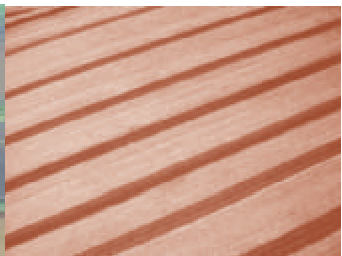
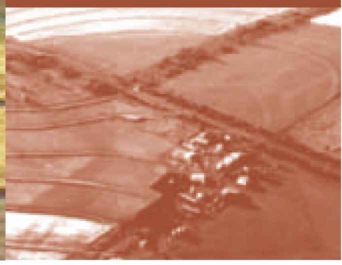
Soil Conservation Measures

Design Manual for Queensland





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Chapter 1

Introduction

Soil erosion remains a major threat to the agricultural lands of Queensland and associated downstream areas. The loss of topsoil through erosion results in a significant loss in productivity. The subsoils that remain are likely to be incapable of supporting viable agricultural enterprises. Advanced erosion leads to rills and gullies that make paddocks unworkable. Runoff from eroding landscapes contains sediment and any nutrients, fertilisers or pesticides that were present in the soil. Downstream impacts include damage to roads and railway lines, siltation of watercourses and water storages and an overall reduction in water quality in creeks, rivers and coastal areas.

The incidence of soil erosion can be spasmodic. Studies in Queensland have shown that a few large events in each decade may be responsible for a large proportion of the total soil loss (Freebairn 2004). This issue must be kept in mind when determining targets aimed at reducing soil erosion and improving water quality. Both farmers and the community can become complacent about soil erosion during periods in which few significant erosion events occur.

1.1 Principles of erosion control

There are three important principles to consider in the control of water erosion:

- use land in accordance with its capability
- protect the soil surface by some form of cover
- control runoff before it develops into an erosive force.

Factors such as soil type and land slope determine how vulnerable a piece of land is to soil erosion and what type of erosion control measures will be required. Land with serious erosion risks may not be suitable for any form of agricultural use or may require a form of land use that is less conducive to soil erosion.

Adequate levels of surface cover play an important role in erosion control by reducing the effects of raindrops falling on bare soils. Surface cover also encourages runoff to spread rather than to concentrate. However, there is a natural tendency for runoff to concentrate as it moves down-slope. Soil conservation structural measures such as contour banks and waterways are used to manage this runoff in upland areas, while strip cropping is used on floodplains.

The role of trees in the control of soil erosion needs some consideration. Trees play a vital role in our landscapes by maintaining biodiversity, providing shade and shelter, recycling nutrients, utilising carbon dioxide and using moisture that may 'leak' into groundwater and contribute to salinity problems. They also provide stability to stream banks and prevent landslip on susceptible steep slopes. In forests, the leaf litter, shrubs, grasses and a variety of other forms of vegetation covering the soil surface, provide protection from erosion. However, if heavy grazing (or high pedestrian traffic in recreational areas) removes the surface cover below trees, erosion may result. The vulnerability of an area to erosion following clearing depends on how the land is managed.

When dealing with soil erosion, various publications refer to the need for riparian vegetation. Strips of riparian vegetation along creeks and rivers are essential for a wide range of reasons including the filtration of groundwater flows moving into the stream (Hunter and Hairsine, 2002). However they have minimal impact in filtering out sediment and nutrients from overland flows exiting eroding paddocks. While the runoff from some areas of cultivation may flow directly into a stream, this is the exception. Runoff will exit most paddocks at one or two well-defined points and flow into a drainage line. Drainage lines then enter creeks, and creeks enter rivers at well-defined points or via floodplains. Concentrated runoff from catchments does not enter creeks and rivers by flowing over their banks. Any attempts to force this to happen, usually results in a very serious gully erosion problem.

To manage water quality problems associated with erosion, it is essential to tackle the problem where it starts. High levels of surface cover are essential to keep soil where it belongs and to prevent it from becoming a water-borne pollutant. Contour banks are very effective sediment traps. When their channels are lined by crops or standing stubble, they provide a very useful filtration function, since the crop or stubble can reduce the velocity of flow by a factor of five compared with channels with bare soil.

Grassed waterways collect runoff from contour banks and provide another opportunity to filter out sediment as the runoff flows towards a natural watercourse. Farm dams or other detention structures such as artificial wetlands can be constructed to further increase the deposition of soil, nutrients and other pollutants from the paddock.

1.2 Past gains

Programs aimed at the control of soil erosion in Queensland commenced in the middle of the last century. By 1950, 16 000 ha of cultivated land in Queensland had become so badly eroded that it had to be withdrawn from cultivation (Ladewig and Skinner 1950). Evidence of this erosion can be observed by examining aerial photographs of upland areas on the Eastern Darling Downs taken in the 1950s.

Considerable gains have been made in the control of soil erosion in Queensland since a concerted effort to manage the problem began in the 1950s:

- Significant areas of steep land have been taken out of cultivation and returned to pasture or native vegetation. This move has largely been driven by economics, since the cultivation of shallow soils on steep slopes is not profitable for most crops.
- Surface cover levels have improved dramatically. Bare soil fallows were the norm in the 1950s and 1960s when stubble was removed by burning and excessive tillage. The use of implements that can handle stubble and the introduction of herbicides suitable for weed control in cropping lands has allowed the adoption of minimum till and zero till practices.
- There has been widespread installation of contour banks and waterways to manage runoff in upland areas and strip cropping to manage floodwaters on floodplains that are subject to erosive flooding.

1.3 Goals for the future

Most farmers have been keen to adopt soil conservation measures. Soil erosion can become a very visible problem and an obvious threat to the future viability of a property. Soil conservation measures provide direct economic benefit through increased farm productivity and reduced wear and tear on machinery. Farmers are also becoming more aware of the impact of their practices on the external environment as well as the marketing advantages provided when consumers are aware that their food is produced in an environmentally friendly manner. The adoption of soil conservation measures is a key ingredient in minimising damage to roads, waterways and drainage networks and in ensuring that the scenic amenity of rural areas is maintained. There are many benefits in ensuring that rural properties are visually attractive to both local residents and tourists.

However, the task of controlling erosion is far from complete:

- There is scope for further improving levels of surface cover
- Many upland cultivated areas are unprotected by contour banks or existing banks are poorly

maintained
- Many waterways that receive runoff from contour banks have stability problems and are in need of maintenance.
- Many floodplain areas subject to erosive flooding are yet to be protected by strip cropping practices
- Extended periods of low rainfall and runoff resulting in minimal erosion can lead to a degree of complacency in relation to the implementation and maintenance of soil conservation measures.

1.4 The Manual

The first publication to deal with the design of soil conservation measures in Queensland was the Queensland Soil Conservation Handbook. It was published in 1966 by the Department of Primary Industries, the government agency responsible for soil conservation at that time. A metric version with minor revisions was produced in 1978.

The primary purpose of this manual relates to the design of soil conservation measures and it is most appropriate to cropping lands. The manual does not describe management practices associated with stubble retention practices such as minimum and zero tillage. It is considered that there is already a considerable amount of information on this topic and there are many agronomists working in machinery and herbicide sales who are available to provide the necessary advice.

Some peripheral information that would not normally be associated with a manual is included. Much of this information is not available in any other published document and it is considered that it will assist practitioners in gaining a greater understanding of the issues relating to soil conservation in cropping lands.

