



Track Drainage

Issue date: 21 November 2023

Effective date: 21 November 2023

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Document information

Owner: Director, Civil Engineering Infrastructure
Asset Management
Safety, Environment and Regulation

Mode: Heavy rail

Discipline: Civil

Document history

Revision	Effective date	Summary of changes
1.0	4/09/2015	First issue as T HR CI 12130 MA – 4/09/2015. Superseded RailCorp standard TMC 421 <i>Track Drainage</i> , version 1.2. Expanded on content of T HR CI 12130 ST <i>Track Drainage</i> and included changes such as: replacement of RailCorp organisation roles and processes with those applicable to the current ASA organisational context; minor amendments and clarification to content; conversion of the standard to ASA format and style.
1.0	21 November 2023	Renumbered as TS 01641:1.0. Version number recommenced in line with new designation. Changes to previous content include removal of superseded content and mandatory requirements included in TS 01638, inclusions of updated references to the <i>Australian Rainfall and Runoff: A Guide to Flood Estimation</i> , inclusion of some climate change considerations, provision of more clarity and background explanations for track drainage guidance, other minor amendments, adjustments to cross-references and clarification to content.

Preface

This manual is the first issue as TS 01641 and it supersedes T HR CI 12130 MA, version 1.0.

This manual provides guidance for the design, construction, and maintenance of effective track drainage systems specified in TS 01638 *Track Drainage* (standard).

This document has been developed to expand upon the content in TS 01638 and forms part of a series of drainage standards and manuals.

The changes from the previous issue include the following:

- removal of superseded content and mandatory requirements included in TS 01638
- inclusions of updated references to the *Australian Rainfall and Runoff: A Guide to Flood Estimation*
- inclusion of some climate change considerations
- provision of more clarity and background explanations for track drainage guidance
- other minor amendments, adjustments to cross-references and clarification to content.

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1 Scope

This document provides track drainage guidance within the rail corridor and includes surface and subsurface stormwater drainage of the track formation, supporting embankments and cuttings and runoff entering the rail corridor.

This manual covers the following aspects of track drainage:

- types of surface drains (including cess drains, catch drains and mitre drains)
- types of subsurface drains (including pipe culverts and aggregate subsoil drains)
- design planning and investigations
- design methods (including stormwater flow and system capacity estimations)
- pipe culvert design considerations (including loading, trenching, backfill, embedment, inlets, outlets and pits)
- construction planning and installation
- maintenance and inspection considerations
- documentation (including design drawing and reporting considerations).

This manual does not include the following:

- waterway and flood design for all non-track drainage culverts (such as across rail corridor drainage systems); for underbridges refer to TS 01713, for earthworks and formations refer to TS 01608, for access roads refer to TS 02391 and for air space and external developments refer to TS 02390 for guidance
- box or arch culvert design or selection; refer to TS 01713 for underbridge and culvert guidance
- drainage for rail corridor related structures such as tunnels, bridges, platforms, track slabs, buildings, airspace developments, external developments, access roads, roads outside the rail corridor, council drains, or properties adjacent to the rail corridor; refer to asset specific standards for their guidance.

Drainage of external developments and properties adjacent to the rail corridor are not specifically covered. However, guidance for submissions to TfNSW, where stormwater discharge onto or through the rail corridor cannot be avoided is included.

2 Application

This manual supplements, and should be read in conjunction with, TS 01638 which specifies track drainage requirements. The guidance given in this document applies to service providers and particularly civil engineers that are involved in track drainage works across the full life cycle

of heavy rail assets in the metropolitan rail area (MRA). Guidance principles can also be applied to other transport modes.

3 Referenced documents

The following documents are cited in the text. For dated references, only the cited edition applies. For undated references, the latest edition of the referenced document applies.

Australian standards

AS 3996 *Access covers and grates*

AS 5100 (all parts) *Bridge design*

AS 5334 *Climate change adaptation for settlements and infrastructure – A risk based approach*

AS/NZS 2566 (all parts) *Buried flexible pipelines*

AS/NZS 3725 *Design for installation of buried concrete pipes*

AS/RISSB 7470 *Human Factors Integration in Engineering Design – General Requirements*

Transport for NSW standards

TS 01547.1 (T MU MD 00006 ST) *Engineering Drawings and CAD Requirements*

TS 01606 (T HR CI 12101 ST) *Geotechnical Problem Management*

TS 01608 (T HR CI 12110 ST) *Earthworks and Formation*

TS 01636 (T MU CI 12140 GU) *Geotechnical Instrumentation and Monitoring Guidelines*

TS 01638 (T HR CI 12130 ST) *Track Drainage*

TS 01640 (T HR CI 12111 SP) *Earthworks Materials*

TS 01642 (T HR CI 12002 ST) *Durability Requirements for Civil Infrastructure*

TS 01658 (T HR CI 12003 ST) *Civil Infrastructure Construction*

TS 01713 (T HR CI 12020 ST) *Underbridges*

TS 01715 (T HR CI 12030 ST) *Overbridges and Footbridges*

TS 02390 (T HR CI 12190 ST) *Service Installations within the Rail Corridor*

TS 02391 (T HR CI 12200 ST) *Access Roads*

TS 02404 (T HR CI 12090 ST) *Airspace and External Developments*

Transport for NSW drawings

CV 0205421 *Track Drainage – Typical Sections and Notes*

CV 0400998 *Ballast Cage (Lobster Pot) with Removable Lid*

Other reference documents

Austrroads, 2018, Research Report, AP-R575-18, *Design of Buried Flexible Pipes*

Austrroads, *Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures*

Austrroads, *Guide to Road Design Part 5: Drainage: General and Hydrology Considerations*

Austrroads, *Guide to Road Design Part 5A: Drainage: Road Surface, Networks, Basins and Subsurface*

Commonwealth of Australia, Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2019, *Australian Rainfall and Runoff: A Guide to Flood Estimation* (referenced as ARR 2019 in this manual)

Department of Planning, Industry and Environment, 2019, *Guide to Climate Change Risk Assessment for NSW Local Government*

The Institution of Engineers, Australia, 1987, *Australian Rainfall and Runoff: A Guide to Flood Estimation* (referenced as ARR 1987 in this manual)

The Institution of Engineers, Australia, 2001, *Australian Rainfall and Runoff: A Guide to Flood Estimation* (referenced as ARR 2001 in this manual)

Note: Appendix A contains a list of other documents not cited in the text that provide additional information and guidance.

4 Terms, definitions and abbreviations

The following terms, definitions and abbreviations apply in this document:

AEP annual exceedance probability; the probability of an event being equalled or exceeded within a year expressed as a percentage (for example, 2% AEP)

ARI average recurrence interval; the average time period between occurrences equalling or exceeding a given value expressed as a number of years (for example, 50 year ARI)

ARR *Australian Rainfall and Runoff: A Guide to Flood Estimation*

catch drain a device that intercepts overland flow or run-off before it reaches the track and related structures such as cuttings or embankments (catch drains are also known as top drains or cut-off drains)

cess area from the edge of the ballast profile to either the edge of the embankment or the toe of the cutting

cess drain drain located at formation level at the side of the track

culvert arch, box, oval or circular shaped structure with integral walls, roof and/or floor

Darcy's law an equation that relates head loss due to friction along a given length of pipe to the average velocity of the fluid flow

DLA dynamic load allowance; the dynamic load allowance for railway live load effects is a proportion of the static railway live load calculated in accordance with AS 5100

down rail identified with back to Sydney as normal, the down rail will be on the left

IFD intensity frequency duration; design rainfall intensities (typically in mm/h) corresponding to selected standard probabilities, based on statistical analysis of historical rainfall

formation an earthworks structure including all foundation, structural treatment and capping layer, on which ballast is laid

main line track main running lines, crossing loops, refuge loops and sidings with a maximum permissible speed greater than 25 km/h

Manning's roughness coefficient numerical measure of the frictional resistance to flow as used in the Manning's formula

mitre drain connected to cess and catch drains to remove water or to provide an escape for water from these drains

MRA the area bounded by Newcastle (in the north), Richmond (in the northwest), Bowenfels (in the west), Macarthur (in the southwest) and Bomaderry (in the south), and all metropolitan connection lines and sidings within these areas, but excluding private sidings.

OHWS overhead wiring structure

peak flow rate the highest flow discharged from the catchment under consideration having evaluated the most critical storm duration with a particular ARI

pipe embedment the zone of pipe support materials including the bed zone, haunch zone, side zone and overlay zone

possession closure of one or more lines to allow work to be carried out in the danger zone using a local possession authority (LPA) or a track occupancy authority (TOA)

rail corridor the extent of land over which a railway line passes (typically fenced along boundaries) that is owned, leased, or otherwise utilised by the rail operator/state

Rational Method a formula expression of peak discharge as proportional to the product of rainfall intensity, catchment area and a runoff coefficient dependent on the catchment basin characteristics

RFFE regional flood frequency estimation; a flood and stormwater flow estimation method

RIM rail infrastructure manager; in relation to rail infrastructure of a railway, means the person who has effective control and management of the rail infrastructure, whether or not the person-

(a) owns the rail infrastructure; or

(b) has a statutory or contractual right to use the rail infrastructure or to control, or provide, access to it

Note: RIM approval or acceptance within TS 01638 refers to written agreement by the Civil design technical manager or equivalent position of the RIM's organisation

sidings all operating lines which are not main line tracks

TfNSW Transport for NSW

TfNSW Central Planroom the physical location where drawing information is stored and managed on behalf of TfNSW

TMP technical maintenance plan

track drainage drainage of the track formation including diversion of water away from cuttings and embankments

ULX underline crossing; the passage of services, such as pipes and cables, crossing below a railway line

5 Introduction to track drainage

Track drainage systems divert stormwater and groundwater away from track formations and the supporting ground and into recognised water courses. For typical ballasted track, rainfall percolates through the ballast and is directed sideways over the soil capping layer of the formation and then away into the track drainage system. Without adequate track drainage, the track formation may become saturated and weakened, which can lead to failure and loss of firm support for the track or flooding of the track. Formation failure may be indicated by mud pumping up through the ballast, vertical and horizontal track alignment problems, heaving or settlement.

Typical track drainage systems comprise surface types such as cess drains, catch drains, mitre drains or grated drains, and subsurface types such as below ground pipes, pits and aggregate drains.

Stormwater catchment areas can include the rail corridor and areas outside the rail corridor for track drainage systems and all inflows need to be accounted for in the design. External stormwater drainage systems that cross from one side of the rail corridor to the other require structures such as box culverts, pipe culverts, open channels and underbridges spanning natural watercourses and constructed floodways. The primary function of these across rail corridor drainage systems is not track drainage; however, they are often used as an outlet for track drainage rail infrastructure.

Regular inspection, examination, routine maintenance and repairs when required of drainage systems are essential to maintaining the integrity of track formation, supporting embankments and cuttings.

Neglect of drainage problems will inevitably lead to track problems.

A summary of drainage principles is also covered at Section 5.1.

5.1 Drainage principles

Drainage principles include the following:

- Allow water to drain away. It is important that water is allowed a flow path downwards and be drained away from the track structure as quickly as possible.
- Keep water flowing. If there are low spots in the drainage path, water will pond and will saturate the sensitive track structure and weaken the material in that area.
- Control the path of water. Water should not be permitted to flow from the drain into areas that will be damaged by water, for example, flowing into sinkholes or from the cess back into the track because of debris in the cess.
- Control the flow rate of water. Water should not flow too slowly as to cause saturation (ponding) or too rapidly as to cause erosion.
- Reduce erosion. Certain materials are prone to erosion and require additional treatment, otherwise drains block rapidly, or slopes become undercut and cause instability.
- Keep water as far away as possible from critical areas. Where the countryside is very flat and recommended grades cannot be achieved, water should be drained away from areas that can be damaged by saturation. For example, allow water to pond at the railway boundary rather than the toe of the embankment.

6 Types of track drainage

Track drainage consists of the following two types:

- surface drainage (also referred to as open drains)
- subsurface drainage (typically piped drains).

Most systems will typically only need surface drainage.

TS 01608 also covers earthworks for railway embankments, cuttings, capping layers and includes typical track formation cross sections and drainage of earthworks.

Further guidance details regarding geotechnical instrumentation, monitoring and problem management are in TS 01606 and TS 01636 for locations where drainage is critical for geotechnical stability.

6.1 Surface drains

Surface drains remove surface run-off before it enters the track structure and collects water percolating out of the track structure.

Basic grading of the ground on either side of the track is a form of surface drainage and allows removal of water flowing out of the track structure.

Shoulder grading may be used in very flat areas where it is difficult to get sufficient fall for either surface or subsurface drains. Figure 1 shows a typical track formation with shoulder grading.

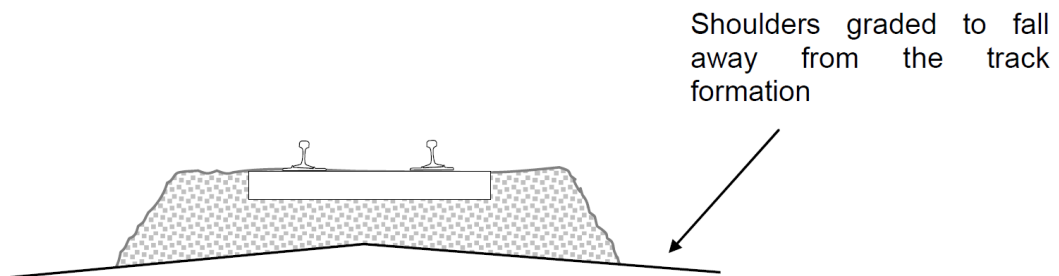


Figure 1 – Typical track formation

There are three main types of surface drainage as follows:

- cess drains
- catch drains
- mitre drains.

Figure 2 shows surface drainage types.

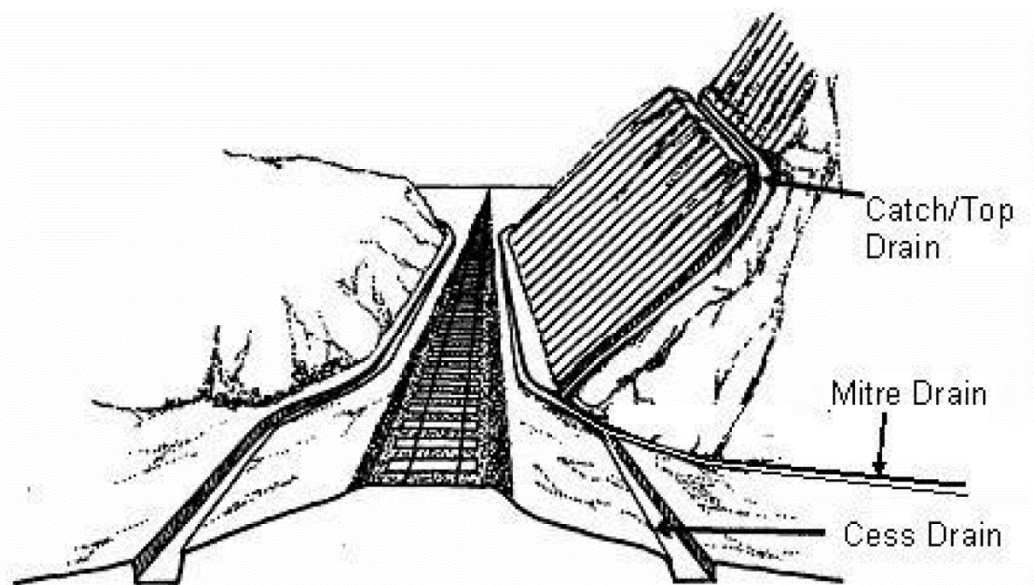


Figure 2 – Surface drainage types

6.1.1 Cess drains

Cess drains are surface drains located at formation level at the side of tracks, to remove water that has percolated through the ballast and is flowing along the capping layer towards the outside of the track formation. Cess drains are primarily intended for the protection of the formation by keeping the formation dry.

Cess drains are typically found in cuttings where water running off the formation cannot freely drain away to the side of the track formation as shown in Figure 3.

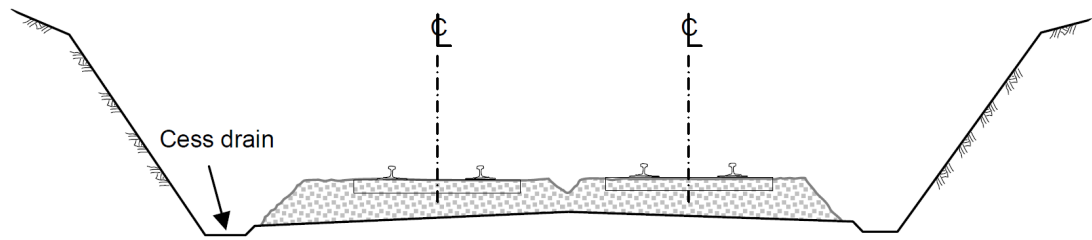


Figure 3 – Cess drain – typical location

Surface drains can be constructed on flat grades, as they are easily cleared of any sediment that may collect in them.

6.1.2 Catch drains

The purpose of catch drains (also known as top drains or cut-off drains) is to intercept overland flow or run-off before it reaches the track. They reduce the possibility of overland flow or run-off causing damage to the track or related structures, such as cuttings or embankments.

Catch drains are generally located on the uphill side of a cutting crest to catch water flowing down the hillside natural surface and remove it prior to reaching the cutting. If this water was allowed to flow over the cutting face, it may cause excessive erosion and subsequent silting up of cess drains. Catch drains positioned near tops of cuttings are also named crest drains.

Catch drains may be used alongside tracks that cut across a slight downhill grade such as near embankment toes.

Figure 4 shows typical catch drain locations.

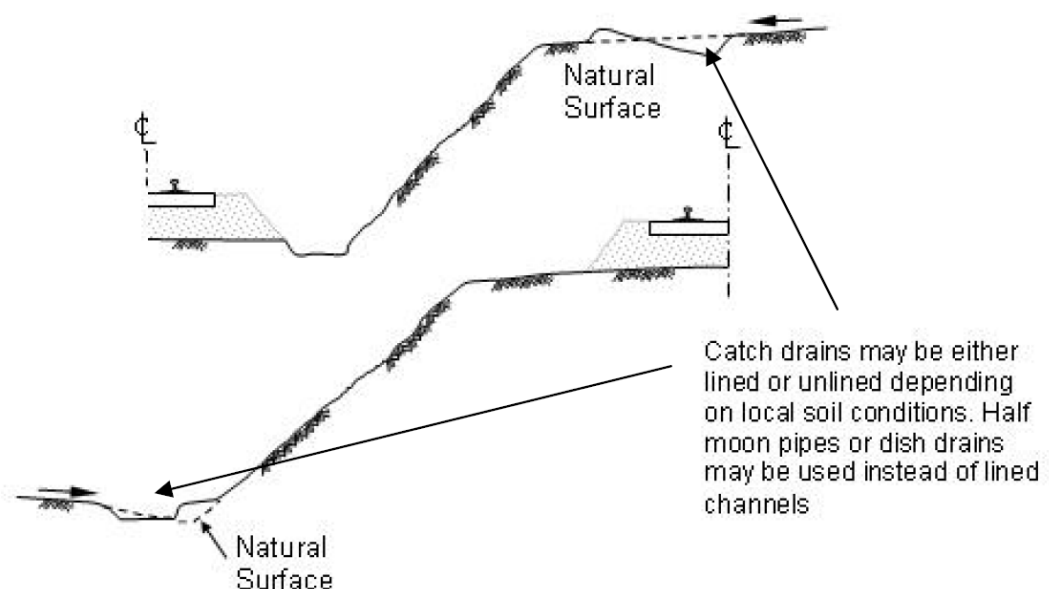


Figure 4 – Typical catch drains

6.1.3 Mitre drains

Mitre drains are connected to cess and catch drains to provide an escape for water from these drains. Mitre drains should be provided at regular intervals to remove water before it slows down and starts to deposit any sediment that it may be carrying. Figure 5 shows typical mitre drains.

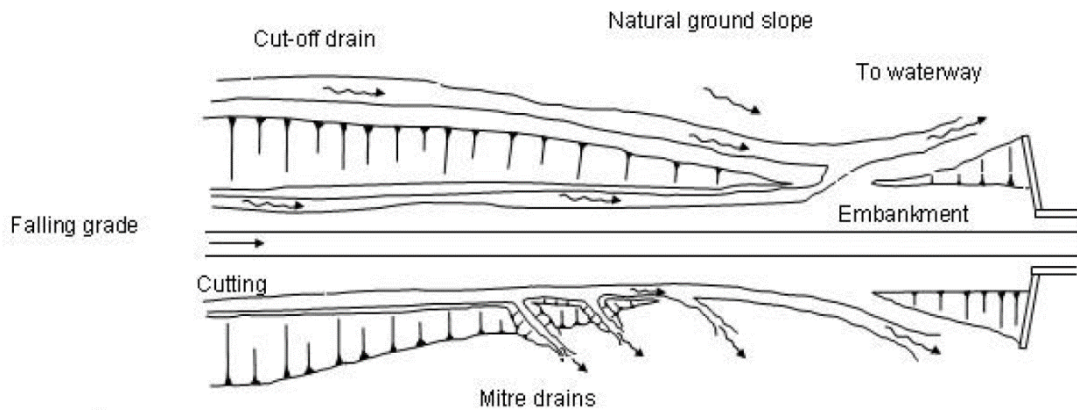


Figure 5 – Typical mitre drains

6.2 Subsurface drains

Subsurface drains are necessary for maintaining the integrity of the track formation and ensuring the stability of earth slopes where surface drains alone are not sufficient.

Subsurface drains are provided along the cess, between, across, or under tracks as required.

Subsurface drains are used for the following:

- drainage of the track structure
- controlling ground water and diverting seepage
- draining slopes
- where adequate surface drainage systems cannot be provided
- where overland flow paths cannot cater for design flow rates
- where the watertable is at or near earthworks level
- relieving water pressure where artesian conditions exist.

Subsurface drains are designed to take surface runoff, ground water and seepage, and water collected from other drainage systems to which the new system is being connected. If a drainage system is required to remove ground water and seepage, a detailed hydrological and geotechnical investigation is necessary to determine the volume of water for the sizing of drains.

Subsurface drains are used where adequate surface drainage cannot be provided due to some restriction or lack of available fall due to outlet restrictions. Locations where these circumstances may occur are the following:

- platforms and trackside structures
- cuttings
- track junctions
- multiple tracks
- bridges
- access roads.

Most systems will only have to cater for surface run-off.

A specific type of subsurface drain is a 'subsoil drain' where an aggregate filled trench (with or without slotted pipes) is constructed towards an outlet point to collect and drain ground water away from particular wet areas. This type of drains are typically used to control low flow seepage zones or where minimum pipe depth requirements cannot be satisfied. In some cases, the slotted pipe is omitted and the seepage flows are directed within the trench via impervious base materials or geotextile materials.

Due to trenching risks with subsurface drainage construction, prior geotechnical investigations are typically required to advise on protection for track formation, nearby structures and slope stability (for example including configurations shown in Figure 6 to Figure 13).

6.2.1 Functions of subsurface drains

Subsurface drainage systems perform the following functions:

- collection of infiltration water that seeps into the formation (capping layer), as shown in Figure 6
- draw-down or lowering of the watertable, as shown in Figure 7
- interception or cut-off of water seepage along an impervious boundary, as shown in Figure 8
- drainage of local seepage such as spring inflow, as shown in Figure 9.

