intensity, beyond which rilling may begin to occur resulting in concentrated, high-velocity flow)

Limitations

Each treatment method is limited to a different maximum bank slope.

Surface roughening produced by dozer track marks is generally best used on sandy soils. On clayey soils there is the risk of soil compaction leading to the formation of minor channel depressions that may concentrate runoff.

Advantages

The benefits of increased slope roughness include:

- increased retention of water on slopes;
- increased water infiltration into the soil;
- reduced runoff volume;
- reduced dust generation.

Inexpensive to implement, but may not be a cost-effective use of heavy machinery on a construction site.

Can improve the stabilisation of topsoil on steep slopes if surface roughening has been applied to the subsoil.

Aids in the establishment of vegetation by allowing water to collect and pool within the cleat marks (track walking).

Disadvantages

Generally of limited value during periods of heavy rainfall.

Questionable benefit on construction sites given the cost and effort of application.

Common Problems

Problems can occur once the soils are saturated and surface runoff begins to move down the slope across the grooves and furrows causing erosion.

Special Requirements

Immediately seed and mulch roughened areas to optimise seed germination and growing conditions.

Existing rutting and gullies should be filled or suitably contoured.

Up-slope runoff should be diverted around treated area if such run-on water is likely to cause erosion.

Seek expert (soil science) advice before deep ripping or furrowing land containing dispersive subsoils.

Site Inspection

Inspect the area for the formation of rill or gully erosion, and where necessary, repeat the surface treatment or improve up-slope drainage control.

Check the furrows/cleat marks are deep enough.

Check the furrows/cleat marks are aligned with the contour.

Application

1. Refer to approved plans for location, extent, and application details. If there are questions or problems with the location, extent, or method of application contact the engineer or responsible on-site officer for assistance.
2. Fill or suitably contour any existing rutting, rilling or gullies.
3. Suitably divert up-slope stormwater runoff around treated area as directed within the approved plans, or otherwise as directed by the site engineer.
4. Apply treatment to the area to the depth and frequency (spacing) specified on the approved plans, or otherwise as directed by the site engineer.
5. Immediately seed and mulch roughened areas to optimise seed germination and growing conditions.

Maintenance

1. During the construction period, inspect the treated area prior to forecast rainfall, daily during extended periods of rainfall, after significant runoff producing rainfall, or otherwise on a weekly basis.
2. Fill erosion rills slightly above the original grade, or regrade the slope as directed to remove the rills.

Type 1 & 2 Sediment Traps – General

SEDIMENT CONTROL TECHNIQUE

Sediment controls can be grouped into four categories based on their ability to trap a specified grain size. The adopted classifications are Type 1, Type 2, Type 3 and 'supplementary' sediment traps. Photos 1 and 2 show examples of Type 1 sediment traps.

Photo 1 – Type C (dry) sediment basin

Photo 2 – Type F (wet) sediment basin

Photos 3 to 6 show examples of Type 2 sediment traps.

Photo 3 – Rock filter dam with geotextile filter

Photo 4 – Rock filter dam with aggregate filter

Photo 5 – Sediment trench (with *rock filter dam* outlet system) located at the base of a fill embankment

Photo 6 – Upstream face of a sediment weir

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Table 1 outlines the typical usage of the various Type 1 and Type 2 sediment control systems.

Table 1 – Typical usage of various Type 1 and Type 2 sediment control techniques

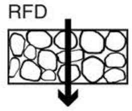
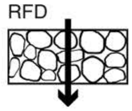
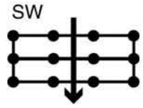
Technique	Code	Symbol	Typical use
Rock Filter Dam: Filter cloth used as the primary filter medium	RFD	RFD 	• Type 2 sediment trap. • Locations where there is sufficient room to construct a relatively large rock embankment. • The incorporation of filter cloth is the preferred construction technique if the removal of fine-grained sediment is critical; however, de-silting and replacement of the fabric can be difficult, and can lead to ongoing poor performance. • Long-term performance benefits from the incorporation of a sediment collection pit.
Rock Filter Dam: Aggregate used as the primary filter medium	RFD	RFD 	• Type 2 sediment trap. • Best used on sandy soils. • Locations where there is sufficient room to construct a relatively large rock embankment. • Aggregate filters are normally used on long-term sediment trap, as well as sediment traps that are likely to be regularly de-silted. • Short-term performance can be impaired if a sediment collection pit is included.
Sediment Basin – Type C	SB	No standard symbol—draw actual basin layout on ESCP	• Type 1 sediment trap. • Best suited to coarse-grained soils. • Used when a major (Type 1) sediment trap is required when working in areas containing coarse-grained, good settling soils.
Sediment Basin – Type F and Type D	SB	No standard symbol—draw actual basin layout on ESCP	• Type 1 sediment trap. • Best suited to fine-grained or dispersive soils. • Best available technique for the control of turbidity within discharged waters. • Used when a major (Type 1) sediment trap is required when working in areas containing fine-grained, dispersive or poor settling soils.
Sediment Trench	SS	SS 	• Type 2 or 3 sediment trap. • Used in long, narrow spaces. • At the base of fill batters where there is limited space between the toe of the batter and the property boundary. • Limited available space often means these traps are only considered a Type 3 system.
Sediment Weir	SW	SW 	• Type 2 sediment trap. • Used where space is limited (i.e. when space is not available for use of a *Rock Filter Dam*). • Used when the sediment trap may be subjected to regular over-topping flows. • Used as a Type 2 drop (field) inlet protection system.

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Table 2 provides guidance on the selection of a sediment control technique for various soil and catchment conditions.

Table 2 – Selection of sediment control technique for minor concentrated flows [1]

	Excavated sediment trap	Filter tube dam	Rock filter dam (geotextile filter)	Rock filter dam (aggregate filter)	Type C (dry) sediment basin	Type F or D (wet) sediment basin	Sediment trench	Sediment weir
Standard drawing code	EST	FTD	RFD	RFD	SB	SB	SS	SW
Typical treatment standard [1]	2/3	2	2	2	1	1	2/3	2
Turbidity control [2]	L	L	M	L	M	H	L	L/M
Catchment area	< 0.25ha				> 0.25ha		< 0.25ha	
Soil properties:								
Sandy soils	✓	✓		✓	✓		✓	✓
Good-settling clayey soils		✓	✓			✓	✓	✓
Fine, slow-settling clay soils						✓		
Dispersive soils						✓		
Flow path geometry:								
Overland flow path		✓					✓	✓
Stormwater inlet		✓						✓
Minor concentrated flow	✓	✓	✓	✓				✓
Large catchment runoff					✓	✓		
Operation life of sediment trap (guide only):								
Less than 3 months	✓	✓	✓	✓	✓	✓	✓	✓
3 to 6 months	✓	[3]	✓	✓	✓	✓	[3]	✓
More than 6 months	✓			✓	✓	✓		✓

[1] Identifies the most likely sediment treatment standard for the technique as Type 1, Type 2 system. "2/3" indicates the system is commonly found operating as either a Type 2 or Type 3 system.

[2] L = low, M = medium, H = high control of turbidity.

[3] Maintenance costs can become excessive in long-term operations unless operating for extended periods during the dry season.

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Sediment Fence

SEDIMENT CONTROL TECHNIQUE

Type 1 System		Sheet Flow	✓	Sandy Soils	✓
Type 2 System		Concentrated Flow	[1]	Clayey Soils	[2]
Type 3 System	✓	Supplementary Trap		Dispersive Soils	

[1] Not recommended in areas of concentrated flow—refer to *U-Shaped Sediment Traps*.

[2] Very limited capture of fine clay particles, but still useful for trapping sand and silt.

Symbol

Photo 1 – Installation of a sediment fence

Photo 2 – Sediment fence located down-slope of multi-dwelling building site

Key Principles

1. Primarily used to collect coarse sediments. Sediment fences have a poor capture rate of the finer sediment particles, thus operators should not expect to see any significant change in the colour or turbidity of water passing through the fence.
2. Treatment is primarily achieved through gravity-induced 'settlement' resulting from the temporarily ponding of sediment-laden water up-slope of the fence. 'Filtration' is only a secondary function of the fabric, if at all.
3. Critical to the effectiveness of a sediment fence is the 'surface area' of the pond that forms up-slope of the fence. Therefore, sediment fences need to be installed such that the total surface area of ponding up-slope of the fence is maximised.
4. Optimum performance can be achieved by installing the fence in a manner that allows water to pond either:
   - uniformly along the fence (i.e. a fence located along a line of constant elevation); or
   - at regular intervals along the fence (i.e. a fence installed at a slight angle to the slope, but with regular 'returns' installed along the length of the fence).
5. Woven and composite fabrics perform slightly different tasks and their selection depends on site conditions.
6. Though often referred to as 'silt fences', a sediment fence is unlikely to trap significant quantities of fine silts (< 0.02mm), thus the term is considered an inappropriate description.
7. A sediment fence in its standard installation is only suitable for the treatment of 'sheet' flows. If concentrated flow exist, such as in a minor drain, then a *U-Shaped Sediment Trap*, or other more appropriate sediment trap should be used.

Design Information

Table 1 provides the recommended **maximum** slope length up-slope of a sediment fence.

Table 1 – Recommended maximum slope length up-slope of a sediment fence on non-vegetated slopes [1]

Batter slope			Horizontal spacing (m)	Vertical spacing (m)
Percentage	Degrees	(H):(V)		
1%	0.57	100:1	60 [2]	0.6 [2]
2%	1.15	50:1	60	1.2
4%	2.29	25:1	40	1.6
6%	3.43	16.7:1	32	1.9
8%	4.57	12.5:1	28	2.2
10%	5.71	10:1	25	2.5
15%	8.53	6.67:1	19	2.9
20%	11.3	5:1	16	3.2
25%	14.0	4:1	14	3.5
30%	16.7	3.33:1	12	3.5
40%	21.8	2.5:1	9	3.5
50%	26.6	2:1	6	3.0

[1] Maximum recommended spacings is based on minimising the risk of rill erosion on low to moderately erodible soil. In areas of highly erodible soil, the slope length may need to be reduced.

[2] Recommended maximum slope length above a sediment fence is 60m.

The maximum slope lengths presented in Table 1 for land slopes steeper than 2% may be represented by Equation 1.

Maximum **horizontal** slope length (m) = $100/(\text{batter slope } (\%))^{0.64}$ (Eqn 1)

The allowable flow rate per meter length of sediment fence should, wherever possible, be determined from actual fabric testing. However, the actual flow rate at any point in time will depend on the degree of sediment blockage of the fabric.

In the absence of testing data, preliminary design flow rates can be obtained from Table 2.

Table 2 – Typical as-new and design flow rates for sediment fence fabric [1]

Depth up-slope of fence (m)	'As new' flow rate (L/s/m)		'Design' flow rate (L/s/m) [2]	
	Woven fabrics	Composite	Woven fabrics	Composite
0.2	2.6	4.8	1.3	2.4
0.4	5.6	10.6	2.8	5.3
0.6	9.0	17.8	4.5	8.9
0.8	12.6	26.2	6.3	13.1

[1] Flow rates are based on simplified test results that may not extrapolate well to actual field conditions.

[2] Suggested 'design' flow rates are based on an assumed 50% sediment blockage of the fabric.

Technical Note:

Australian Standards indicate that the flow rate through geotextiles for a given hydraulic head can be determined by extrapolating the measured flow rate at a hydraulic head of 100mm. Such analysis is **not** appropriate for woven fabrics such as sediment fence fabric. Hydraulic performance must be determined by appropriate physical testing at or above the required hydraulic head.

(a) Choice of fabric

Woven fabrics (Photo 3) are generally preferred on large sites when the service life is expected to extend over several storm events. Composite fabrics (Photo 5) are generally preferred on small soil disturbances such a building sites, or when the sediment fence is the last line of defence prior to the runoff discharging from the site or entering a water body.

Table 3 provides guidance on the selection of the preferred sediment fence fabric.

Table 3 – Preferred use of sediment fabrics

Fabric type	Preferred conditions of use
Woven fabrics	• Large sites when the service life is expected to extend over several storm events. • Up-slope of a Type 1 or Type 2 sediment trap.
Composite non-woven fabrics with a woven backing	• Small soil disturbances such a building sites. • When the sediment fence constitutes the last line of defence up-slope of a water body.

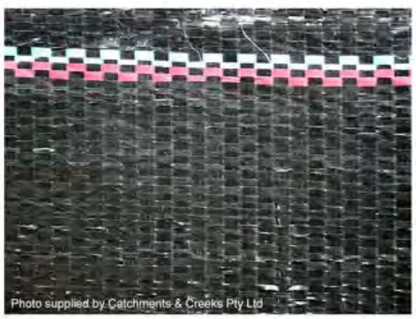

Photo 3 – Traditional woven sediment fence fabric

Photo 4 – Shade cloth MUST NOT be used

Composite fabrics, incorporating a non-woven fabric with woven fabric backing, typically have a higher flow rate (when first installed) due to the additional needle punching required to 'sew' the two fabrics together.