There are four sections in the manual:
- Section A Planning
- Section B Runoff estimation
- Section C Channel design
- Section D Special applications.

Section A Planning
This section is mostly related to broadacre cropping and includes information on legal aspects of planning. Some chapters in other sections also have relevance to soil conservation planning eg. the chapter on horticultural applications.

Section B Runoff estimation
There are two steps associated with the design of soil conservation structures. Firstly, an estimate is required of the rate of flow that the structure will be required to accommodate. This section describes the processes related to runoff with a special emphasis on the impacts of stubble retention practices. Two methods of estimating runoff for small rural catchments are described.

Section C Channel design
The second step associated with the design of soil conservation measures involves the design of a structure that can accommodate the design runoff. This section includes some general design principles as well as chapters on contour and diversion banks and waterways.

Section D Special applications
This section includes information on floodplain management. Future editions of this manual are expected to cover topics on soil conservation in horticulture, property infrastructure, gully erosion control and stream stability.

The focus of this manual is on erosion by water. While wind erosion is a very significant problem in the more arid grazing lands of inland Queensland, it is generally not a serious issue in cropping areas. Most soils cultivated in Queensland have a heavy texture and form relatively large aggregates that are too coarse to become airborne when strong winds are blowing. Soils with a sandy texture are susceptible to wind erosion but cultivation of such soils is generally uneconomic in the Queensland environment. These soils have very low moisture storage capacity and low fertility – their use in Queensland is limited to small areas for horticulture or vegetable growing where irrigation is available. As with the control of erosion by water, the provision of cover on the surface of the soil is the key to the control of wind erosion.

A bibliography is included which attempts to capture all of the Queensland references that are relevant to the design of soil conservation measures. It should be noted that most of the references dated prior to 1995 were prepared by staff of the Department of Primary Industries—the state agency responsible for soil conservation programs up until that time. The bibliography includes references to the land management field manuals that have been prepared for most of the cropping lands of the state. These manuals provide useful information on land resources and land management with specific references to soil conservation. In many cases they provide more specific information relating to the design of soil conservation measures than can be provided in this manual, which has a statewide context.

For ease of use, frequently used tables and charts are included in Appendix 3. ■

Chapter 2

Property planning for soil conservation

This chapter had minor updates in 2013 to reflect changes to the names of government departments and their web addresses since 2004.

The preparation of an effective soil conservation plan requires consideration of many issues including soil types, topography, current and proposed land use and management, remnant vegetation, property infrastructure and run-off coordination with neighbouring properties and road and rail drainage. The planning process also provides opportunities to improve the overall property layout to achieve greater efficiencies in managing the property. This chapter relates mostly to situations that apply in broadacre cropping where contour banks and waterways are used.

A soil conservation plan can be a component of a farm management system where landholders consider personal, financial, natural resource and environmental management and other issues involved in farm business management. As this manual relates to the design of soil conservation measures, this chapter concentrates on aspects related to the planning of these measures.

Historically, property development often occurred in a haphazard manner as different owners made their mark. Decisions on which land to clear and how to use it as well as location of infrastructure such as buildings, fences, tracks, watering points were often made ‘on the fly’ and for short-term goals. Once such decisions were made, they were not easy to correct and landholders learnt to live with past mistakes. The preparation and implementation of a soil conservation plan provides an opportunity to correct some past planning decisions that may have led to problems or inefficiencies.

With tree crops, it is especially important to implement adequate surface and subsurface drainage requirements before planting the trees. If not done properly, it is difficult and expensive to carry out remedial measures once soil losses start to occur after the trees have become established.

While the planning of some runoff control layouts can be straightforward, others can be more complex and require the consideration of a number of optional layouts. This is especially so when consultation is required with neighbours and authorities responsible for infrastructure such as roads and railway lines. A significant amount of time may be required to evaluate options on paper and it may be necessary to do some preliminary surveying in the field before deciding on the best option.

While farmers can acquire the skills to do their own planning, it is desirable to seek the expertise of someone with experience in this area. Such a person can play a similar role to that of an architect of a building, taking into account the needs of the property owner and preparing a plan that will be both practical and technically sound and which takes into account possible impacts on adjacent lands and other resources.

Other chapters related to planning for soil conservation are as follows:

- Chapter 9 *Contour banks*
- Chapter 10 *Diversion banks*

- Chapter 11 *Waterways*
- Chapter 12 *Floodplain applications*

2.1 Preparation of a soil conservation plan

This topic is discussed under the following headings:

- Section 2.1.1 Land capability assessment and land use
- Section 2.1.2 Planning on a catchment basis
- Section 2.1.3 Legislative and regulatory requirements
- Section 2.1.4 Coordination with road and rail drainage
- Section 2.1.5 Locating property infrastructure
- Section 2.1.6 Consideration of cadastral boundaries
- Section 2.1.7 The mapping base
- Section 2.1.8 Collection of data and information
- Section 2.1.9 The property inspection
- Section 2.2 Evaluating layout options
- Section 2.3 Designing the structures
- Section 2.4 Obtaining acceptance to the plan
- Section 2.5 Implementation
- Section 2.6 Management and maintenance
- Section 2.7 Monitoring the plan.

The following additional information is provided in appendices:

- Appendix 1 Aerial photo interpretation
- Appendix 2 Land capability/suitability/use
- Appendix 3 Design aids for soil conservation measures.

2.1.1 Land capability assessment and land use

A basic principle in soil conservation planning is that land needs to be used within its capability. Using it beyond that capability leads to environmental instability and degradation, and ultimately to economic failure of the farmer and impoverishment of the community (Stone and Titmarsh, 1997).

Different crops require different soil characteristics for optimum growth. Each management unit on the property should be examined and an assessment made of its present productivity. Alternative uses for each should be considered, and estimates made of the cost of converting to that land use, the costs of production and the returns likely to be obtained.

A number of land capability/suitability assessment systems that have been used for describing land in Queensland are listed in Appendix 2. These have been provided to assist with the interpretation of many existing soil conservation plans that contain this information.

Historically, there have been many examples in Queensland where unsuitable land was used for cultivation with land slope, soil fertility and depth, moisture holding capacity and soil physical restrictions being the most common limiting factors. However economic limitations have reduced the viability of growing crops in such areas and in most cases this land has been returned to pastures and/or native vegetation. The presence of contour banks on much of this land provides evidence that it was once cultivated. If cropping was to become a more profitable enterprise, it is likely that there would be more pressure on marginal land to be cultivated.

2.1.1.1 The Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation (USLE) came into use in the 1970s and can be used to evaluate the potential soil loss from a farming activity (Rosewell 2001). Different management options can be considered and their potential soil loss compared. The equation is written as:

A = RKLSCP

Where
A = average soil loss in tonnes/hectare/year
R = rainfall erosivity factor
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cropping factor
P = supporting practices factor.

The factors R, K, L and S determine how much soil would be lost if the soil was maintained in a bare condition with no soil conservation practices applied. This figure is then reduced by the C (crop and pasture management) and P factors (such as contour cultivation).

It should be noted that the P factor only accounts for contour cultivation and not the use of contour banks. As contour banks reduce slope length, they are taken into account by the L factor. However the USLE does not take into account the fact that besides reducing the effective land slope, contour banks manage runoff to prevent it from concentrating and becoming an erosive force as it proceeds down the slope. This concentration leads to rill and gully erosion.