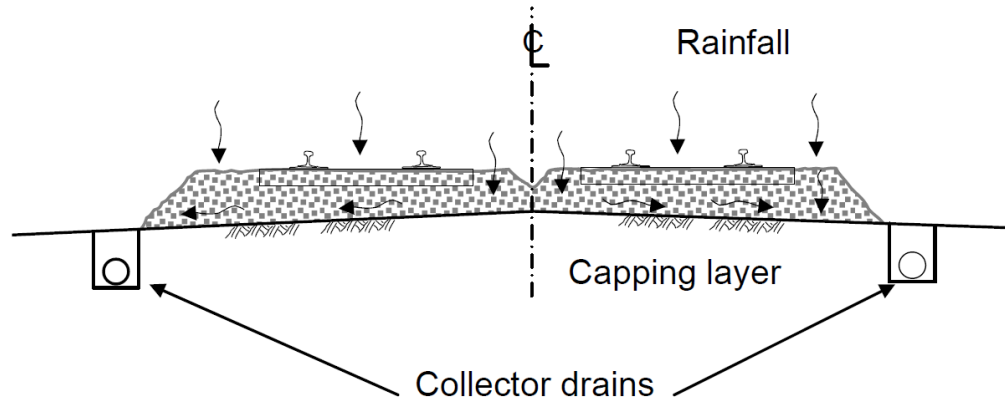


Figure 6 – Collection of water seeping into the ballast structure

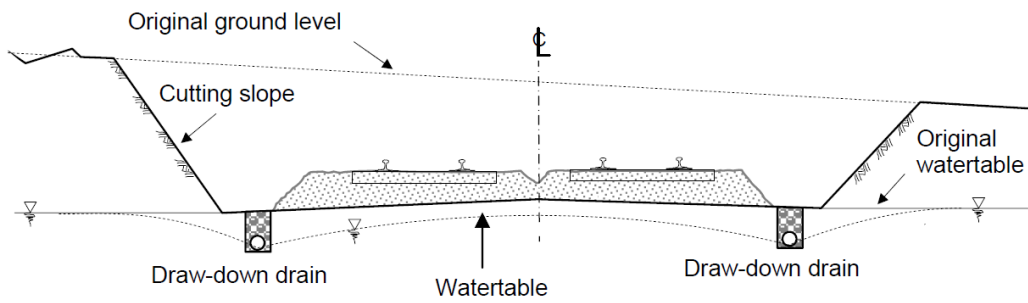
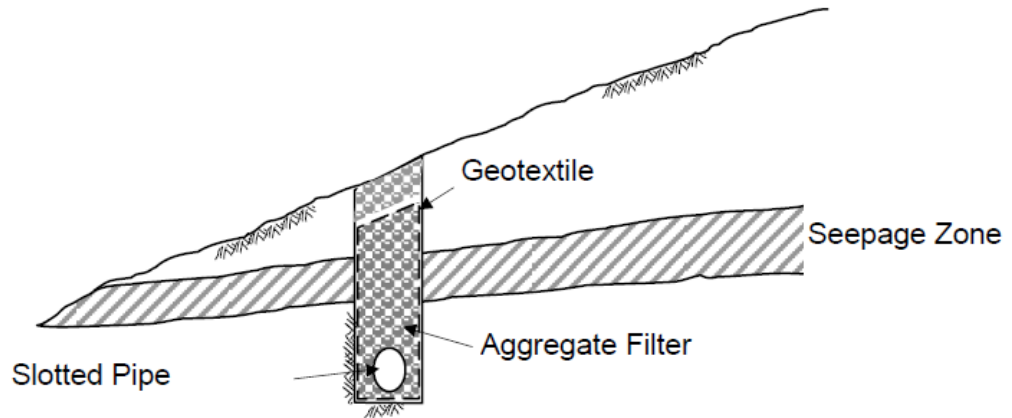
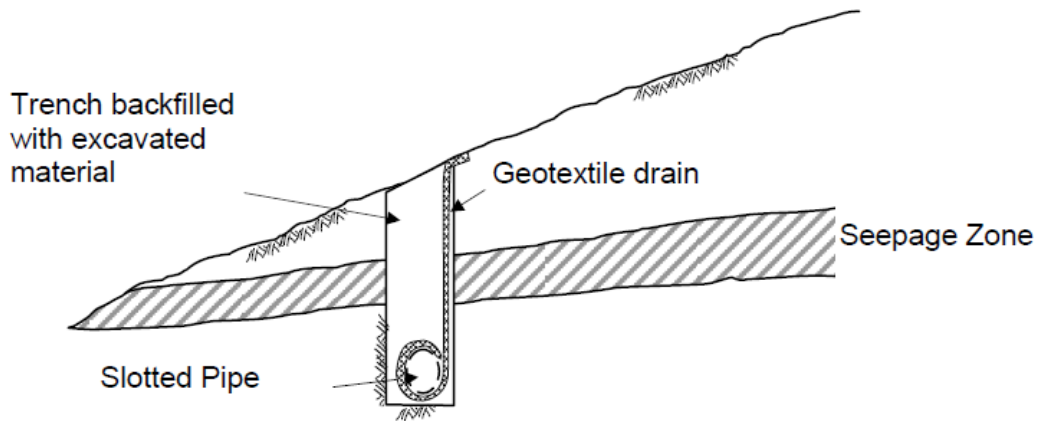


Figure 7 – Lowering the watertable



Type 1: Aggregate, geotextile and slotted pipe drain



Type 2: Geotextile drain

Figure 8 – Interception and cut-off of seepage water

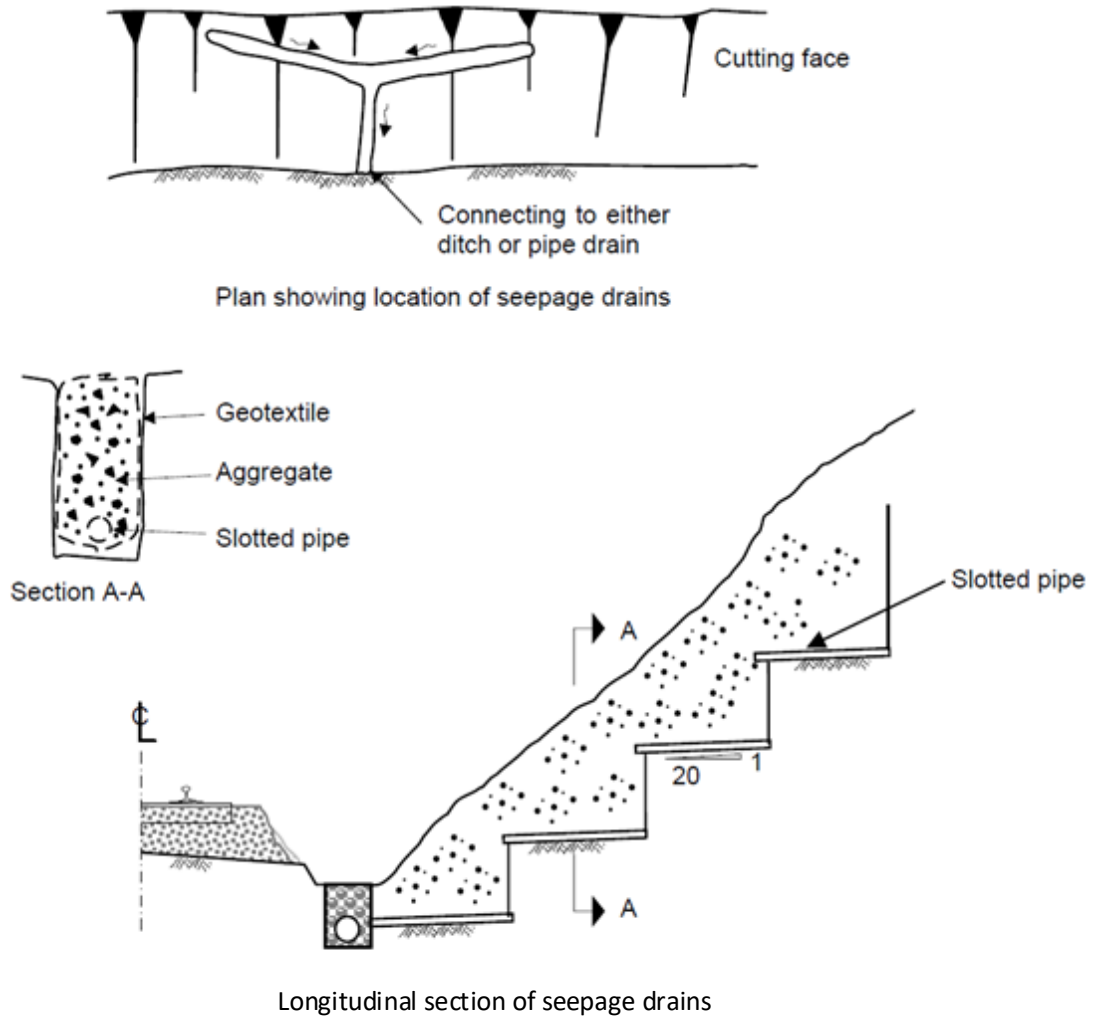


Figure 9 – Drainage of local seepage

6.2.2 Types of subsurface drains

Subsurface drains normally used for track drainage can be classified into three types according to their location and geometry as follows:

- longitudinal drain as shown in Figure 10
- transverse subsoil drain as shown in Figure 11
- drainage blankets as shown in Figure 12.

A subsurface pipe crossing under track would be classified as a transverse subsurface drain and also as a ULX. CV 0205421 provides details of transverse ULX and longitudinal subsurface pipe drain typical sections.

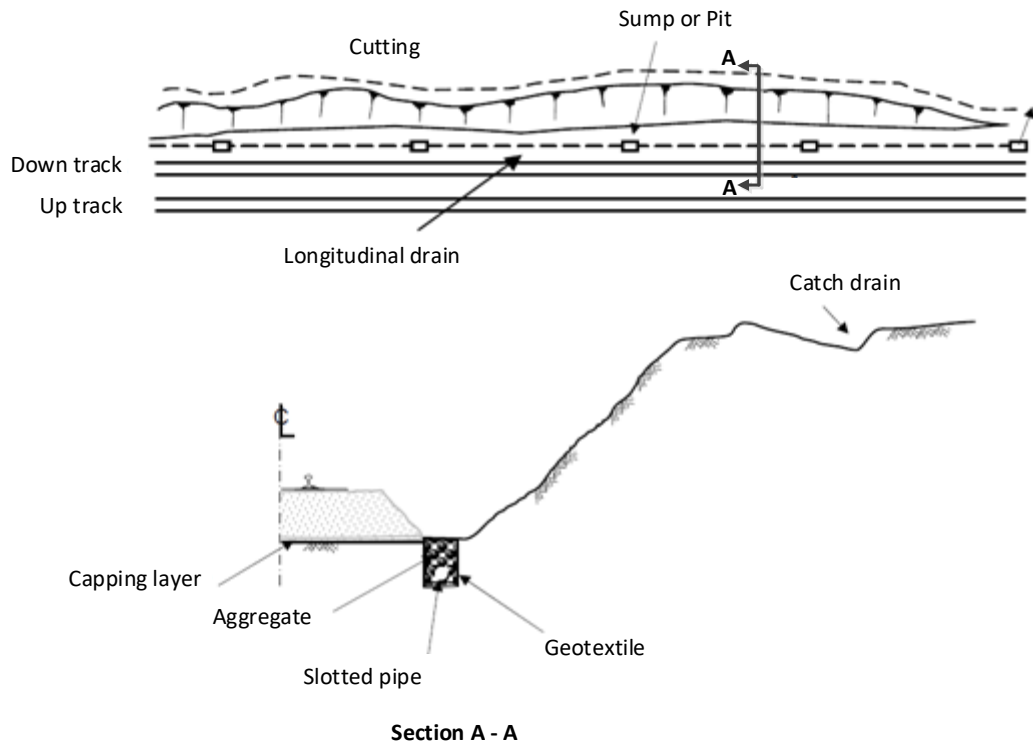


Figure 10 – Typical longitudinal drain arrangement

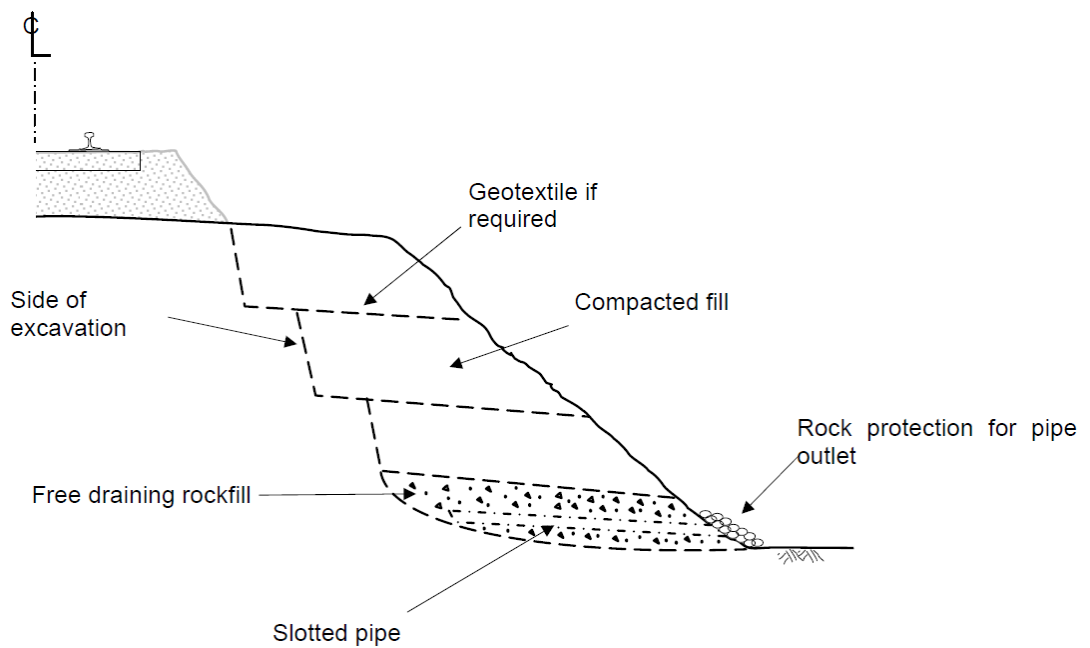


Figure 11 – Typical transverse subsoil drain

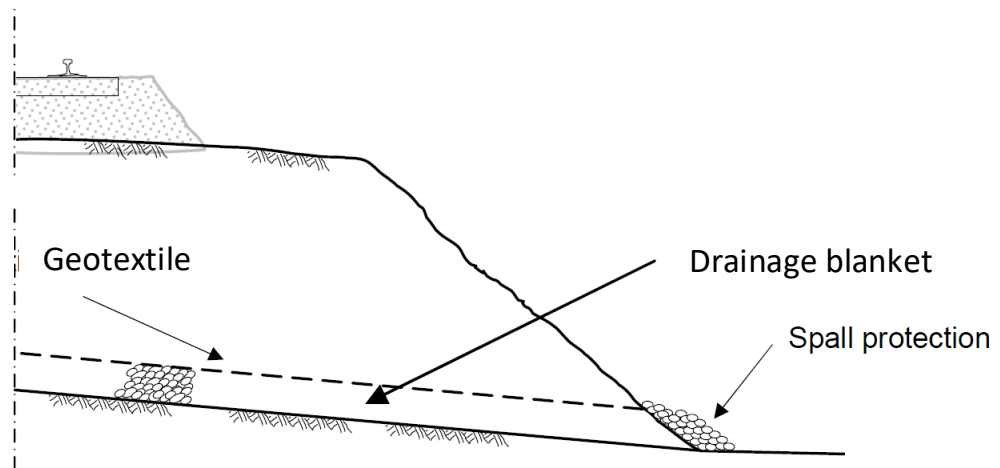


Figure 12 – Typical drainage blanket

Two other types of subsurface drainage are horizontal drains and vertical drains as shown in Figure 13.

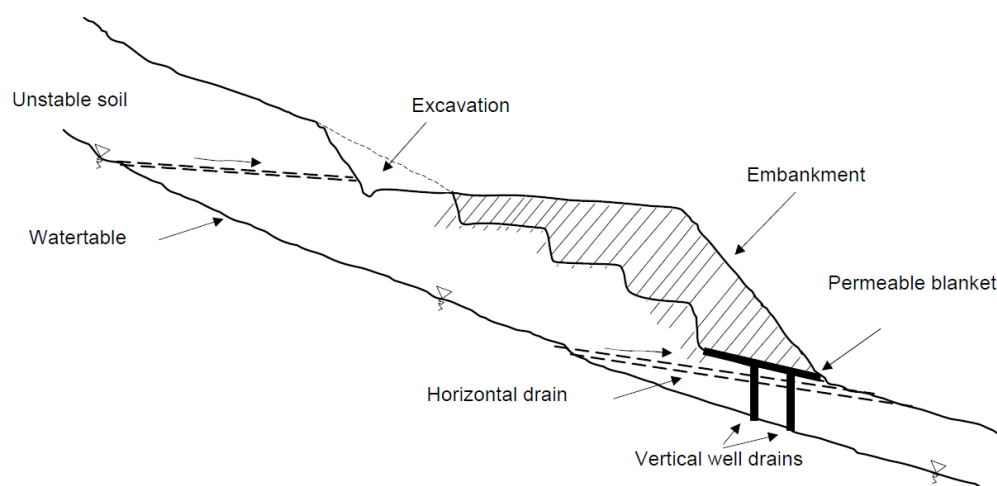


Figure 13 – Typical horizontal and vertical drain arrangement

Horizontal and vertical drains are more specialised and are seldom used for track drainage.

Horizontal drains are generally used to drain wet soils and accelerate consolidation of earth structures.

Vertical drains may also be used to accelerate consolidation. Another type of vertical drain is used to drain water from behind retaining walls or bridge abutments.

6.2.3 Subsurface drain material types

Subsurface drains can also be classified according to the materials used in the drain. For example, a subsurface drain can be classified as one of, or a combination of, the following:

- aggregate drains
- pipe drains

- geotextile drains.

6.2.3.1 Aggregate drains

Aggregate drains consist of permeable granular material. The aggregate should be coarse enough to be free draining, but not too small so as to allow the migration of fines into or through the permeable material. Nominal size gravels for aggregate drains are in TS 01638. Subsoil pipes are usually included within the aggregate zone to improve flow capacity. The graded aggregate is typically wrapped in a geotextile as shown in Figure 14.

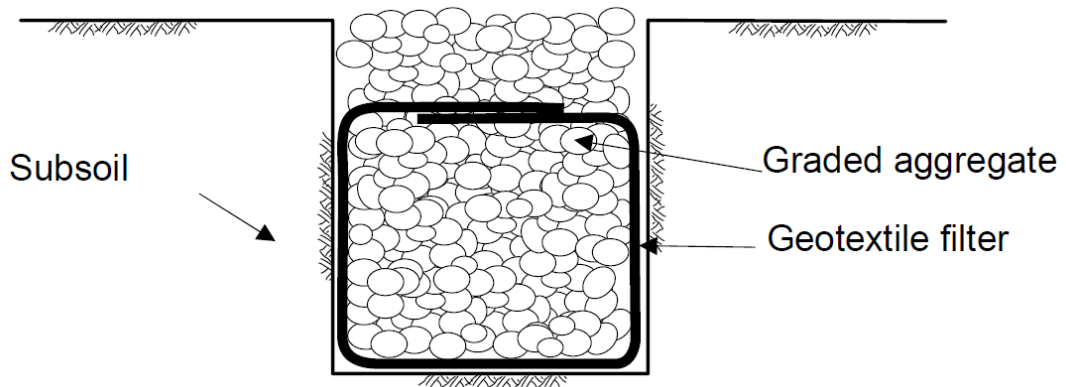


Figure 14 – Cross-section of an aggregate drain

6.2.3.2 Pipe drains

Pipe drains consist of solid, perforated or slotted pipes, installed by trenching and backfilling. Some type of filter material around the pipe or permeable backfill is normally required to minimise clogging of the drain perforations or slots. See Figure 15, Figure 16, and Figure 17 for typical piped drains installed in impervious and pervious soils.

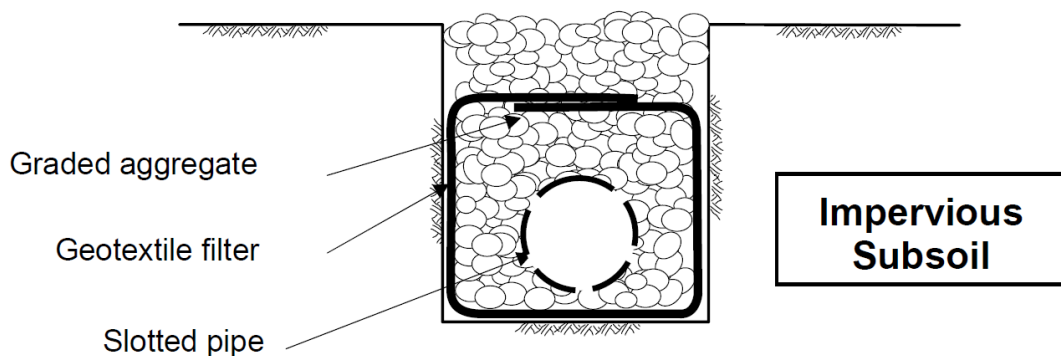


Figure 15 – Cross-section of a typical subsoil drain used in impervious soil (for example, clayey soils)

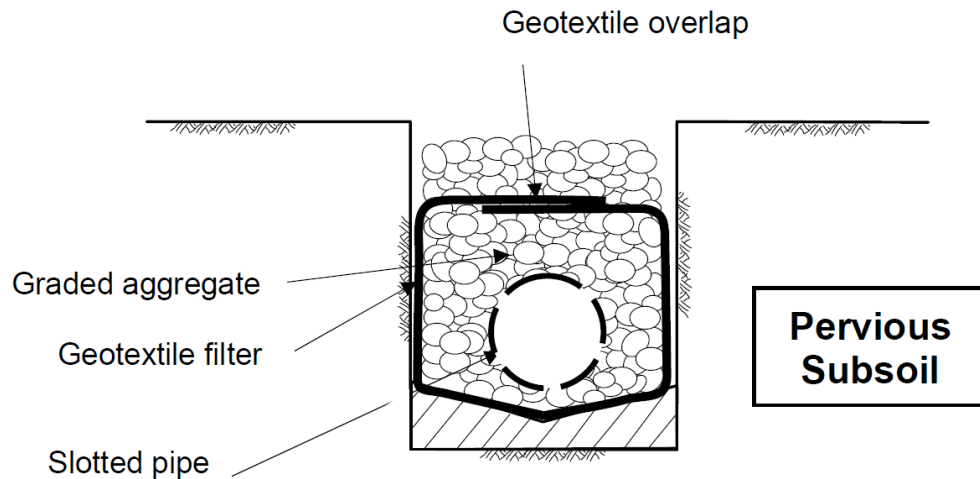


Figure 16 – Cross-section of a typical subsoil drain used in pervious soil (for example, sandy soil)

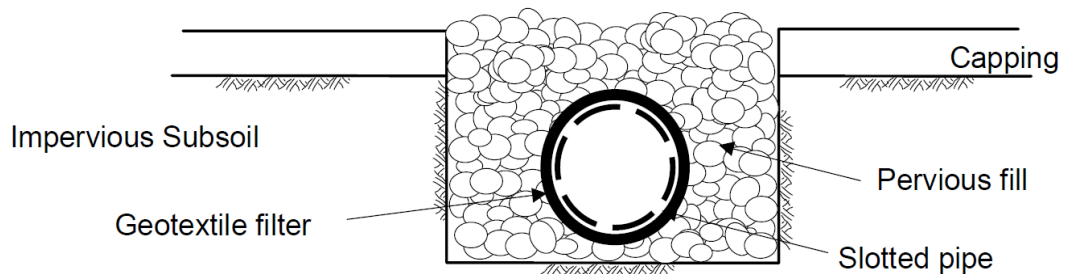


Figure 17 – Cross-section of a subsoil drain where the pipe is wrapped in geotextile (alternative slotted pipe system)

At some locations, the RIM can stipulate a larger than nominated pipe for access inspection requirements.

6.2.3.3 Geotextile drains

A geotextile drain may be a horizontal, vertical, or inclined fabric blanket installed to collect subsurface water and convey it along a falling pathway to an outlet. The drain needs to act as a filter to keep soil particles out of pores and prevent clogging. An example is shown in Figure 18.

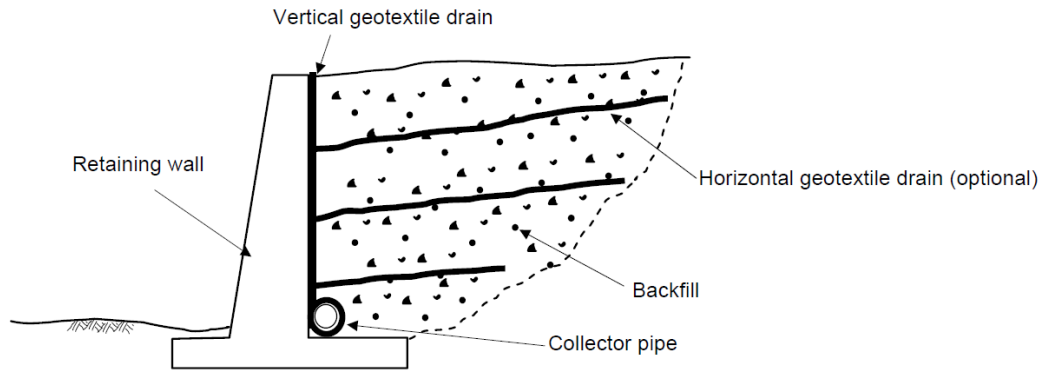


Figure 18 – Geotextile drain behind a retaining wall. A similar arrangement may be used behind bridge abutments

6.2.3.3.1 Other types of subsurface drain

Where large volumes of water may need to be removed by subsurface drains, a carrier pipe may be used in conjunction with a collector drain, as shown in Figure 19. With this arrangement the collector drain does not need to carry all the water. The advantage of this arrangement is that excess (large volumes of) water is removed from the collector drain therefore preventing it seeping into the subgrade again at a point further down the drainage route.

Figure 19 shows a typical arrangement for a collector drain and carrier pipe located between two tracks. The subsurface water is collected by the collector drain between the two sumps (pits) shown. The collector drain then conveys the water to the downstream sump (pit) where it can enter the carrier pipe and be removed without any risk of it re-entering the subgrade.

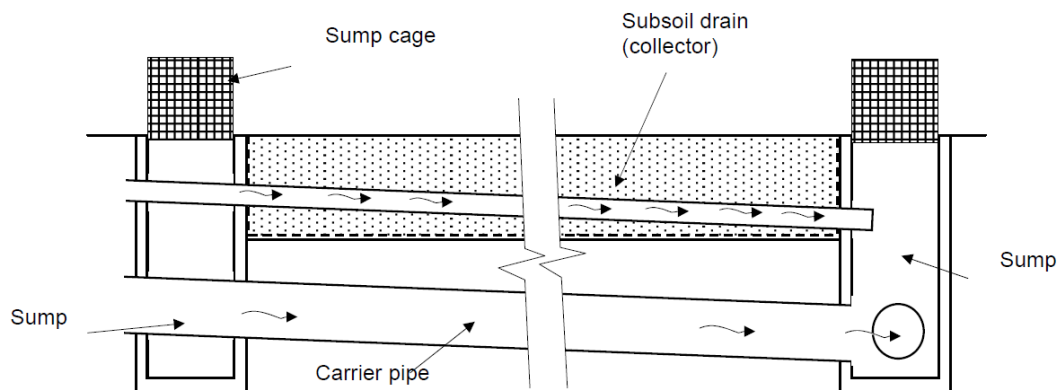


Figure 19 – Subsoil collector drain plus a larger carrier pipe

Section 8.4.10 has an example of a similar type of system used in yard drainage.

6.2.4 Inlets and outlets

There are various types of inlets and outlets in use for subsurface drains.