Composite fabrics are installed with the woven fabric as the down-slope face of the fence.

Photo 5 – Composite fabric with the woven (black) backing being the down-slope face of the sediment fence

Photo 6 – Filter cloth MUST NOT be used unless used in the construction of a 'Filter Fence' adjacent to a stockpile

Sediment fence fabric must be manufactured from either woven UV-stabilised polyester or polypropylene fabric, or a non-woven geotextile reinforced with a UV-stabilised polyester or polypropylene mesh.

Table 4 provides the recommended material properties of woven fabrics.

Table 4 – Recommended woven sediment fence material property requirements

Material property	Test method	Units	Typical value
Flow rate	AS 3706.9	$L/s/m^2$ (under 100 mm head)	15
Wide strip tensile strength	AS 3706.2	kN/m	10 both directions
Pore size (EOS) (O_{95})	AS 3706.7	mm x 10^{-3}	< 250
Mass per unit area	AS 3706.1	gsm	90
UV resistance	AS 3706.11	% retained (672 hours)	
Width	–	mm	730–910

Table 5 provides the recommended material properties of composite fabrics.

Table 5 – Recommended composite sediment fence material property requirements

Material property	Test method	Units	Typical value
Flow rate	AS 3706.9	$L/s/m^2$ (under 100 mm head)	145
Wide strip tensile strength	AS 3706.2	kN/m	17 both directions
Pore size (EOS) (O_{95})	AS 3706.7	mm x 10^{-3}	110
Mass per unit area	AS 3706.1	gsm	225
UV resistance	AS 3706.11	% retained (672 hours)	
Width	–	mm	730–910

(b) Location of a sediment fence

Wherever practical, the sediment fence should be installed along the contour, thus maintaining sheet flow conditions across the fence. If located at an angle to the contour, the fence needs to be installed with regular 'returns' to avoid water concentrating along the fence. Even if the fence is located along the contour, the use of regular returns is still recommended (refer to Figure 1).

The maximum spacing of fence 'returns' should be 20m if the fence is installed along the contour, or 5 to 10m (depending on slope) if located at an angle to the contour (Figure 2).

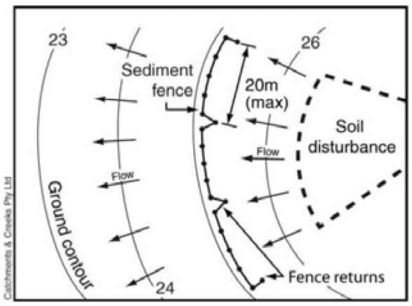

Figure 1 – Fence installed along the contour

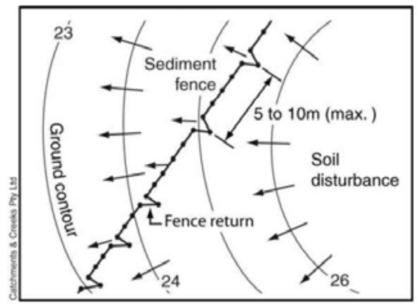

Figure 2 – Fence install down a slope

Wherever practical, allow at least 4.5m between the sediment fence and a single-storey building; 7.5m between the fence and a multiple-storey building; and at least 2m between the fence and the toe of a fill slope or stockpile (Figure 3).

A double sediment fence (Figure 4, Photo 8), or sediment fence with up-slope straw bale (Photo 7) can be used to reduce the risk of shifting fill damaging the fence.

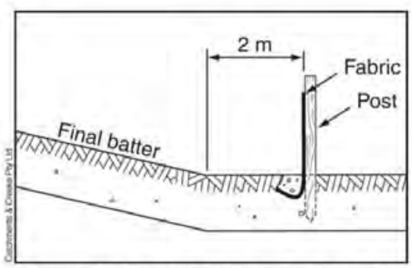

Figure 3 – Fence installation at base of slope

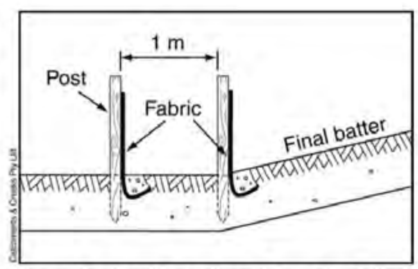

Figure 4 – Double sediment fence installed at the based of a fill slope

Photo 7 – Use of straw bales to prevent direct contact of stockpiles with the fence

Photo 8 – Double sediment fence

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(c) Installation of a sediment fence

At least 300mm of fabric must be buried in either a 200mm trench (Figure 8, Photo 13), or under a continuous 100mm high layer of sand or aggregate (Photo 15), but **not** earth.

Straw bales can be placed up-slope of the fence (Figure 9) to retain settled sediment away from the fabric, thus improving the ease of ongoing maintenance (i.e. sediment removal). Alternatively, a small trench can be formed along the contour, up-slope of the fence.

Both ends of the fence should be turned up the slope to minimise the risk of flow bypassing around the ends of the fence (Figure 5, Photo 21).

Support posts should be spaced no greater than 3m if the fence is supported by a top support wire or weir mesh backing (Figure 7), otherwise no greater than 2m (Figure 6). The recommended maximum spacing of support posts is summarised in Table 6.

Table 6 – Maximum spacing of support post

Maximum post spacing	Installation condition
2m	No support wire or backing mesh.
3m	Support weir attached along top of the fabric at 1m intervals. Wire mesh or PVC safety mesh backing.

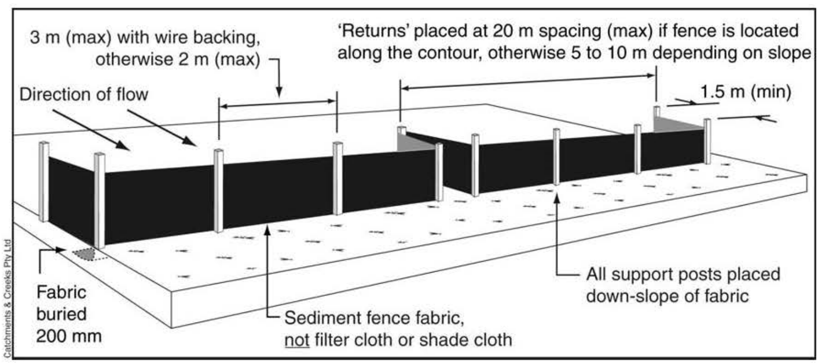

Figure 5 – Typical installation of a sediment fence

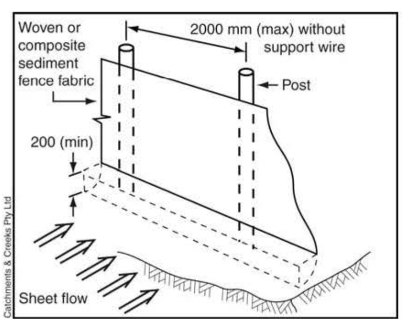

Figure 6 – Installation of a sediment fence without wire backing

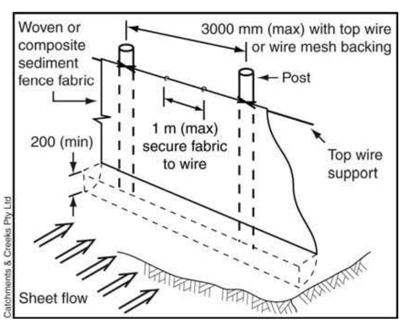

Figure 7 – Installation of a sediment fence with top wire support

Wherever possible, construct the sediment fence from a continuous roll. To join fabric either attach each end to individual stakes (Figure 10), holding the stakes together, rotate the stakes 180 degrees, then drive the two stakes into the ground; or overlap the fabric to the next support post (Figure 11).

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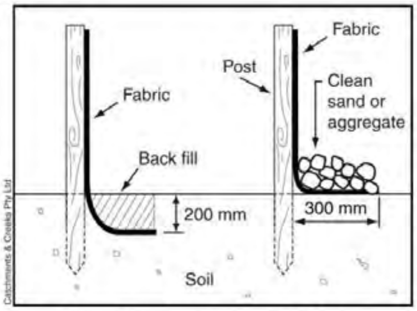

Figure 8 – Anchoring the fabric

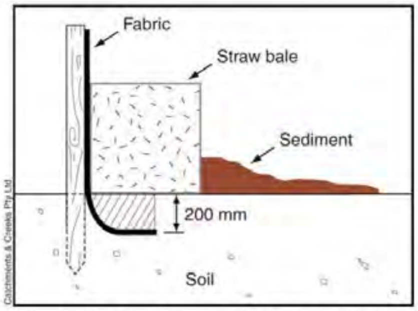

Figure 9 – Use of straw bales as a fabric-sediment separator

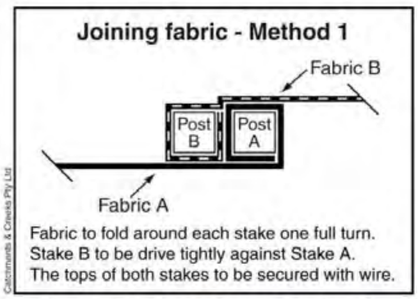

Figure 10 – Joining fabric (Option 1)

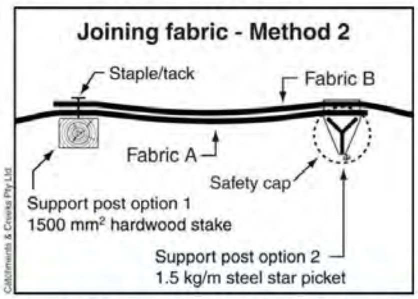

Figure 11 – Overlapping fabric (Option 2)

Photo 9 – Sediment fence placed along the contour

Photo 10 – Use of fence 'returns'

Photo 11 – Placement of fence off the contour with regular fence 'returns'

Photo 12 – Alternative design of a fence 'return'

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Photo 13 – Trenching the fabric

Photo 14 – Inappropriate installation

Photo 15 – Bottom of fabric buried under aggregate

Photo 16 – Inappropriate use of sand to bury the fabric

Photo 17 – Straw bales placed up-slope of fence to separate sediment and fabric

Photo 18 – Inappropriate installation of the posts up-slope of the fabric

Photo 19 – Inappropriate junction

Photo 20 – Gaps in fence are not allowed

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Photo 21 – Installation without backing weir/mesh

Photo 22 – Installation with top wire support

Photo 23 – Installation with weir mesh

Photo 24 – Installation using fence support

Photo 25 – Installation with safety fencing used as support

Photo 26 – A sediment fence braced for possible high flows

Photo 27 – Example of tacking

Photo 28 – Safety cap on a steel stake

Photo 29 – Flow diversion by fence

Photo 30 – No end return

Photo 31 – Damage by shifting fill

Photo 32 – Fence placed too close to fill

Photo 33 – Evidence of hydraulic wash-out under fence caused by poor trenching

Photo 34 – Sediment not removed after storm

Photo 35 – Flow allowed to bypass the fence

Photo 36 – Spill-through weirs must not discharge onto unstable land

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(d) Use of spill-through weirs

Where appropriate, spill-through weirs can be installed into the fence to reduce hydraulic pressure and reduce the risk of hydraulic failure.

The required width (W) of the spill-through weir depends on the nominated design flow rate. The weir flow equation for a rectangular spill-through weir is provided below as Equation 2, as well as tabulated in Table 7.

$$Q = 1.7\,W\,H^{3/2} \quad \text{(Eqn 2)}$$

where: Q = Design flow rate (usually 0.5 times the 1 in 1 year ARI peak discharge) [m^3/s]
W = Weir width [m]
H = Hydraulic head = height of upstream water level above weir crest [m]

Table 7 – Flow rates passing over a spill-through weir (m^3/s)

Hydraulic head, H (m)	Spill-through weir width, W (m)									
	0.3	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**
0.10	0.016	0.027	0.054	0.081	0.108	0.134	0.161	0.188	0.215	0.242
0.15	0.030	0.049	0.099	0.148	0.198	0.247	0.296	0.346	0.395	0.444
0.20	0.046	0.076	0.152	0.228	0.304	0.380	0.456	0.532	0.608	0.684
0.25	0.064	0.106	0.213	0.319	0.425	0.531	0.638	0.744	0.850	0.956
0.30	0.084	0.140	0.279	0.419	0.559	0.698	0.838	0.978	1.12	1.26
0.35	0.106	0.176	0.352	0.528	0.704	0.880	1.06	1.23	1.41	1.58
0.40	0.129	0.215	0.430	0.645	0.860	1.08	1.29	1.51	1.72	1.94

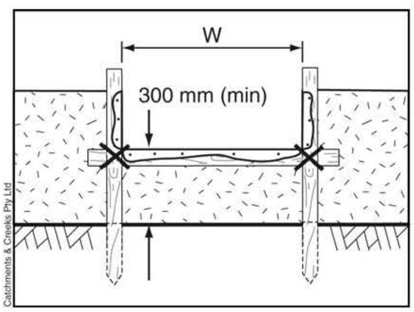

Figure 12 – Spill-through weir profile

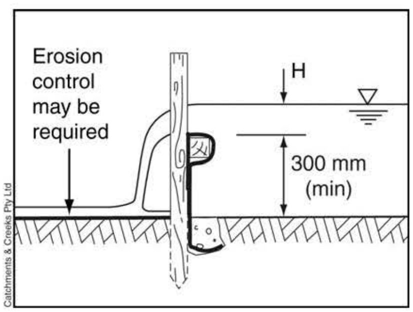

Figure 13 – Side profile of a spill-through weir

Photo 37 – Spill-through weir (down-slope side) with rock splash pad

Photo 38 – Spill-through weir with outlet chute

Photo 39 – Spill-through weir with up-slope aggregate filter

Photo 40 – Inappropriate placement of fence and installation of spill-through weir

If large sediment flows are expected, then a *Coarse Sediment Trap* can be used as an outlet structure for a sediment fence as shown in Figure 14. However, in most circumstances, a more elaborate outlet system would be required such as a Type 1 or Type 2 sediment trap.