For many years, the figure of 12.5 tonnes/ha/year (5 tons/acre/year) soil loss was considered to be an acceptable upper limit for good quality cropping soils. This rate of soil loss represents around 1mm in depth of soil per year which is a coarse estimate of the rate of soil formation. However, current thinking is that the aim should be for a soil loss of less than 12.5 tonnes/ha. A soil such as a Sodosol with a shallow A horizon should have much lower acceptable soil losses than say a deep alluvial soil on a floodplain.

Long-term soil loss experiments comparing different levels of fallow treatment on the eastern Darling Downs (Freebairn and Wockner 1986) have measured average annual soil losses of up to 60 tonnes/ha/year under bare fallow treatments. In the same trial, treatments involving the use of stubble retained on the soil surface between well maintained contour banks reduced average annual soil losses to 5 tonnes/ha/annum.

While the USLE is a useful research and education tool, it has rarely been used for the planning of on-ground soil conservation measures in Queensland. Experienced soil conservationists can readily assess land capability. The two primary methods of controlling soil erosion on a given piece of cultivation land are to maximise surface cover and to manage runoff with structures such as contour banks or mounds on upland areas and strip cropping on floodplains. These practices can readily be implemented without reference to the USLE. Current technology enables farmers to maintain high levels of surface protection although this can be limited by droughts, fertility decline, grazing, hay making, or the use of crops that provide minimal levels of cover (e.g. sunflower, cotton, mung beans and chick peas). Contour bank spacings are primarily determined by land slope as discussed in Chapter 9 *Contour banks*.

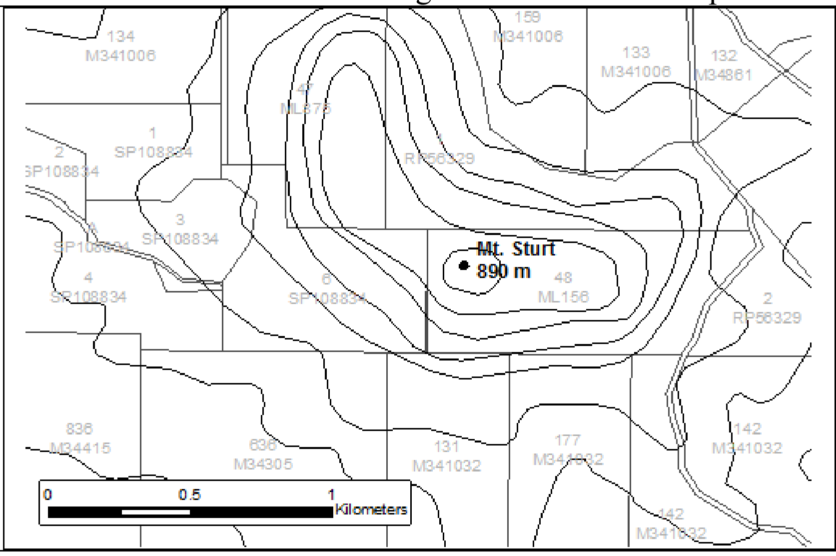
A spatial version of the USLE has been developed for catchment scale planning in Queensland (Brough *et al.* 2004). This soil erosion assessment map provides a framework for government and catchment community groups to focus their activities in areas where the risks of potential soil erosion are greatest. At a broader scale, this information is available for the whole of Australia (Lu *et al.*2001).

2.1.2 Planning on a catchment basis

It is necessary to address runoff control planning on a natural catchment basis and within bounds set by other features such as roads, railways and water supply channels. Each farm is part of one or more natural catchment areas. Even though it may be tempting to address erosion on a paddock level, the problems of inappropriate land use or uncontrolled runoff can seldom be separated from other areas of the property or adjoining land. In preparing a plan, it is important to get an appreciation of where a property fits within the local catchment. This involves getting a feel for the big picture before coming down to the farm level and finally to specific paddocks or problem areas. When looking at solutions, there is a need to check that the actions taken at a point in a paddock do not cause problems downstream—either within the farm or to neighbouring property including roads and railway lines.

Some of the difficulties related to planning on a sub-catchment are linked to the manner in which the land was originally surveyed. Early surveyors had little resource information at their disposal and the future use of the land had not been well established. Figure 2.1 illustrates an example of where a mountain on a spur of the Great Dividing Range on the southern Darling Downs was subdivided in the traditional rectangular pattern with little recognition of topography, natural catchments and drainage lines.

Figure 2.1 Land subdivisions often had little regard for natural landscape features



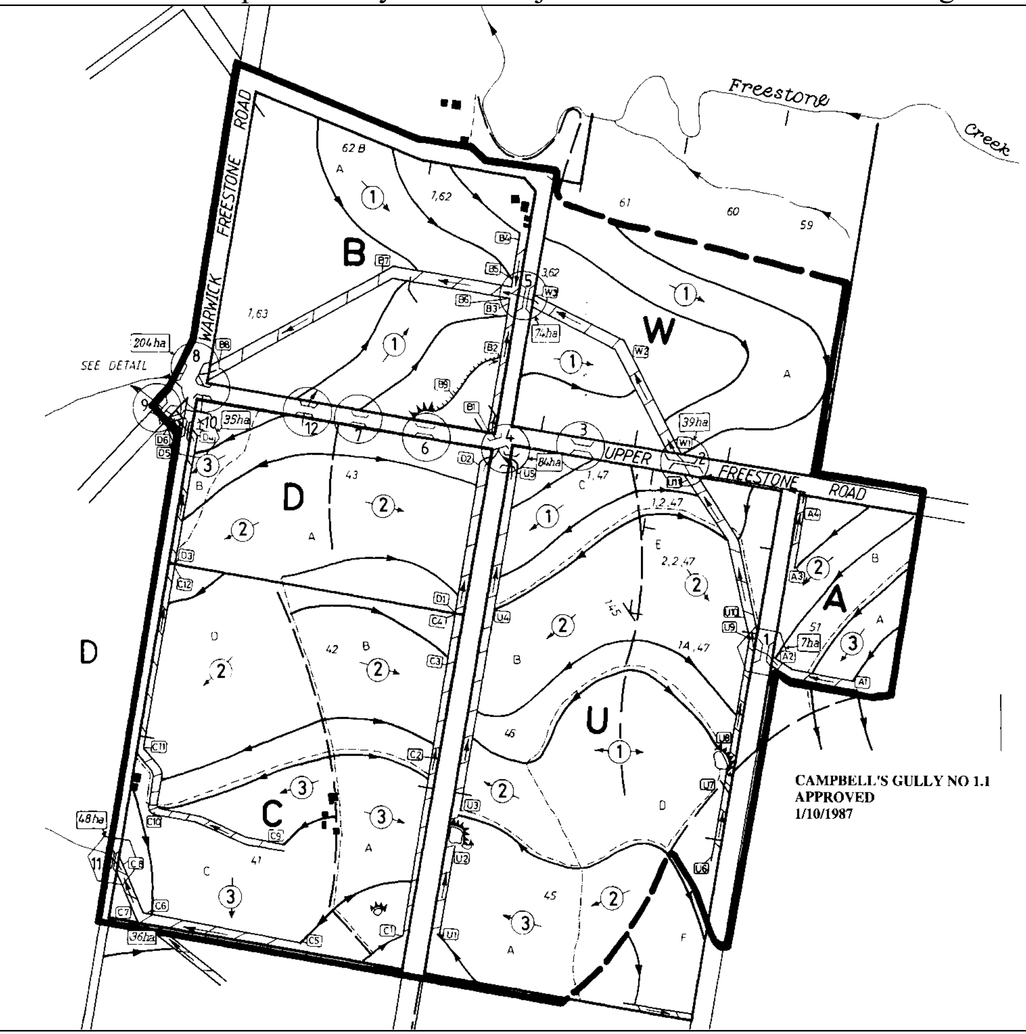
Town planners and land developers should be aware of the principles discussed in this chapter when considering subdivision proposals in rural areas. Ideally, property boundaries should conform with natural features and 'straight line' boundaries are usually not the best solution. Crothers 1991 addresses this issue in the booklet *Rural subdivision planning – Guidelines for subdivision design.*