The main purpose of inlet and outlet protectors is to reduce erosion. As pipe embedment materials can be particularly prone to erosion, these protectors installed at the ends of pipe lines can also provide an adequate barrier to the embedment materials. Where outlet velocities are

expected to be high, some form of energy dissipater should be installed. In addition, where the sediment load of the water being discharged from a drainage system is high, a silt trap could be installed as shown in Figure 20. Whole-of-life maintenance also needs to be considered when ongoing or routine cleaning needs are introduced.

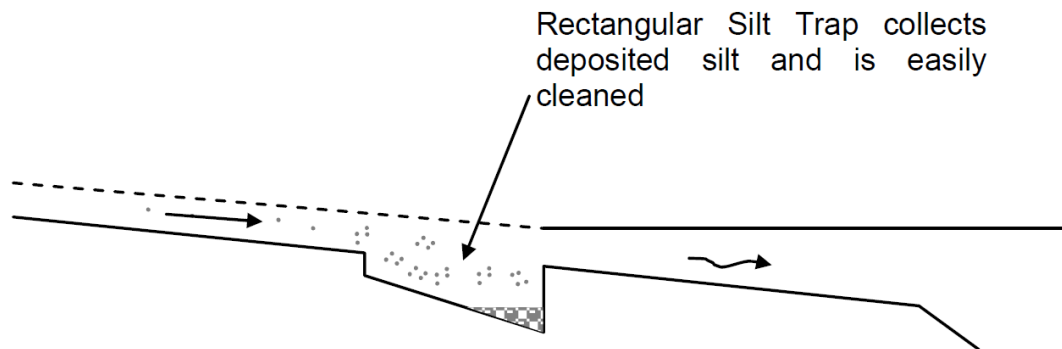


Figure 20 – Typical silt trap installed in drains with high sediment loads

Some typical examples of inlet and outlet protection are the following:

- precast or insitu concrete pits (also referred as sumps) as shown in Figure 19
- grouted sand bags as shown in Figure 21
- precast or insitu concrete headwalls as shown in Figure 22
- gabions with cut off walls as shown in Figure 23
- revetment mattress as shown in Figure 24
- spalls grouted or hand packed as shown in Figure 25.

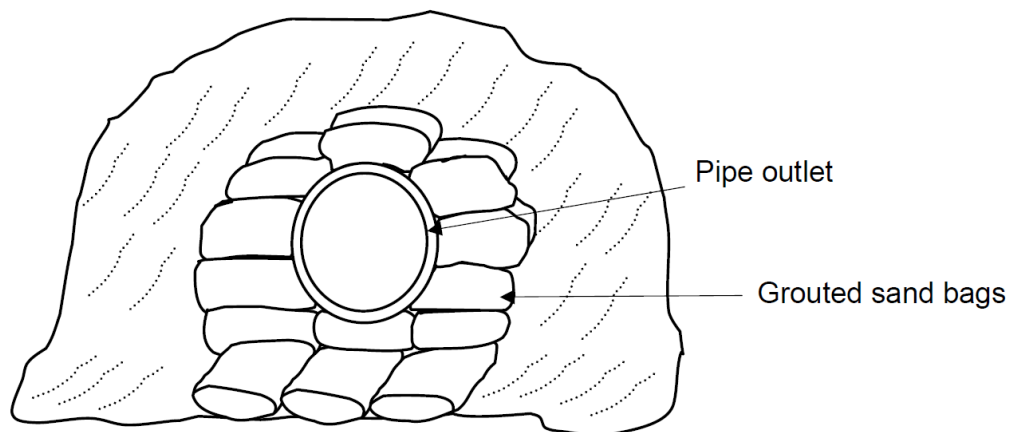


Figure 21 – Grouted sand walls

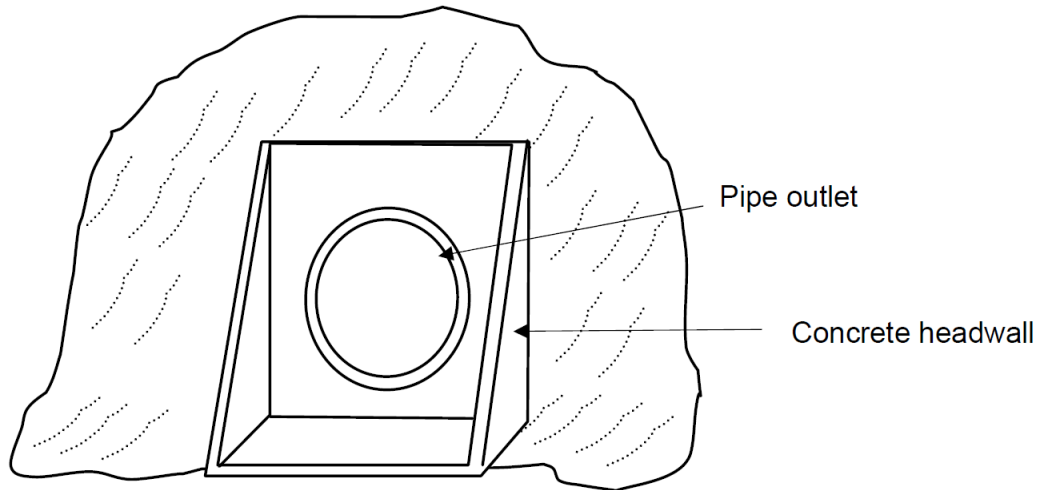


Figure 22 – Concrete headwall

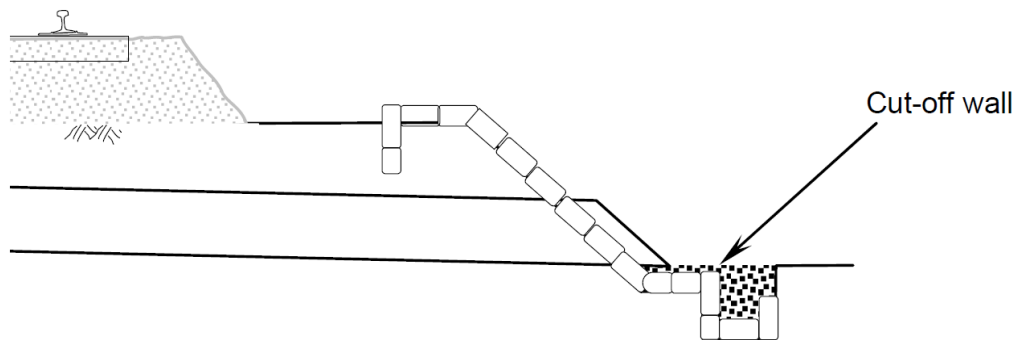


Figure 23 – Gabion headwall

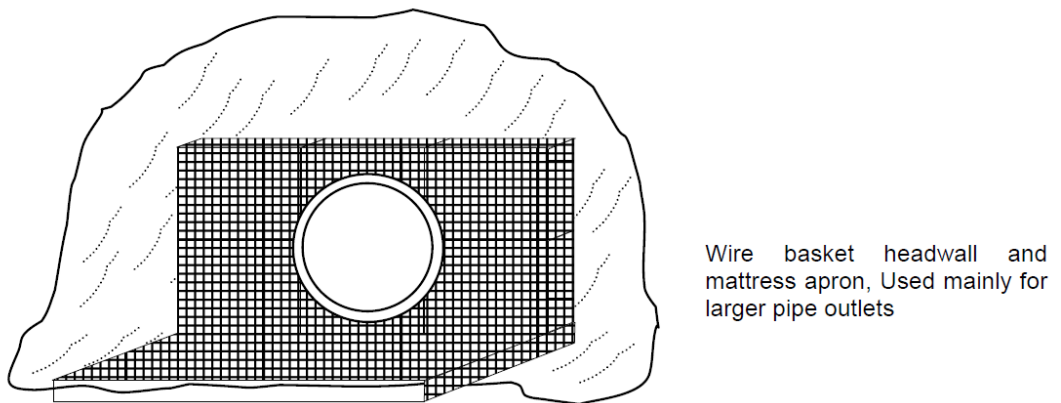
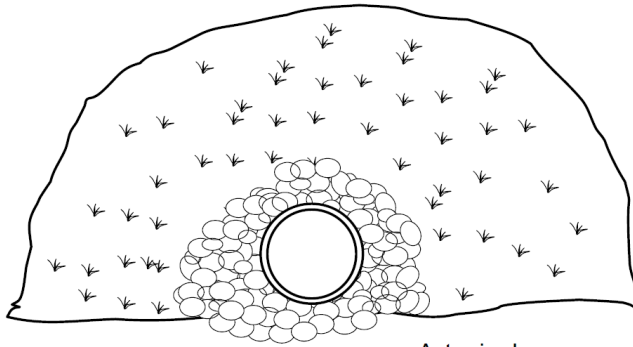


Figure 24 – Revetment mattress



A typical arrangement of hand packed walls. Cut-off wall should be provided at the bottom of the headwall to prevent the wall being scoured out and washed away, particularly on the down stream side.

Figure 25 – Spalls used as a headwall

NOTE: As mentioned in Figure 25, on the downstream side of the outlet, water getting under the headwall structure and causing scouring and the eventual washaway of the headwall is a problem that cannot be overlooked. The best way to help prevent this occurring is to provide a cut-off wall at the end of the headwall (see Figure 23 for an example).

Ballast cages (also referred to as lobster pots) are also used when inlet pits are near to ballasted track to prevent ballast spilling into the inlet pit and subsurface drainage system. TS 01638 specifies ballast cage design criteria. CV 0400998 provides details of ballast cages.

7 Design of track drainage

TS 01638 specifies design criteria for track and related structures to be drained effectively using either surface or subsurface drainage systems. Asset specific standards also specify related drainage design criteria for that asset type.

Proper drainage design, using recognised and approved design processes enables problems to be discovered early and construction to be performed easier.

Only designers with appropriate track drainage competency and experience should design track drainage systems.

The overall design process includes the initial concept through to the detailing of the drain capacity and components required.

Flow charts of the design process are provided in Appendix B.

A drainage design checklist is provided in Appendix C.

7.1 Design peak flow criteria

Track drainage system capacity is specified in TS 01638 which requires design for at least the peak flow rate calculated using the Rational Method, adopting the appropriate design ARI (or equivalent AEP) for track drainage.

The design ARI (AEP) for non-track drainage pipe culverts that cross the rail corridor such as regional or council stormwater drains are covered by TS 01713 and AS 5100. TS 01608 covers flood levels or equivalent ARI for earthwork embankments.

Where catchment areas for track drainage networks include flows from both within the rail corridor and flows from outside the rail corridor (such as regional waterways or across corridor flows), then the design ARI (AEP) for the outside rail corridor catchment area portion needs to satisfy the higher (serviceability and ultimate limit state) design requirements of TS 01713 and TS 01608. Therefore, surface and subsurface track drainage capacities often need to be increased to cater for higher flows for these catchment area combinations. For a main line track example, the minimum serviceability design peak flow rate entering needs to be based on the 100 year ARI (1% AEP) for the outside rail corridor catchment portion and the 50 year ARI (2% AEP) event for the within rail corridor catchment portion. For drainage systems with significant outside rail corridor catchment area portions, of say 25% or more of the total catchment area, then it is usually simpler and more conservative to use the 100 year ARI (1% AEP) event for all the catchment area for track drainage calculations.

When designing sizes for track drainage system components, TS 01638 includes the following:

- surface drainage flow capacity to be greater than the design peak flow rate without overtopping the channel
- drainage pits along the subsurface pipe network to not overflow at the peak flow rate
- where track is on a flood plain, the earthworks formation level not to be overtopped in a 1 in 100 year flood (via reference to TS 01608).

When sizing drains, both surface drain and subsurface drain capacities can be utilised.

General hydraulic design guidance, including freeboard provisions, is also in *Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures*.

7.1.1 Australian Rainfall and Runoff methods

ARR 1987 was completely revised in 2016 and published in 2019. ARR 2019 introduced new methods and newly refined intensity IFDs compared to ARR 1987. The RFFE method in ARR 2019 estimates simplistic flow however its applicability may not be suitable for railway track drainage. For example, rail corridor catchments typically have cleared land and include construction of drainage systems which are not applicable for the RFFE. Furthermore rail

corridor catchment areas for track drainage are typically less than 0.5 km² and therefore have lower accuracy with the RFFE method.

The Rational Method is covered in ARR 1987 and was updated in ARR 2001. The majority of existing track drainage on the network has been designed using the ARR 1987 and ARR 2001.

As the Rational Method is no longer covered in detail in ARR 2019 and as ARR 2019 methods are typically not suited for simple track drainage catchments, the Rational Method as covered by ARR 1987 and ARR 2001 and used in conjunction with the associated 1987 IFDs are still adopted for typical track drainage flow estimations. The 2016 IFDs associated with ARR 2019 are reported to estimate peak flow rates less than 1987 IFDs. For new track drainage designs, peak flow rate or discharge rate determined using both ARR 2019 and ARR 1987 respective IFDs should be assessed and compared in the hydrological investigation, however the greater or more conservative peak flow discharge rate should be adopted for design.

The ARR Data Hub, accessed by searching the ARR website, can be used as a tool for design inputs. The Bureau of Meteorology website contains the 1987 and the more recent 2016 IFDs.

Comparison of hydrology methods for road drainage and flood design are also in *Guide to Road Design Part 5: Drainage: General and Hydrology Considerations* which describes the limited use for the Rational Method for small catchments and use of either the RFFE or runoff routing methods for larger or more complex rural and urban catchments. Additional information on the Rational Method background and application is also covered in *Guide to Road Design Part 5: Drainage: General and Hydrology Considerations*.

7.1.2 Climate change

Climate change assessment ensures drainage infrastructure can be resilient to climate change impacts. Guidance for climate change considerations in flood estimation are covered generally in ARR 2019 and more specifically in chapter 6 of Book 1 in ARR 2019. Depending on the track drainage whole-of-life risks for the site, climate change effects can be estimated by the designer. For design guidance only, some potential drainage design adjustment considerations can include the following:

- rainfall intensity increase of ARR 2019 or ARR 1987 data by a nominal factor (estimated increases have been reported as say 10% minimum approximately)
- assume a design peak rate of discharge for the next less frequent storm event indicator, for example, assume a 100 year ARI (1% AEP), rather than a 50 year ARI (2% AEP) design event
- sea level rise to align with proven local NSW rates of increase (estimated long term trend increase rates which have been reported up to around 1 mm/year, and future predictions can be obtained and estimated from tide data records and reports such as related to Fort Denison, Sydney)

- sea level change due to potential atmospheric pressure storm surge (estimated sea level differences have been reported as approximately 100 mm linked to a pressure change of 10 hPa)
- future projected rates of rainfall intensity and sea level change factors (such as estimated from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Meteorology (BOM))
- recommendations from TfNSW technical guides for climate change adaption or similar publications
- enhanced design life of the drainage structure for a project specified durability.

Any adjustments due to climate change need to be explained and reasoned within the associated design report. Design stormwater flows and water levels for both the estimated climate change case and the case without climate change allowances should be included in design reports.

When undertaking climate change risk assessments, guidance on the approach can be obtained from AS 5334 and *Guide to Climate Change Risk Assessment for NSW Local Government*.

7.1.3 Surface drainage design

Refer to TS 01638 for surface drainage design including cess drains, catch drains and mitre drains.

Figure 26 shows the dimensions of two channel types, trapezoidal and rectangular for cess drains. If concrete is used to form a channel, then the dimension 'B' may be reduced to zero thereby producing a vertical face.

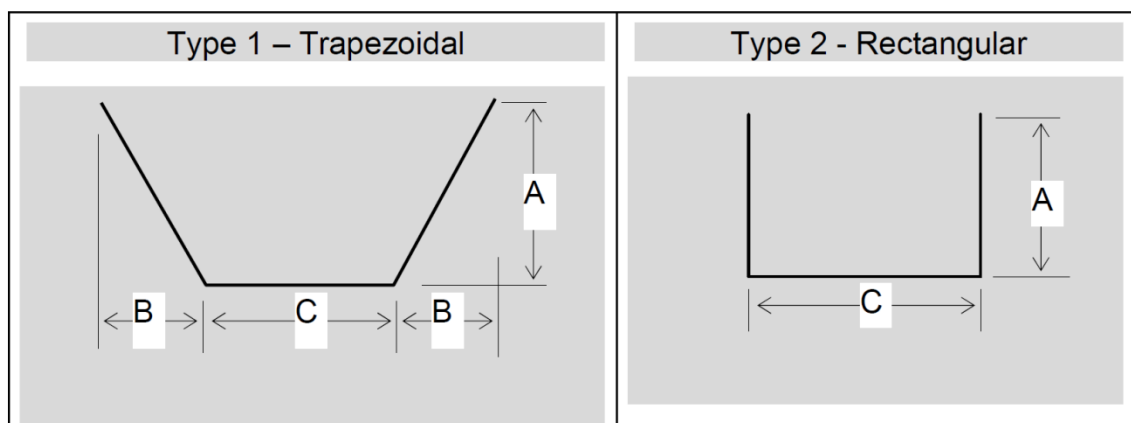


Figure 26 – Channel types

For catch drains and batter drains, half round pipes can be used as noted in TS 01638. Half round pipes are typically manufactured from a full-sized pipe. Design aspects for half round pipes includes size selection for peak flow rates, potential blockages, soil scouring, erosion,

ground anchoring and durability to satisfy heavy rail standard requirements. For ease of maintenance and allowances for blockages, over-sized half pipes are used and are typically at least 225 mm diameter.

7.1.4 Subsurface drainage design

Refer to TS 01638 for subsurface drainage design.

Design criteria for subsurface drains includes the following:

- traffic loads, including construction traffic
- pipes
- trenching
- backfill
- pipe embedment
- inlets and outlets
- pits
- aggregate drains
- flushing points
- geotextiles.

After the layout and required capacity of the drain has been established, it is necessary to detail the various items that will make up the system. This enables the correct components to be ordered quickly in the construction phase.

General underground piped network guidance, including subsurface drainage and pipe velocity provisions are also in *Guide to Road Design Part 5A: Drainage: Road Surface, Networks, Basins and Subsurface*. General guidance for design of plastic pipes is in AP-R575-18.

7.2 Design investigation

Design investigation involves establishing the scope of the investigation and the type and characteristics of drainage system required.

7.2.1 Scope of investigation

The main objective of a design investigation is to establish the requirements of the drainage system and any restrictions that may be imposed on the system.

Aspects that need to be covered in the design investigation can include the following:

- Problem identification.

That is the drainage objective, what area is to be drained and for what reason.

- Determination of the information required.

That is, location, outside influences, fall available, possible outlets, access, site safety requirements, and so forth.

- Collection and study of all available existing information.

All available information from adjacent sites and the locality in general needs to be studied before embarking on any fieldwork. This will often save unnecessary fieldwork or may point out particular problems or aspects that should receive special attention.

Included in this stage is a full services search which involves the check of the location of both TfNSW and public utility services. This may also involve site inspections with representatives from various bodies to accurately locate services and the positions then be marked, either on a plan or pegged. Services search information is also covered in TS 02390.

Other types of information that may be of use are aerial photographs, maps (topographic, geological, soil, and so forth), charts, and meteorological and hydrological information.

- Site inspection.

A checklist prepared prior to the actual site investigation so that the maximum amount of information can be extracted from the site in a minimum time (see the form in Appendix D).

- Items to be investigated during a site inspection can include the following:
 - access to and from the proposed site and any possible restrictions
 - existing natural drainage paths and risks associated with any diversion
 - type and location of any existing flow paths, drainage systems and any possible reasons for its failure
 - the position and condition of any existing drainage outlets
 - any other likely drainage outlets, their conditions and any likely restrictions because these may affect the design of the drainage system
 - adjacent structures that may impact on the drainage design, or where the drainage design may cause instability to the structure

- Catchment area estimation.

The catchment area for the drainage system needs to be estimated during the site inspection. This may be checked by comparison with maps of the area.

A further inspection may be required at a later stage so that the applicable area can be appropriately surveyed to establish the available fall and invert level for the inlet and outlet.

7.2.2 Determination of the type of drainage system required

On completion of the design investigation, information gathered is to be compiled and a decision made on the type of drainage system that is most suitable.

The type of system chosen for each location is dependent on the site restraints, water source, track structure, and long-term maintenance issues. The two types of drainage systems are surface and subsurface.

If possible, surface drains are typically used in preference to subsurface drains since surface drains are easily inspected and maintained. The available cross section area for flow along surface drains is often more than subsurface drains and combinations can also be an alternative for some constrained sites.

Note: Care needs to be taken to ensure that the right drainage system is designed for each location. For example, using a slotted system to drain surface run-off may not be the best solution that could have been collected by pits with unslotted carrier pipes or even a surface only drainage system. Slotted pipes could lead to a quicker failure of the system by allowing an easier route for water to pass (seep) into the formation.

7.3 Estimation of the required drainage system capacity

At this point, the site requirements and restrictions, the drainage type, and the layout of the proposed drainage system should be known.

The next step is to estimate the quantity of water that the drain will need to carry, so that the size of the drain and its various components may be determined.

The quantity of water (Q_{PF}) that the drain is required to carry generally is given by Equation 1.

$$Q_{PF} = Q_R + Q_S + Q_C$$

Equation 1 – Quantity of water that a drain is required to carry at peak flow

Where:

Q_{PF} = water quantity (m^3/s or l/s)

Q_R = run-off quantity collected (m^3/s or l/s)

Q_S = subsurface water quantity intercepted (m^3/s or l/s)

Q_C = collected water quantity from a drain of a connecting system (m^3/s or l/s)

The calculated quantity (Q_{PF}) represents the peak flow that the drain will be required to carry, for a short time only.

The quantity (Q_R) is calculated for the catchment size and critical rainfall duration by using the Rational Method.

The value of intercepted subsurface water ' Q_s ' is difficult to determine. If a drainage system is required to remove intercepted subsurface water, a detailed hydrological investigation or geotechnical investigation, or both is usually required.

The volume of water conducted from other systems, ' Q_c ', is estimated from the outlet capacity of the system to which the new system is being connected. Provided the catchment area, drain size, and slope are known (or can be measured), the maximum value of ' Q_c ' can be determined using the Rational Method. This information may also be available from the authority owning the asset (such as a council).

If the connecting system is a complex network of drainage, a detailed study may be required.

Account needs to be taken of all water flowing onto the rail corridor from adjoining properties and streets.

Potential blockages such as those due to accumulation of sediments and debris within surface and subsurface drains can be accounted for by reducing the available cross-sectional area for the estimation calculations for trial drain size and water velocity steps. Minimum potential blockage percentages are in TS 01638.

Separate estimations are applicable for the cases with and without climate change allowances, see Section 7.1.2.

7.3.1 Average recurrence interval

To use the Rational Method, it is necessary to adopt a relevant ARI or equivalent AEP. This is an approximate estimate of how often a particular event will occur on average. For example, an ARI of 1 in 50 years means that a particular storm event is likely to occur on average only once in every fifty years (not necessarily every fifty years). A 50 year ARI is equivalent to a 2% AEP event and can also be described as, for any given year there is a 2% chance of this flood event occurring or being exceeded. There is also a chance that a 50 year ARI (2% AEP) storm event could occur more than once in a single year.

Comparison of ARI and AEP equivalent values and preferred terminology are covered in figure 1.2.1 in ARR 2019.

The probability terms used in this manual are the same as those adopted in ARR and the *Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures*.

7.3.2 The Rational Method

The Rational Method provides a method for calculating the peak rate of discharge of a storm event for a specific ARI or AEP. This simplistic method used for small catchments derives a peak flow rate and does not include temporal pattern zones nor routing models that are used in other hydrological models.

If incorporating computer modelling in the design process, then a range of storm events representing varying rainfall duration needs to be investigated. The drainage design will be carried out adopting the critical rainfall event.

Hydrology and hydraulic computer packages can be utilised for the design of track drainage. The following procedure deals with hand calculation methods only.

The Rational Method is detailed fully in *Australian Rainfall and Runoff* (ARR 1987 and ARR 2001). For some comparison of ARR methods, including the Rational Method IFD use, see Section 7.1.1.

The ARR 2001 publication recommends the following steps for flow rate determination for sites in eastern New South Wales (the form in Appendix E breaks down these steps and can be used as a calculation sheet):

1. Calculate the critical rainfall duration (t_c) for the area under investigation

Two methods may be adopted to calculate the critical rainfall duration. These methods are the following:

- equal area stream slope – recommended for hilly or undulating sites as it gives a more realistic flow response time (refer to ARR 2001 for this procedure)
- basic formulae (for Eastern New South Wales), given by Equation 2.

$$t_c = 0.76 A^{0.38}$$

Equation 2 – Critical rainfall duration – basic formula for Eastern NSW

Where:

t_c = critical rainfall duration (in hours)

A = catchment area (km²)

The catchment areas required for peak flow rate calculations need to be determined using (in order of preference) site survey, site measurements, or suitably scaled topographic maps.

2. Calculate the critical 50 year design rainfall intensity ($I_{cr,50}$)

This step comprises of looking up a series of basic rainfall intensities, skewness factors, and geographical factors from contour style maps found in Volume 2 of the ARR 2001 guide.

These values can be plotted on a log-Pearson Type III diagram (LP III) or incorporated in interpolation formulas found in Book 2 of ARR 2001 volume 1.

From either of these two methods the 50 year design rainfall intensity ' $I_{cr,50}$ ' for the critical duration t_c can be determined.

3. Determine the 50 year run-off coefficient (C50) for the geographical area by determining the following:

- read the 10 year run-off coefficient value (C_{10}) from Figure 1.1 in Volume 2 of the ARR 2001
 - geographical zone B is adopted from Figure 1.2 ARR 2001 – for Sydney Metropolitan Area
 - interpolate or calculate the 50 year frequency factor FF_{50} from Table 1.1 ARR 2001 based on site elevation
 - calculate $C_{50} = C_{10} \times FF_{50}$ (no units)
4. Calculate the 50 year peak flow rate (Q_{50})

Adopt the Rational Method formula, given by Equation 3.

$$Q_{50} = F \times C_{50} \times I_{cr,50} \times A$$

Equation 3 – Rational Method formula

Where:

Q_{50} = peak flow rate (m^3/s) for ARI = 50 years

F = conversion factor to balance units used.