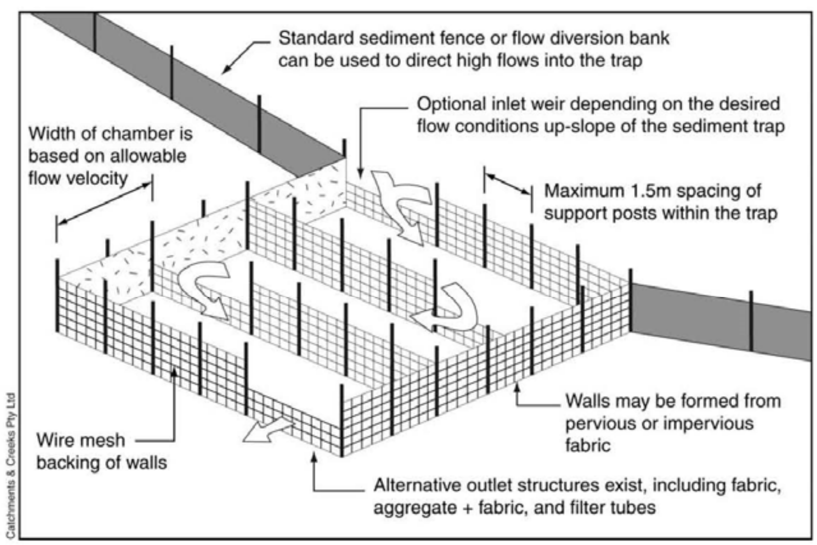

Figure 14 – Coarse sediment trap outlet structure

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Description

A sediment fence consists of specially manufactured woven fabric attached to support posts. The typical height of the fence is around 600 to 700mm.

Most sediment fences are self-supporting; however, in appropriate circumstances the fence may be attached to an existing porous structure such as a property fence.

The fabric may be manufactured from either woven fabric, or a composite of woven and non-woven fabrics. The incorporation of a woven fabric is essential for the control of water flow needed to allow adequate temporary ponding up-slope of the fence.

Purpose

Used as a Type 3 sediment trap on small catchments, or as a supplement to Type 1 or 2 sediment traps on large catchments.

Limitations

Though often referred to as a 'silt fence', these Type 3 sediment traps have little impact on fine silts (< 0.02mm).

A sediment fence in its standard installation is only suitable for the treatment of 'sheet' flows. If concentrated flow exist, such as in a minor drain, then a *U-Shaped Sediment Trap*, or other more appropriate sediment trap should be used.

Most fabrics have an effective service life of around 6 months (check with manufacturer or distributor).

Advantages

Reasonably easy to install.

Has the ability to control sediment runoff close to the source of the erosion.

Disadvantages

Time-consuming to install, which often results in poor installation.

Easily damaged by construction equipment and shifting earth (Photos 31 & 32).

Can cause the concentration of stormwater runoff if poorly located, or installed.

Sediment fences are one of the most missed used sediment control devices, usually because they are either not installed in appropriate locations, or are installed in a manner that does not allow adequately water ponding up-slope of the fences.

Common Problems

If not installed along the contour, a sediment fence can result in flows being deflected along the fence (Photo 29).

If the ends of the fence are not turned up the slope, water and sediment can pass around the end of the fence (Photo 30).

If gaps exist in the fence (Photos 19 & 20), then water is prevented from ponding up-slope of the fence, thus sedimentation does not occur.

Excessive spacing between support posts is a common problem. In extreme cases this can result in the fabric sagging close to the ground.

Fabric not adequately connected to the support posts or backing wire.

The bottom of the fabric not adequately buried into the ground or under a suitable layer of sand or aggregate. If such fences are subjected to significant storms, the bottom of the fence can 'blow-out' causing erosion down-slope of the fence (Photo 33).

Spill-through weirs may not have been installed in large catchments or areas of high rainfall, thus increasing the risk of flow damage to the fence.

Crest of spill-through weir set too close to the ground (should be at least 300mm above ground level).

Crest of spill-through weir is set above the ground level at the ends of the fence, thus allowing flow bypassing rather than discharge over the weir (Photo 40).

Special Requirements

Woven fabrics are generally preferred on large sites when the service life is expected to extend over several storm events. Composite fabrics are generally preferred on small soil disturbances such a building sites, or when the sediment fence is the last line of defence prior to the runoff entering a water body.

Ideally, the sediment fence should be installed along the contour, thus maintaining sheet flow conditions across fence. If located across the contour, the fence should be installed with regular 'returns' to avoid water concentrating along the fence.

At least 300mm of fabric must be buried in either a 200mm trench, or under a continuous, 100mm high layer of sand or aggregate, but not earth.

Straw bales can be placed up-slope of the fence to retain bulk sediment away from the fabric, thus improving the ease of sediment removal. Alternatively, a small trench can be formed along the contour, up-slope of the fence. However, in all cases the aim should be to minimise high sediment flows so that such fence modifications become the exception, not the rule!

Where appropriate, spill-through weirs can be installed into the fence to reduce hydraulic pressure and reduce the risk of hydraulic failure.

Location

Install along the contour wherever possible.

Allow at least 4.5m between the fence and single-story buildings; 7.5m between the fence and multiple-story buildings; and at least 2m between the fence and the toe of a fill slope or stockpile.

Site Inspection

Ensure the sediment fence will adequately pond water up-slope of the fence.

Ensure the fabric is adequately buried.

Check the spacing of support posts/stakes.

Check for excessive sediment deposition.

Investigate the source of excessive sediment deposits.

Ensure the selection of appropriate fabric (i.e. woven or composite).

Check for damage to the fabric.

Check for erosion down-slope of any spill-through weirs.

Ensure the fence is not concentrating or diverting flows in an undesirable manner.

Materials

- Fabric: polypropylene, polyamide, nylon, polyester, or polyethylene woven or non-woven fabric, at least 700mm in width and a minimum unit weight of 140GSM. All fabrics to contain ultraviolet inhibitors and stabilisers to provide a minimum of 6 months of useable construction life (ultraviolet stability exceeding 70%).
- Fabric reinforcement: wire or steel mesh minimum 14-gauge with a maximum mesh spacing of 200mm.
- Support posts/stakes: 1500mm^2 (min) hardwood, 2500mm^2 (min) softwood, or 1.5kg/m (min) steel star pickets suitable for attaching fabric.

Installation

1. Refer to approved plans for location, extent, and required type of fabric (if specified). If there are questions or problems with the location, extent, fabric type, or method of installation contact the engineer or responsible on-site officer for assistance.
2. To the maximum degree practical, and where the plans allow, ensure the fence is located:
   (i) totally within the property boundaries;
   (ii) along a line of constant elevation wherever practical;
   (iii) at least 2m from the toe of any filling operations that may result in shifting soil/fill damaging the fence.
3. Install returns within the fence at maximum 20m intervals if the fence is installed along the contour, or 5 to 10m maximum spacing (depending on slope) if the fence is installed at an angle to the contour. The 'returns' shall consist of either:
   (i) V-shaped section extending at least 1.5m up the slope; or
   (ii) sandbag or rock/aggregate check dam a minimum 1/3 and maximum 1/2 fence height, and extending at least 1.5m up the slope.
4. Ensure the extreme ends of the fence are turned up the slope at least 1.5m, or as necessary, to minimise water bypassing around the fence.
5. Ensure the sediment fence is installed in a manner that avoids the concentration of flow along the fence, and the undesirable discharge of water around the ends of the fence.
6. If the sediment fence is to be installed along the edge of existing trees, ensure care is taken to protect the trees and their root systems during installation of the fence. Do not attach the fabric to the trees.
7. Unless directed by the site supervisor or the approved plans, excavate a 200mm wide by 200mm deep trench along the proposed fence line, placing the excavated material on the up-slope side of the trench.

8. Along the lower side of the trench, appropriately secure the stakes into the ground spaced no greater than 3m if supported by a top support wire or weir mesh backing, otherwise no greater than 2m.
9. If specified, securely attach the support wire or mesh to the up-slope side of the stakes with the mesh extending at least 200mm into the excavated trench. Ensure the mesh and fabric is attached to the up-slope side of the stakes even when directing a fence around a corner or sharp change-of-direction.
10. Wherever possible, construct the sediment fence from a continuous roll of fabric. To join fabric either:
    (i) attach each end to two overlapping stakes with the fabric folding around the associated stake one turn, and with the two stakes tied together with wire (Method 1); or
    (ii) overlap the fabric to the next adjacent support post (Method 2).
11. Securely attach the fabric to the support posts using 25 x 12.5mm staples, or tie wire at maximum 150mm spacing.
12. Securely attach the fabric to the support wire/mesh (if any) at a maximum spacing of 1m.
13. Ensure the completed sediment fence is at least 450mm, but not more than 700mm high. If a spill-though weir is installed, ensure the crest of the weir is at least 300mm above ground level.
14. Backfill the trench and tamp the fill to firmly anchor the bottom of the fabric and mesh to prevent water from flowing under the fence.
15. If it is not possible to anchor the fabric in an excavated trench, then use a continuous layer of sand or aggregate to hold the fabric firmly on the ground.

Additional requirements for the installation of a spill-through weir

1. Locate the spill-through weir such that the weir crest will be lower than the ground level at each end of the fence.
2. Ensure the crest of the spill-through weir is at least 300mm the ground elevation.
3. Securely tie a horizontal cross member (weir) to the support posts/stakes each side of the weir. Cut the fabric down the side of each post and fold the fabric over the cross member and appropriately secure the fabric.
4. Install a suitable splash pad and/or chute immediately down-slope of the spill-through weir to control soil erosion and appropriately discharge the concentrated flow passing over the weir.

Maintenance

1. Inspect the sediment fence at least weekly and after any significant rain. Make necessary repairs immediately.
2. Repair any torn sections with a continuous piece of fabric from post to post.
3. When making repairs, always restore the system to its original configuration unless an amended layout is required or specified.
4. If the fence is sagging between stakes, install additional support posts.
5. Remove accumulated sediment if the sediment deposit exceeds a depth of 1/3 the height of the fence.
6. Dispose of sediment in a suitable manner that will not cause an erosion or pollution hazard.
7. Replace the fabric if the service life of the existing fabric exceeds 6-months.

Removal

1. When disturbed areas up-slope of the sediment fence are sufficiently stabilised to restrain erosion, the fence must be removed.
2. Remove materials and collected sediment and dispose of in a suitable manner that will not cause an erosion or pollution hazard.
3. Rehabilitate/revegetate the disturbed ground as necessary to minimise the erosion hazard.

Sediment Basins

SEDIMENT CONTROL TECHNIQUE

Type 1 System	✓	Sheet Flow		Sandy Soils	✓
Type 2 System		Concentrated Flow	✓	Clayey Soils	✓
Type 3 System		Supplementary Trap		Dispersive Soils	[1]

[1] Settlement of dispersive soils may be achieved through the flocculation of 'wet' sediment basins.

Symbol

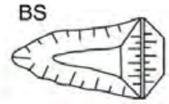

Photo 1 – Example of a 'dry' (Type C) sediment basin

Photo 2 – Example of a 'wet' (Type F/D) sediment basin

Key Principles

1. Sediment trapping can be achieved by both particle settlement within the settling pond (all basin types), and by the filtration of minor flows passing through the aggregate or geotextile filter (dry basins).
2. For continuous flow basins (i.e. dry basins) the critical design parameter for optimising particle settlement is the 'surface area' of the settling pond. For plug flow basins (i.e. wet basins) the critical design parameter is the 'volume' of the settling pond.
3. The critical design parameter for the filtration process (dry basins) is the design flow rate for water passing through the filter, which is related to the depth of water (hydraulic head), and the surface area and flow resistance of the filter.
4. Even if a basin is full of water, it can still be effective in the removal of coarse sediment from any flows passing through the basin. Therefore, unlike permanent stormwater settling ponds, high flows resulting from storms in excess of the 'design storm' should **not** be bypassed around a construction site sediment basin.