A key element of a runoff control plan is to define how runoff flows through a catchment. This may involve the coordination of flow from one property to another and across roads and railway lines, and tramlines in sugar cane areas. Other utilities such as pipelines, power lines and underground cables also need to be taken into account. Figure 2.2 provides an illustration of some of the complexities involved in preparing a runoff control plan. It is part of a Project Plan covering six properties in the Warwick district. The codes A, B, C, D, U and W represent properties under different ownership when the plan was adopted in 1987.

Liaison with neighbours and agencies responsible for infrastructure such as roads, railway lines, cables and pipelines is necessary for runoff coordination. Failure to do this could cause damage to such infrastructure and landholders responsible for such damage may be liable for meeting the cost of repairs. Landholders have a 'duty of care' responsibility not to cause nuisance or harm to neighbours (refer to Section 179 of the *Property Law Act 1974*).

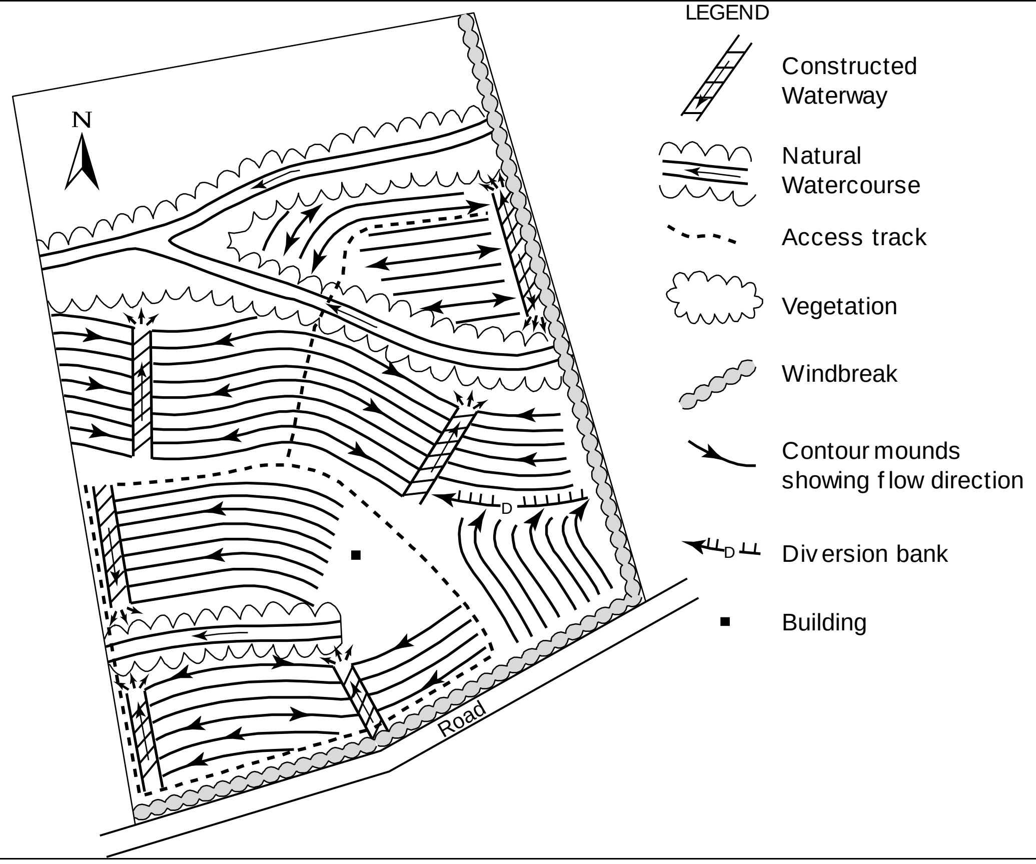
Runoff coordination issues tend to be most complex on certain combinations of topography and property size, where overland flow passes through several properties before it meets a well-defined watercourse. This situation is most applicable to the eastern Darling Downs, Atherton Tableland, Inland Burnett and some cane growing areas. In these districts, a drainage line may pass through as many as 10 properties as it flows from the most remote part of the catchment into a watercourse.

Figure 2.2 Part of the Campbells Gully No 1.1 Project Plan on the southern Darling Downs



Planning is easier in the more extensive cropping areas where one or two properties may cover a catchment. It can also be reasonably straight forward in many coastal areas with steep topography where drainage lines are normally well defined and there is limited scope for the construction of artificial waterways that would flow from one property to another. Figure 2.3 is an example of a soil conservation plan for a banana plantation illustrating how the runoff from the plantation is confined to natural watercourses. Such a plan would have minimal impact on the drainage patterns for neighbouring land.

Figure 2.3 Soil conservation plan for a banana plantation



Co-ordinated runoff control planning is based on the principle that a property should accept the runoff from higher land, which it would receive under natural conditions. It is preferable that runoff is allowed to remain in its natural catchment. However to achieve a practical soil conservation layout, it is often necessary to move runoff from one sub-catchment to another. There are occasions when the manner in which the land was originally subdivided may lead to some debate as to how runoff should be routed. Past siltation may also have been responsible for modifying runoff patterns making it unclear as to the location of the 'original' drainage pattern. The use of historical aerial photography or the collection of topographic data in the field, may be necessary to provide clues as to the location of such patterns.

The situations described above are easily resolved when neighbours are co-operative. However unco-operative neighbours may result in a lack of consensus as to how runoff should be co-ordinated. Resolution of such issues requires careful negotiation between all parties including representatives of agencies responsible for the various utilities that may be involved, such as roads, railways, telecommunications, and electrical infrastructure. The *Soil Conservation Act 1986* contains a process for dealing with situations where formal agreement to a proposed plan cannot be obtained.

2.1.3 Legislative and regulatory requirements

When preparing a plan for soil conservation purposes, planners and landholders should take into account any legislative and regulatory requirements that may affect the property. Relevant controls may exist as part of Planning Schemes approved by Local Governments, or by legislation related to catchment development, natural resource management, soil conservation, water allocation and management, vegetation management, environmental protection, or protection and management of public lands and utilities. Relevant information about the *Soil Conservation Act 1986* follows.

2.1.3.1 The Soil Conservation Act 1986

The principal aim of the *Soil Conservation Act 1986* is to provide a mechanism to assist with the successful coordination of runoff between properties. The act is available on-line by typing 'soil conservation act Queensland' into a web search engine. The Queensland government fact sheet L83 *Soil Conservation Planning in Cropping Lands* provides summarised information about this legislation (available from the Queensland government webpages at www.qld.gov.au (type the title in the search box).