= 0.278 if A is in km^2

= 0.000278 if A is in hectares (ha)

C_{50} = run-off co-efficient for ARI = 50 years

$I_{cr,50}$ = average rainfall intensity (mm/h) for the critical duration

A = catchment area (km^2 or ha)

The peak flow rate is used in determining how much water is likely to rain onto a catchment and therefore enabling the sizing of the drainage system under consideration.

7.4 Estimating surface drain size

The steps outlined in Section 7.4.1 to Section 7.4.8 are used to determine the required size of surface drainage.

7.4.1 Step A: Determine the required channel capacity

Prior to estimating the size of a surface drain, the required capacity either needs to be known or calculated using Equation 1.

For surface drains, ' Q_s ' and ' Q_c ' can usually be neglected. In this case, Equation 1 becomes $Q_{PF} = Q_R = \text{Peak flow rate } (m^3/s)$.

7.4.1.1 Example 1

A rainfall run-off quantity of 0.15 m³/s was calculated to act on a catchment for the 50 year ARI critical duration storm (from the Rational Method). There is no subsurface water intercepted, but a nearby stormwater pipeline enters the channel and adds 0.07 m³/s. What is the total water quantity the channel will need to be designed for?

7.4.1.2 Solution 1

The design flow capacity can be determined from Equation 1.

$$Q_{PF} = Q_R + Q_S + Q_C = 0.15 + 0 + 0.07 = 0.22 \text{ m}^3/\text{s}.$$

The channel will need to be sized to take a 0.22 m³/s flow rate or greater.

7.4.2 Step B: Select a Manning's roughness coefficient

A value of the roughness coefficient 'n' can then be selected from Table 1 to Table 5 depending on the pipe or channel type.

Table 1 – Manning's roughness coefficient – closed conduits

Channel material	Roughness coefficient 'n'
concrete pipe or box	0.012
corrugated steel pipe – helical	0.020
vitrified clay pipe	0.012
HDPE pipe	0.012
fibre cement pipe	0.010
P.V.C. pipe	0.009
steel pipe	0.009 – 0.011

Table 2 – Manning's roughness coefficient – lined open channels

Channel material	Roughness coefficient 'n'
concrete lining	0.013 – 0.017
gravel bottom concrete sides	0.017 – 0.020
gravel bottom rip rap sides	0.023 – 0.033
asphalt rough	0.016
asphalt smooth	0.013

Table 3 – Manning's roughness coefficient – unlined channels – earth uniform section

Channel material	Roughness coefficient 'n'
clean channel	0.016 – 0.018
with short grass	0.022 – 0.027

Channel material	Roughness coefficient 'n'
gravelly soil	0.022 – 0.025

Table 4 – Manning's roughness coefficient – unlined channels – earth fairly uniform section

Channel material	Roughness coefficient 'n'
no vegetation	0.022 – 0.025
grass plus some weeds	0.030 – 0.035
dense weeds	0.030 – 0.035
clean sides gravel bottom	0.025 – 0.030
clean sides cobble bottom	0.030 – 0.040

Table 5 – Manning's roughness coefficient – rock surfaced channels

Channel material	Roughness coefficient 'n'
smooth and uniform	0.035 – 0.040
jagged and irregular	0.040 – 0.045

For guidance, tables 6.2.1, 6.2.2 and 6.2.3 in ARR 2019 also includes roughness coefficient values for various surfaces.

7.4.3 Step C: Determine the slope of the drain

The minimum slope of a drain is 1 in 200 (that is, 1 m fall vertically for every 200 m horizontally), though a minimum slope of 1 in 100 is preferred for self-cleaning purposes. It should be noted that as the slope of the drain becomes flatter, the tendency for a drain to become blocked due to sediment build-up increases. Consequently, the maintenance of the drain also increases.

For drain self-cleaning, design water velocities of approximately at least 0.6 m/s during low ARI storm events of say 6 months can also assist.

7.4.4 Step D: Select a trial channel size

Using the value of slope 'S' and the roughness coefficient 'n' selected previously, the capacity of the trial drain can be calculated using Equation 4 (Manning's formula) or a simplified version using Equation 5.

$$Q = (1/n) \times A \times R^{0.87} \times S^{0.5}$$

Equation 4 – Manning's formula

Where:

Q = flow rate or capacity (m³/s)

n = roughness co-efficient. From Table 1, Table 2, Table 3, Table 4 or Table 5

A = channel cross-sectional area

R = hydraulic radius – examples given in Table 6

R = A/P where P = wetted perimeter (that is, the surface in contact with the water)

S = slope of the drain

If $X = A \times R^{0.67}$ then Equation 4 becomes:

$$Q = (1/n) \times X \times S^{0.5}$$

Equation 5 – Simplified version of Manning's formula

See Table 6 for values of 'X' for various channels. See Figure 26 – Channel types for a review of the trapezoidal and rectangular channel types referred to in Table 6.

Table 6 – Calculation of X value for various channel sizes

No.	Channel dimension (mm) 'A'	Channel dimension (mm) 'B'	Channel dimension (mm) 'C'	Area (m ²)	Wetted perimeter (m)	Hydraulic radius (m)	X (eqn 5)
1	200	-	300	0.060	0.700	0.086	0.012
2	200	-	450	0.090	0.850	0.106	0.020
3	200	200	300	0.100	0.860	0.115	0.024
4	200	300	300	0.120	1.021	0.118	0.029
5	200	200	450	0.130	1.016	0.128	0.033
6	300	-	450	0.135	1.050	0.129	0.034
7	300	200	300	0.150	1.021	0.147	0.042
8	300	300	300	0.180	1.149	0.157	0.052
9	450	-	450	0.203	1.350	0.150	0.057
10	300	200	450	0.195	1.171	0.167	0.059
11	300	450	300	0.225	1.382	0.163	0.067
12	300	300	450	0.225	1.299	0.173	0.070
13	300	200	600	0.240	1.321	0.182	0.077
14	300	450	450	0.270	1.532	0.176	0.085
15	450	-	600	0.270	1.500	0.180	0.086
16	300	300	600	0.270	1.449	0.186	0.088
17	300	450	600	0.315	1.682	0.187	0.103
18	300	200	900	0.330	1.621	0.204	0.114
19	450	300	450	0.338	1.532	0.220	0.123
20	300	300	900	0.360	1.749	0.206	0.125
21	450	-	900	0.405	1.800	0.225	0.150

No.	Channel dimension (mm) 'A'	Channel dimension (mm) 'B'	Channel dimension (mm) 'C'	Area (m ²)	Wetted perimeter (m)	Hydraulic radius (m)	X (eqn 5)
22	450	450	450	0.405	1.723	0.235	0.154
23	450	300	600	0.405	1.682	0.241	0.157
24	300	450	900	0.405	1.441	0.281	0.174
25	450	450	600	0.473	1.873	0.252	0.188
26	450	300	900	0.540	1.982	0.272	0.227
27	450	450	900	0.608	2.173	0.280	0.260
28	600	600	600	0.720	2.297	0.313	0.332
29	600	600	900	0.900	2.597	0.347	0.440

Note: Smaller channels tend to become blocked with built up sediment very quickly.

7.4.4.1 Example 2

For a trapezoidal channel (shown in Figure 27) with a slope of 1 in 200 and a roughness coefficient 'n' of 0.030. Calculate the channel capacity using Equation 4 and Equation 5 with Table 6.

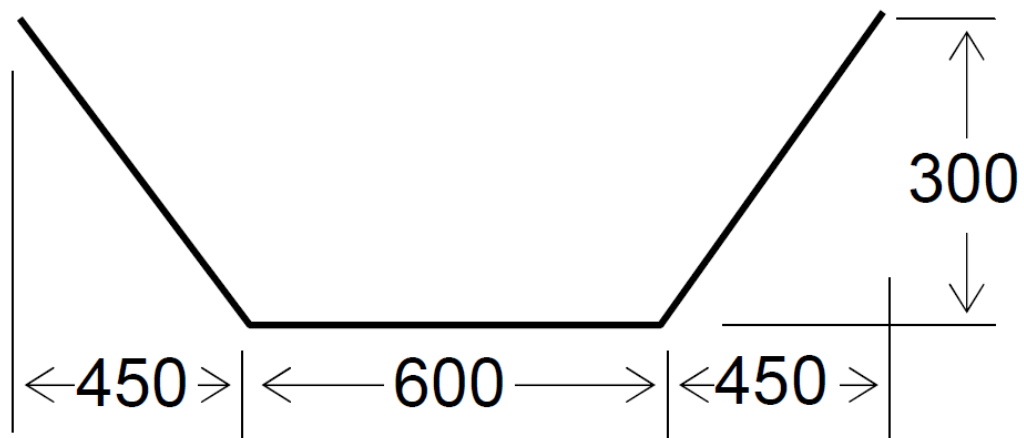


Figure 27 – Sample trapezoidal channel

7.4.4.2 Solution 2 – using Equation 4

The inputs and calculations and the solution to Example 2 using Equation 4 is as follows:

$$S = 1 \text{ in } 200 = 0.005$$

$$n = 0.030$$

$$A = (600 \times 300) + 2 \times (0.5 \times 300 \times 450)$$

$$A = 315,000 \text{ mm}^2$$

$$A = 0.315 \text{ m}^2$$

$$R = A/P$$

$$P = 2 \times \sqrt{((300) \times 2 + (450) \times 2) + 600}$$

$$P = 1682 \text{ mm}$$

$$P = 1.682 \text{ m}$$

$$R = 0.315 / 1.682$$

$$R = 0.187 \text{ m}$$

$$Q = 1/n \times A \times R^{0.67} S^{0.5}$$

$$Q = 1/0.03 \times 0.315 \times (0.187)^{0.67} \times (0.005)^{0.5}$$

$$Q = 0.243 \text{ (m}^3\text{/s)}$$

7.4.4.3 Solution 2 – using Equation 5 and Table 6

The inputs and calculations and the solution to Example 2 using Equation 5 and Table 6 is as follows:

$$S = 0.005$$

$$n = 0.030$$

$$\text{From Table 6, } X = 0.103$$

Equation 5

$$Q = 1/n \times X \times S^{0.5}$$

$$Q = 1/0.03 \times (0.103) \times (0.005)^{0.5}$$

$$Q = 0.243 \text{ (m}^3\text{/s)}$$

7.4.5 Step E: Check channel capacities

Once the capacity of the trial drain is determined 'Q' it will be compared with the required capacity found using Equation 1 'Q_{PF}'. If the capacity of the trial drain 'Q_{PF}' is considerably greater or lesser than the required capacity 'Q', then a new trial drain should be selected and steps (c) and (d) repeated until the trial capacity is approximately equal to or slightly greater than the required capacity.

7.4.5.1 Example 3

Check that the channel in Example 2 has sufficient capacity to cater for the design storm as calculated in Example 1.

7.4.5.2 Solution 3

The channel capacity 'Q' of 0.243 m³/s (Example 2) is greater than the design storm flow rate 'Q_{PF}' of 0.220 m³/s (Example 1). Therefore, it has sufficient capacity.

7.4.6 Step F: Calculate water velocities

Once the required capacity is obtained, the flow velocity of water within the channel may be calculated.

The velocity is calculated using Equation 6.

$$V = Q / A$$

Equation 6 – Flow velocity of water

Where:

V = velocity (m/s)

Q = flow rate (m³/s) calculated using Equation 1

A = area of selected channel (m²)

7.4.6.1 Example 4

Calculate the flow velocity of water within the channel in Example 2.

7.4.6.2 Solution 4

Q = 0.22 m³/s

A = 0.315 m² (from example 1 – assumed flowing full)

V = Q/A = 0.220/0.315 = 0.69 m/s

7.4.7 Step G: Check channel lining

In some cases, it may only be possible to install a small drain and the flow through this drain may have a velocity greater than the maximum permissible velocity, and consequently the channel needs to be lined.

Table 7 shows the maximum permissible velocity of varying ground coverings.

Table 7 – Maximum permissible velocities for various types of channel lining

Channel type	Velocity (m/s)
Fine sand	0.45
Silt loam	0.60
Fine gravel	0.75
Stiff clay	0.90
Coarse gravel	1.20
Shale, hardpan	1.50
Grass Covered	1.8

Channel type	Velocity (m/s)
Stones	2.5
Asphalt	3.0
Boulders	5.0
Concrete	6.0

Lining a channel changes the roughness coefficient 'n', and therefore the capacity of the channel may be altered either up or down (See Table 1 to Table 5).

A lining is selected such that the allowable velocity for the type of lining is greater than that calculated in step F. This is used as a first trial value.

7.4.7.1 Example 5

The channel in example 4 is lined with grass covering. Is it sufficient to withstand the flow velocity?

7.4.7.2 Solution 5

Velocity of water in channel = 0.69 m/s (solution 4).

The maximum permissible velocity of grass lining = 1.8 m/s (Table 7).

Therefore, grass has the required resistance and the lining is sufficient.

7.4.8 Step H: Completion

If the capacity of the channel is inadequate or the ground cover velocity insufficient then modifying the channel size, slope, or lining type will need to be done until all aspects are satisfactory.

7.4.9 Complete example

The following is a complete example.

7.4.9.1 Example 6

Calculate the required channel size and lining type given that the required capacity of the channel is 0.40 m³/s. The existing soil is clay.

7.4.9.2 Solution 6:

Trial 1: Try unlined with existing earth clay soil

Step A: No subsurface water or connecting system. So $Q_{PF} = 0.40 \text{ m}^3/\text{s}$

Step B: $n = 0.016$ (Table 3)

Step C: Adopt $S = 0.01$ (desirable minimum slope)

Step D: Select channel no. 14 from Table 6. $A = 0.270 \text{ m}^2$. $X = 0.085$

$$Q = 1/n \times X \times S^{0.5} = (1/0.016) \times (0.085) \times (0.01)^{0.5} = 0.53 \text{ m}^3/\text{s} \text{ (Equation 5)}$$

Step E: Channel capacity $0.53 \text{ m}^3/\text{s} >$ design capacity $0.40 \text{ m}^3/\text{s}$. Okay.

Step F: $V = Q/A = 0.40/0.270 = 1.48 \text{ m/s}$ (Equation 6)

Step G: Clay has permissible velocity capacity of 0.9 m/s (Table 7) which is less than the design flow of 1.48 m/s . Therefore could modify size or change lining. Opt for a change of lining type to grass covered (capacity 1.8 m/s).

Step H: Need to redo calculations, as n will change

Trial 2: Try lining with higher permissible velocity – say grass lining

Steps A, B & C: $Q_{PF} = 0.40 \text{ m}^3/\text{s}$. $n = 0.024$ (Table 3). $S = 0.01$

Step D: Same channel no. 14 from Table 6. $A = 0.270 \text{ m}^2$. $X = 0.085$

$$Q = (1/0.024) \times (0.085) \times (0.01)^{0.5} = 0.35 \text{ m}^3/\text{s} \text{ (Equation 5)}$$

$< 0.4 \text{ m}^3/\text{s}$ therefore no good. Could modify size or change lining.

Noting that grass lining on clay will likely need special treatment for a practical solution.

Trial 3: Try smoother lining, with high permissible velocity – say smooth asphalt

Steps A, B & C: $Q_{PF} = 0.40 \text{ m}^3/\text{s}$. $n = 0.013$ (Table 2). $S = 0.01$

Step D: Same channel no. 14 from Table 6. $A = 0.270 \text{ m}^2$. $X = 0.085$

$$Q = (1/0.013) \times (0.085) \times (0.01)^{0.5} = 0.65 \text{ m}^3/\text{s} \text{ (Equation 5)}$$

Step E: Channel capacity $0.65 \text{ m}^3/\text{s} >$ design capacity $0.40 \text{ m}^3/\text{s}$. Okay.

Step F: $V = Q/A = 0.40/0.270 = 1.48 \text{ m/s}$ (Equation 6)

Step G: Asphalt has capacity of 3.0 m/s (Table 7) which is greater than the design flow of 1.48 m/s . Therefore, it is satisfactory.

Step H: Channel no. 14 laid in bitumen at a 1% slope is satisfactory.

7.5 Estimating subsurface drain size

Subsurface drain design involves calculating the required size of pipe drains and aggregate drains, taking into consideration capacity, type, roughness coefficient, slope, strength, and environment. The steps outlined in Section 7.5.1 are used to determine the required size of subsurface drainage pipes.

7.5.1 Pipe drains

7.5.1.1 Step A: Determine the required pipe capacity

Prior to estimating the size of a subsurface drain, the required capacity will either be known or calculated using Equation 1. See Section 7.3 for more detail.

7.5.1.2 Step B: Select the pipe type

The pipe type selected should be adopted based on the suitability of the system to the site. Unslotted pipes will be used for undertrack pipes, whereas either slotted or unslotted pipes can be used elsewhere.

Acceptable subsurface pipe materials by type are detailed in TS 01638.

7.5.1.3 Step C: Adopt a Manning's roughness coefficient

A value for pipe roughness 'n' can be obtained from the manufacturer for the product being adopted. Table 1 details typical values that are also acceptable.

7.5.1.4 Step D: Determine the slope of the pipe

The pipe slope will be determined from the geometry of the site to best suit site constraints. However, the minimum pipe slope is 1 in 200 (although a slope of 1 in 100 is preferable for self-cleaning purposes). The steeper the slope, the lesser the maintenance requirements.

7.5.1.5 Step E: Select a pipe size

A trial pipe size can be found using Table 8 by selecting a pipe where 'Q' is greater than the peak flow required 'Q_{PF}'.

Alternatively, the capacity of the pipe can be found by using Manning's formula (Equation 4).

Table 8 – Capacities for various pipe types and sizes

Pipe diameter	Pipe material	Drain slope	Max flow Q (l/s)
225	F.C.	1 in 100	58.3
225	F.C.	1 in 200	41.2
225	Concrete	1 in 100	53.0
225	Concrete	1 in 200	37.4
300	F.C.	1 in 100	125.6
300	F.C.	1 in 200	88.8
300	Steel	1 in 100	104.6
300	Steel	1 in 200	74.0
300	Concrete	1 in 100	114.1

Pipe diameter	Pipe material	Drain slope	Max flow Q (l/s)
300	Concrete	1 in 200	80.7
375	F.C.	1 in 100	227.7
375	F.C.	1 in 200	161.0
375	Steel	1 in 100	175.1
375	Steel	1 in 200	123.8
375	Concrete	1 in 100	207.0
375	Concrete	1 in 200	146.6
450	F.C.	1 in 100	370.3
450	F.C.	1 in 200	261.8
450	Steel	1 in 100	264.5
450	Steel	1 in 200	187.0
450	Concrete	1 in 100	336.6
450	Concrete	1 in 200	238.0
525	F.C	1 in 100	558.7
525	F.C	1 in 200	395.0
525	Concrete	1 in 100	507.9
525	Concrete	1 in 200	359.1
600	F.C.	1 in 100	797.7
600	F.C.	1 in 200	564.0
600	Steel	1 in 100	498.5
600	Steel	1 in 200	352.5
600	Concrete	1 in 100	725.1
600	Concrete	1 in 200	512.7

Notes to Table 8

1. FC = fibre cement pipe
2. Steel = corrugated steel pipe
3. Concrete = concrete or vitrified clay pipe
4. PVC = polyvinyl chloride pipe
5. To convert m³/s to l/s, multiply by 1000 (that is, 1000 litres = 1 cubic metre)
6. The values of Manning's roughness co-efficient used in the calculations for the values given in Table 8 are as follows:
 - concrete: n = 0.011
 - fibre Cement: n = 0.010
 - P.V.C.: n = 0.009

- steel (100 – 300 dia): $n = 0.012$
- steel (375 dia): $n = 0.013$
- steel (450 dia): $n = 0.014$
- steel (600 dia): $n = 0.015$.

7.5.1.6 Step F: Check the water velocities within the pipe

Using Equation 5 ($V = Q/A$), the velocity of flow within the pipe can be determined. The flow velocity within the pipe needs to be at an acceptable level so as not to cause damage to the pipe surface. The manufacturer has recommended maximum limits.

7.5.1.7 Step G: Determine the strength of the pipe (pipe class)

The pipe needs to be checked to see if it is suitable for the design and construction loads that are imposed on it. The method of calculation of pipe strength is to follow the relevant Australian standard (for example, AS/NZS 3725).

Truck vehicle loading standard configuration diagrams that are used in track drainage are provided in Appendix G. Railway traffic loading configurations are in TS 01713. Refer to TS 01638 for particular road traffic load and dynamic effect requirements.

For guidance, if pipes are within a 45 degree projection of the outside of the sleeper (in any direction), then railway loading needs to be included. Dynamic loads will also be applied.

If pipes are situated within a 45 degree projection of the outside of an access road (in any direction) then the loads applicable to the access vehicle need to be included. Dynamic loads will also be applied. Where pipes are near access roads or in a location that could be subject to vehicles above, then vehicle loading should also be considered.

Pipe strength is also highly dependent on the type of trench excavation, fill material, and compaction technique. When determining the class of pipe to be specified in a drainage system, type 'U' bedding should be assumed, even if better bedding is specified on the drawings. Most track drainage is constructed during track possessions where the specified placement and compaction of bedding material cannot always be achieved. It is noted that type 'U' bedding is used only for design purposes involving possession work and is not to be constructed. Refer to pipe requirements in TS 01638 also.

Where slotted pipes are used, strength reductions for the slots need to be included in the design and will be based on manufacturer's recommendations.

Manufacturer supplied computer software is acceptable for this purpose of pipe strength design, provided it is in accordance with AS/NZS 3725 or AS/NZS 2566.

Minimum strength requirements for acceptable pipes are detailed in TS 01638.

7.5.1.8 Complete example:

7.5.1.8.1 Example 7

A rainfall run-off quantity of 0.10 m³/s was calculated to act on a catchment for the 50 year ARI critical duration storm (from the Rational Method). There is no subsurface water intercepted, but a nearby stormwater pipeline enters the system and adds 0.02 m³/s. What size reinforced concrete pipe is required to satisfy flow requirements?

7.5.1.8.2 Solution 7

Step A: The design flow capacity can be determined from Equation 1

$$Q_{PF} = Q_R + Q_S + Q_C = 0.10 + 0 + 0.02 = 0.12 \text{ m}^3/\text{s}$$

Step B: Reinforced concrete (given)

Step C: Roughness $n = 0.011$ (from Table 8 – notes)

Step D: Pipe slope 1 in 200 (given)

Step E: From Table 8, a 375 mm diameter RC pipe has capacity of 146.6 l/s (0.146 m³/s) which is greater than the design flow capacity. In addition, the size is greater than the 225 mm minimum.

Step F: Water velocity within the pipe $V = Q/A = 0.12/(3.142 \times 0.375 \times 0.375/4) = 1.1 \text{ m/s}$ which is less than the acceptable limit for concrete (6 m/s). Therefore, okay.

7.5.2 Aggregate drains

Aggregate drains are only suitable for use where small flow or seepage is expected. If a larger flow is expected, a slotted pipe should be added to the system, and then the drain should be sized as described previously. A typical example of an aggregate drain is a blanket drain.

Another type of aggregate drain is a French drain.

Aggregate drains are to be lined with a geotextile.

The capacity of an aggregate drain may be determined using Darcy's law as shown in Equation 7.

$$Q = k \times i \times A$$

Equation 7 – Darcy's law

Where:

Q = flow (m³/s)

k = permeability of the aggregate

i = hydraulic gradient or slope

A = cross-sectional area (m²)

The permeability of clean gravel can range from 0.01 m/s to 1.0 m/s. The aggregates used in aggregate drains are either 20 mm nominal diameter or 53 mm diameter (ballast). The permeability of these aggregates is as follows:

- 20 mm aggregate k = 0.15 m/s
- 53 mm aggregate k = 0.40 m/s.

Equation 7 may be simplified if $K = k \times i$, and Equation 8 becomes:

$$Q = K \times A$$

Equation 8 – Simplified version of Darcy's law

Table 9 shows values for 'K' for use in Equation 8 to determine the capacity of aggregate drains.

Table 9 – Values of $K = k \times i$ for various slopes

Slope	K = k × i (m/s), for 20 mm aggregate	K = k × i (m/s), for 53 mm aggregate
1 in 100	0.00150	0.0040
1 in 200	0.00075	0.0020
1 in 300	0.00050	0.0013
1 in 400	0.00038	0.0010
1 in 500	0.00030	0.0008

7.5.2.1.1 Example 8

If $Q = 0.01 \text{ m}^3/\text{s}$ or 10 l/s an aggregate drain using 20 mm aggregate at a slope of 1 in 200, what size drain is required?

7.5.2.1.2 Solution 8

$Q = K \times A$, this may be rearranged to: $A = Q/K$

Therefore:

$$A = 0.01 / 0.00075$$

$$A = 13.3 \text{ m}^2$$

For the same flow using 53 mm aggregate at a slope of 1 in 200, the area required is:

$$A = 0.01 / 0.002$$

$$A = 5.0 \text{ m}^2$$

7.6 Other design considerations

In addition to track drainage design aspects within this manual and those covered in TS 01638, further associated considerations are noted in Sections 7.6.1 to 7.6.5.

7.6.1 Durability

Associated durability considerations with track drainage design can include the following:

- The durability cover requirements established from TS 01642, may dictate the minimum concrete wall thickness and materials that can be utilised in drainage elements.
- When selecting a pipe, the type of environment (whether the water is abrasive, acidic or alkaline) needs to be considered. The manufacturer's specifications in relation to the various environmental conditions and circumstances for which the pipe is deemed to be suitable can provide guidance.