Design Information

This fact sheet summaries design requirements for three types of temporary sediment basins, Type C for coarse-grained soils, Type F for fine-grained soils, and Type D for dispersive soils. Detailed design procedures are provided in Appendix B of the IECA (Australasia) "Best Practice Erosion and Sediment Control" document.

Sediment basins should be designed and operated in a manner that produces near clear-water discharges (i.e. total suspended solids concentrations not exceeding 50mg/L) during non-overtopping events, especially following periods of light rainfall.

Summary of design requirements

Table 1 provides a summary of the recommended design requirements.

Table 1 – Summary of sediment basin design requirements

Parameter	Type C basin	Type F & D basins
Soil characteristic	Less than 33% of soil finer than 0.02mm and no more than 10% of soil dispersive.	**Type F:** More than 33% of soil finer than 0.02mm. **Type D:** More than 10% of soil dispersive, or where turbidity control is essential.
Settling pond sizing, surface area (A_s), or settling volume (V_s)	$A_s = 3400\ H_e\ (Q)$ Q = 0.5 times 1 in 1yr flow	$V_s = 10\ R_{(Y\%,\ 5\text{-day})}\ C_V\ A$
Length to width ratio	Hydraulic efficiency factor (H_e) is reduce with increasing length to width ratio	L:W of 3:1 is highly desirable
Minimum depth of settling zone	0.6m	0.6m
Sediment storage volume	100% of settling volume	50% of settling volume
Use of inlet chamber	Desirable if length to width ratio is less than 3:1, or if inflow is concentrated with high flow velocity.	
Internal baffles	Desirable if length to width ratio is less than 3:1	
Use of outlet chamber	Essential if skimmer pipe outlet system is employed	Use depends on type of outlet system adopted
Control inflow conditions	Used to control erosion at inlets and, where practicable, ensure the inflow pipe invert is above the spillway crest elevation.	
Pre-treatment pond	Used to reduce the cost and frequency of de-silting operations.	
Primary outlet	Ensure choice of outlet system is compatible with basin type.	
Emergency spillway minimum design capacity	Less and 3 month design life: capacity of 1 in 10 year ARI. 3 to 12 months design life: capacity of 1 in 20 year ARI. Greater than 12 months design life: capacity of 1 in 50 yr ARI.	
Elevation from top of riser pipe outlet to spillway crest	300mm (min)	N/A
Freeboard from maximum pond water level to top of virgin soil bank	150mm (min)	150mm (min)
Freeboard from maximum pond water level to top of fill embankment	300mm (min)	300mm (min)
Minimum freeboard along spillway chute	300mm (min)	300mm (min)
Minimum embankment crest width	2.5m	2.5m
Maximum gradient of access ramp	6:1	6:1
Chemical flocculation	As required to satisfy water quality objectives.	**Type F:** As required to satisfy water quality objectives. **Type D:** Essential

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Design procedure:

Step 1 – Assess the need for a sediment basin

Sediment basins are recommended for any sub-catchment with a catchment area exceeding 2500m^2 and an estimated soil loss rate that exceeds the equivalent of 150t/ha/yr.

Step 2 – Selection of the required type of basin

Selection of the type of sediment basin is governed by the site's soil properties as outlined in Table 2.

Table 2 – Selection of basin type

Soil and/or catchment conditions [1]	Basin type
Less than 33% of soil finer than 0.02mm (i.e. $d_{33} > 0.02$mm) and no more than 10% of soil dispersive. [2]	Type C basin
More than 33% of soil finer than 0.02mm (i.e. $d_{33} < 0.02$mm) and no more than 10% of soil dispersive. [2]	Type F basin
More than 10% of soil dispersive [2], or when a Stormwater Management Plan (SMP), or adopted Water Quality Objectives (WQOs) specify strict controls on turbidity levels and/or suspended solids concentrations for discharged waters.	Type D basin

[1] If more than one soil type exists on the site, then the most stringent criterion applies (i.e. Type D supersedes Type F, which itself supersedes Type C).

[2] The percentage of soil that is dispersive is measured as the combined decimal fraction of clay (<0.002mm) plus half the percentage of silt (0.002–0.02mm), multiplied by the dispersion percentage.

Step 3 – Determine the basin location

Sediment basins should be located within a sub-catchment so as to maximise its overall sediment trapping capabilities of that sub-catchment. Issues that need to be given appropriate consideration include:

- Locate all basins within the relevant property boundary.
- Locate sediment basins above the 1 in 5 year ARI flood level. Where this is not practicable, then all reasonable efforts should be taken to maximise the flood immunity of the basin.
- Avoid locating a basin in an area where adjacent construction works may limit the operational life of the basin.
- Ensure basins have suitable access for maintenance and de-silting.

Step 4 – Diversion of 'clean' water around a basin

Up-slope 'clean' water should be diverted around the sediment basin to decrease the size and cost of the basin and increase its efficiency. The adopted flow diversion systems may need to be modified for each stage of construction as new areas of land are first disturbed, then stabilised.

'Clean' water is defined as water that has not been contaminated within the property, or by activities directly associated with the construction/building works.

Step 5a – Sizing of the settling pond, Type C basins

The settling pond within a Type C sediment basin is divided (horizontally) into two zones: the upper *settling zone* and the lower *sediment storage zone* as shown in Figure 1.

The minimum volume of the upper settling zone is defined by Equation 1.

$$A_s = 3400\, H_e\, (Q) \qquad \text{(Eqn 1)}$$

where:
- A_s = Surface area of settling pond at the base of the settling zone [m^2]
- H_e = Hydraulic efficiency correction factor
- Q = design flow rate [m^3/s]

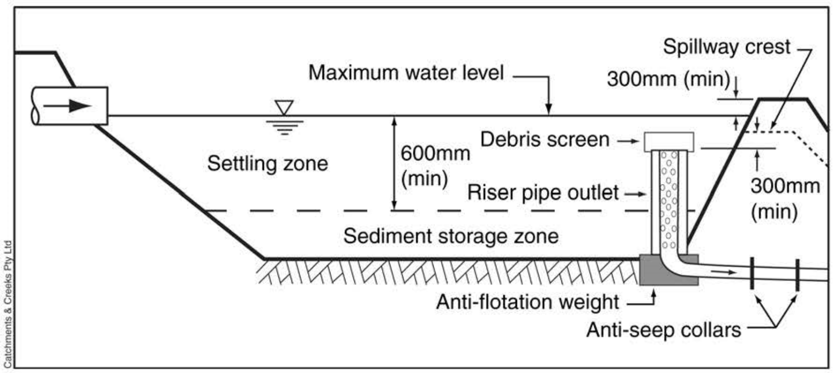

Figure 1 – Type C *Sediment Basin* with riser pipe outlet (long section)

Unless otherwise required by a regulatory authority, the design flow rate (Q) for a Type C sediment basin must be 0.5 times the peak discharge for the 1 in 1 year ARI storm.

The minimum recommended depth of the settling zone is 0.6m, or L/200 for basins longer than 120m (where L = effective basin length). Settling zone depths greater than 1m should be avoided if settlement velocities are expected to be slow.

The desirable minimum length to width ratio of 3:1, otherwise internal baffles need to be used wherever practicable to prevent short-circuiting of flows.

The hydraulic efficiency correction factor (H_e) depends on flow conditions entering the basin and the shape of the settling pond. Table 3 provides recommended values of the hydraulic efficiency correction factor.

Where available space does not permit construction of the ideal sediment basin, then a smaller basin may be used; however, erosion control and site rehabilitation standards need to be appropriately increased to a higher standard to compensate.

A Type C sediment basin that is less than the ideal size should be considered either a Type 2 or Type 3 sediment trap based on the effective particle settlement capabilities.

Table 3 – Hydraulic efficiency correction factor (H_e)

Flow condition within basin	Effective [1] length:width	H_e
Uniform or near-uniform flow conditions across the full width of basin. [2] For basins with concentrated inflow, uniform flow conditions may be achieved through the use of an appropriate inlet chamber arrangement.	1:1	1.2
	3:1	1.0
Concentrated inflow (piped or overland flow) primarily at one inflow point and no inlet chamber to evenly distribute flow across the full width of the basin.	1:1	1.5
	3:1	1.2
	6:1	1.1
	10:1	1.0
Concentrated inflow with two or more separate inflow points and no inlet chamber to evenly distribute flow across the full width of the basin.	1:1	1.2
	3:1	1.1

[1] The effective length to width ratio for sediment basins with internal baffles is measured along the centreline of the dominant flow path.

[2] Uniform flow conditions may also be achieved in a variety of ways including through the use of an inlet chamber and internal flow control baffles.

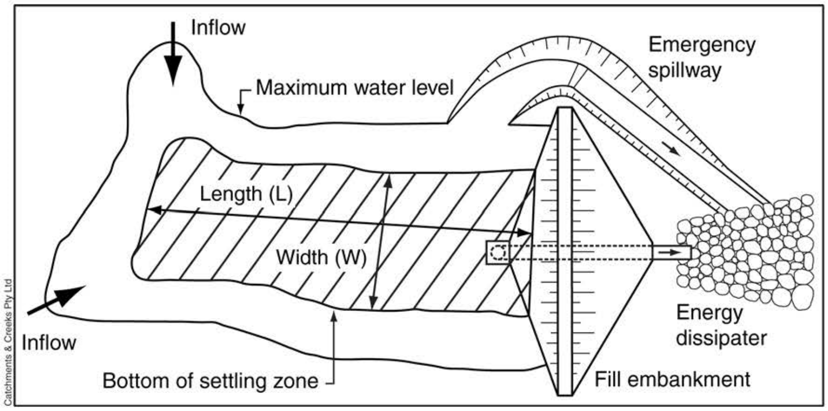

Figure 2 – Type C sediment basin with riser pipe outlet (plan view)

Step 5b – Sizing of the settling pond, Type F & D basins

The settling pond within a Type F or Type D sediment basin is divided (horizontally) into two zones: the upper *settling zone* and the lower *sediment storage zone* as shown in Figure 3.

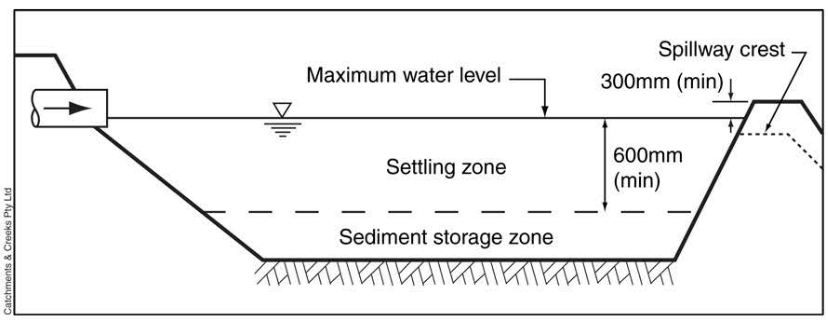

Figure 3 – Settling zone and sediment storage zone

The minimum volume of the upper settling zone is defined by Equation 2.

$$V_S = 10.\ R_{(Y\%,5\text{-day})}\ .\ C_V\ .\ A \qquad \text{(Eqn 2)}$$

where: V_S = volume of the settling zone [m^3]

$R_{(Y\%,5\text{-day})}$ = Y%, 5-day rainfall depth [mm]

C_V = volumetric runoff coefficient

A = effective catchment surface area connected to the basin [ha]

The regulatory authority should provide the required design rainfall probability (Y%) and rainfall depth (R) for a given location.

The minimum recommended depth of the settling zone is 0.6m, or L/200 for basins longer than 120m (where L = effective basin length). Settling zone depths greater than 1m should be avoided if settlement velocities are expected to be slow.

The desirable minimum length to width ratio of 3:1 is recommended for Type F and Type D basins. The length to width ratio is important for Type F and Type D basins because they operate as continuous-flow settling ponds (as per Type C basins) once flow begins to discharge over the emergency spillway.

Step 6 – Determination of sediment storage volume

The sediment storage zone lies below the settling zone as defined in Figure 4. The recommended sediment storage volume can be determined from Table 4.

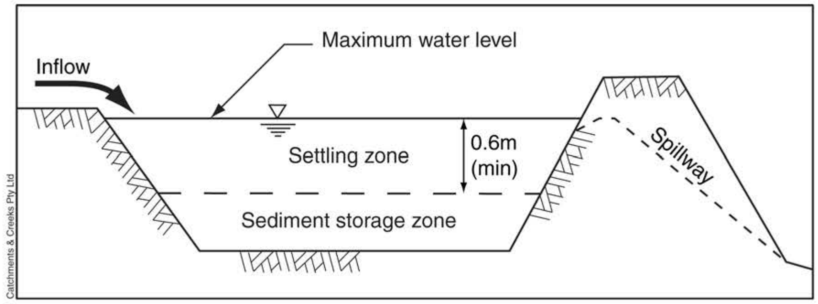

Figure 4 – Settling zone and sediment storage zone

Table 4 – Sediment storage volume

Basin type	Sediment storage volume
Type C	100% of settling volume
Type F and Type D	50% of settling volume

Alternatively, the volume of the sediment storage zone can be determined by estimating the expected sediment runoff volumes over the desired maintenance period, typically not less than 2 months.