The Act provides for two types of approved plans:

- Property plans
- Project plans.

Both approved property plans and project plans are binding on all present and future owners and the Crown. Information relating to the existence of soil conservation plans that have been approved under the *Soil Conservation Act 1986* is available from the Department of Natural Resources and Mines.

It is especially important to obtain any plans that may exist on neighbouring properties to ensure that any future planning will be compatible with existing plans. Most of the plans approved under the *Soil Conservation Act 1986* relate to properties on the eastern Darling Downs, reflecting the necessity to coordinate the flow of runoff between many properties in this location. However such planning has also been carried out in all other cropping districts in Queensland including Bundaberg, the Central Highlands and the Atherton Tablelends.

Both approved property plans and project plans can be modified to accommodate circumstances that differ from those applying at the time of approval. Plans may be amended, or their approval may be revoked. This involves similar procedures to those used in the approval processes used for both types of plan.

Property plans

An approved property plan is a plan approved under the provisions of the *Soil Conservation Act 1986.* The plan consists of a map and specifications for the soil conservation structures and practices necessary to control erosion. It may cover the whole of a property or just part of it.

The Act does not prescribe any situation when it is necessary for an approved property plan to be prepared. This legislation simply provides a mechanism that allows for a soil conservation plan to go through an approval process should a landholder submit an application to the Department of Natural Resources and Mines. There are three principal benefits to having a plan approved:

- Runoff flow, between adjoining properties is coordinated. The agreed to runoff pattern cannot be casually changed by subsequent landholders, as these plans are binding on current and future landowners. However formal amendment of a plan is possible.
- Objections from neighbours who do not agree with the proposed soil conservation measures can be formally accepted and considered through the plan approval process. Soil conservation works or measures can then be implemented in accordance with the approved plan without the threat of civil action lawsuits upon the individual landholder.
- The Act provides that a landholder is not liable for any damage or injury which another party may claim is the result of soil conservation measures being implemented, as long as the measures are in accordance with the approved plan.

A plan is developed in consultation with the landowner, neighbours affected by the plan and other authorities (eg. those responsible for roads, railway lines and tramlines in sugar cane areas).

The Act defines where a proposed plan is deemed to affect other land. Generally, land is affected if the implemented plan will change or concentrate the runoff flow pattern between the land covered by the plan and adjoining land, or land separated from it only by a road.

After the plan has been finalised, the affected landholders and authorities may indicate their agreement by signing their acceptance of the plan that can then be approved. If one or more landholders do not agree to the plan it may be publicly advertised. The plan is opened for public inspection for a minimum of 21 days. Determinations are made on any objections that are submitted. Objectors may, within 42 days, lodge an appeal against such a determination with the Land Court. The plan may then be approved or rejected in accordance with the final ruling.

The act has provision for a runoff co-ordination notice to be issued in situations where runoff flow is not in accordance with an approved property plan. The notice may require an owner to take appropriate action to discharge or receive runoff in accordance with the plan. Failure to comply with a notice can result in the issue of a court order to comply and/or a fine.

Project plans

The project planning provisions of the Act are intended for the planning of a group of properties in a catchment. They are also used where key soil conservation works (community works) are proposed to be the responsibility of a statutory authority. Project plans usually cover around 10 to 20 properties. Most project plans have been prepared for the eastern Darling Downs and cane growing districts in the Kolan and Isis shires near Bundaberg prior to 1998. No new project plans have been prepared since this date.

A project plan is prepared in consultation with individual owners and representatives of local authorities and other relevant government agencies. The plan is opened for public inspection for a minimum of 21 days. Determinations are made on any objections that are submitted. Objectors may, within 42 days, lodge an appeal against such a determination with the Land Court Depending on the outcome of any appeals, a project plan may then be submitted to Governor in Council for approval.

A soil conservation order can be issued requiring an owner of land to comply with a project plan. Failure to comply with a soil conservation order can result in the issue of a court order and/or a fine. Alternatively, the Director-General of DNRM can take whatever action is necessary to ensure compliance with the plan, and the owner is liable for the expenses incurred.

2.1.4 Coordination with road and rail drainage

When planning a soil conservation layout, every attempt should be made to make use of existing road and rail cross-drainage structures such as culverts, inverts and floodways. However, in some cases it will be necessary to modify an existing structure or to build a new one. Negotiations with the relevant agency responsible for the structure (referred to as the 'road controller') are necessary to determine planning options, required specifications, options for funding the works and date of construction. In cane-growing areas, it may be necessary to negotiate with the sugar mill responsible for maintaining tramlines for transporting cane to local mills.

The use of roads as a site to locate waterways should be avoided. Roads were seldom surveyed with the intention of them being a corridor for managing concentrated flows from surrounding catchments. There is generally insufficient width in the road corridor to construct a waterway of adequate width. The use of such an area will often result in runoff being diverted out of its natural location. This can have an adverse impact on downstream areas when the runoff must eventually return to its natural location. If it is considered that there is no alternative to the use of the road corridor in which to locate a waterway the proposal must be discussed with the relevant road controller.

Where it is desired to utilise an unused road as a location for runoff disposal or even to cross it with contour banks (if the same person owns or leases from the State, the land on either side of the road), an application can be submitted for the road to be permanently closed. The application is made to the relevant authority. If the application for permanent closure is successful, the road is closed and included in the tenure of the person who submitted the application and the soil conservation works can proceed.

If it is not possible for the road to be closed, the 'road controller' should be approached to determine if there are any other options such as the temporary closure of a road. It would need to be borne in mind that a temporarily closed road can at any time be re-opened if it is required for use as a road. Any works constructed on a temporarily closed road would need to be able to be easily removed or modified if the road is to be re-opened. It is recommended that the following notation be included on the plan as a reminder that unused roads have been used for water dispersal:

> *Approval has been obtained for unused roads to be utilised for soil conservation purposes on this plan. Amendment of this plan may be necessary if the road is to be opened for public use or for any other reason put forward by the agency responsible for the road.*

Where a road has been temporarily closed or where approval has been obtained to construct soil conservation works on an unused road, there may be a requirement to obtain any development approvals required under the town planning scheme from the local government where the land is located.

Roads and rail lines may have a significant impact on runoff flow patterns on floodplains and this topic is dealt with in more detail in Chapter 12, *Floodplain management.* This situation is especially applicable to the extensive cultivated floodplains of the Condamine and MacIntyre Rivers.

2.1.5 Locating property infrastructure

The location of infrastructure such as access tracks and fences can have a significant effect on runoff patterns leading to infrastructure damage and erosion of adjacent areas. Well-sited and well-constructed property improvements will provide many years of low maintenance service with minimal adverse impacts.

The direction in which a track or fence is orientated to the contour has significant implications for runoff management. The options for preparing a property plan illustrated in figures 2.7 to 2.13 are relevant to this issue.

2.1.6 Consideration of cadastral boundaries

Many properties are made up of a number of individual lots of land. In some intensively subdivided areas such as the eastern Darling Downs, a property could include 10 or more individual lots. If it is likely that some of the lots could be sold as a separate entity in the foreseeable future, then this needs to be taken into account in the planning process. This issue needs to be considered by the landholder during the preliminary planning stages.