7.6.2 Drainage positioning

Associated drainage positioning considerations with track drainage design can include the following:

- The possible effects of non-standard ballast profiles, other track infrastructure and track geometry needs to be considered. Higher than standard blockage factors need to be considered particularly for sag pits.
- The configuration issues arising from placing straight pipes alongside curved tracks needs to be considered (for example, this situation may require reduced pit or sump centres).
- Where surface drains running longitudinal to track are steeper than existing ground lines then the channel depth will become deeper. For a type 1 trapezoidal channel profile as shown in Figure 26, this means that the trench width will also become wider. Both types need to be drawn correctly in plan view, and not shown as a symbol line. This will ensure that the impact on adjacent structures can be determined more accurately.
- The permanent effects of the drainage system located alongside existing structures such as OHWSs, retaining walls, platforms, embankments, needs to be identified and taken into account together with the likelihood of destabilising an existing structure during the excavation stage.
- Where catch drains slopes are less than 1 in 100, an additional formed levee bank of at least 200 mm high combined with a larger set back between the cutting crest and the catch drain channel can reduce risk of blockage overflows down the cutting face.

7.6.3 Pipes

Associated pipes and pipeline considerations with track drainage design can include the following:

- TS 01638 specifies that pits are to be located at the transition between pipe sizes and at changes in pipe direction and abrupt changes in pipe grade. This also implies that pipelines are to have a straight alignment between pits.
- Pipelines with abrupt changes in direction, either to horizontal or vertical alignment, also need to be designed for associated internal water pressure forces, appropriate ground anchoring, thrust blocks and pipe jointing systems.
- Steep pipes with varied loading along its length (such as changing from railway load to access road or no live loads), need to be checked for possible pipe separation, pipe sliding effects and the need for pipe ground anchoring.
- Where longitudinal subsurface pipes need to be installed at substandard shallow depths to allow adequate subsoil drainage flows, then no-fines concrete embedment can be considered for enhanced pipe protection such as for vehicle loading. Concrete pipe encasement or higher strength class pipes can also be considered for particular unslotted pipe applications subject to high surcharge loads or when near other track side structure footings.
- High water table areas considerations include use of slotted pipes and controlling of pipe floatation effects.

7.6.4 Excavations

Associated excavation and geotechnical considerations with track drainage design can include the following:

- As surface excavations for deeper pipe systems may need trench benching or temporary shoring, constructability and risk of ground settlements are key design considerations, particularly when drainage trench is near to other infrastructure such as bridges, OHWS, retaining walls, platforms, other footings, services and the like.
- Installation of subsurface drainage trenches along toes of cuttings and embankments can affect slope stability which involves geotechnical advice. Alternative shallow surface drains can also be considered to reduce risks.
- Track baulks comprising of a series of steel beams connected to sleepers can be considered to strengthen trackwork over small excavations and poor ground.
- Where trenched ULX pipe installations cannot be placed perpendicular to the track alignment due to site constraints, then orienting the trench wall angle perpendicular to the

track for the backfill zone above the overlay zone could be considered to minimise differential settlements along the sleeper length and associated potential track twist effects.

- Trenching for pipelines in hard rock zones need geotechnical considerations regarding ease of excavation and potential differential track stiffness effects for ULX installations.
- Potential conflicts with existing services needs consideration. On site conducted service searches and the locations of these services indicated on the design documentation needs investigation and verification. Service searches can be supplemented by non-destructive trial pits to ensure the accuracy of the service search information and determine the depths of the services.

7.6.5 Maintenance

Associated maintenance considerations with track drainage design can include the following:

- Track drainage systems that may not be fully complying such as flatter slopes, longer pit spacings or say closer to ballasted track often required increased frequency of inspection and clearing. Maintenance tasks for drainage assets, both planned and unplanned, together with expected frequencies are typically summarised in a general or site specific TMP.
- Human factors integration such as ease of undertaking installation and maintenance and adequate visibility for inspection tasks. Refer to AS/RISSB 7470 for more information.

8 Construction of track drainage

This section deals briefly with the various forms of drainage construction.

One important consideration is that each site needs to be assessed on its own merits. No two sites are the same. This will be taken into account when selecting the site protection, equipment, and personnel required for each particular site.

This section discusses the various steps involved in the construction of both surface and subsurface drainage systems.

Standard construction and specification requirements are covered in TS 01638 and TS 01658.

8.1 Line and grade set out

The line and grade of the drainage system, whether surface or subsurface, can be set out by one or a combination of the following methods:

- a. stakes, spikes, shiners (small reflective metal discs), marks, or crosses set at the surface on an offset from the desired centre line
- b. stakes set in the trench bottom on the pipeline as the rough grade for the pipe is completed

- c. elevations given for the finished trench grade and pipe invert while laying the pipe or excavating the trench is in progress.

Of these three methods, method (a) is the most commonly used for track drainage.

Method (a) involves stakes, spikes, shiners, or crosses being set on the opposite side of the trench from where the excavated material is to be cast at a uniform offset, in so far as practicable, from the drain's centreline. A table known as a cut sheet is prepared. This is a tabulation of the reference points giving the offset and vertical distance from the reference point to either: the trench bottom, the pipe invert, or both. When laying the pipe it may be more practical to give two vertical distances, one to the trench bottom (excavation depth), and one to the top of the pipe, which is generally easier to measure to than the pipe invert. The grade and line may be transferred to the bottom of the trench by using batter boards, a tape and level, or patented bar tape and plumb bob unit.

This method may be adapted to suit. For example, it is common practice to have the proposed route surveyed with the reference points marked on the datum rail (either the down rail or the low rail on a curve). The offset and vertical height may be easily transferred from the rail by use of a straight edge, spirit level, and tape (see Figure 28).

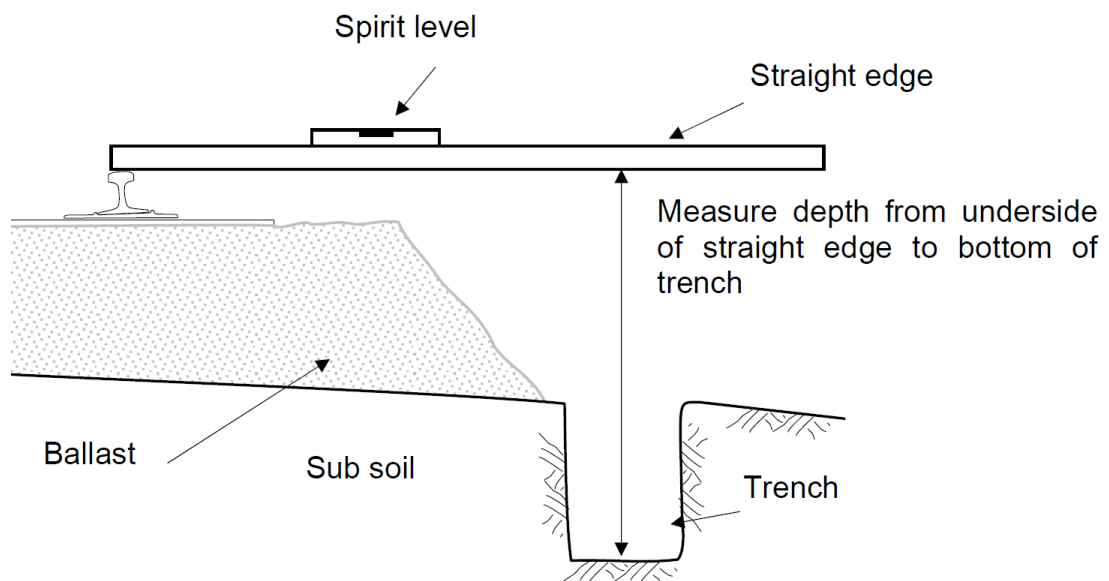


Figure 28 – Method of measuring the depth of a trench and offset to pipe centreline

If the track is on a constant grade that is suitable for the pipeline and trench, this grade may be adopted. This gives a constant vertical depth from the datum rail to the trench bottom and pipeline, making construction and grade control much easier.

Another method of controlling the line and grade is the use of lasers. A laser beam is passed through the centre of the pipeline at the desired grade. It strikes opaque targets attached to the end of the pipe, and the pipe may then be either lifted (packed) or lowered until the laser passes through the centre of the target.

8.2 Site preparation

The amount of preparation varies from site to site. Operations that should be classified as site preparation include the following:

- clearing
- removal of unsuitable soils
- preparation of access roads
- detours and bypasses
- improvements to and modification of existing drainage
- location, and protection or relocation of existing services and utilities (refer to TS 02390).

The success of the construction phase depends to a great degree on the thoroughness of the planning and the execution of the site preparation work.

8.3 Excavation

With favourable ground conditions, excavation can be accomplished in one simple operation. Under conditions that are more adverse, it may require several steps, such as clearing, rock breaking, ripping or blasting, and excavation. When excavating for a pipeline, the trench at and below the top of the pipe should be wide enough to ensure adequate compaction on the sides of the pipe can be achieved. The minimum width on either side of the pipe is specified in TS 01638.

The amount of excavation and the types of equipment required may vary, so each site needs to be assessed on its merits to determine the type and quantity of equipment necessary.

Excavation near structures or platforms is specified in TS 01638, TS 01608 and TS 01640.

Particular conditions that should be taken into account when selecting equipment include the following:

- site access
- size and amount of excavation necessary
- site conditions, that is, firm or boggy ground conditions
- location and availability of plant
- whether the plant item required has to be floated to the site (if so the offloading conditions and a suitable area should be checked)
- services in the area.

Typical items of plant (equipment) utilised are the following:

- highrail or tyred boomed excavators
- backhoe
- tiltable dozers
- graders
- front end loaders
- tracked excavators
- hydraulic excavators
- bogie tippers and 4WD dumpers.

8.4 Surface drain construction

Surface drains remove surface water from near the tracks, and construction of the drains involves surveying, excavating, and (where needed) lining of channels.

8.4.1 Surface preparation

The main purpose of surface drains is to remove surface water from near the tracks and disperse it as quickly as possible. To do this, the drainage trench or ditch should be constructed at a uniform even grade, with no low sections where water may pond and seep into track formation, thereby defeating the purpose of the drainage system.

The grade of the drainage trench should be a minimum of 1 in 200 where practicable. Flatter grades require more regular inspection and maintenance, since they tend to become blocked with sediment more quickly than drains with steeper grades.

Where the velocity of the water is greater than that shown in Table 7 in Section 7.4.7, some form of scour protection is required, for example, lining the channel. Where doubts exist as to the erodibility of a soil, geotechnical advice needs to be sought. Where any surfaces are cleared of vegetation, these areas should be re-vegetated at the end of construction, to prevent unnecessary build-up of silt in nearby drains.

8.4.2 Construction steps

The steps involved in construction of surface drains are the following:

1. Survey the proposed drainage route. This may be carried out during the preliminary investigation.
2. Establish and mark out reference points for use during construction. Marking out may consist of paint marks on the datum rail or star pickets. The interval used for the reference

marks depends on the length of the drainage system. For example, for a short drain the interval may be five metres.

3. Clear the site. This should be part of any site preparation work carried out. This may involve relocation of signal troughing, clearing vegetation, and so forth.
4. Excavate to required level. When excavating the trench, use a bucket width equal to the width of the trench base, then add a batter to the sides of the trench formed. Monitor excavation with the method described in Section 8.1. Once the trench has been constructed, level and compact the trench base making sure that no low points exist.
5. Check for risk of erosion. If this is expected to be high, the drain may require lining.
6. Clean up the site and re-vegetate any denuded slopes.

Note: It is good practice to work from the lowest to the highest point. That way, if work is interrupted for any reason, at least part of the drainage system will function correctly if it rains before completion.

8.5 Subsurface drain construction

Section 8.5.1 to Section 8.5.6 detail construction methods for the following subsurface drains:

- longitudinal drains
- lateral drains
- blanket drains
- horizontal and vertical drains
- pipe drain using unslotted pipes
- sump or pit installation.

8.5.1 Longitudinal drain construction

The basic construction steps for longitudinal drains and their drainage components are as follows:

1. Set out and excavation:
 - a. Survey the site.
 - b. Establish the reference points. These may be paint marks on the rails or star pickets. The purpose of these marks is to provide points from which the depth of the trench and pipe invert level may be measured accurately. (See Section 8.1).
 - c. Excavate to the desired level and grade. The type of equipment used to excavate the trench differs from location to location, depending on such parameters as access, material, volume to be excavated, and clearances for the safe operation of equipment.

- d. Confirm excavation dimensions. The depth of the excavation depends on the pipe location, and outlet and inlet requirements. For pipes running parallel to the track, the minimum pipe cover is to be 600 mm below the design cress level. Where this is not feasible, the minimum pipe cover is to be 300 mm below the design cress level or 1000 mm below the adjacent rail level (whichever produces the lowest invert level). The design track formation profile will be as set out on design drawings. Standard track formation profiles are specified in TS 01608. The width of trenches should only be as wide as necessary to ensure proper installation and side compaction. The minimum width will be pipe diameter plus 150 mm on each side. For longitudinal drains located either within 2500 mm of the track centre line or between tracks where track centres are less than 6000 mm, the minimum trench width will be pipe diameter plus 100 mm on each side. Figure 29 provides a visual representation of these width requirements. A vertical sided trench with no support may only be suitable for a shallow trench. Geotechnical advice may be sought to determine if shoring or benching is required for certain ground conditions or deeper trenches.

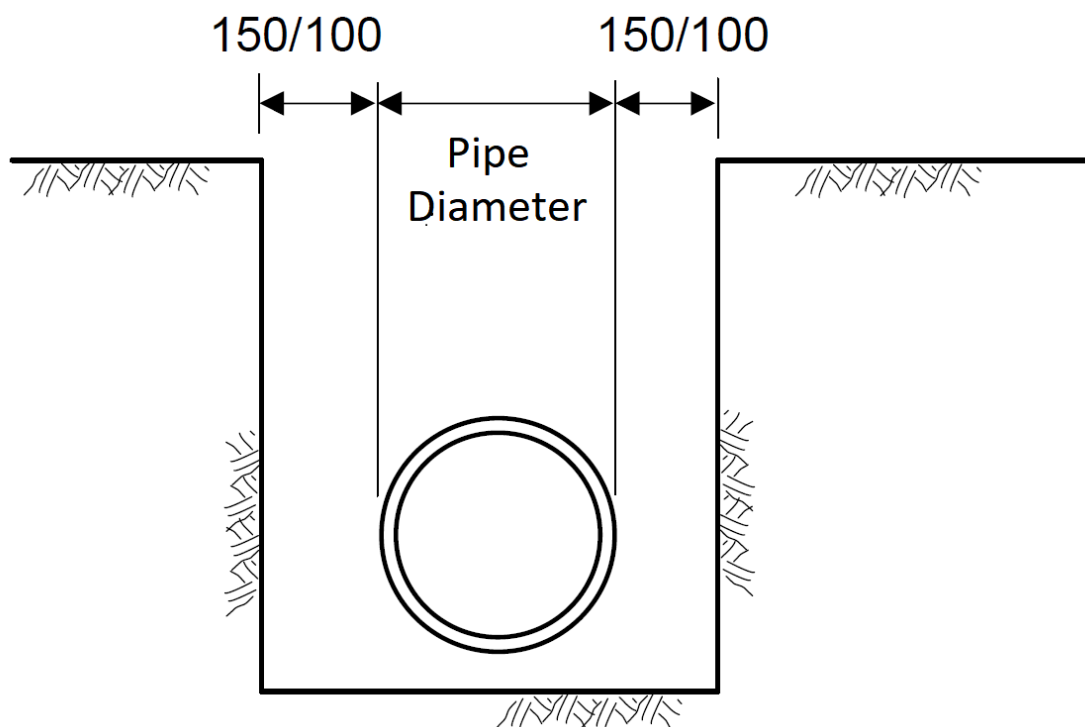


Figure 29 – Trench width

2. Install drainage system – the method of installing types of subsurface drain depends on the type of subsoil and other conditions encountered. Installation steps differ for impervious soils, pervious soils, slotted pipes, unslotted pipes, outlet restrictions and ash pockets.
3. Impervious soil – aggregate filled excavation (typically most clays are relatively impervious) – also see Figure 15:

- a. Lay the geotextile in the bottom of the trench. Where joints need to be made in the geotextile, a minimum overlap of 1 m should be made.
 - b. Place a layer of aggregate in the bottom of the trench approximately 50 mm thick. The aggregate used for this should be 20 mm nominal size.
 - c. Lay the pipe sections, one section at a time, on top of the aggregate.
 - d. Place pits or sumps or both, and remove knockouts.
 - e. Check and adjust the pipe level and grade if necessary by packing aggregate under the pipe.
 - f. Place aggregate around and over the pipe, tamping the embedment aggregate on the sides of the pipe as the trench is filled in layers no greater than 150 mm thick. Once the pipe is covered, complete the filling of the trench compacting the aggregate in layers no greater than 150 mm thick, using a vibrating plate compactor or similar.
 - g. Fold geotextile over the top of the trench, ensuring that the ends are overlapped a minimum of 300 mm.
 - h. Place a minimum 100 mm thick layer of aggregate over the geotextile and grade the surface.
 - i. pack knockouts from the inside of the pits using sand or cement mortar (or geotextile if detailed in this manner).
 - j. complete associated works (for example, pit lids or pots, ballasting, and so forth).
4. Pervious soil – aggregate filled excavation (typically most sandy soils) – also see Figure 16.
- When laying a drain in pervious soil, it is necessary to place an impervious layer in the base of the trench. Typical impervious layers are concrete, cement or lime stabilised fill, or clay fill. The impervious layer is to be 100 mm thick at the edges of the trench and slope towards the centre of the trench, where it is to be 50 mm thick. Once an impervious layer is installed, the remaining construction steps are the same as steps 3 a to 3 j for drains in impervious soils above.
5. Geotextile wrapped slotted pipes – also see Figure 17.
- Sometimes it is beneficial to wrap the pipe with a geotextile rather than around the outside of a trench. In this case, repeat the procedure of step 3 'impervious soil' with the exception of: replacing step 3 a with 'the geotextile is wrapped and lapped a minimum 300 mm around the pipe' and step 3 g is not required.
6. Earth filled excavations (typically unslotted or solid pipes):
- a. Place bedding sand or roadbase in the trench and compact as per the design.
 - b. Lay the pipe sections, one section at a time on top of the bedding.

- c. Check and adjust the pipe level and grade if necessary. Adjust pipes by removal of base material or ramming additional bedding under the pipe. Alternatively, slings may be used around pipe ends.
 - d. Place pits or sumps or both and remove knockouts.
 - e. Place side zone material and compact to the required relative density as shown on the drawing (typically involves tamping the embedment soil on the sides of the pipe as the trench is filled in layers no greater than 150 mm thick).
 - f. Place a 150 mm maximum layer of material over the pipe and use a vibrating plate compactor or similar to compact the fill to the required relative density. Repeat backfilling and compaction until fill is at final level.
 - g. Pack knockouts from the inside of the pits using sand or cement mortar (or geotextile if detailed in this manner).
 - h. Complete associated works (for example, pit lids or pots, ballasting, and so forth).
7. Limited length due to outlet restrictions – in some locations, a subsurface piped drain cannot be located deep enough to prevent it being disturbed by track maintenance machines. In this case, the pipe may be wrapped in geotextile, and then placed in the trench on a bed of aggregate to allow any adjustments to the level and grade of the pipe to be made. The trench may then be filled with a suitable pervious fill and compacted in layers.
8. Ash pockets – where isolated pockets of ash are encountered, an impervious membrane may be placed in the trench before the fabric is laid. This membrane should cover the ash pocket and extend approximately 2 m either side of it. The remainder of the drain is constructed as set out in 'impervious soil' above. This method is used only where the soil on either side of the ash pocket is impervious; otherwise, the drain is constructed as per 'pervious soil' above. If an impervious membrane is not available, the section of the drain above the ash pocket may be constructed as for a drain in a pervious soil. See Figure 30 for the treatment of ash pockets.

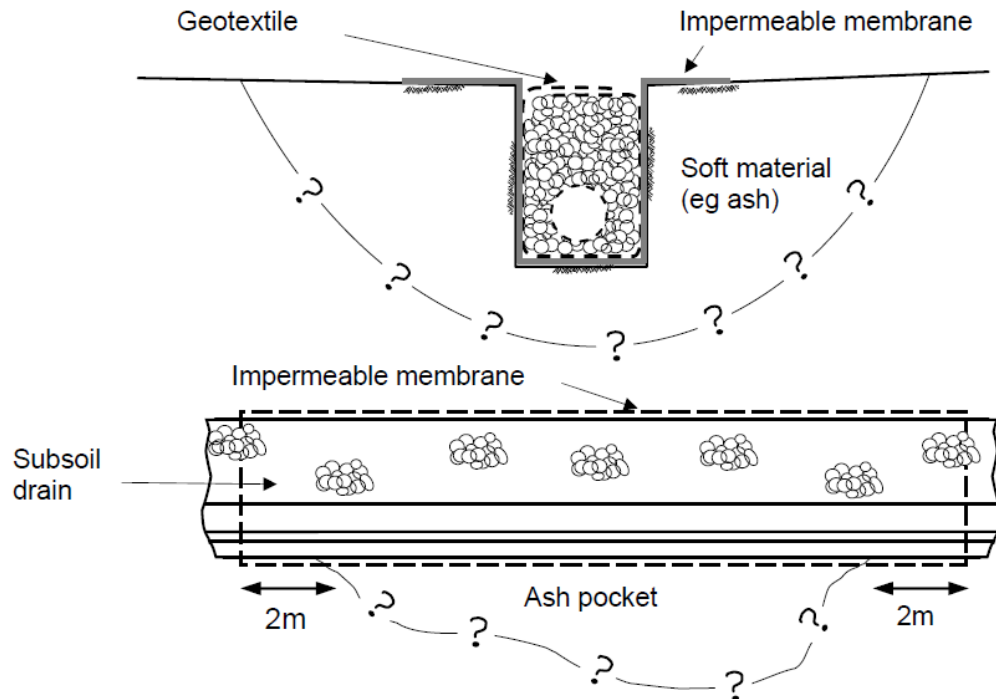


Figure 30 – Construction of a drain over an ash pocket

8.5.2 Lateral subsurface drain construction

Lateral surface drains are typically part of a piped carrier system and also used to drain near turnouts and isolated water pockets in embankments. The construction of lateral piped drains is similar as that for longitudinal drains. The main differences are the deeper depth of the pipe below rail level (which is a minimum of 1200 mm) and more stringent requirements for under track installations as specified in TS 01638. Refer also to CV 0205421.

For embankment drainage, a lateral trench is excavated to the desired level, using a backhoe or similar, with the base graded to fall. Refer also to Figure 11.

The construction methods for lateral subsurface drains are the same as for longitudinal drains. For lateral subsurface drain construction methods under track, see 'set out and excavation' and 'earth filled excavations' in Section 8.5.1.

8.5.3 Blanket drain construction

Blanket drains are typically found at the base of embankments. Blanket drains are usually constructed during embankment construction, embankment widening, or repairs to a slip. The construction steps are as follows:

1. excavate – for embankment widening or slip repair, steps should be cut into the existing embankment (refer to TS 01608)
2. level and compact the base with a fall away from the embankment centre
3. lay out the geotextile – any joints should have a minimum 1 m overlap

4. place aggregate, usually 20 mm to 53 mm nominal size aggregate up to 300 mm thick (laid and compacted in layers)
5. fold sides of geotextile up over the top of the aggregate, then cover with a layer of geofabric over the top of the aggregate
6. place riprap (100 mm to 150 mm stone) over the exposed face of the drainage blanket as protection
7. build up the embankment to the desired level and compact in layers.

Also see Figure 12.

8.5.4 Horizontal and vertical drains

Horizontal and vertical drains are not often used for track drainage however the following is noted:

- The most commonly used vertical drain is used to drain water from behind retaining walls and bridge abutments. This drain consists of a geotextile layer placed at the back of the wall and connected to a pipe at the base of the wall.
- Water reaching the geotextile can flow along the plane of the fabric that is down the back of the wall, and is then removed by the pipe at the base. This may also be combined with horizontal layers of geotextile to collect water seeping through the embankment or backfill behind the wall, which is conducted towards the vertical drain, and then to the carrier pipe and removed.
- Horizontal and vertical drains may be placed during construction and backfilling, or an area behind the wall can be excavated for their installation.

8.5.5 Construction of an unslotted pipe drain

Follow the procedure as per step 6 'earth filled excavation' in Section 8.5.1.

8.5.6 Sump installation

Refer to TS 01638 for sump (or pit) installation standard requirements.

At the location at which a sump is to be placed, the trench is widened and deepened to accommodate for the sump. The base of the trench is then levelled and covered with a layer of compacted sand or road base, which is a minimum 150 mm deep. This layer may be added to so that the sump is positioned at the correct height.

Prior to placing the sump, the wafer of concrete covering the inlet and outlet is knocked out to approximately the desired size. Drains using slotted pipes and geotextile are connected to sumps as shown in Figure 31. Once the pipe is in place, any remaining gaps between the pipe and the sump are grouted. The trench is then filled and compacted.