Step 7 – Select internal and external bank gradients

Recommended bank gradients are provided in Table 5.

Table 5 – Suggested bank slopes

Slope (H:V)	Bank/soil description
2:1	Good, erosion-resistant clay or clay-loam soils
3:1	Sandy-loam soil
4:1	Sandy soils
5:1	Unfenced Sediment Basins accessible to the public
6:1	Mowable, grassed banks.

All earth embankments in excess of 1m in height should be certified by a geotechnical engineer/specialist as being structurally sound for the required design criteria and anticipated period of operation.

If public safety is a concern, and the basin is not to be fenced (not recommended), and the basin's internal banks are steeper than 5:1(H:V), then at least one bank should be turfed a width of at least 2m from top of bank to the toe of bank to allow egress during wet weather.

Step 8 – Design of flow control baffles

Baffles may be used for a variety of purposes including:

- energy dissipation (inlet chambers);
- the control of short-circuiting (internal baffles);
- minimising sediment blockage of the low-flow outlet structure (outlet chambers).

The need for flow control baffles should have been established in Step 5a based on the basin's length to width ratio. Both inlet baffles (inlet chambers) and internal baffles can be used to improve the hydraulic efficiency of the basin, and thus reduce the size of the settling pond through modification of the hydraulic efficiency correction factor.

(a) Inlet chambers

Flow control baffles or similar devices may be placed at the inlet end of a sediment basin to form an inlet chamber (Figures 5 & 6). These chambers are used to reduce the adverse effects of inlet jetting caused by concentrated, point source inflows. The objective of the inlet chamber is to produce near-uniform flow conditions across the full width of the settling pond.

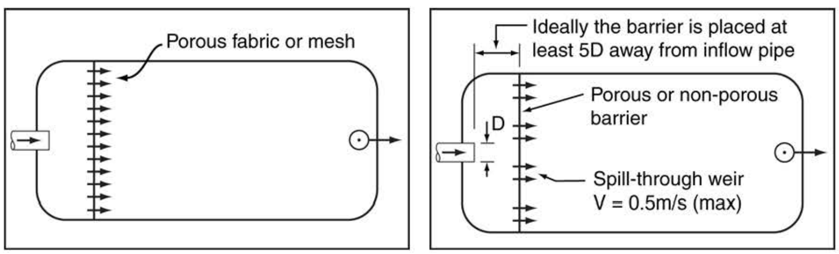

Figure 5(a) – Porous barrier inlet chamber

Figure 6(a) – Alternative inlet chamber design

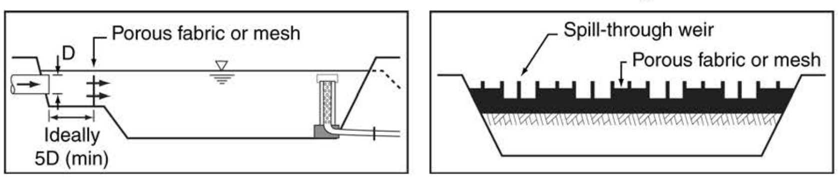

Figure 5(b) – Typical layout of inlet chamber with opposing inlet pipe (Type C basin)

Figure 6(b) – Barrier with multiple spill-through weirs

The use of an inlet chamber is usually governed by the need to adopt a low hydraulic efficiency correction factor (H_e) in Step 5a. The incorporation of inlet baffles should be given serious consideration within Type C basins if the expected velocity of any concentrated inflows exceeds 1m/s.

Table 6 summaries the design of various inlet chambers.

Table 6 – Design of various inlet chambers

Baffle type	Discussion
Shade cloth	Typical spacing between support posts is 0.5 to 1.0m.
Perforated fabric	Heavy-duty plastic sheeting or woven fabric perforated with approximately 50mm diameter holes at approximately 300mm centres. Typical spacing between support posts is 0.5 to 1.0m.
Barrier with spill-through weirs	A porous or non-porous barrier constructed across the full width of the settling pond.

(b) Internal baffles

Internal baffles are used to increase the effective length-to-width ratio of the basin. Figure 7 demonstrates the arrangement of internal flow control baffles for various settling pond layouts.

If internal baffles are used, then the flow velocity within the settling pond must not exceed the sediment scour velocity of 0.2m/s for 0.02 to 0.10mm critical particle diameters respectively.

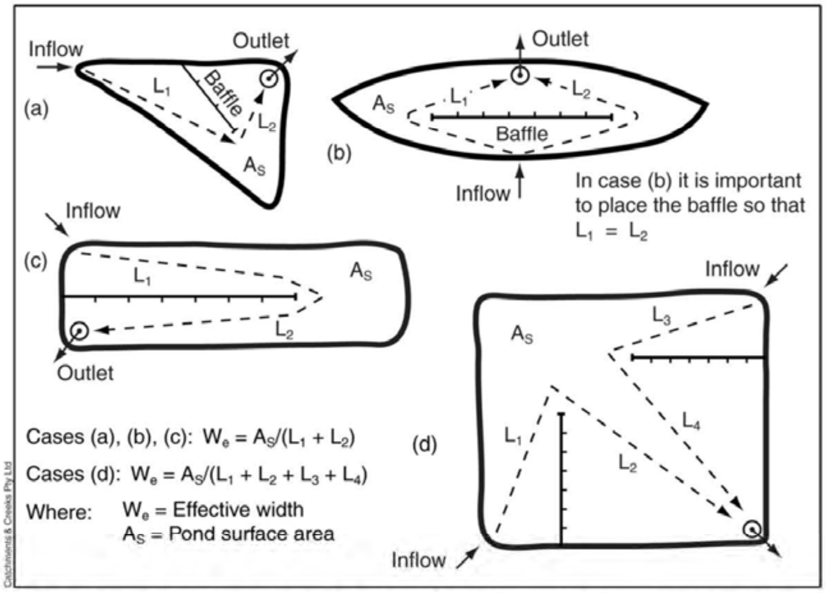

Figure 7 – Typical arrangement of internal flow control baffles (after USDA, 1975)

The crest of these baffles should be set level with, or just below, the crest of the emergency spillway. This is to prevent the re-suspension of settled sediment during severe storms (i.e. flows in excess of the basin's design storm should be allowed to overtop these baffles).

Photo 3 – Inlet chamber can also act as mixing chambers for the addition of flocculants

Photo 4 – Internal baffle extending the flow path between the basin inlet (left) and the basin outlet (right)

(c) Outlet chambers

Outlet chambers (Figures 8 & 9) are used to keep the bulk of the settled sediment away from certain low-flow outlet systems, particularly riser pipe outlets and flexible skimmer pipe outlets.

The use of an outlet chamber is mandatory when a flexible skimmer pipe outlet system is employed (Photo 6).

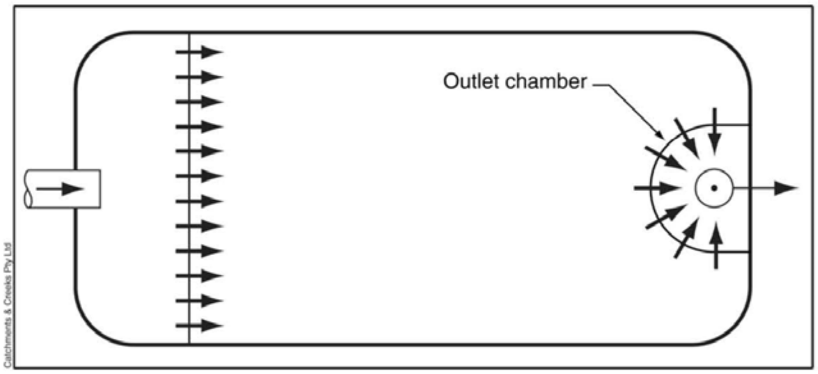

Figure 8 – Typical arrangement of outlet chamber (plan view)

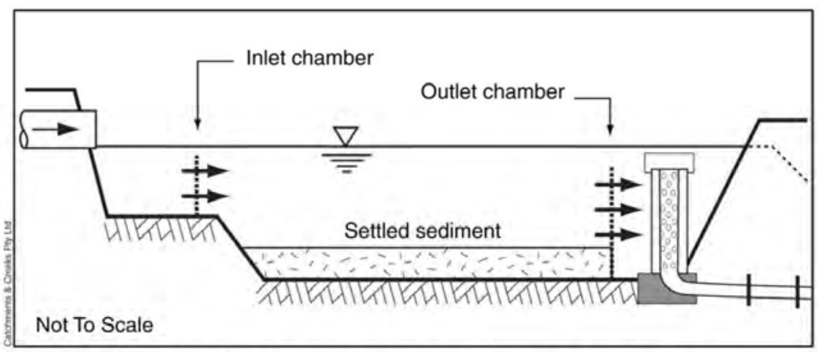

Figure 9 – Typical arrangement of outlet chamber (long section)

Photo 5 – Outlet chamber

Photo 6 – Outlet chamber surrounding a flexible skimmer outlet device

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Step 9 – Design of the basin's inflow system

Surface flow entering the basin should not cause erosion down the banks of the basin. If concentrated surface flow enters the basin (e.g. via a *Catch Drain*), then an appropriately lined *Chute* (Photo 7) will need to be installed at each inflow point to control scour.

If flow enters the basin through pipes, then wherever practicable, the pipe invert should be above the spillway crest elevation to reduce the risk of sedimentation within the pipe. Submerged inflow pipes must be inspected and de-silted (as required) after each inflow event.

Constructing an appropriately designed pre-treatment pond or inlet chamber (Step 8) can be used to both improve the hydraulic efficiency of the settling pond, and reduce the cost and frequency of de-silting the main settling pond.

Where space is available, the construction of an inlet (pre-treatment) pond (Figure 10) or inlet chamber (Step 8) can significantly reduce the cost of regular de-silting activities for large and/or long-term basins.

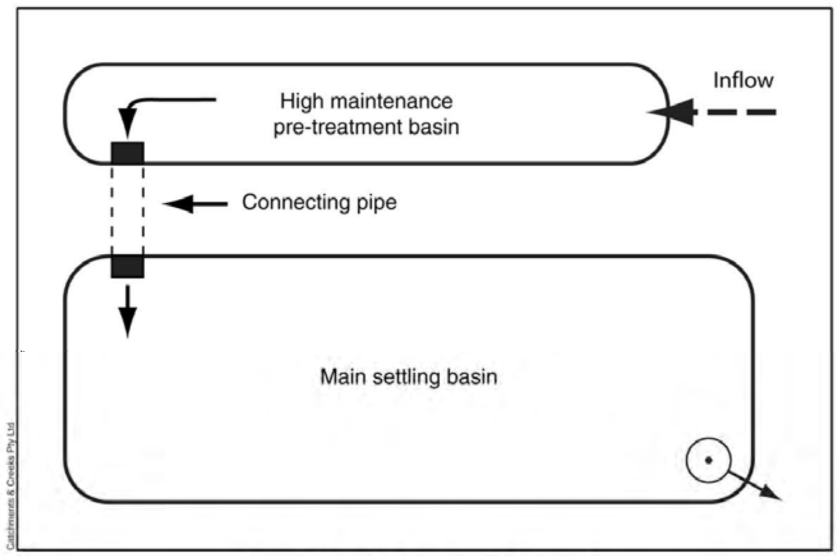

Figure 10 – Pre-treatment inlet pond

Photo 7 – Stabilise inflow chute

Photo 8 – Litter screen placed on inlet of permanent sediment basin

Step 10 – Design of the primary outlet system

Dry basins (Type C only) require a formal outlet system in the form of either a riser pipe outlet or floating skimmer system (Photo 11). Gabion wall, *Rock Filter Dam*, and *Sediment Weir* outlet systems are **not** recommended unless a Type 2 sediment retention system has been specified.

The hydraulics of a Type C basin's primary outlet system must ensure that the peak water level is at least 300mm below the crest of the emergency spillway during the basin's nominated design storm.

Wet basins (Type C, F or D) usually require a pumped outlet system. Alternatively, if a piped outlet exists, then a flow control valve must be fitted to the outlet pipe to allow full control of the basin discharge (note, Type C basins can be operated as wet basins with pumped outlets).

Photo 9 – Twin riser pipes in the process of being installed

Photo 10 – Riser pipe with aggregate filter and trash screen

Photo 11 – Skimmer outlet system

Photo 12 – Skimmer pipes must be protected from sediment build-up

Photo 13 – Low-flow sand filter outlet system on a permanent sediment basin

Photo 14 – Sand filter outlet system during installation

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Step 11 – Design of the emergency spillway

All elevated sediment basins (i.e. not fully recessed below natural ground, Photo 17) require the construction of a formally designed emergency spillway. Spillways are critical engineering structures that need to be designed by suitably qualified persons.

The minimum design storm for sizing the emergency spillway is defined in Table 7.