In most cases it is impractical to prepare a 'self-contained' plan for all individual lots. Such planning would lead to small paddocks and inefficient layouts with short contour banks and numerous waterways. However, it is desirable to consider the presence of individual lots during the planning process and there should be opportunities to locate some structures that are aligned to lot boundaries. Where fences on lot boundaries are removed, it is desirable to retain any original survey pegs.

Where a soil conservation layout is prepared that effectively combines a number of lots, it is recommended that the following endorsement be printed on the face of the plan:

> *In order to achieve more efficient soil conservation layouts, some lot boundaries have been disregarded in the preparation of this plan. Amendment of this plan may be necessary if the sale of any lot makes the plan unworkable.*

2.1.7 The mapping base

When preparing a runoff control plan, a map of the area needs to be prepared at an appropriate scale. A scale of 1:10 000 is suitable for most runoff control planning in Queensland. However, on small properties with intensive horticultural crops, a scale of 1:5 000 or larger is preferable. On extensive properties with very large paddocks, a scale of 1:20 000 may be acceptable. A map based on aerial photography or high resolution satellite imagery is a useful aid to the planning process allowing for a better appreciation of the location of proposed works.

Current information about property boundaries, survey control information, survey plan history, land tenure and actions on land parcels is available from the Department of Natural Resources and Mines. A selection of this information can be integrated into one map—called a SmartMap based on a property, locality or any geographical area. SmartMaps are available from DNRM service centres and can be ordered online. For more information, check the DNRM website (www.dnrm.qld.gov.au).

2.1.7.1 Aerial photography and satellite imagery

Both aerial photography and satellite imagery are valuable aids to soil conservation planning. The Department of Natural Resources and Mines has a large collection of current and historical aerial photography. The most common scales of aerial photographs are 1:25 000 in more closely settled areas; 1:40 000 in less closely settled areas and 1:80 000 in remote areas (generally west of 144 degrees longitude). In the more closely settled areas, aerial photographs are taken about every 10 years. Other areas are photographed less frequently.

Aerial photography can be rectified —by use of a Geographic Information Systems (GIS) program—to produce true-to-scale property maps with a cadastral overlay. Satellite imagery has the advantage that much more recent imagery at scales suitable for property mapping is available.

For more information about mapping bases and the use of property maps check the following fact sheets on the Queensland Government website —www.qld.gov.au (search for the fact sheet title).

- L70 *A guide to property mapping*
- L71 *Choosing a property map*
- L72 *Property mapping – Useful sources of information*
- L73 *Property mapping – Adding information*
- L74 *Property mapping – Measuring distances and areas*.

2.1.8 Collection of data and information

Topics covered in this section include:

- existing soil conservation plans
- topographic information
- vegetation mapping
- soils and land use.

2.1.8.1 Existing soil conservation plans

Checks should be made with the Department of Natural Resources and Mines to determine if there are any existing soil conservation plans for the property to be planned as well as in the surrounding sub-catchment.

2.1.8.2 Topographic information

Some form of topographic information is essential for the planning and design of soil conservation structures. Topographic maps are produced by the Department of Natural Resources and Mines (www.dnrm.qld.gov.au) and Geoscience Australia (http://www.ga.gov.au). Scales range from 1:2 500 to 1:1 000 000. Broad-scale maps (1:100 000 and greater) are available for the whole state, while more detailed maps are generally available only for more closely settled areas.

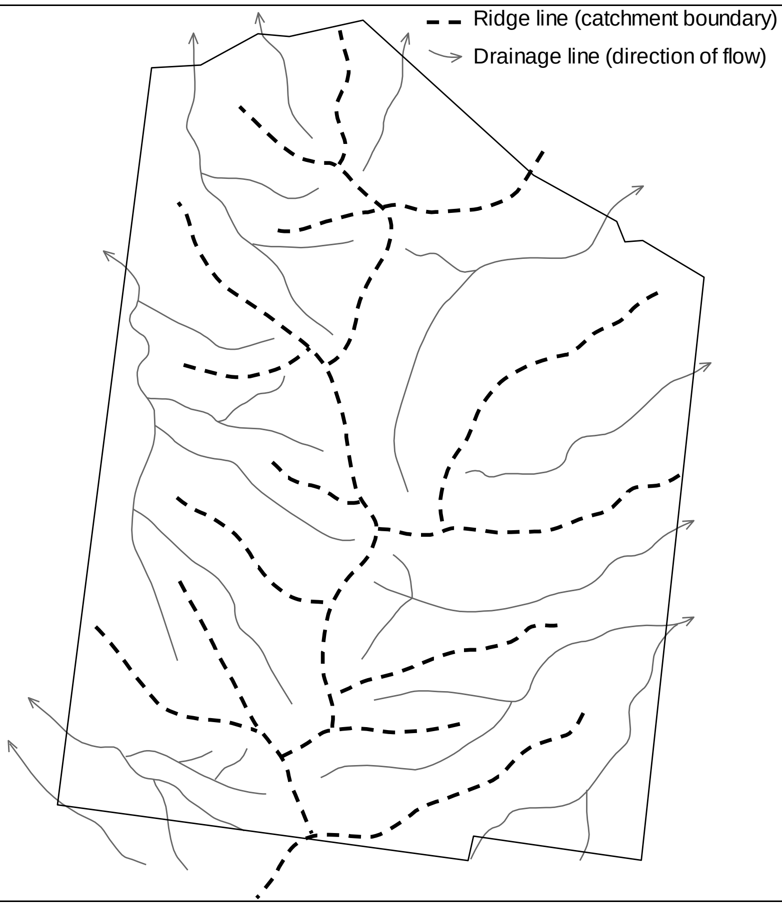
Topographic image maps (orthophoto maps) produced by DNRM are available for some areas. They have contour lines over an aerial photograph background with an accurate scale ranging from 1:2 500 to 1:25 000.

For most runoff control planning, topographic information is required at a scale of 1:5 000 to 1:10 000 with a contour interval of at least 2.5-5m . This information is normally available for more closely settled areas but not for extensively cropped areas such as the Central Highlands and areas to the west of the Darling Downs.

Topographic information can be obtained in the field by using surveying equipment. On the floodplains of the Darling Downs, the Queensland Government has carried out detailed topographic surveys to collect data to assist in the planning of strip cropping layouts to aid in floodplain management. On individual properties, conventional surveying equipment can be used to establish trial contour lines (i.e. 'formlines') or sightings can be made onto fence posts, trees etc. If detailed topographic information is required in order to prepare a soil conservation plan, a business that specialises in the acquisition of such data may need to be employed.

A more traditional option for obtaining basic topographic information is by studying paired aerial photographs through a stereoscope. An example of information obtained from a stereo survey is shown in Figure 2.4. This enables the location of major drainage lines and the catchment boundaries between them. On land slopes below 2%, it is more difficult to interpret this information. If some parts of the property are difficult to interpret, such situations should be noted for later confirmation during a property inspection. Once catchments and drainage lines have been identified, it is possible to roughly 'estimate', on paper, the location of contour lines for use in determining some layout options for contour banks and waterways. The accuracy of the estimate will depend on the skills and experience of the person doing the planning. The actual position of such structures will need to be located by field survey.

Figure 2.4 Example of topographic information obtained from a stereoscopic survey of aerial photographs



Where possible, it is recommended to 'split' contour banks on ridge lines to allow runoff to remain in its natural catchment and the split provides an excellent location for an access track. However, the exact location of broad ridges and broad depressions cannot be pinpointed on most topographic maps. If contour banks are to be split on a broad ridge, the exact location of the split will not be determined until the contour banks are surveyed in the field. The location of those splits may need to be temporarily identified with a marker such as a steel peg on each survey line. The split locations can then be sighted and modified if necessary to provide a well-aligned access track.