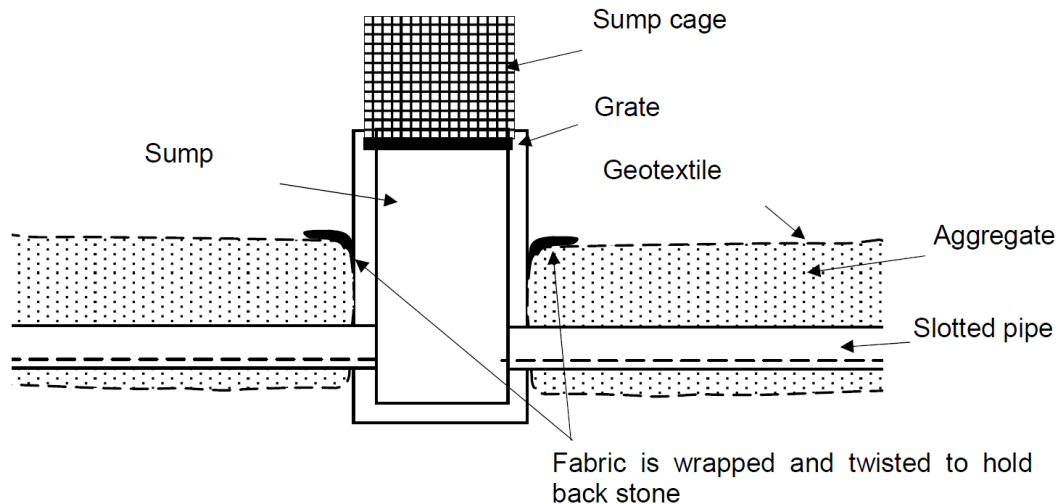


Figure 31 – Method of joining longitudinal subsoil drain to sumps

8.6 Other types of construction

Other pipeline construction methods, which are seldom used for track drainage include the following:

- pipe jacking
- directional drilling
- tunnelling
- augering
- cast in place.

Some specialised pipe installation methods are also briefly covered in TS 02390.

8.7 Inlets and outlets

Refer to TS 01638 for inlets and outlets standard requirements.

Some typical examples of inlet and outlet protection are the following:

- precast concrete units
- grouted sand bags as shown in Figure 21
- concrete as shown in Figure 22
- gabions with cut off walls as shown in Figure 23
- revetment mattress as shown in Figure 24
- spalls grouted or hand packed as shown in Figure 25.

Inlet and outlet protection is to be installed as shown on the drawings and in accordance with manufacturers' instructions.

Typical details for a gabion headwall are shown in Figure 32.

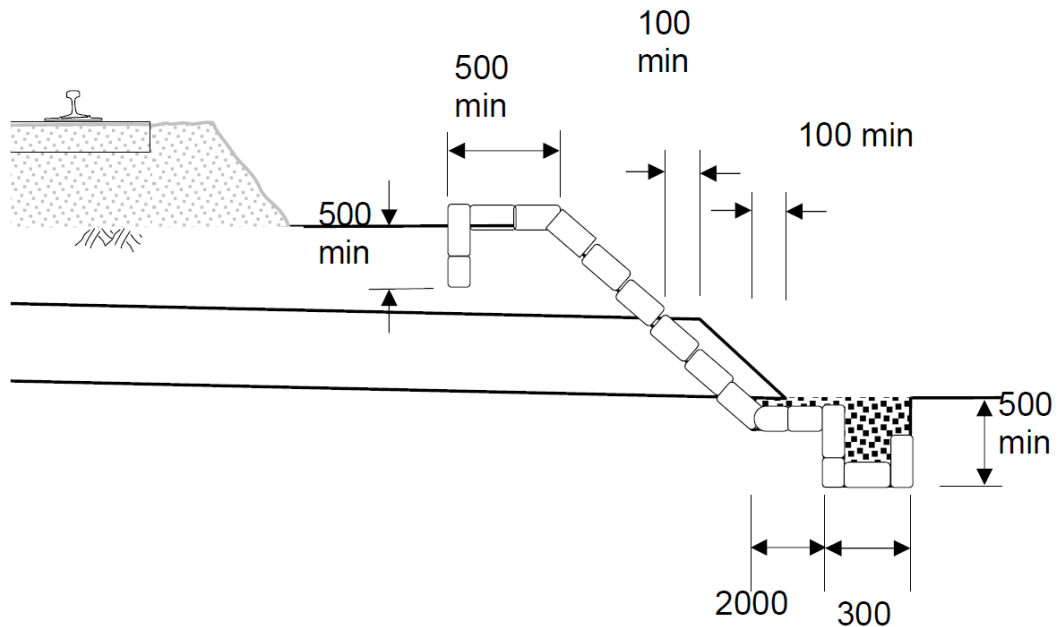


Figure 32 – Gabion headwall – typical details

9 Maintenance of track drainage

Considerations for maintenance of track drainage include adequate site examinations and knowledge of drainage principles, indications and causes of ineffective drainage, typical problems and their solutions, preparation for flooding and keeping accurate records.

9.1 Site examination considerations

Without regular and routine site examinations of drains and understanding of drainage and track principles, potential track drainage problems may be unnoticed and then lead to more severe consequences. A summary of drainage principles is in Section 5.1. Examination procedures and documents are typically provided by the RIM.

9.1.1 Track maintenance

Good track maintenance and effective track drainage are closely associated. The stability and condition of the track and the formation is intimately related to the effectiveness of the drainage systems.

The consequences of poor or blocked drains can range from small areas of foul ballast to large washaways or embankment failures.

Water needs to be drained away from the track as quickly as possible, so that it does not affect the track stability.

Where subsurface drainage work has been carried out, the outlets need to be kept clean to allow water to run-off.

The cesses in cuttings need to be kept formed so that the water will not run at the toe of the batter slope. On banks, the cesses need to be graded away from the track.

Where track formation bog holes exist, ample ballast should be kept on hand to replace the continued loss of ballast through fettling. The attention of the maintainer needs to be drawn to this so that they can have drainage work carried out, when practicable.

Effective drainage is a major factor in minimising maintenance work necessary on welded track.

9.1.2 Indications of ineffective track drainage assets

Indications of ineffective track drainage include the following:

- formation failure or slips
- heaving or settlement of formation or track
- contaminated or dirty ballast
- mud or soil material pumping up through ballast
- pumping or moving sleepers under train loads
- rotting timber sleepers
- poor track alignment or settlement (vertical or horizontal)
- poor operation of turnouts and special trackwork
- pumping rail joints and track crossings
- silted or blocked drains
- blocked outlets or pits
- missing or misaligned gratings
- broken concrete surface drains or pipes or pits
- erosion
- pools of water or ponding
- ground or structure movements.

9.1.3 Possible causes of ineffective track drainage assets

Possible causes of ineffective track drainage include the following:

- broken pipes or drains
- flat gradients
- street gutters flows
- septic tanks
- blockages
- stormwater catchment area changes
- unlawful diversion of water by property owners
- groundwater
- vegetation.

9.1.4 Examination tasks for track drainage assets

To maintain good track drainage, typical observations for the site maintainer can include the following:

- drain locations compared to asset records
- which way the water flows
- where the water discharges
- sources of water inflows
- drainage structure condition
- track and formation condition
- any stormwater catchment area changes
- any changes from previous inspections.

Pools of stagnant water lying near the track should be drained and the problem that caused them rectified. The proper action in this situation is to do the following:

- locate the problem
- clear any minor blockages immediately to drain the pools
- repair any weak spots, where feasible
- check all drains have proper cross-fall and grading.

If site crews cannot do the necessary rectification work, they should do the following:

- request extra staff, material or equipment
- record and report defects to their appropriate manager for corrective action
- request enhanced design and construction and monitoring solutions for the assets.

Backhoes, bobcats, small bulldozers, and dumpers are some equipment that can be used to clear drains.

9.2 Surface drainage

Maintenance operations carried out on surface drains usually fall into one, or a combination of the following:

- vegetation and weed control
- removal of debris from other track maintenance activities
- removal of sediment
- regrading.

A build-up of weeds and other vegetation within the surface drain tends to slow the passage of water through the drain, which, in turn, allows sediment to settle leading to a blockage of the drain. Such a blockage can render a drain useless and lead to a decline in the effectiveness of other drains in the system. For example, if a catch drain at the top of a cutting becomes blocked, water may overflow the drain, run down the cutting face thereby increasing erosion of the face, and the cess drain will eventually block up due to the additional sediment load.

Weeds and vegetation can be removed using weed control practices.

Sleepers and rails, for example, left in the cess drains after maintenance work, tend to act as dams allowing water to pond alongside the track and seep into the formation. This will also allow sediment to settle. Old sleepers and rails should be removed to a suitable storage site for disposal or reuse at the completion of any track work.

When a drain fills with sediment, whether it is due to a blockage or a flat grade, this sediment should be removed and the drain regraded if necessary. The type of equipment used to remove the sediment depends on the extent of the blockage and the accessibility (equipment used may range from a shovel to an excavator). Regrading is sometimes necessary due to scouring, or to increase the grade of the drain slightly to reduce the amount of sediment that can settle in the ditch (channel).

Where cutting faces are exposed, therefore undergoing unnecessary cutting face erosion leading to an acceleration of sediment build-up in cesses, these cutting faces need to be protected. Forms of protection commonly used are spray grasses, seeding, sodding, and shotcrete.

Table 10 contains a summary of surface drain maintenance which typically includes cess, catch and mitre drains.

Table 10 – Summary of maintenance of surface drains

Surface drain problems encountered	Possible remedies
Blockages from weeds	Remove or herbicide.
Blockages from old sleepers, rail, and so forth	Should be removed and drain regraded. Old sleepers and rails should be removed when replaced and not left lying in the drain. If not removed from site, sleepers should be gathered up and disposed of.
Blockages from other discipline infrastructure	Approach other disciplines about equipment relocation.
Blockages from spillages and spent ballast	Remove and regrade drain.
Silt build up, water ponding, and overflow as a result of blockages	Clean out drain and regrade if necessary.
Uneven grades	Regrade drain.
Animal (rabbit) burrows are also a problem in some areas	Relocate animals and fill in burrows.
Poorly graded	Regrade the drain.
Scour – especially at outlets for catch drains above cuttings, where drains tend to be steep thereby producing high velocities	Use more regular outlets, thereby producing less water at lower velocities at each outlet. Or regrade or line the drain or do both.
Scour – especially for cess drains.	Regrade or line the drain. If necessary, provide some means of retarding the flow out of these drains. Reline with improve surface material.
Water ponding on shoulder	Regrade the shoulders so that they fall away from the track.

9.3 Subsurface drainage

Maintenance of subsurface drainage involves inspection, cleaning, unblocking, and repairing of pipes, sumps (pits), and outlets.

9.3.1 Pipes and sumps

Pipes and sumps are susceptible to blockages due to ballast and rubbish from the track, tree roots in search of water, siltation, and pipe breakages or crushing.

Sumps can be cleaned by digging the sediment, ballast, and rubbish out of the silt traps, or by using a vacuum device (mainly used for deep sumps). Sumps filled with ballast are most effectively cleaned using post-hole shovels, but these are ineffective for the removal of fine non-

cohesive silt. Square nose shovels of varying widths are suitable only where sediment fills the silt trap. Where a sump is deeper than two metres, it becomes too difficult to clean using shovels. In this case, a vacuum device may be used.

After the sumps have been cleaned, the adjoining pipes can be cleaned if necessary, by rodding, hydroblasting, or similar.

Rodding of the pipes involves the pushing of a circular plug, of slightly less diameter than the inside of the pipe, through the pipe using flexible rods. Rodding is done working from sump to sump, starting at the downstream end. Any sediment or other debris pushed out of the pipe is then cleaned out of the sumps.

Hydroblasting involves the removal of sediment by using a low-pressure, high volume water jet. Low-pressure with high volume is used because high-pressure low volume water jets tend to damage pipes. Hydroblasting is most effectively carried out using experienced contractors. The process involved is as follows:

1. Sections of the pipe network are cleaned from sump to sump working from the outlet pipe.
2. Various nozzles are used to break up any encrustations and remove debris. This is done by either jetting it out into the sump or by relying on the volume of water and the grade of the pipe to create a self-cleaning effect and remove any sediment.
3. After this operation is completed, the sumps are cleaned either by the methods previously mentioned or by sludge pumps.
4. This process is then repeated in the next pair of sumps and so on.

Care needs to be taken to replace any displaced sump grates or covers removed during the cleaning and inspection of the drainage system.

Table 11 contains a summary of subsurface drainage maintenance.

Table 11 – Summary of maintenance of subsurface drains

Type of subsurface drain	Problems encountered	Possible remedies
Pipe, aggregate geotextile filter and sump type drain (longitudinal drains)	Blockages such as rubbish and ballast	Clean out rubbish and ballast.
Pipe, aggregate geotextile filter and sump type drain (longitudinal drains)	Silt	Hydroblast or rod pipe. Remove sludge with sludge pump or shovel.
Pipe, aggregate geotextile filter and sump type drain (longitudinal drains)	Scour outlet	Provide scour protection or decrease water velocity, or do both.

Type of subsurface drain	Problems encountered	Possible remedies
Sump grates and covers	Blocked by rubbish and silt	Remove cover or grate or both, then clean sump if necessary. Clean and replace grates and cover. Remove rubbish and so forth from site.
Aggregate and geotextile drains such as blankets	Blocked outlets	Remove vegetation. Clean outlets. Ensure no water ponds at outlets.
Outlets	Scour	Provide scour protection or decrease water velocity, or do both.
Outlets	Blockages	Clear away vegetation from outlet. Clear any other debris away from outlet, for example, spent ballast and so forth.

9.3.2 Outlets

Outlets are the most critical element of a subsurface drainage system because they are susceptible to events that can impede the free flow of water. The main concerns are blockages due to weed growth, siltation of the adjacent ditch or stream, debris from the track or slope, and the activities of animals or humans. A system of marking outlets of subsurface drains should be implemented to enable easy location of outlets.

Outlets and outlet markers should be inspected and repaired, if necessary, as part of routine maintenance at least once a year. As with the inspection of other drainage system components, this should preferably be carried out in the period of least rainfall.

9.4 Typical problems and solutions

Section 9.4.1 to Section 9.4.11 covers typical drainage problems, suggests possible reasons for their occurrence, and provides practical maintenance solutions that range from simple cleaning to upgrading drainage.

9.4.1 Cuttings

Drainage problems are exhibited by the following:

- water ponding
- poor track alignment and level through the cutting
- pumping of mud up through the ballast
- rock pumping.

The main causes of these problems are the following:

- Poorly graded cess drains.
- Blocked cess drains, that is, drains silted up due to cutting face erosion or debris (for example, sleepers and spent ballast).
- Foul ballast, that is, spillages from coal and wheat trains or mud causing the water to be trapped in the ballast. Another possible cause is the damming of water caused by the dumping of spoil by ballast cleaners at the ballast toe.

Another problem associated with cuttings is where catch drains have been provided but not maintained leading to water ponding within the drains. Water ponding in drains can result in the saturation of the cutting face which would lead to slipping, slumping, or piping of the cutting face. This may also allow water to overflow the drains and run down the cutting face causing excessive cutting face erosion, which in turn causes the cess drain to silt up quicker.

There are a number of solutions to these problems depending on the size of the cutting and the number of tracks. These solutions are discussed in Section 9.4.2 and Section 9.4.3.

9.4.2 Narrow or steep cuttings

Depending on the severity of the problem, it may only be necessary to clean, regrade the cess, and ballast clean the problem section.

Alternatives include concrete lining the drain and installing a protective mesh system to prevent loose ballast entering or install subsoil drains subject to geotechnical input. Where possible, the cess can be deepened and a subsoil drain installed, and the ballast is then allowed to fall over the drain. If the surface (cess) drain becomes blocked (that is, silted up) the subsurface water is still being drained away from the formation. This system can also be used for multiple tracks, provided the formation be in good condition and graded towards the cess drains, otherwise, the formation may need to be reconstructed.

9.4.3 Wide cuttings

In wider cuttings or if widening of the cutting is possible, the cess drains need only be deepened and widened so that water is drained out of and away from the track and does not prevent water flowing away from the track.

This method should be used where easy access is available, allowing regular maintenance to be carried out.

Note: Cutting faces should be stabilised to reduce erosion and subsequent silting up of cess drains. For example, spray grassing and organic mesh lining.

9.4.4 Embankments

The main drainage problems associated with embankments are water being trapped in the ballast due to fouling of the ballast (either from spillages or mud), and the build-up of spoils from previous ballast cleaning operations.

Another problem is that of water ponding at the embankment base, which may lead to slips. This water may cause saturation of the embankment base consequently causing further consolidation and settlement of the embankment.

To prevent water being trapped in the ballast, leading to formation failures, the shoulders of the embankment need to be kept clean and graded away from the track. Windrows of spent ballast cannot be allowed to build up on embankment shoulders. Depositing ballast cleaning spoil over the side of the embankment slope can cause water to be trapped in the embankment itself. The spent ballast tends to form an impermeable layer over the outside of the embankment.

Catch drains will be installed and maintained such that water is prevented from ponding at the embankment base. An alternative to catch drains in flat areas is to grade surrounding ground away from the embankment such that if water does pond in the area, it is away from the embankment base.

At areas of heavy seepage through embankments, a transverse subsoil drain should be installed to drain the water from the embankment, thereby reducing the possibility of embankment saturation and any resulting problems.

On multiple tracks where drainage problems have been encountered it may be necessary to install a transverse drain with suitable outlets to drain water effectively from the ballast and embankment.

Note: Embankment faces should be stabilised to reduce erosion problems (for example, spray grassing, sodding, geotextile, organic mesh lining).

9.4.5 Formation soft spots or bog holes

Because soft spots or bog holes are often the result of water collecting in depressions in the formation, as caused by inadequate or poorly maintained drains, the first consideration should be to upgrade or clear existing drainage.

The provision of suitable drainage to preserve the stability of the formation is of prime importance.

The disposal of the impounded water from these depressions is achieved by excavating to the lowest level and providing suitable permanent outlet drains.

Before deciding the actual method of treatment, the local conditions need to be investigated. The objective of the investigation is to try to determine the source of the water and to obtain the depth of the water pocket or depression.

To investigate a soft spot, trial holes are sunk at approximately 2 m intervals. This will determine the depth of ballast and soft formation. This enables selection of the best type of drainage system or solution to the problem.

The procedure to follow in the solution to the problem is as follows:

1. Determine the position and depth of the outlet drain or 'tap' drain by using trial holes to locate the depth of ballast or the soft area.
2. Excavate and remove the 'soft spot' and foul ballast. The lower level of the trench for any sub drains used needs to be graded longitudinally at least 1:100 toward the outlet drain. Sub drains should be lined or covered with a geotextile fabric and filled with clean new ballast.
3. Cess drains are also upgraded so that surface water will not penetrate the treated area upon completion of the work. Where possible, they should be widened and graded uniformly to the mouth of the cutting. This will help in allowing the water to run freely away.
4. If the capping layer has been disturbed then it is then restored with crossfall angled towards the drains.
5. The track is restored with 'clean' new ballast and resurfaced.

9.4.6 Scour and washaways

During heavy and prolonged rain, the normal drainage channels provided might not be able to deal with the extra water flowing through them, with the result that flooding occurs.

In flat country, embankments may become submerged and saturated. If the water level rises uniformly on both sides of the bank, the head difference is similar and there will not be a great amount of water flow. As a result, little damage will typically occur. If, however, the flooding is confined to one side of the line, bridge and culvert openings will be liable to scour. Should the water overtop the track, very serious damage can result. The amount of damage will be dependent on the velocity or rate of flow of the water. Any steps taken to reduce the velocity therefore will assist in reducing damage.

The danger point is reached as water first commences to trickle over the formation. Scouring then starts, first in the ballast and then in the formation. If there is a large difference in the water levels on the two sides of the bank, the velocity will be high and damage extensive.

9.4.6.1 Temporary repairs

During heavy flooding, washaways may be numerous. They may range from small sections of ballast washed away to deep cuts where the whole embankment has been removed. The method of doing temporary repairs will depend on the nature and size of the washaway and the materials and equipment available.

If the ballast only is scoured out and it is not possible to get ballast to the site, quick repairs may be made by redistributing the remaining ballast. This will lower the track into a long 'slack' and is only a temporary measure to restore traffic. Repairs that are more permanent need to be completed as soon as possible.

Where shallow scouring of the formation occurs, continuous sleeper pigsties may be used. For deeper scouring, pigsties, trestles, and temporary beams will be required.

Permanent repairs will then require the closure of the track and reconstruction of the embankment and possible protective lining installation along the flow path surface or drainage redesign.

9.4.7 Ground slips

A slip is considered a significant geotechnical earthwork failure of the ground. Slips need not be large to cause serious damage and are very dangerous in that they can occur suddenly and without warning.

It is desirable, in the initial construction of the track, to avoid unsuitable soils and site conditions need to be dealt with as they are found. Suitable backfill and unsuitable soil materials are to be considered when designing foundations.

Terracing and flattening of slopes will assist in bringing about stable conditions. Cuttings, in soft material or in slopes liable to fail, may be widened to provide space for falling debris clear of the track. Material removed from cuttings should not be placed on or pushed over embankment sides without prior investigation of the embankment stability. Embankments can only be widened using the correct procedures.

Geotechnical advice on the appropriate batter slope, terraces, and procedures for the widening of embankments needs to be sought.

Small slips may be foreseen and prevented by the removal of loose material or the building of some form of protective structure. The removal of only the 'toe' of a slip will lead to increased sliding. When it is necessary to clear the toe, only the minimum quantity to permit the passage of trains should be removed. Mud flows, which result mainly from heavy rainfall, cannot always be foreseen and prevented but continual maintenance of catch drains will assist in reducing their incidence.

Slips may be of several types or include features such as those in Sections 9.4.7.1 to 9.4.7.3.

9.4.7.1 Flow movements

The soil material of a hillside or side slope may become so saturated with water that it moves downward in the form of a mud flow. The rate of flow may be slow or rapid depending on the degree of saturation and type of material. The slopes from which the flow starts need not be steep if excess water is present.

The potential effect of this type of slip is to cover the track, push it out of line, or destroy any form of support or retaining wall.

9.4.7.2 Shear failure

Sometimes an embankment or hillside is composed of soil without any great strength or cohesion between its particles. It may be standing too steeply and cracks may develop which will permit the entrance of water.

Movement of a large part of the slope takes place slowly at first, but can become very rapid as complete failure takes place.

This type of slip may occur at any time, even many years after the railway is constructed. The effect on the track is seen as a depression if the movement is minor or a total loss of support if major movement occurs.

9.4.7.3 Slope adjustment

This is a natural occurrence due to erosion. Quantities of spoil or rock fall away from the sides of cuttings and fall onto the track. They may be composed of fine material or rocks that are large enough to derail trains.

Protection against the damage can be afforded by periodically removing any loose stones, and by the provision of a wide bench at the toe of the cutting in which debris may collect clear of the track.

9.4.8 Platforms

The main problem associated with platforms is the ponding of water that consequently causes formation failures, exhibited as poor track alignment, pumping sleepers, and bog holes.

The solutions available depend upon the severity of the problem. The solutions include the following:

- Clean all sumps and pipes.
- Install a suitable drainage system in the 6-foot.
- Recondition track and install subsurface drainage system.
- Completely excavate problem area and replace with densely compacted fill up to the next formation level, then provide a 150 mm compacted granular capping layer and 300 mm of ballast cover. During reconstruction, install a subsurface drainage system.

At stations with island platforms there is often a problem with water ponding at the ends of the platform. This can be remedied by placing a sump in the 6-foot (the area between two tracks) connected to an existing drainage system or suitable outlet.

Note: Run-off from station buildings and platforms can be piped into sumps subject to some conditions. This provides relatively clean water which can be used to help flush drainage systems.

Refer to TS 01638 for track drainage associated with platforms and other trackside structures.

9.4.9 Turnouts and special trackwork

With the increased axle loads and cyclic forces exerted on turnouts it takes very little water for them to start pumping mud up through the ballast, consequently fouling the ballast and compounding the problem.

Some solutions to this problem are as follows:

- Deepen and widen the cess drains on each side to drain water from the ballast and keep it clear of the formation.
- Install subsurface drains under problem areas during turnout reconditioning or renewal. Major problem areas are under heel blocks and crossings. These are points where the most pounding (greatest impact load) tends to occur.
- In some cases, during turnout and crossing renewals, asphaltic concrete has been used as a capping layer to help make the formation more impermeable, thereby giving it a longer life.

Refer to TS 01638 for standard requirements for turnouts and special trackwork, including critical zones to avoid when trenching nearby.

9.4.10 Yard drainage

The problems associated with yard drainage are similar to those of any other track work except on a larger scale. On most lines, the drainage needs to cater for between one and four tracks, but in yards there are usually many more. In addition, yards tend to be constructed on very flat areas, so there is very little fall available for surface and subsurface drainage systems.

The simplest solution for any drainage problems in yards is to clean and regrade cesses and provide regular outlets in the form of sumps, such that the best possible grades can be applied to the surface drains.

The most effective method is to have the formation crossfalls graded as shown in Figure 33 (subsurface drains not shown for clarity).

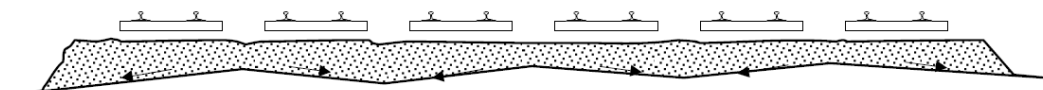


Figure 33 – Typical 'saw tooth' formation used in yards

Subsurface drains are located at the low points. If large flows are expected it may be necessary to install carrier pipes. Carrier pipes may be placed at a deeper level thereby allowing the grades of subsoil drains to be increased between sumps. Figure 34 shows a carrier pipe arrangement.

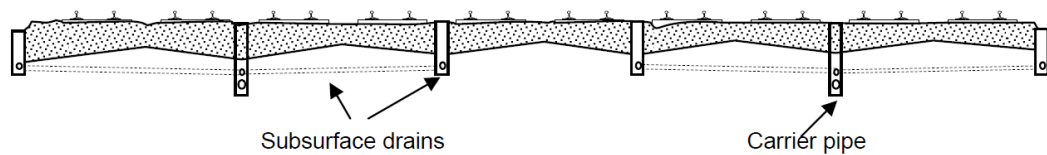


Figure 34 – Carrier pipe arrangement used in yards

Refer to TS 01638 for standard requirements for multiple tracks.