Table 7 – Recommended design standard for emergency spillways

Design life	Minimum design storm ARI
Less than 3 months operation	1 in 10 year
3 to 12 months operation	1 in 20 year
Greater than 12 months	1 in 50 year
If failure is expected to result in loss of life	Probable Maximum Flood (PMF)

The crest of the emergency spillway is to be at least:

- 300mm above the primary outlet (if included);
- 300mm below a basin embankment formed in virgin soil;
- 450mm below a basin embankment formed from fill.

In addition to the above, design of the emergency spillway must ensure that the maximum water level within the basin during the design storm specified in Table 7 is at least:

- 300mm below a basin embankment formed from fill;
- 150mm plus expected wave height for large basins with significant fetch length.

The approach channel can be curved upstream of the spillway crest, but must be straight from the crest to the energy dissipater as shown in Figure 11. The approach channel should have a back-slope towards the impoundment area of not less than 2% and should be flared at its entrance, gradually reducing to the design width at the spillway crest.

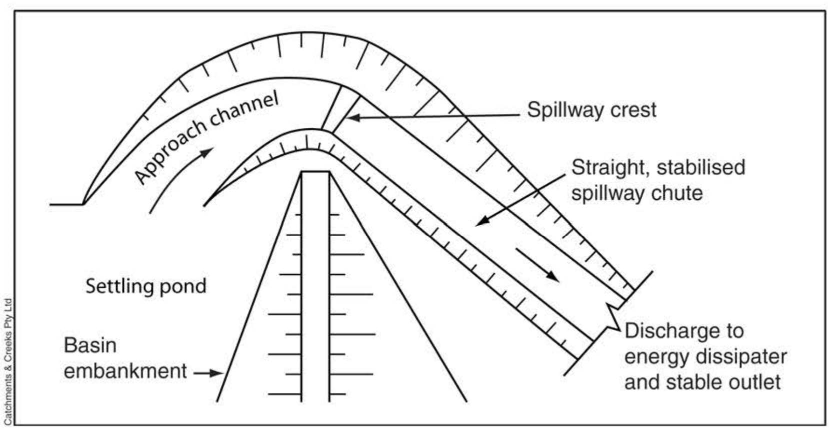

Figure 11 – Emergency spillway cut into virgin soil to side of fill embankment

All reasonable and practicable efforts must be taken to construct the spillway in virgin soil (Photo 16), rather than within a fill embankment (Photo 15). Placement of an emergency spillway within a fill embankment can significantly increase the risk of failure.

The downstream face of the spillway may be protected with grass, concrete, rock, rock mattresses, or other suitable material as required for the expected maximum flow velocity. Grass-lined spillway chutes are generally not recommended for sediment basins due to their long establishment time and relatively low scour velocity.

Photo 15 – Emergency spillway located within the fill embankment

Photo 16 – Emergency spillway located within virgin soil to the side of the embankment

For rock and rock mattress lined spillways, it is important to control seepage flows through the rocks located across the crest of the spillway. Seepage control is required so that the settling pond can achieve its required maximum water level prior to discharging down the spillway. Concrete capping of the spillway crest (Photo 18) can be used to control excess seepage flows.

Photo 17 – Fully recessed basin with natural ground forming the spillway

Photo 18 – Rock-lined spillway—note concrete sealing of the spillway crest

It is important to ensure that the spillway crest has sufficient depth and width to fully contain the nominated design storm peak discharge. Photo 20 shows a spillway crest with inadequate depth or flow profile.

Photo 19 – De-watering pipe intake must not rest on the basin floor

Photo 20 – Spillway crest with inadequate depth or profile

A suitable energy dissipater will be required at the base of the spillway. The recommended hydraulic freeboard down the spillway chute is 300mm to contain the turbulent whitewater.

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Step 12 – Determination of the basin's overall dimensions

If a sediment basin is constructed with side slopes of say 3:1 (H:V), then the basin may be 5 to 10m longer and wider than the length and width of the settling pond determined in Step 5. It is important to ensure the overall dimensions of the basin can fit into the available space.

The minimum recommended embankment crest width is 2.5m, unless justified by hydraulic/ geotechnical investigations.

Where available space does not permit construction of the ideal sediment basin, then a smaller basin may be used; however, erosion control and site rehabilitation measures must be increased to an appropriate higher standard to compensate. If the basin's settling pond surface area/volume is less than that required in Step 5, than the basin must be treated as a Type 2 or Type 3 sediment control system.

Step 13 – Locate maintenance access (de-silting)

Sediment basins can either be de-silted using long-reach excavation equipment operating from the sides of the basin, or by allowing machinery access into the basin. If excavation equipment needs to enter directly into the basin, then it is better to design the access ramp so that trucks can be brought to the edge of the basin, rather than trying to transport the sediment to trucks located at the top of the embankment. Thus a maximum 6:1 (ideally 10H:1V) access ramp will need to be constructed.

If the sediment is to be removed from the site, then a suitable sediment drying area should be made available adjacent to the basin, or at least somewhere within the basin's catchment area.

Step 14 – Define the sediment disposal method

Trapped sediment can be mixed with on-site soils and buried, or removed from the site. If sediment is removed from the site, then it should be de-watered prior to disposal. De-watering must occur within the catchment area of the sediment basin.

Step 15 – Assess need for safety fencing

Construction sites are often located in publicly accessible areas. In most cases it is not reasonable to expect a parent or guardian of a child to be aware of the safety risks associated with a neighbouring construction site. Thus fencing of a sediment basin is usually warranted even if the basins are located adjacent to other permanent water bodies such as a stream, lake, or wetland.

Responsibility for safety issues on a construction site ultimately rests with the site manager; however, each person working on a site has a duty of care in accordance with the State's work place safety legislation. Similarly, designers of sediment basins have a duty of care to investigate the safety requirements of the site on which the basin is to be constructed.

Photo 21 – Sediment basin with poor access for de-silting operations

Photo 22 – Temporary fencing of a construction site sediment basin

Step 16 – Define the rehabilitation requirements for the basin area

The Erosion and Sediment Control Plan (ESCP) needs to include details on the required decommissioning and rehabilitation of the sediment basin area. Such a process may involve the conversion of the basin into a component of the site's permanent stormwater treatment network.

On subdivisions and major road works, construction site sediment basins often represent a significant opportunity for conversion into either: a detention/retention basin (Photo 23), bioretention system, wetland, or pollution containment system. In rural areas, basins associated with road works are often constructed within adjacent properties where they remain under the control of the landowner as permanent farm dams.

In some circumstances it will be necessary to protect newly constructed permanent (future) stormwater treatment devices from sediment intrusion during the construction phase. With appropriate site planning and design the protection of these permanent stormwater treatment devices is generally made easier if the sediment basin is designed with a pre-treatment inlet pond (Figure 10). The pre-treatment pond can remain as a coarse sediment trap during the maintenance and building phases, thus protecting the newly formed wetland or bioretention system located within the basin's main settling pond.

Continued operation of the sediment basin during the building phase of subdivisions (i.e. beyond the specified maintenance phase) is an issue for negotiation between the regulatory authority and the land developer on a case-by-case basis.

During the construction, decommissioning, rehabilitation, or reconstruction of a sediment basin, the basin area including settling pond, embankment and spillway, must be considered a construction site in its on right. Thus, these works must comply with normal drainage, erosion, and sediment control standards. This means that appropriate temporary sediment control measures will be required down-slope of the sediment basin during its construction and decommissioning.

Upon decommissioning of a sediment basin, all water and sediment must be removed from the basin prior to removal of the embankment (if any). Any such material, liquid or solid, must be disposed of in a manner that will not create an erosion or pollution hazard.

Photo 23 – Permanent sediment basin within residential estate

Photo 24 – Sediment basins converted to permanent stormwater treatment ponds on highway project

Under normal circumstances, a sediment basin must not be decommissioned until all up-slope site stabilisation measures have been implemented and are appropriately working to control soil erosion and sediment runoff in accordance with the specified ESC standard. This may require the basin to be fully operational during part of the maintenance and operational phases.

If an alternative, permanent, outlet structure is to be constructed prior to stabilisation of the up-slope catchment area, then this outlet structure must not be made operational if it will adversely affect the required operation of the sediment basin during the construction phase.

Step 17 – Specification of the basin's operational procedures

Sediment basins can be operated as either 'dry' or 'wet' basins as described below.

- Dry basins are free draining basins that allow water to commence discharging from the low-flow outlet system as soon as water enters the basin.
- Wet basins are designed to retain sediment-laden water for extended periods allowing adequate time for the gravitational settlement of fine sediment particles. Operation of these basins may be assisted through the use of chemical flocculants. Ideally these basins are not drained until a suitable water quality is obtained within the basin.

Type F and Type D basins must be operated as wet basins with the settled/treated water decanted from the basin as soon as a suitable water quality is achieved. Thus, as soon as conditions allow, the basin must be maintained in either a dry-bed condition, or with a water level no greater than the top of the sediment storage zone.

On each occasion when a Type F or Type D basin cannot be de-watered prior to being surcharged by a following rainfall event, the operator must record such an event and report it to the appropriate regulatory authority. Where appropriate, alternative operating procedures may need be adopted in consultation with the regulatory authority in order to achieve optimum environmental protection.

A Type C basin may be operated as either a dry basin or wet basin; however, when operated as a wet basin, the settled water does not necessarily need to be decanted from the settling pond after achieving the desired water quality. This means that the water can be retained on-site for revegetation purposes and dust control.

A Type C basin operating in a wet condition is still sized in accordance with the design requirements for a normal Type C basin; however, a low-flow drainage system is not necessarily incorporated into the basin, thus potentially saving significant construction and maintenance costs.

Table 8 provides a summary of the attributes of the various operational conditions.

Table 8 – Attributes of various types of *Sediment Basins*

Attribute	Type C dry basin	Type C wet basin	Type F and Type D wet basins
Soil type within catchment	Sandy soils	Sandy soils	Clayey or dispersive soils
Critical design parameter	Surface area at base of settling zone	Surface area at base of settling zone	Volume of settling zone
Desirable water level condition before a storm	Empty	Any condition	No greater than top of sediment storage zone
De-watering system	Low-flow piped drainage system (riser pipe)	Pumping	Pumping
Chemical flocculation	Only if specified water quality objectives fail to be achieved	Only if specified water quality objectives fail to be achieved	As necessary, but usually required for Type D basins

Type F and D basins are typically designed for a maximum 5-day cycle, that being the filling, treatment and discharge of the basin within a maximum 5-day period. In some tropical regions this may not be practicable, and either a shorter or longer time frame may be required. The use of a shorter time period usually requires application of fast acting coagulants, which may require a much higher degree of environmental management compared to gypsum.

Appropriate coagulation of sediment basins is required if the contained water does not achieve a specified water quality standard, usually 50mg/L. In cases where a poor discharge water quality is achieved, a Type C basin may need to be operated as if it was a Type F or Type D basin in order to satisfy specified water quality objectives.

Certification of Sediment Basin Construction

BASIN IDENTIFICATION CODE/NUMBER: ....

LOCATION: ....

Legend: ✓ OK ✗ Not OK N/A Not applicable

Construction:

Item	Consideration	Assessment
1	Sediment basin located in accordance with approved plans.	....
2	Embankment material compacted in accordance with specifications.	....
3	Critical basin and spillway dimensions and elevations confirmed by as-constructed survey.	....
4	Required freeboard adjacent embankments and spillway confirmed by as-constructed survey.	....
5	Placement of rock on chute and upstream face of spillway in accordance with design details and standards.	....
6	Placement of rock within energy dissipation zone downstream of spillway in accordance with design details and standard.	....
7	All other sediment basin requirements in accordance with design details and standards.	....
8	As-constructed plan prepared for basin and spillway.	....

INSPECTION OFFICER .... **DATE** ....

SIGNATURE ....

Geotechnical:

Item	Consideration	Assessment
9	Suitable material used to form all embankments.	....
10	Appropriate compaction achieved in embankment construction (if observed).	....
11	No foreseeable concerns regarding stability or construction of the basin and spillway.	....

INSPECTION OFFICER .... **DATE** ....

SIGNATURE ....

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Description

A purpose built dam designed to collect and settle sediment from sediment-laden runoff. It usually consists of a settling pond, a low-flow drainage or manual decant system, and a high-flow emergency spillway.

Purpose

Sediment basins generally perform two main functions: firstly the settlement of coarse-grained sediment particles (e.g. sand and coarse silt) from waters passing through the basin, and secondly either:

(i) the filtration of fine sediments (e.g. fine silt and clay) from waters passing through the filtration system attached to the low-flow outlet;

(ii) the settlement of fine-grained particles from those waters retained within the basin following a storm event.

Limitations

Generally used on catchments greater than 0.25ha.

The installation of a sediment basin does not replace the need for appropriate on-site drainage and erosion control measures.

Sediment basins operating in a free-draining mode (dry basins) have limited control over turbidity, especially that resulting from dispersive soils, unless chemical treated.

Advantages

Sediment basins need be designed and operated in a manner that produces near-clear water discharge (i.e. total suspended solids concentrations not exceeding 50mg/L), especially following periods of light rainfall.