For further information about the use of topographic maps, check the fact sheet L75 *Using topographic maps* on the on the Queensland Government website —www.qld.gov.au (search for the fact sheet title).

2.1.7.3 Vegetation

Maps showing regional ecosystems (vegetation types) for Queensland, at a scale of 1:100 000, are produced, and these may identify where clearing restrictions may apply. For more information check the DNRM website (www.dnrm.qld.gov.au).

2.1.7.4 Soils and land use

A series of Land Resource Bulletins and Land Management Field Manuals contain useful information about land resources, climate, vegetation and land use and management at scales from 1:25 000 to 1:500 000. Broad-scale maps (>100 000) will not accurately identify the soils at a specific location but provide an indication of the soil types likely to occur in a specific area. If necessary, additional soils information can be obtained by taking soil samples or by employing a soil surveyor.

The Land Management Field Manuals listed below are available in PDF format by searching the Department of Environment and Heritage Protection library catalogue. For more details about these manuals check the Queensland Government website —www.qld.gov.au.

- **Atherton-Mareeba** Land Management Field Manual
- **Central Darling Downs** Land Management Manual
- **Crows Nest** Land Management Field Manual
- **Dawson-Callide** Land Management Field Manual
- **Inglewood Shire** Land Management Manual
- **Roma** Land Management Field Manual
- **SE Darling Downs** Land Management Field Manual
- Understanding and Managing Soils in the **Central Highlands**
- Understanding and Managing Soils in the **Inland Burnett** District
- Understanding and Managing Soils in the **Moreton** Region
- Understanding and Managing Soils in the **Murilla, Tara and Chinchilla Shires**
- Understanding and Managing Soils in the **Stanthorpe-Rosenthal** Region
- **Waggamba** Land Management Field Manual
- **Wandoan** Land Management Field Manual

Note that the following manuals are no longer available because more accurate soils information is now available.

- **Coastal Burnett** Districts Land Management Manual
- **Maryborough** Districts Land Management Field Manual

More detailed soils information is available for some selected areas, eg, Banana, Kilcummin, Goodar and Roma 1:100 000 sheet areas and the Toowoomba, Kurrawa sheets (CSIRO).

Further information about soils and land use can be obtained from the CSIRO Land and Water library in Adelaide (www.clw.csiro.au) or from NRM regional bodies.

2.1.9 Property inspection

Planners can more readily get the confidence of landholders if they have familiarity with the property before setting foot on it. Before inspecting a property, any relevant information previously described in this chapter should be collected.

A useful way of becoming familiar with a property before making a visit is to study paired aerial photographs under a stereoscope. Another option is to study satellite imagery, where oblique views provide an indication of the topography of a property.

Appendix 1 provides some advice on the interpretation of aerial photographs. Historical aerial photography can also be checked to obtain a greater appreciation of the past development and land use of the property. Since the location of drainage lines and watercourses may have changed over the years, old photography can provide some clues as to the location of past runoff and landuse patterns. Soon after the property visit, it can be useful to take another look at the aerial photographs to try to resolve any doubtful areas that may have resulted from the initial stereo survey.

On large properties , where the homestead may be several kilometres from the road , it is advisable for planners to become orientated as soon as they arrive at the entrance to the property and to check the map and make observations as they drive to the homestead. Sometimes a person's sense of direction can let them down, particularly on cloudy days when there is no sun to help with orientation. Landholders will also appreciate the fact that you have been observant and that you are taking a keen interest in their property.

It is most important that the landholder accompanies the planner, at least for the initial inspection. The planner should closely observe infrastructure such as gateways, tracks, electric fences, and other things that will allow for easy movement around the property during subsequent inspections.

Initial discussions with the landholder should include the following issues:

- Overall goals and priorities for the property
- Areas needing the most urgent attention
- Any proposed changes in the future use of the land. This has a significant impact on optimal paddock size with significant differences between a property used for broad-acre cereal growing (large paddocks and long contour banks) compared to one used for horticultural crops or dairy farming (smaller paddocks and shorter contour banks).
- The need to consider individual lots of land when developing the plan. What are the chances that some of the lots are likely to be sold separately in the future and what impact would this have on the chosen runoff control plan? Is there an opportunity to amalgamate existing lots?; and maybe, if necessary at a later date to subdivide in a manner that would be more suitable to the soil conservation layout?
- Attitude in relation to making modifications to the existing fencing. During the planning

process, it is useful to think about natural catchments and land resource boundaries rather than being restricted by the existing fence layout.
- Where waterways need to be constructed, is the landholder aware that, depending on seasonal conditions, it may take several years before a waterway becomes adequately stabilised with suitable grasses?
- Information about neighbouring landholders and possible impacts on, or from, adjacent lands. It is important to know about the willingness of neighbours to participate in the planning process and whether or not there is already a soil conservation plan for their property, the progress made in the implementation of the plan, and the maintenance of existing works. It is also worth finding out if the neighbours have any future plans such as expanding their area of cultivation or implementing new soil conservation measures.

For complex issues, the finalising of a plan on the first visit to a property should be avoided, as first impressions can be deceiving. An open mind is necessary, and it is best to avoid getting a quick 'fix' on a solution until the whole property has been inspected and discussions have been held with neighbours and road authorities where necessary. In some cases, detailed topographic information, that was not available during the property visit, may reveal a different viewpoint to that gained at the initial inspection. If the planner is getting 'bogged down' in a particular area, it can be best to move on to another part of the property. Difficult planning issues may sometimes be resolved when viewed from a different direction or perspective.

It is essential to follow the property tour on the base map that will preferably have an aerial photograph or satellite image as a background. The landholder should be encouraged to assist in interpretation. GPS equipment and vehicle odometers are useful to accurately plot the information on the plan and for checking the accuracy of the scale on the plan.

Any public roads adjoining a property, as well as property roads and fencelines are good places from which to collect useful information such as road cross-drainage points, ridges and drainage lines.

The points listed below should be noted during property inspections.

2.1.9.1 Land issues

- Land types
- Extent of existing erosion and other forms of land degradation (salinity, seepage areas scalded areas, declining pasture/crop growth)
- Land slopes at key locations (including potential sites for waterways where designs will be required). A clinometer or an abney level can be used for quick checks if no suitable topographic information is available. Slopes are normally expressed as a percentage. In some low sloping situations, the eye can often be deceived by the lie of the land—what appears up may in fact be down and *vice versa*. Broad floodplains can be particularly deceptive in terms of which way the land is sloping. A useful tip for floodplains is that the general slope of land in a particular location will usually be away from the closest mountains.
- Well defined changes in land slopes
- Catchment boundaries (ridge lines)
- Key locations such as rocky outcrops, protected vegetation, that may restrict construction of soil conservation measures.

2.1.9.2 Water issues

- Points where runoff enters and leaves the property and the presence of cross-drainage structures in adjacent roads and railway lines
- Location and condition of drainage lines and other areas where it may be necessary to construct waterways to receive runoff from contour banks and any suitably grassed areas that can be used for safe disposal of runoff
- The suitability of locations in watercourses where it may be necessary to discharge runoff from a constructed waterway, diversion bank or contour bank
- Existing dams and possible locations for future storages
- Location of watering points and pipelines if the property is used for grazing
- The presence of any structures on floodplains that may impact on flood flows.