9.4.11 Bridge abutments and retaining walls

Unless adequate weep holes are installed during construction and kept clear by routine maintenance, weep holes tend to block, trapping water behind the abutment or retaining wall. This causes saturation of the earth (fill) behind the walls, which can lead to further consolidation and settlement of the fill.

Weep holes are required at and above the capping layer level as well as at the base of a wall. Weep holes should also be located at regular intervals down the wall, so if the bottom holes become blocked the upper ones can still allow some water to escape.

Existing weep holes should be cleared during routine bridge maintenance. New holes should be bored through the wall if no holes exist or the existing holes are inadequate, especially if there are no weep holes present above the capping layer level.

9.5 Preparation for flooding

Preparation for flooding involves collecting historical data to assist with decisions, making emergency plans, and issuing them to relevant staff.

9.5.1 General

Each region is to have an emergency plan for dealing with major flooding that would affect train operations.

Major flooding can occur with little warning and quick action may be necessary without time to prepare.

Flood plans are to be documented and regularly updated. Copies are to be issued to each team manager and other senior staff. In particular, a copy is to be part of the handover notes for relief officers.

Local regional staff should be the railway source for forecasting the effect of a flood on railway facilities and be the adviser to railway network operations. The civil maintainer is best to arrange this service when a flood is forecast.

Other flood plan considerations could include any associated dam release procedures and potential rail corridor impacts, emergency contacts and back up equipment reserves such as pumps, barriers and life jackets.

9.5.2 Historical information

The collection of data during flooding is most valuable in planning measures that will reduce or avoid damage by future floods.

The heights of maximum water levels at bridges, culverts, and on railway embankments should be marked so that flood levels may be recorded.

At large bridges, the water level may be different at each end or on upstream and downstream sides. Levels at all of these points should be recorded. Any appreciable difference in the upstream and downstream flood levels at a bridge may indicate an inadequate waterway.

The records of previous floods in each river in the region are to be kept up-to-date.

Frequency and severity of flooding are usually available on working plans and office files. Other instructions require all flood heights to be recorded.

Local councils, government agencies and other local bodies can provide a wealth of information on flood heights that will allow upriver peak height information to be related to timing and severity of railway bridge flooding levels.

Local papers and local residents can also advise on the time the river takes to rise, water movements, and other essential local knowledge.

Bureau of Meteorology rainfall patterns assist in assessing run-off rates, saturation figures, as well as river peaks and times.

From all available information, a river flow chart should be prepared that will provide an accurate forecast of the effect of future floods in the river systems on railway facilities once upriver reports are received.

9.6 Maintenance records

Accurate up-to-date asset records stored in a manner for easy access is essential for effective maintenance of track drainage. Records can include site locations, kilometrages, drawings, reports, past flooding levels, examinations and defect details. As drainage assets can include interconnected networks of surface drains and hidden pipes installed over many years, summarising into a simple single data management system is challenging. Graphical

information system displays and references to as built drawings with levels can provide useful visualisations of physical assets for ease of locating and understanding of drainage functions.

Long term maintenance management plans detail the actions and frequency of inspection and maintenance tasks to maintain the system over its design life. Unusual or non-standard or more complicated drainage systems often need additional inspection and cleaning activities than would be covered by typical maintenance plans.

Responsibility needs to be clearly defined in the maintenance plan. For example, the maintenance plan needs to show who is responsible for the nominated inspection and who is responsible for carrying out the maintenance tasks and who needs to be contacted for further technical advice.

Track drainage asset management data and maintenance requirements, including developing TMPs is covered in TS 01638.

10 Documentation guide

Sections 10.1 to 10.2.4 provide a guide for external consultants in the preparation of design drawings and hydrology reports for minor track drainage projects within the rail corridor as well as external party development works discharging onto or through the rail corridor where this has been approved by the standards concession process.

The guidance is provided to achieve standardisation of documentation and is also applicable to field staff inputs to track drainage design.

All documentation is to be retained as covered in TS 01638 asset management requirements.

Minor drainage works within the rail corridor include open cess, pipes, pits, covers such as lobster cages, and minor under track drainage openings.

Standard documentation requirements are covered in TS 01638.

10.1 Drawing guide

Typically, most rail drainage projects are site specific in that they have different site constraints, varying terrain, and unique rainfall catchments, however many details of track drainage remain generic. The aspects outlined in Section 10.1.1 to Section 10.1.10 are considered the minimum information that should be detailed on track drainage drawings.

10.1.1 General

Refer to TS 01547.1 for CAD drafting.

All drawings are to be completed using CAD (Microstation or AutoCAD). There is to be only one drawing sheet per CAD file.

Drawings are to be detailed using standard TfNSW drawing sheets (A1 size). An electronic template file of the standard TfNSW title block can be downloaded from the TfNSW website.

Each drawing is to have a unique electronic document management system (EDMS) number. These numbers can be requested from the TfNSW Central Planroom.

Title blocks are to be filled out in accordance with TS 01547.1.

Requirements for work-as-executed drawings progressively updated during construction are covered in TS 01658. Final as-built drawings are to be then submitted to TfNSW as covered in TS 01547.1.

10.1.2 Plan

Plan drawings require the following:

- Drainage layout drawn at a minimum scale of 1:200 with Sydney shown on the left.
- The layout will include identification or marking of drainage pits and sumps, for example pit P1, P2, and so forth.
- All railway tracks (including turnouts, crossovers, and sidings) to be shown and labelled, for example, Main West – Down.
- Kilometrage marks to be shown along the track – say at 20 m centres. Text labelling at even 100 m centres (20.100 km). Note that OHWS numbers might not coincide with track kilometrage.
- Show the north point.
- Indicate and label railway boundary line.
- Show the design storm events and flood levels (for example, 50 year ARI (2% AEP)).
- Show the top and bottom of cuttings, embankments, drainage channels, depressions, and so forth.
- Show and label trackside furniture – if applicable (for example, signal footings, signal troughing, air lines, train stops, services, face of platforms, retaining walls, bridge abutments and piers, and so forth).
- Show and label any applicable surveyed items (for example, trees, power poles, nearby buildings, edge of roads or access roads, and so forth).
- Show locations of any external services (as determined from a dial before you dig request submitted by the consultant).
- Existing drainage to be indicated and labelled (dotted if they are to be removed).
- Proposed drainage with dimensions of extent, pipe size or type or class. Arrows indicating flow direction. Each pit to be labelled (for example, P1).

- Extent of scour protection (dimensioned and labelled fully).
- Pipe jacking – temporary excavation lines shown and pipe jacking direction indicated.
- OHWS shown with footing outline and structure number indicated. Note that an OHWS comprises a pedestal and either piled or spread footing base. Normally only the pedestal is visible. TfNSW bridges and structures design personnel might be able to help determine the footing size and type if a structure number is known.

The plan will be drawn from and based on a detail survey. However, at the discretion of TfNSW (due to time or budgetary restraints), a schematic layout such as a track diagram may be inserted into the drawing. If a track diagram is used, then the following note is to be included alongside:

- this plan has been taken from track books and is not to scale
- the effects of track curvature and clashes with existing OHWS footings or trackside furniture are to be confirmed on site prior to ordering materials or construction or both
- the possible effects of undermining of existing structures have been investigated and are covered in the design.

10.1.3 Locality map

The following is required for locality maps:

- a street directory format showing the general area is to be included
- label “From Sydney” and “To Country” at the edge of the map
- label showing north point
- circling and identification of site of works.

10.1.4 Typical sections and cross-sections

The following is required for typical sections and cross-sections:

- drawn at a suitable and legible scale (usually 1:20 is adequate)
- showing the track, ballast, and cross-fall of the track formation
- showing nearest track and dimension the offset to the centreline of the drainage system
- dimension the depth below rail of the pipe system and the pipe cover to ground surface
- indication of the width of trench, pipe type or size, geofabric type and fill and bedding material – dimension and label the compaction layers
- if an open channel is adopted, fully dimension the channel and label any scour protection. A table can be incorporated if the channel size varies along the length.

- if different methods of pipe installation are covered, then a typical section is required for each method (for example, cess pipe installation different from undertrack pipe installation)
- cross-sections are typically required at all track crossings, adjacent to OHWS and where there is a change in track configuration.

10.1.5 Longitudinal sections (for pit or pipe and open channel)

The following is required for longitudinal sections:

- a separate longitudinal section is required along all pipe or drainage lines
- draw at a suitable scale (vertical exaggeration can be used to highlight grades)
- table along the bottom of the longitudinal section with headings indicating 'Track km', 'design rail level (low rail)', 'cess level' and 'pipe invert level'
- indicate track kilometrage, rail levels, and cess levels at a minimum of 20 m centres and at pit locations
- indicate pipe invert level at all pit locations
- indicate grade and extent of pipe runs and open channel
- all levels nominated need to be to Australian Height Datum (AHD). Where assumed level is adopted, the assumed benchmark needs to be clearly identified.

10.1.6 Additional details

Include any additional details that are essential for the construction of the project. These may be individual details or separate drawings and may include items such as (but not limited to) the following:

- how new pipes are to be joined in with existing drainage
- energy dissipating device details
- scour protection details
- pipe jacking collaring
- detention basin details
- lobster pot details
- temporary support of existing structures
- pipe and pit anchor structures.

10.1.7 Pit table

A pit table is to be included and will be set up in the format as shown in Table 12.

Table 12 – Pit table format

Pit no.	Pit type	Riser	Top
P1	# 1/ 600 sq. x 1200 deep (internal)	# 1/ 300 high riser # 1/ 150 high riser	1/ 150 high LID. 1/ HD galv. cast iron grate (class B)*. 1/ ballast cage

Note # – designates step irons required in pit.

Note * – class D grates or covers satisfying AS 3996 would typically be applicable for pits without a ballast cage.

10.1.8 Drawing notes

Drawing notes can include the following:

- design criteria (for example, design: ARI of 50 years or AEP of 2%, loading: pipes designed for 300 LA load allowance plus DLA train live load, design life of 120 years for buried elements, climate change rainfall intensity allowance of 10%, blockage factor of 10% and so forth)
- pipe or pit particular notes (for example, surcharge loadings, characteristic concrete strength, exposure classification)
- design standards and specifications
- any other notes particular to the project (for example, staging, shotcreting, and so forth).

10.1.9 References (drawings)

The first drawing in the set is to reference all other drawings. The remaining drawings need to refer to the first drawing and any other drawing that is referred to in the details on that sheet.

10.1.10 Typical example drawings

Examples of typical drainage design drawings are in Appendix F.

10.2 External party development discharging onto or through the rail corridor

Guidance for submissions to TfNSW for external party developers regarding the minimum supporting documentation is covered in Sections 10.2.1 to 10.2.4. The requirements of TS 02404 and any standards concession and development control requirements would also apply.

10.2.1 Hydrology and hydraulics report

A hydrology or hydraulics investigation report needs to be prepared by a Technically Assured Organisation (TAO). The investigation and analysis will include any possible impacts of any additional discharge downstream or backwater effect upstream. This is to include discharge into council stormwater systems.

The report needs to investigate an ARI of 50 years (2% AEP) and should investigate a range of storms from 5 minutes to 24 hour duration. Where any regional waterway or across corridor drainage aspects are involved, then TS 01713 and the associated 100 year ARI (1% AEP) flood event requirements as a minimum would apply for underbridges and culverts.

Note: TfNSW will typically accept reports done for 100 year ARI flood events (as stipulated by some councils) as long as the results satisfy TfNSW requirements.

It is TfNSW's policy to reject any submission where the development will adversely affect discharge rates onto or through the rail corridor. To control this, the developer may be required to incorporate a retention and detention system within the developer's property. Such a system will be covered in the hydrology and hydraulics report. It will also be the consultant's responsibility to submit a 'long-term maintenance management plan'.

It is TfNSW's policy to reject any submission where the development will increase scouring potential within the railway boundary. A drainage solution particular to the site may be required to disperse flow effectively. Alternatively, provision of scour protection may be required.

Where the existing track drainage is found to be inadequate to accommodate the site discharge, the developer will document the upgrade of the track drainage required at their costs. The costs (to be borne by the developer) will include of upgrading of the TfNSW drainage system.

10.2.2 Drawings

Where upgrading of the TfNSW track drainage system is required, or additional drainage works are required within the railway boundary, the documentation needs to be prepared in accordance with Section 10.1.

Where the developer confines all drainage works to within their property, they need to supply a layout plan that conveys the overall stormwater drainage system. This will include any pipes, pits, basins, channels, and downpipes, and is to include the outline of the proposed dwelling and ground contour lines (including any ground level survey points taken). Any labelling of pipes or pits or both will conform to the labelling conducted in the hydraulics and hydrology report. All pipe inverts will be clearly identified in plan or on cross-sections. Any non-related information will be filtered out.

For construction works carried out within the railway boundary, work-as-executed drawings are to be submitted once works have been completed.

10.2.3 Long term maintenance management plan

Where a developer incorporates a detention and retention system to control discharge, then a long term maintenance management plan will be required. This will detail the actions and frequency of inspection and maintenance tasks to maintain the system effectively over its design life.

Responsibility needs to be clearly defined in the maintenance plan. For example, the maintenance plan needs to show who is responsible for the nominated inspection and who is responsible for carrying out the maintenance tasks.

Any costs incurred by TfNSW as a direct consequence of failure of the stormwater system will be passed onto the developer or owner.

10.2.4 Other considerations

The developer will seek the appropriate approval from the affected council or other relevant authorities and parties.

The cost of design, documentation, and construction for any works within the railway boundary will be borne by the developer. The developer will ensure that works are carried out in accordance with railway safety requirements with appropriate TfNSW safety accreditation for all workers.

Appendix A Further reading

The following documents have not been directly referred to in this manual but are included here as suggested reading. These documents may assist with providing important background information on track drainage.

Transport for NSW drawings

CV 0115011 *Ballast retaining wall*

CV 0277517 *'L' Retaining Wall – Type 1*

CV 0497068 *Pipe Culverts Headwalls to Suit Pipes 225-600 mm Diameter*

CV 0497069 *Pipe Culverts Headwalls to Suit Pipes 675-1800 mm Diameter*

CV 0517943 *Single Pipe Headwall to Suit Pipes 225-600 mm Diameter*

CV 0517944 *Single Pipe Headwall to Suit Pipes 675-600 mm Diameter*

CV 0517945 *Twin Pipe Headwall (Splayed Wings) to Suit Pipes 225-600 mm Diameter*

CV 0517946 *Twin Pipe Headwall (Splayed Wings) to Suit Pipes 675-1800 mm Diameter*

CV 0517947 *Twin Pipe Headwall (Straight Wings) to Suit Pipes 225-600 mm Diameter*

CV 0517948 *Twin Pipe Headwall (Straight Wings) to Suit Pipes 675-1800 mm Diameter*

R0200 *Road Stormwater Drainage Series drawings*

Other referenced documents

NSW Roads and Maritime Services, *Technical Guide – Standard Pavement Subsurface Drainage Details*

Appendix B Flow charts

Three flow charts are shown to illustrate the overall design process, the surface drainage design process, and the subsurface drainage design process.

B.1 Overall design process

Figure 35 shows the generic design process applicable to all drainage systems.

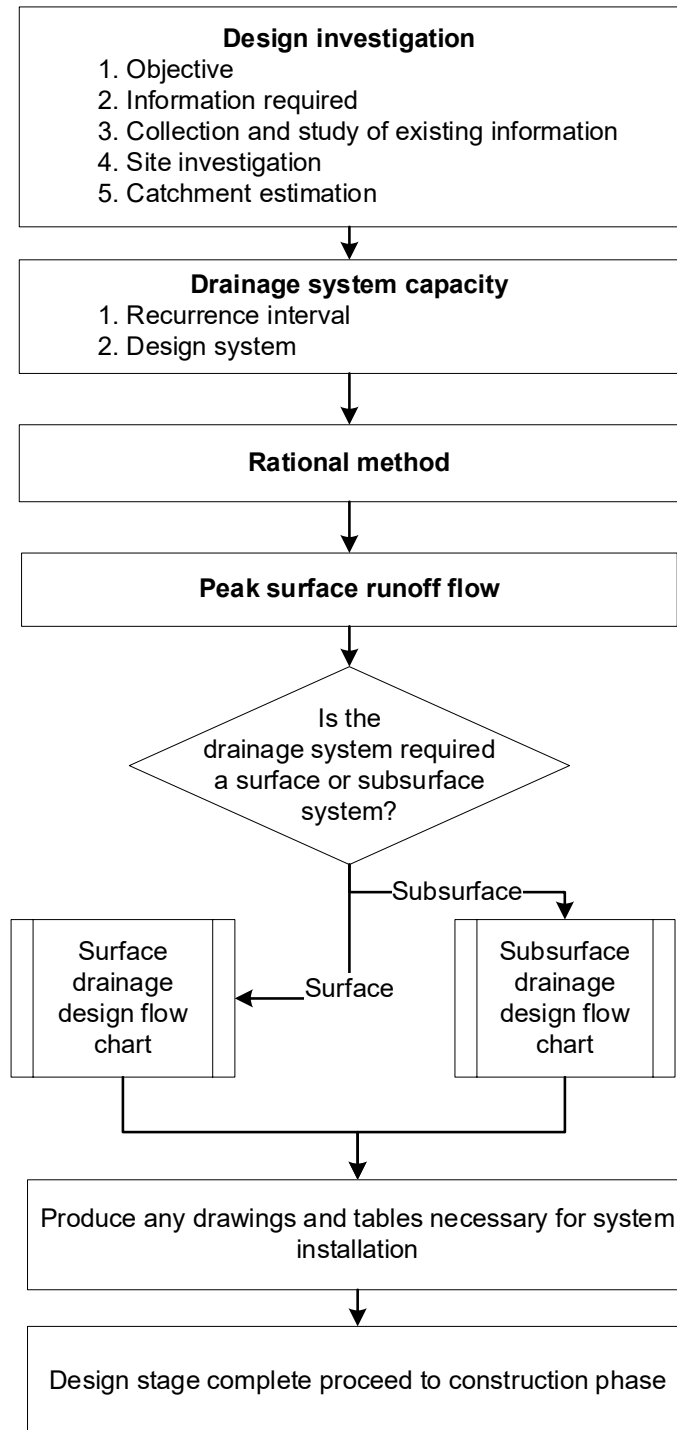


Figure 35 – Overall design process flow chart

B.2 Surface drainage design

Figure 36 shows the design process specific to surface drainage.

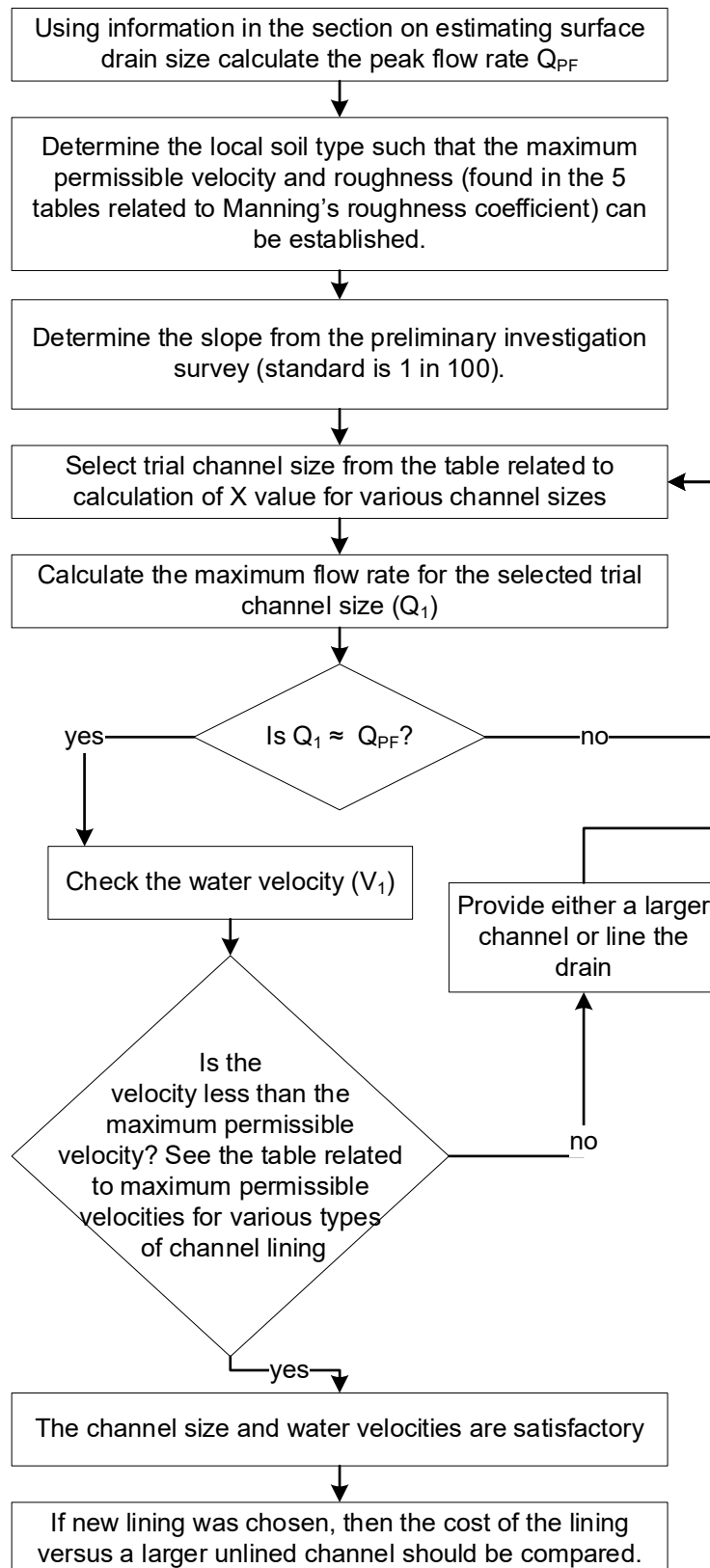


Figure 36 – Surface drainage design flow chart

B.3 Subsurface drainage design

Figure 37 shows the design process specific to subsurface drainage.

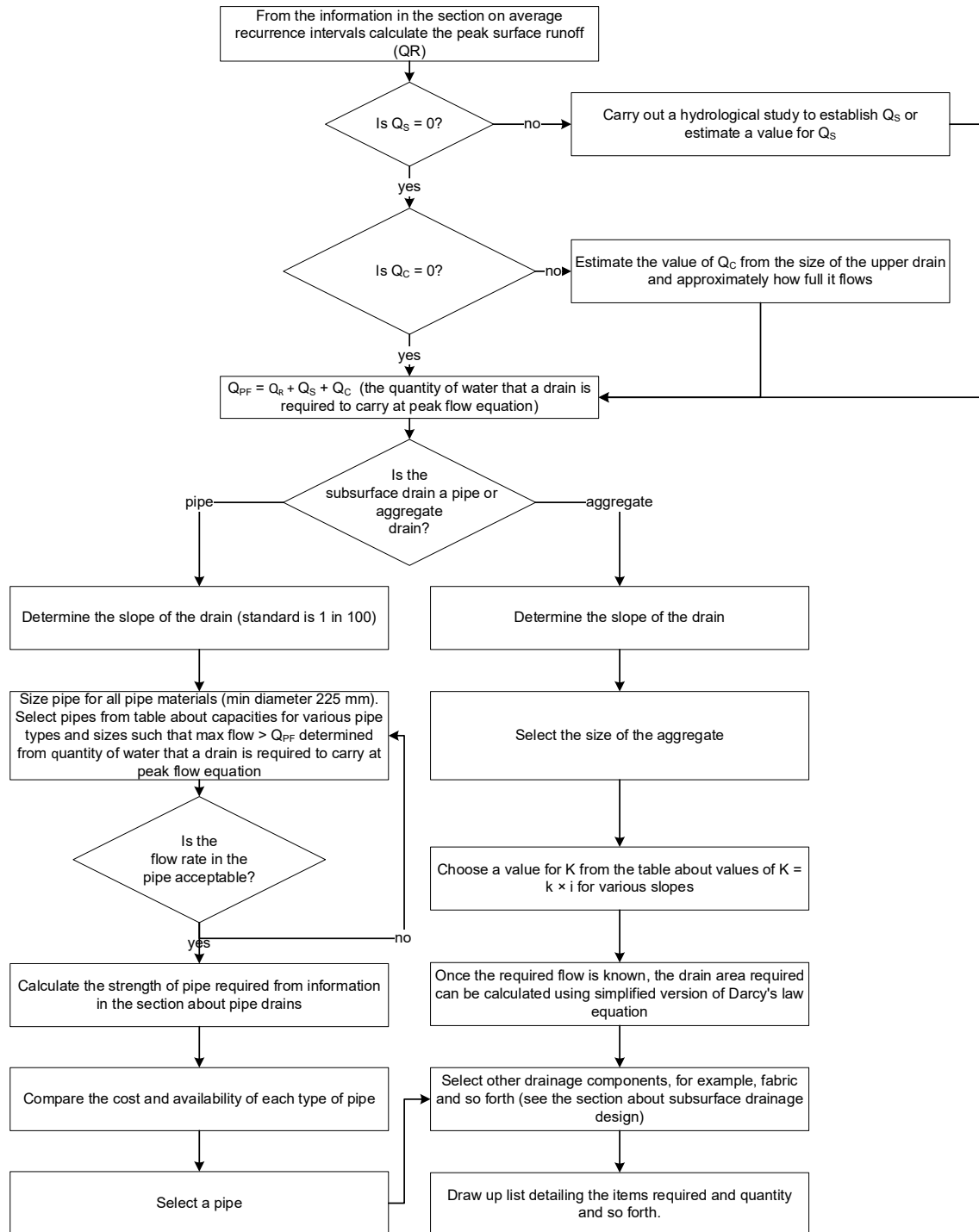


Figure 37 – Subsurface drainage design flow chart

Appendix C Drainage design investigation checklist

The following checklist provides a useful guide and checklist form template when undertaking track drainage design investigations.