It is the ability of sediment basins to reduce turbidity levels (wet basins) that allows these Type 1 sediment traps to significantly reduce the potential ecological harm caused by urban construction.

Even when a basin is full of water, it can still be effective in the removal of coarse sediment from any flows passing through the basin.

Very high capture rate for coarse sediments.

Can be an effective control of fine sediment and turbidity during the frequent 'minor' storms if suitably operated.

Can be converted into a permanent wetland or detention basin for ongoing stormwater management after completion of the construction phase.

Disadvantages

Chemical dosing of basins can be difficult to automate.

Basins are difficult and expensive to relocate if the construction or drainage layout changes.

Decommissioned and backfilled sediment basins generally attract lower land values and are best integrated into open space areas, or the site's permanent stormwater management system.

Common Problems

Sediment blockage of free-flow outlet systems (dry basins).

Difficulties in repairing the low-flow outlet system once sediment blockage has occurred.

Inadequate room made available to construct the sediment basin.

Poor access available to maintain the basin.

Poor hydraulic design and/or construction of the emergency spillway.

Special Requirements

The sediment trapping efficiency of a sediment basin can be increased by:

- reducing the energy (jetting) of inflow;
- construction basins as close as practicable to the ideal 10:1 length to width ratio;
- avoiding bends in the flow path of water through the settling pond that may cause secondary currents and dead-water areas;
- avoiding wind shear on large basins that could cause secondary currents and sediment re-suspension.
- where practicable, operating both wet and dry basins in a manner that allows them to fully drain before the next significant inflow event, thus allowing settled sediment to 'cement' together on the bed of the basin.

Early integration of the basin into the construction phase is essential.

Avoid constructing sediment basins in dispersive soils. Where this is unavoidable, the basin should be lined with a non-dispersive or treated soil, especially the banks.

Overland flow should enter the basin via a stabilised chute. It should not be allowed to cause erosion down the banks of the settling pond.

Medium to high velocity piped inflows may require an energy dissipater or inlet baffle to break-up the inflow jet.

Internal baffles may be required in 'dry' basins to improve the movement of water through the settling pond.

An outlet baffle or barrier may be required to reduce the build-up of sediment and mud around the primary outlet filter (dry basins).

Sediment basins should be fenced if a public safety risk exists.

Location

Basins need to be located such that they intercept runoff from the largest possible portion of the disturbed site.

Basins generally should not collect runoff generated from off-site areas.

Must be located so that construction and maintenance access is available.

Where practicable, an area of level land should be available adjacent to the basin to allow de-watering of excavated sediment.

Preferably located above the 1 in 5 year flood level if located on or near a watercourse floodplain.

Allow room between the toe of the embankment and the downstream property boundary for provision for safety fencing, the spillway outlet, and all necessary energy dissipation measures.

Site Inspection

Check the dimensions of the basin.

Check for scouring around, or damage to the inlets and outlets.

Check for damage to the emergency spillway and displacement of rocks.

Check the level of sediment build-up.

Check all internal and external banks for erosion.

Check the measures introduced to control inflow jetting (wet and dry basins).

Check for trash build-up on inlet screens.

Check for water passing through earth embankments that could lead to a piping failure and bank collapse.

Materials

- Earth fill: clean soil with Emerson Class 2(1), 3, 4, or 5, and free of roots, woody vegetation, rocks and other unsuitable material. Soil with Emerson Class 4 and 5 may not be suitable depending on particle size distribution and degree of dispersion. Class 2(1) should only be used upon recommendation from geotechnical specialist. This specification may be replaced by an equivalent standard based on the exchangeable sodium percentage.
- Riser pipe: minimum 250mm diameter.
- Spillway rock: hard, angular, durable, weather resistant and evenly graded rock with 50% by weight larger than the specified nominal (d_{50}) rock size. Large rock should dominate, with sufficient small rock to fill the voids between the larger rock. The diameter of the largest rock size should be no larger than 1.5 times the nominal rock size. The specific gravity should be at least 2.5.
- Geotextile fabric: heavy-duty, needle-punched, non-woven filter cloth, minimum 'bidim' A24 or equivalent.

Construction

1. Notwithstanding any description contained within the approved plans or specifications, the Contractor shall be responsible for satisfying themselves as to the nature and extent of the specified works and the physical and legal conditions under which the works will be carried out. This shall include means of access, extent of clearing, nature of material to be excavated, type and size of mechanical plant required, location and suitability of water supply for construction and testing purposes, and any other like matters affecting the construction of the works.
2. Refer to approved plans for location, dimensions, and construction details. If there are questions or problems with the location, dimensions, or method of installation, contact the engineer or responsible on-site officer for assistance.
3. Before starting any clearing or construction, ensure all the necessary materials and components are on the site to avoid delays in completing the pond once works begin.

4. Install required short-term sediment control measures downstream of the proposed earthworks to control sediment runoff during construction of the basin.
5. The area to be covered by the embankment, borrow pits and incidental works, together with an area extending beyond the limits of each for a distance not exceeding five (5) metres all around must be cleared of all trees, scrub, stumps, roots, dead timber and rubbish and disposed of in a suitable manner. Delay clearing the main pond area until the embankment is complete.
6. Ensure all holes made by grubbing within the embankment footprint are filled with sound material, adequately compacted, and finished flush with the natural surface.

Cut-off trench:

7. Before construction of the cut-off trench or any ancillary works within the embankment footprint, all grass growth and topsoil must be removed from the area to be occupied by the embankment and must be deposited clear of this area and reserved for topdressing the completing the embankment.
8. Excavate a cut-off trench along the centre line of the earth fill embankment. Cut the trench to stable soil material, but in no case make it less than 600mm deep. The cut-off trench must extend into both abutments to at least the elevation of the riser pipe crest. Make the minimum bottom width wide enough to permit operation of excavation and compaction equipment, but in no case less than 600mm. Make the side slopes of the trench no steeper than 1:1 (H:V).
9. Ensure all water, loose soil, and rock are removed from the trench before backfilling commences. The cut-off trench must be backfilled with selected earth-fill of the type specified for the embankment, and this soil must have a moisture content and degree of compaction the same as that specified for the selected core zone.
10. Material excavated from the cut-off trench may be used in construction of the embankment provided it is suitable and it is placed in the correct zone according to its classification.

Embankment:

11. Scarify areas on which fill is to be placed before placing the fill.
12. Ensure all fill material used to form the embankment meets the specifications certified by a soil scientist or geotechnical specialist.
13. The fill material must contain sufficient moisture so it can be formed by hand into a ball without crumbling. If water can be squeezed out of the ball, it is too wet for proper compaction. Place fill material in 150 to 250mm continuous layers over the entire length of the fill area and then compact before placement of further fill.
14. Place riser pipe outlet system, if specified, in appropriate sequence with the embankment filling. Refer to separate installation specifications.
15. Unless otherwise specified on the approved plans, compact the soil at about 1% to 2% wet of optimum and to 95% modified or 100% standard compaction.
16. Where both dispersive and non-dispersive classified earth-fill materials are available, non-dispersive earth-fill must be used in the core zone. The remaining classified earth-fill materials must only be used as directed by *[insert title]*.
17. Where specified, construct the embankment to an elevation 10% higher than the design height to allow for settling; otherwise finished dimensions of the embankment after spreading of topsoil must conform to the drawing with a tolerance of 75mm from the specified dimensions.
18. Ensure debris and other unsuitable building waste is not placed within the earth embankment.
19. After completion of the embankment all loose uncompacted earth-fill material on the upstream and downstream batter must be removed prior to spreading of topsoil.
20. Topsoil and revegetate/stabilised all exposed earth as directed within the approved plans.

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Spillway construction:

21. The spillway must be excavated as shown on the plans, and the excavated material if classified as suitable, must be used in the embankment, and if not suitable it must be disposed of into spoil heaps.
22. Ensure excavated dimensions allow adequate boxing-out such that the specified elevations, grades, chute width, and entrance and exit slopes for the emergency spillway will be achieved after placement of the rock or other scour protection measures as specified in the plans.
23. Place specified scour protection measures on the emergency spillway. Ensure the finished grade blends with the surrounding area to allow a smooth flow transition from spillway to downstream channel.
24. If a synthetic filter fabric underlay is specified, place the filter fabric directly on the prepared foundation. If more than one sheet of filter fabric is required, overlap the edges by at least 300mm and place anchor pins at minimum 1m spacing along the overlap. Bury the upstream end of the fabric a minimum 300mm below ground and where necessary, bury the lower end of the fabric or overlap a minimum 300mm over the next downstream section as required. Ensure the filter fabric extends at least 1000mm upstream of the spillway crest.
25. Take care not to damage the fabric during or after placement. If damage occurs, remove the rock and repair the sheet by adding another layer of fabric with a minimum overlap of 300mm around the damaged area. If extensive damage is suspected, remove and replace the entire sheet.
26. Where large rock is used, or machine placement is difficult, a minimum 100mm layer of fine gravel, aggregate, or sand may be needed to protect the fabric.
27. Placement of rock should follow immediately after placement of the filter fabric. Place rock so that it forms a dense, well-graded mass of rock with a minimum of voids. The desired distribution of rock throughout the mass may be obtained by selective loading at the quarry and controlled dumping during final placement.
28. The finished slope should be free of pockets of small rock or clusters of large rocks. Hand placing may be necessary to achieve the proper distribution of rock sizes to produce a relatively smooth, uniform surface. The finished grade of the rock should blend with the surrounding area. No overfall or protrusion of rock should be apparent.
29. Ensure that the final arrangement of the spillway crest will not promote excessive flow through the rock such that the water can be retained within the settling basin an elevation no less than 50mm above or below the nominated spillway crest elevation.

Establishment of settling pond:

30. The area to be covered by the stored water outside the limits of the borrow pits must be cleared of all scrub and rubbish. Trees must be cut down stump high and removed from the immediate vicinity of the work.
31. Establish all required inflow chutes and inlet baffles, if specified, to enable water to discharge into the basin in a manner that will not cause soil erosion or the re-suspension of settled sediment.
32. Install a sediment storage level marker post with a cross member set just below the top of the sediment storage zone (as specified on the approved plans). Use at least a 75mm wide post firmly set into the basin floor.
33. If specified, install internal settling pond baffles. Ensure the crest of these baffles is set level with, or just below, the elevation of the emergency spillway crest.
34. Install all appropriate measures to minimise safety risk to on-site personnel and the public caused by the presence of the settling pond. Avoid steep, smooth internal slopes. Appropriately fence the settling pond and post warning signs if unsupervised public access is likely or there is considered to be an unacceptable risk to the public.

Maintenance of Sediment Basin

1. Inspect the sediment basin during the following periods:
   - (i) During construction to determine whether machinery, falling trees, or construction activity has damaged any components of the sediment basin. If damage has occurred, repair it.
   - (ii) After each runoff event. Inspect the erosion damage at flow entry and exit points. If damage has occurred, make the necessary repairs.
   - (iii) At least weekly during the nominated wet season (if any) otherwise at least fortnightly.
   - (iv) Prior to, and immediately after, periods of 'stop work' or site shutdown.
2. Clean out accumulated sediment when it reaches the marker board/post, and restore the original storage volume. Place sediment in a disposal area or, if appropriate, mix with dry soil on the site.
3. Do not dispose of sediment in a manner that will create an erosion or pollution hazard.
4. Check all visible pipe connections for leaks, and repair as necessary.
5. Check all embankments for excessive settlement, slumping of the slopes or piping between the conduit and the embankment; make all necessary repairs.
6. Remove all trash and other debris from the basin and riser.
7. Submerged inflow pipes must be inspected and de-silted (as required) after each inflow event.

Removal of Sediment Basin

1. When grading and construction in the drainage area above a temporary sediment basin is completed and the disturbed areas are adequately stabilised, the basin must be removed or otherwise incorporated into the permanent stormwater drainage system. In either case, sediment should be cleared and properly disposed of and the basin area stabilised.
2. Before starting any maintenance work on the basin or spillway, install all necessary short-term sediment control measures downstream of the sediment basin.
3. All water and sediment must be removed from the basin prior to the dam's removal. Dispose of sediment and water in a manner that will not create an erosion or pollution hazard.
4. Bring the disturbed area to a proper grade, then smooth, compact, and stabilise and/or revegetate as required to establish a stable land surface.

APPENDIX D. ESCP CHECKLIST

5.10 Erosion & Sediment Control Plan Checklist

LOCATION OF DEVELOPMENT ....

....

REVIEWER .... **DATE** ....

SIGNATURE ....