Drainage design and investigation checklist

Project identification

Location: _____

Line: _____

Details: _____

Project number or identification: _____

File: _____

Design delivery manager: _____

Target dates: _____

Delivery plan prepared: Yes No

Documentation: In-house External

Deliverable requirements

Hydrology and hydraulics report	<input type="checkbox"/>
Investigation report	<input type="checkbox"/>
Detailed design	<input type="checkbox"/>
Technical specification	<input type="checkbox"/>
Scope of works	<input type="checkbox"/>
Review of external design report	<input type="checkbox"/>

Prepared by: _____

Scope of work and project brief

What type of drainage is it? (i) track (ii) bridge – UB/culvert (iii) external party development

<input type="checkbox"/>	(i)	<input type="checkbox"/>	(ii)	<input type="checkbox"/>	(iii)
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No		
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No		

Has a scope of works been provided for Civil Works?

Has a project brief been provided?

What type of drainage is it? (i) track (ii) bridge – UB/culvert (iii) external party development	(i)	(ii)	(iii)
Have the key design parameters been defined in the scope or brief?	Yes	No	
Are mandatory legislative or regulatory requirements defined in the scope or brief?	Yes	No	N/A
Have any validation methods been established in the scope or brief?	Yes	No	N/A
Is a technical maintenance plan (TMP) required?	Yes	No	N/A
Has functional and performance requirements been identified by the client?	Yes	No	
Have interface requirements been scoped?	Yes	No	N/A
Are there any future proposals that have been identified (for example, access road, embankment widening, quadruplication, turnbacks, upgrades, track lifts, and so forth)?	Yes	No	
Do installation or maintenance manuals need to be developed or changed?	Yes	No	
Do you know the class of line?	Yes	No	N/A
Do you know the speed?	Yes	No	N/A
Do you know the maximum axle load?	Yes	No	N/A
Do you know the operation (inspection and maintenance regime, and so forth)?	Yes	No	N/A
Do you know the usage factors such as numbers of trains?	Yes	No	N/A
Will the configuration change affect the conditions of operation?	Yes	No	
Is training required prior to the installation of the design?	Yes	No	
Have all the stakeholders (both internal and external) been identified?	Yes	No	

Discipline interface – track

Impact on track vertical and horizontal alignment (for example, is there a need to lift or move the tracks)?	Yes	No
Are design track levels (low rail) known?	Yes	No

Discipline interface – geotechnical

Are founding parameters required for drainage design?	Yes	No
Are there any possible stability concerns with adjacent structures or embankments?	Yes	No

Discipline interface – survey

Is a detailed survey scope required?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
Is additional surveying required to define the catchment area (for example, cross-sections, additional points)	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
Do existing drainage systems and services need to be identified?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
Items required surveying (cross out or add as appropriate) – existing drainage, pipe sizes, locations of pits, invert levels, inlet and outlet , cess levels, rail levels, existing OHWS and footings, visible services, banks, ballast edge, road edge, site markers, survey pegs, fenceline, trees, surface levels, define wingwalls, water level, local depressions, sketches	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No

Discipline interface – electrical

Are there any Electrical requirements such as electrolysis, transmission lines, and other services?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
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Discipline interface – services

Has TfNSW internal services searches been conducted?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
Has 'Dial Before You Dig' external services searches been carried out?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
Does it look possible that conflict will exist with structure footings	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No

Discipline interface – external bodies

Have external hydrology reports been carried out in the area (for example, local council and previous reports)?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
Are external bodies required to be involved?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
local council	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
road authority	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
environmental authority	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
water authorities	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
land owner	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
external development	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No

Consultant: _____

Will any proposed configuration changes impact on TfNSW's accreditation with Minister of Transport?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
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Will any proposed configuration changes require approval from external bodies (authorities, local councils, and so forth)?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

Site data

Is the proposed works located in an (i) embankment, (ii) cutting, or (iii) open track

<input type="checkbox"/>	(i)	<input type="checkbox"/>	(ii)	<input type="checkbox"/>	(iii)
--------------------------	-----	--------------------------	------	--------------------------	-------

Project type: (i) renewal, (ii) refurbishment (UB and culvert), or (iii) upgrading for track drainage

<input type="checkbox"/>	(i)	<input type="checkbox"/>	(ii)	<input type="checkbox"/>	(iii)
--------------------------	-----	--------------------------	------	--------------------------	-------

Is there possible impact with existing structures – OHWS, signal gantry, bridges, footings (for example, alignment conflicts, undermining of footings, embankment stability concerns)?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

Site access – is there an existing access road?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

Is there surrounding drainage systems? For example, local council, RMS, private parties

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

Are there possible scouring concerns or evidence of site scouring?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

Are details (drawings) of existing drainage available?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

Are there physical interfaces with other property owners or Stakeholders?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

road crossings (including private crossings)

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

interface between earthworks and other properties

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

drainage flow to other properties

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

installations such as pipelines laid within the corridor

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

private sidings and bridges

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

other statutory authority requirements for example, environment?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

Hazard and risk identification and analysis

Are there hazard sources from any of the following?

normal operation

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

environment

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

equipment failure

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

improper use or maintenance

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
--------------------------	-----	--------------------------	----

Are there risks to any of the following?

— —

Are there hazard sources from any of the following?

maintenance or construction staff	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
public	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
operators	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
other equipment	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No
environment	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No

Has the design and analysis considered the effect of potential hazards and risks during the following?

construction, including any temporary works required as part of the project	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
maintenance	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
operation	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
decommissioning and disposal	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
Have possible mitigation measures been identified and documented?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A

Design and documentation checklist

Hydrology and hydraulics

Has proper hydrology and hydraulics calculations (including correct design parameters) been carried out by staff with the proper competency?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
For complex hydrology studies – has an external service provider been nominated?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A

Hydrology report and investigations

Has the following information been documented:

document control table (revision no, date, details, signatures)	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
site description and background	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
options for refurbishment or renewal	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
catchment details	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
design methodology	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
hydrology parameters adopted	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
hydraulic parameters adopted	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
other design input (for example, survey, recorded flooding, measured values, consultation with councils or authorities)	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
analysis results	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
conclusions and recommendations	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A

Has the following information been documented:
recommendation and concurrence by stakeholders
Comments:

Yes No N/A

Detailed design drawings

Has the following information been documented:

- location and description and extent of the drainage works
- drawing sheets and title block to TfNSW current standards
- plan view (Sydney on the left, layout of drainage, existing drainage, banks and depressions, all tracks labelled, north point, boundary line, OHWS, services, scour protection, flow direction, survey items, and so forth)
- locality map
- typical sections(offsets to rail, depth to rail, cover to pipe, trench details, compaction layers, geofabric, scour protection, pipe labelled)
- longitudinal section along each pipe run (includes, track km, design low RL, cess level, pipe invert levels, grades)
- relevant notes – design criteria, reference to appropriate standards and manufacturers.
- drawing references
- additional details (join with existing, energy dissipaters, scour protection, pipe jacking, detention basin, lobster pots, temporary support, and so forth)
- specific maintenance requirements, for example, retention basin – responsibilities and frequency of silt removal
- Do the design document and the information it contains comply with the standards?
- Does the design reflect sound engineering practice?
- Have all known relevant project constraints have been considered?
- Is this document fit for purpose?
- Is it suitable for construction use?
- Is it suitable for record (plan room) purposes?
- Does the design generally comply with the TfNSW track drainage guide?

<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A
<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/>	N/A

Drawing check

Accuracy – are dimensions correct?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Accuracy – is the drawing to scale?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Clarity – is the designer's intention clear?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Clarity – is sufficient information given?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Practicality – can the work be constructed as efficiently as possible?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Consistency – is the drawing consistent with existing drawings of the same type?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Regarding the question immediately above – if not, can the change be justified?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/> N/A
Standards – have relevant drafting standards and practices been adhered to?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Standards – is the drawing presentation consistent with TfNSW drafting standards?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
References – are all the necessary cross-references included?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Status – has the drawing status been updated? For example, from tendering and construction	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Title – is the drawing titled according to TfNSW practice?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	
Corrections – if corrections have already been marked on a previous check print held by the checker, are they included in the current print?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	<input type="checkbox"/> N/A
Distribution – have the drawings been distributed to the relevant stakeholders by the Design Delivery Manager (DDM)?	<input type="checkbox"/>	Yes	<input type="checkbox"/>	No	

Verification and approval

The drawing has been signed by the drafter, drawing checker, and designer Yes No

Drafting checker

I certify that I have completed the drafting check.

Signature: _____ Printed name: _____ Date: _____

The drawings reflect the design intent, details, and completeness. Yes No

Designer

I certify that I have completed all required actions.

Signature:

Printed name:

Date:

Have independent actions have been taken to verify the design as detailed on the drawings?

Yes

No

N/A

Independent verifier

I certify that I have completed an independent design check.

Signature:

Printed name:

Date:

The design, drafting, and checking functions have been carried out by people with appropriate competency.

Yes

No

The design and drawing reflect sound engineering practice.

Yes

No

Reviews at progressive stages have been carried out with the client, to ensure that the design takes into account the client's needs, the functional requirements and constraints of all relevant codes, standards, regulations, practices and statutory requirements.

Yes

No

N/A

Comments:

The drawing is satisfactory for construction purposes.

Yes

No

The design phase for the discipline is complete.

Yes

No

Has the relevant information been entered in bridge management system?

Yes

No

TfNSW standards have been applied.

Yes

No

Approver

I certify that I have reviewed the design and have approved its issue.

Signature:

Printed name:

Date:

Accepted

I have accepted the design for use by TfNSW.

Signature:

Printed name:

Date:

Appendix D Drainage design site investigation form

The following form provides a useful template form and checklist when undertaking on-site track drainage design site investigations.

Date: _____

1. Location (that is, track region and kilometrage):

2. Track structure to be drained:

3. Condition of existing drainage system (if any):

4. Length of drainage system:

5. Restraints? Such as inlet and outlet, existing adjacent structures, track curvature, and so forth:

6. Estimate catchment area:

7. Site access:

8. Any specific site safety requirements:

9. Conduct services search. Any visible services noted:

10. Other comments:

11. Photographs: to be attached.

12. Site sketch:



Map 4.7 – 1 h duration, 50 year ARI	${}^{50}i_{1h}$	=	mm/h
Map 5.7 – 12 h duration, 50 year ARI	${}^{50}i_{12h}$	=	mm/h
Map 6.7 – 72 h duration, 50 year ARI	${}^{50}i_{72h}$	=	mm/h
Map 7c – skewness factor G	G	=	
Map 8 – geographical factor F2	F2	=	
Map 9 – geographical factor F50	F50	=	
From ARR 2001 Book 2 figure 5.1 – Run-off coefficient for a 10 year ARI	C_{10}	=	
Calculate 6 min duration, 2 year ARI.	${}^2i_{6min}$		mm/h
From ARR 2001 Book 2 formulae B(3.1). ${}^2i_{6min} = F2 ({}^2i_{1h})^{0.9}$			
Calculate 6 min duration, 50 year ARI.	${}^{50}i_{6min}$	=	mm/h
From ARR 2001 Book 2 formulae B(3.2). ${}^{50}i_{6min} = F50 ({}^{50}i_{1h})^{0.6}$			
6. Determine the critical rainfall intensity $I_{cr,50}$ for the critical duration t_c and an ARI of 50 years.			
Method 1: Graphical method. Plot the points in step 5 on a Log-Pearson Type III Interpolation diagram (see Diagram 2.2 in ARR 2001) and join lines between these 2 year and 50 year ARIs. Refer to ARR 2001 Volume 1, Book 2.			
Method 2: Adopt ARR formulas that interpolate between rainfall durations. Determine modified intensity values ($I_{1h,50}$, $I_{12h,50}$, $I_{72h,50}$) using skew lines at the bottom of the graph. Plot these values as well as ${}^{50}i_{6min}$ on the duration interpolation diagram 2.1 and read off the critical 50 year intensity, $I_{cr,50}$. Refer to section A.3 of ARR 2001 Book 2.			
Method 3: Utilise computer software (for example, “IFD” or “Drains”) by entering values from step 5.			
	$I_{cr,50}$	=	mm/h
7. Determine the 50 year run-off co-efficient C_{50} .			
C_{10} – from step 5.	C_{10}	=	
Geographical zone. From figure 1.2 ARR 2001 Book 4.	zone	=	zone B (for Sydney Metro area)
Determine frequency factor (FF50). Using formulas or interpolating values given in table 1.1 of ARR 2001 Book 4.	FF_{50}	=	
Calculate $C_{50} = C_{10} FF_{50}$	C_{50}	=	

8. Calculate the 50 year peak flow rate Q_{50} using the Rational Method. This represents the amount of water that will flow on a catchment for the critical 50 year storm.

$$\text{Conversion factor for formulae} \quad F \quad = \quad 0.278$$

$$F = 0.278 \text{ if } A \text{ is in km}^2$$

$$Q_{50} = F C_{50} I_{cr,50} A \quad Q_{50} \quad = \quad \text{m}^3/\text{sec}$$

from ARR 2001 Book4 equation 1.1

9. Determine the required drain capacity

To calculate use figures 2.18, 2.19, 2.20, 2.21, and equations 2.3, 2.4, 2.7, and 2.8 in ARR 2001.

$$Q_R = \text{run-off quantity collected} = Q_{50} \quad Q_R \quad = \quad \text{m}^3/\text{sec}$$

$$Q_S = \text{subsurface water intercepted} \quad Q_S \quad = \quad \text{m}^3/\text{sec}$$

$$Q_C = \text{watering entering from another system (for example, separate drainage line)} \quad Q_C \quad \text{m}^3/\text{sec}$$

$$Q_{PF} = Q_R + Q_S + Q_C = \quad Q_{PF} \quad \text{m}^3/\text{sec}$$

Note: this procedure determines the amount of water passing at a single point based on the original catchment area. If multiple catchment areas are incorporated into a system, then this process should be repeated for each catchment.

For information, a worked example for Eastern NSW and similarly Western NSW is in ARR 2001 Book 4.

Peak flow rate values accounting for climate change predictions and potential blockages also needs to be calculated.

Because of the repetitive and time-consuming nature of this procedure, it is recommended that such method be entered into a spreadsheet, or computer program. Alternatively, hydrology software incorporating ARR methods may be a cost-effective method to use in preference.

Appendix F Drawings: typical examples

Typical examples of engineering drawings are shown in Figure 38 to Figure 41.

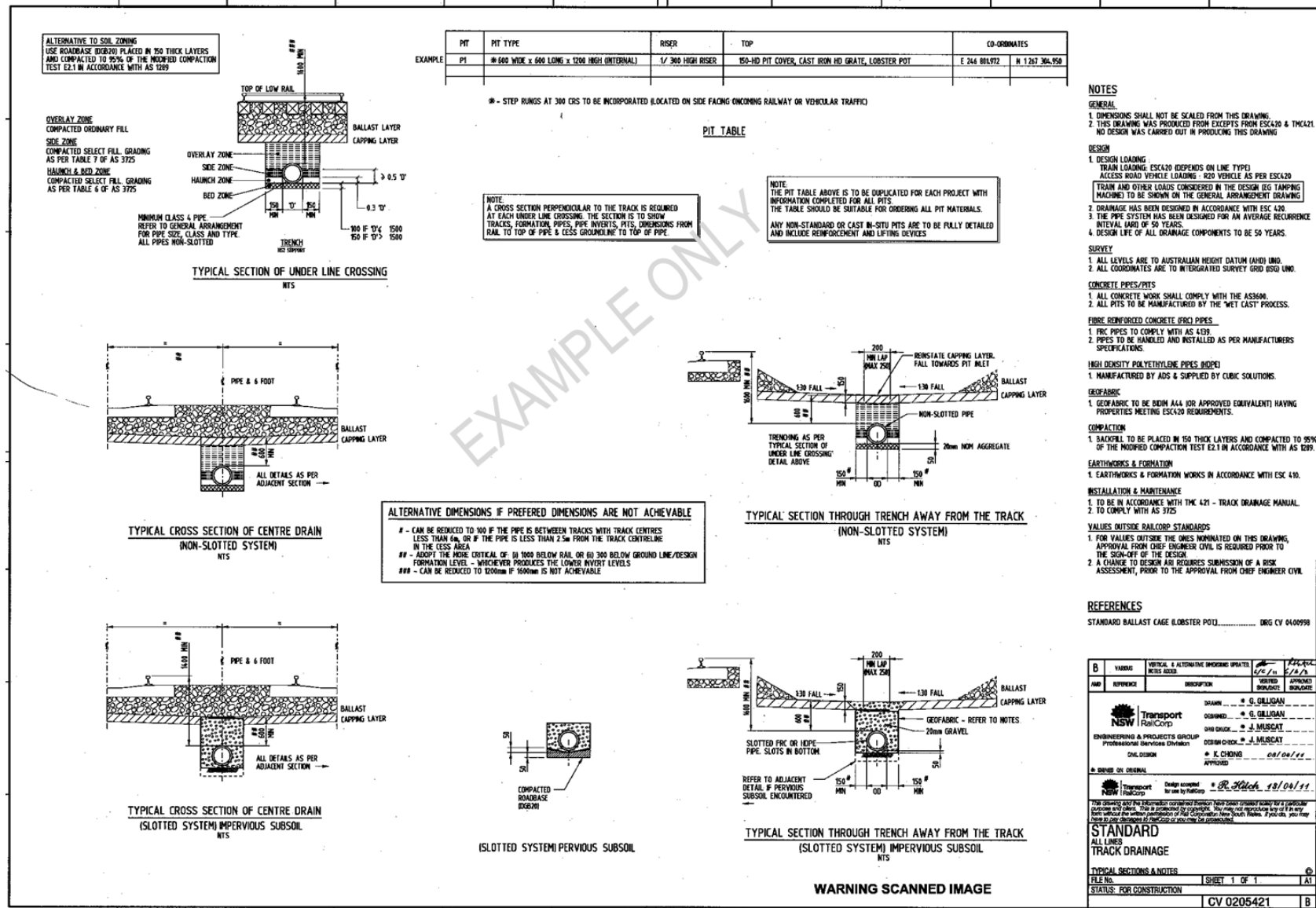


Figure 38 – Example drawing 1 – typical cross sections

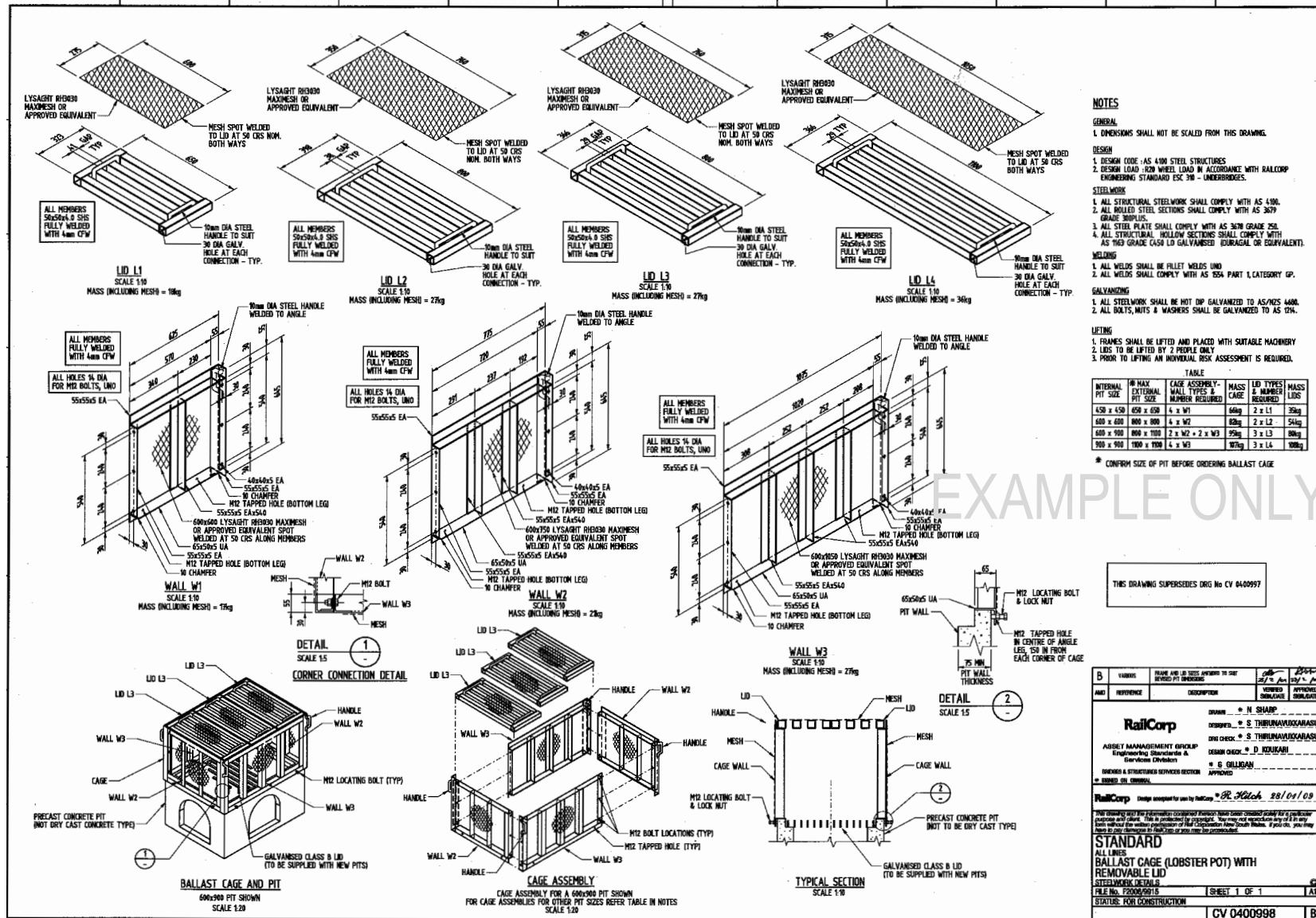


Figure 39 – Example drawing 2 – ballast cage steelwork

Appendix G T44 and R20 truck vehicle loading configuration

The R vehicle is a standard rigid truck with the same configuration as the prime mover portion (first three axles) of the standard T vehicle and the numerical portion is the vehicle's gross mass in tonnes. The vehicle's axle spacings in mm and axle loads in tonnes are shown in Figure 42. The R20 vehicle axle loadings equate to 4 t for the leading axle and 8 t for each of the two rear axles. The tyre contact area for each wheel is assumed to be 200 mm by 200 mm. Design road traffic loads in TS 01638 are nominated as at least the T44 vehicle as specified in TS 01715. The R20 vehicle has been included for historic purposes as earlier versions of the track drainage standard included this loading configuration.

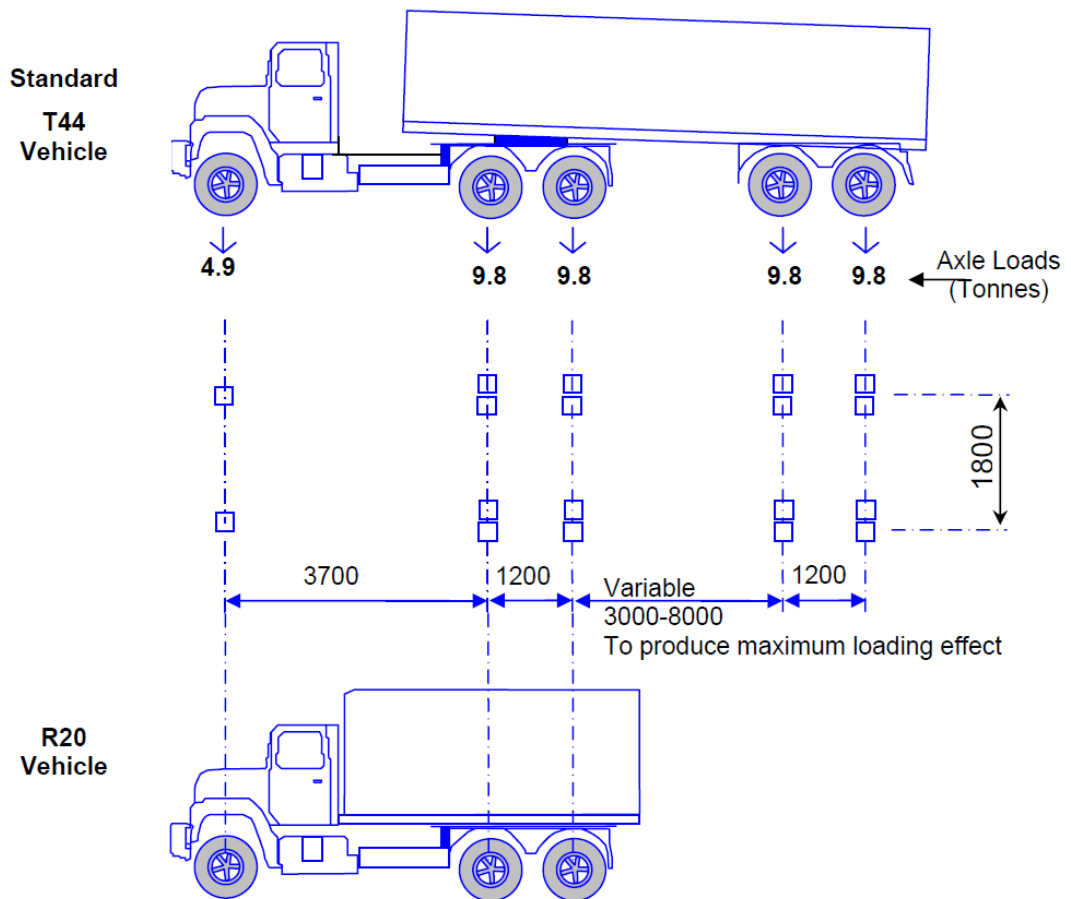


Figure 42 – Design vehicle configurations