N/A – not applicable

✔ – acceptable controls adopted

✗ – measures are not acceptable, or a potential problem exists

Part A: Initial plan review

Item	Consideration	Assessment
1	*Erosion Hazard Assessment Form* completed for the site.	....
2	*Supporting Documentation* supplied with the ESCP.	....
3	Copy of calculation sheets supplied.	....
4	ESC specifications and construction drawings supplied.	....
5	Inspection and Test Plan (ITP) supplied	....
6	Legend provided to identify all ESC measures on the plans.	....
7	ESC *Installation Sequence* supplied.	....
8	*Installation Sequence* is appropriate for the site conditions.	....
9	*Installation Sequence* clearly indicates which sediment control measures must be installed prior to land disturbance.	....
10	Soil test results (including soil erodibility) supplied.	....
11	Extent of land disturbance (including cut and fill areas) shown.	....
12	Adequate identification/protection of non-disturbance areas.	....
13	Protected trees and buffer zones identified.	....
14	Appropriate staging of land clearing.	....
15	On-site watercourses and riparian zones protected.	....
16	Existing and/or final contours shown (as required).	....
17	Location of all ESC measures clearly shown.	....
18	All ESC measures located within the property.	....
19	Plans signed by appropriate professional(s).	....

Part B: Site assessment

Item	Consideration	Assessment
20	On-site water "values" and discharge standards (water quality objectives) identified.	....
21	Soil Map provided.	....
22	Location of potential dispersive soils identified.	....
23	Location of potential acid sulfate soils identified.	....
24	Potential landslip/mass movement areas identified.	....
25	High and extreme erosion risk areas identified and protected.	....
26	Soils of extreme pH identified and amelioration specified.	....

Part C: Site establishment

Item	Consideration	Assessment
27	Site access points limited to the minimum necessary, clearly identified on plans, and appropriate controls specified.	....
28	Drainage controls indicated on the entry/exit pad (if necessary).	....
29	Site office and car parking areas identified and provided with adequate drainage, erosion and sediment controls.	....
30	Technical notes included on best practice site management including dust, chemical, oil, fuel, litter and debris control.	....
31	Stockpile locations clearly identified and located away from protected vegetation and overland flow paths.	....
32	Stockpiles located at least 5m away from top of watercourse banks.	....
33	Adequate up-slope drainage controls (if necessary) and down-slope sediment controls placed adjacent to stockpiles.	....
34	Temporary access roads/tracks identified, with appropriate drainage/erosion controls specified.	....
35	*Temporary Watercourse Crossings* identified and protected.	....
36	*Temporary Watercourse Crossings* are appropriate for fish passage requirements.	....
37	Minimum non-disturbance zone between unsealed access tracks and the edge of streams is at least the width of the stream (measured at the top of the bank) or 30m whichever is the lesser.	....

Part D: Drainage controls

Item	Consideration	Assessment
38	Construction Drainage Plans prepared for each major stage of earthworks.	....
39	All temporary construction roads and access tracks shown on the Construction Drainage Plans.	....
40	Temporary drainage controls designed to the appropriate standard and hydraulic analysis provided.	....
41	Hydraulic analysis indicates appropriate flow velocities.	....
42	Hydraulic analysis indicates appropriate flow capacity.	....
43	Flow from "clean" external catchments diverted around/through site in a non-erosive manner.	....
44	Internal "dirty" water drainage lines identified and directed to sediment controls.	....
45	Appropriate drainage controls located immediately up-slope of neighbouring, down-slope residential areas.	....
46	All site drainage inflow and outflow points identified.	....
47	All water discharges from the site at legal points of discharge.	....
48	All water discharges through stabilised outlets onto stable land.	....
49	Maximum spacing of drains on long, open soil slopes is appropriate for the gradient and soil type.	....
50	Appropriate flow velocity controls (e.g. *Check Dams*) or scour controls (e.g. turf or *Erosion Control Mats*) specified.	....
51	*Catch Drains* or *Flow Diversion Banks* located at top of cut and fill batters.	....
52	Temporary *Catch Drains* not indicated on dispersive soils.	....
53	Rock *Check Dams* not specified in shallow (i.e. < 500mm deep) drains.	....
54	Water flow is appropriately conveyed down constructed earth slopes (e.g. through *Slope Drains* or *Chutes*).	....
55	All *Slope Drains* and *Chutes* have stabilised inlets and outlets.	....
56	Appropriate drainage controls on unsealed roads and access tracks.	....
57	Technical notes require all runoff from newly constructed roofs to be immediately connected to drainage system.	....
58	Overland flow appropriately controlled around *Temporary Watercourse Crossings*.	....

Part E: Erosion control

Item	Consideration	Assessment
59	The erosion control standard is consistent with the rainfall erosivity, environmental risk, and clay content of exposed soil.	....
60	The erosion control standard is consistent with the requirements of regulatory authority.	....
61	Application rates specified for mulching.	....
62	Specified mulch stabilisation measures are appropriate for the soil slope (gradient).	....
63	Appropriate drainage controls installed to minimise mulch being washed off the slope/site.	....
64	Synthetic (plastic) mesh reinforced *Erosion Control Blankets* not specified in or adjacent to susceptible wildlife habitats.	....
65	Emergency short-term erosion control measures specified (e.g. in event of construction delays, pre-storm activities).	....
66	Technical notes indicate what additional works are required if construction occurs during the wet season.	....
67	Dust control measures specified.	....
68	Disturbed soil with an Exchangeable Sodium Percentage (ESP) greater than 6% is to be treated to control soil dispersion.	....

Part F: Site stabilisation/revegetation

Item	Consideration	Assessment
69	Vegetation Management Plan and/or Landscape Plan provided.	....
70	Site stabilisation/rehabilitation plan provided.	....
71	Minimum soil protective cover of 70 % specified on ESCP or in the Supporting Documentation.	....
72	Appropriate soil preparation measures specified prior to revegetation.	....
73	Timing and specification for any temporary vegetation is provided.	....
74	Application of permanent site revegetation is appropriately staged.	....
75	Minimum specifications for imported topsoil supplied.	....
76	Specifications and application rates for soil adjustments provided (soil report).	....
77	Specifications and application rates for seeding, mulches and hydraulically applied soil covers provided.	....

Part G: Supplementary sediment controls

Item	Consideration	Assessment
78	Every appropriate opportunity has been taken to trap sediment as close to the initial source of erosion as is practicable without placing sediment controls in locations where they could cause hydraulic, erosion, or safety issues.	....
77	Sediment traps placed on public roadways will not cause safety issues.	....
79	No sub-catchment relies solely on supplementary sediment control measures.	....
80	*Straw Bales* are not specified for sediment control, unless justified by exceptional circumstances (e.g. as a short-term control during the installation of the primary sediment trap).	....
81	The ESCP provides sufficient information to control the installation and use of supplementary sediment traps.	....

Part H: Sediment control "sheet" flow

Item	Consideration	Assessment
82	No sediment-laden water leaves the site untreated.	....
83	"Sheet flow" control measures (e.g. *Buffer Zones, Grassed Filter Strips, and Sediment Fence*) not specified in areas of concentrated flow.	....
84	*Grass Filter Strips* will not cause water to be diverted along the up-slope edge of the filter strip.	....
85	The width of sediment control *Buffer Zones* is appropriate for the land slope (gradient).	....
86	Geotextile *Filter Fences* are only used to control sediment runoff from earth stockpiles.	....
87	*Sediment Fences*:	
	(a) Located and detailed (i.e. with regular "returns") such that runoff will pond uniformly or a regular intervals along the fence.	....
	(b) Ends of each fence turned up the slope to control flow bypass.	....
	(c) Each fence clearly identified as either "woven" or "non-woven" as appropriate, otherwise a summary table is provided identifying the fabric specification for each fence.	....
	(d) Specifications show a maximum 2m spacing of support post.	....
	(e) The fence is located at least 2m from base of fill slopes.	....
	(f) Specifications (design details) show adequate trenching of fabric.	....
		....

Part I: Sediment control "concentrated" flow

Item	Consideration	Assessment
88	Appropriate sediment control standard specified (i.e. Type 1, Type 2, or Type 3)	....
89	Location of all sediment control measures clearly shown.	....
90	The location and operation of sediment control measures will not cause safety issues or flooding of adjacent properties.	....
91	Straw bale check dams not specified for sediment control.	....
92	Appropriate sediment control measures are specified for all "sag" and "on-grade" kerb inlets.	....
93	Appropriate sediment control measures specified for all field (drop) inlets.	....
94	Appropriate sediment control measures specified for all culverts and pipe inlets.	....
95	Where specified on stormwater outlets, end-of-pipe sediment traps are located well downstream (e.g. 10 x pipe dia.) of outlet.	....
96	Type 2 sediment traps (e.g. *Rock Filter Dams, Sediment Trenches, Sediment Weirs*):	
	(a) Have adequate up-slope pond area.	....
	(b) Have an appropriately sized sediment collection pit.	....
	(c) Designed for an appropriate storm frequency.	....
97	Appropriate access is provided to all sediment traps for maintenance and sediment removal.	....
98	Appropriate sediment control measures are specified for de-watering operations specified (technical notes).	....
99	Sediment controls are placed within streams ONLY as a last resort, and only with written approval from all appropriate Regulatory Authorities.	....
100	Sediment controls placed in and around drainage channels are appropriate for the expected flow conditions.	....

Part J: Sediment Basins

Item	Consideration	Assessment
101	The location and operation of *Sediment Basins* will not cause safety issues or flooding of adjacent properties.	....
102	Type of each *Sediment Basin* is appropriate for the soil conditions.	....
103	Soil testing and all design calculations provided for all *Sediment Basins*.	....
104	Appropriate construction specifications provided for all basin embankments.	....
105	Actual size (including all dimensions) of each *Sediment Basin*, including spillway, is shown on the plans.	....
106	Sediment-laden water is able to flow to the required basin during all stages of earthworks and soil disturbance.	....
107	All *Sediment Basins* have:	
	(a) Stable inflow conditions.	....
	(b) Inlet baffle (if required).	....
	(c) Minimum 3:1 length to width, otherwise baffles installed.	....
	(d) Suitable access for de-silting and maintenance.	....
	(e) Stabilised emergency spillway and energy dissipater.	....
	(f) Stabilised batters/embankments.	....
	(g) Safety or exclusion fencing (as required).	....
	(h) Operating conditions and water quality standards specified.	....
		....
108	Riser pipe outlet systems for "dry" basins:	
	(a) Debris/anti-vortex inlet screen specified.	....
	(b) Anti-flotation weight specified.	....
	(c) Details for riser pipe filtration system specified.	....
	(d) Anti-seepage collars specified.	....
		....
109	Appropriate monitoring and maintenance requirements for all *Sediment Basins* provided.	....
110	Basin sizing, hydraulic design (spillway) and embankment specification certified by appropriate professionals.	
	(a) Review of spillway hydraulics.	....
	(b) Geotechnical review of embankment construction & stability.	....
	(c) ESC specialist review of basin selection and design.	....

Part K: Instream works

Item	Consideration	Assessment
111	All necessary site data (soil and flow conditions, stream type, site access conditions).	....
112	All necessary State and local government approvals have been obtained.	....
113	*Temporary Watercourse Crossings* (e.g. construction access) have been reduced to the minimum practical number.	....
114	Instream disturbance is limited to the minimum necessary to complete the proposed works.	....
115	Instream disturbances have been appropriately staged to minimise exposure to storm runoff and stream flows.	....
116	Instream works have been programmed for that time of the year that will minimise overall potential environmental harm:	
	(a) avoiding seasonal high flows;	....
	(b) avoiding periods of likely fish migration;	....
	(c) avoiding active bird migration periods (RAMSAR wetlands).	....
117	Instream structures are not located on, or adjacent to, unstable or highly mobile channel bends.	....
118	Construction works will not unnecessarily disturb instream or riparian vegetation.	....
119	Wherever reasonable and practicable, overbank disturbances will be limited to only one bank.	....
120	Stormwater runoff moving towards the channel from adjacent areas will be appropriately diverted around soil disturbances.	....
121	Where stormwater cannot be diverted around soil disturbances, stabilised bank *Chute*(s) have been provided to carry stormwater down the channel banks in a non-erosive manner.	....
122	Wherever reasonable and practicable, dry-weather channel flows are diverted around in-bank disturbances:	
	(a) dry channel conditions expected;	....
	(b) flow diversion using cofferdams and bypass pipes;	....
	(c) flow diversion using instream *Isolation Barriers*.	....
123	Appropriate temporary erosion control measures (if necessary) have been proposed.	....
124	Synthetic reinforced erosion control blankets/mats have not been specified where there is a potential threat to wildlife.	....
125	All reasonable and practicable measures have been taken to avoid the need for instream sediment control measures within flowing streams.	....
126	Proposed instream sediment control measures are appropriate for the expected site access and stream flow conditions.	....
127	Appropriate material de-watering procedures and process areas have been identified.	....
128	Appropriate bed, bank and overbank rehabilitation measures have been proposed.	....

Part L: Site monitoring and maintenance

Item	Consideration	Assessment
129	Site inspection program supplied.	....
130	Monitoring and Maintenance Program provided for all drainage, erosion and sediment controls.	....
131	Water quality monitoring program supplied, including construction phase Water Quality Objectives (WQOs).	....
132	Water quality monitoring locations/stations identified.	....
133	Appropriate safety issues addressed for site monitoring and data (e.g. water sample) collection.	....
134	Adequate ESC maintenance requirements have been specified either on the ESCP or within the Supporting Documentation.	....