2.1.9.3 Vegetation issues

- Tree clearing permits that may apply to any part of the property
- Opportunities for revegetation including wildlife corridors, shelter belts, rehabilitation of degraded areas
- Condition of riparian vegetation
- Vegetation clumps and corridors and their impact on proposed soil conservation structures
- The occurrence of pest plants and the risks of specific soil types to invasion by potential weeds
- Suitability of species for stabilising waterways, runoff disposal areas, or degraded areas.

2.1.9.4 Infrastructure (public and on-farm)

- Fence locations, and their condition - are there any options for modifying the layout to improve workability?
- Location and standard of existing soil conservation works, both on the property and on adjacent lands
- Levee banks
- Irrigation infrastructure (private or public)
- Gas and water pipelines, power and telephone lines and cables
- Access tracks
    - are they well positioned ?
    - what is their condition/standard?
    - are there opportunities to re-locate them?
- Stock yards and buildings.
- Road/rail cross-drainage structures

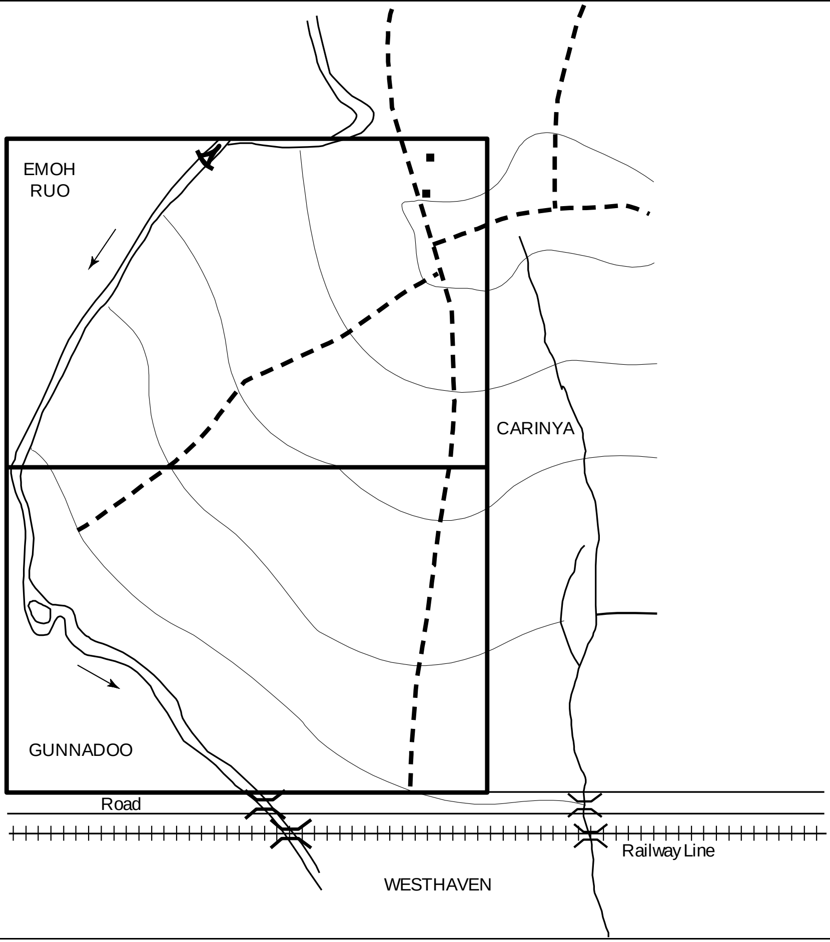
2.2 Evaluating layout options

Figure 2.5 shows an area of land for which a soil conservation plan is to be prepared. The blocks Emoh Ruo, Gunnadoo, Carinya and Westhaven have different land titles. However they could be separate properties under different ownership or they could be individual paddocks on the one property. The intention is to prepare a runoff control plan for Emoh Ruo and Gunnadoo featuring contour banks and waterways. The land use can be assumed to be dryland cereal or forage cropping.

The aim of this example is to prepare a number of options that may be considered in developing a suitable soil conservation layout. The following information is deliberately not provided in order to consider a broader range of options:

- the map scale
- land slope
- land capability
- proposed land use
- the extent of clearing and
- existing internal fencing.

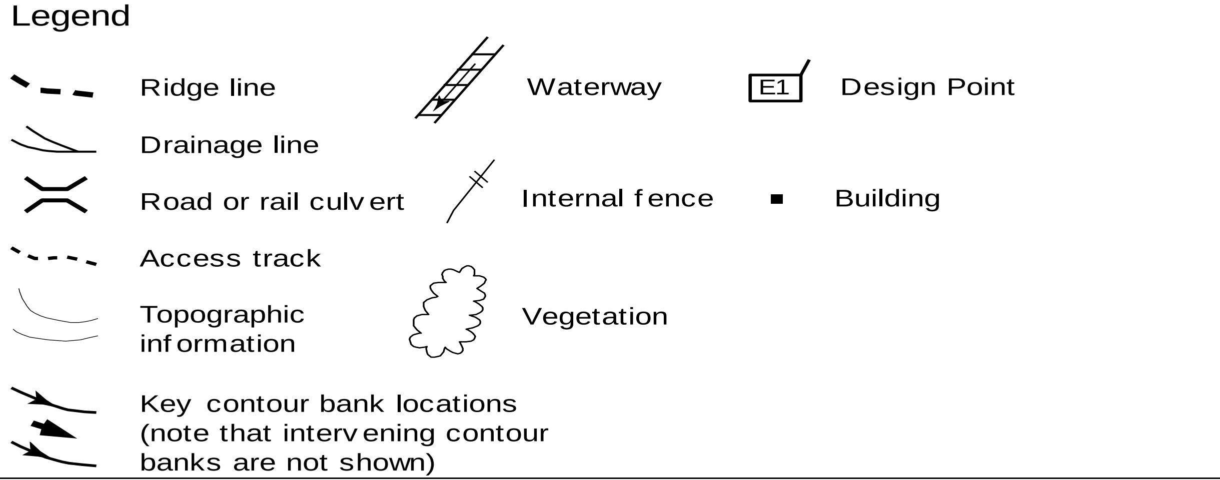
Figure 2.5 Map of an area for which a soil conservation plan is to be prepared



The following information should be shown on each plan using the legend provided in Figure 2.6:

- key contour banks including flow directions
- waterways and runoff disposal areas
- diversion banks
- design points
- catchment boundaries (ridge lines)
- vegetation
- fences
- access tracks
- road and rail cross-drainage points.

Figure 2.6 Legend used in the planning options



The topographic information in Figure 2.5 provides a firm indication as to the general position and orientation of the contour banks to be constructed. The land slope and the proposed land use will largely determine the contour bank spacing. What needs to be determined is in which direction the contour banks will flow and where they will discharge.

Ridge lines have been identified on Figure 2.5. However it should be noted that they are very ‘broad’ and it is open for debate as to whether or not they should be defined as ‘ridges’. However such lines define catchment boundaries and they need to be considered in the planning process.

Waterways will need to be constructed to collect the discharge from the contour banks unless they can discharge onto an adjacent grassed area or a stream riparian zone. They can be constructed either in, or away from natural drainage lines (as discussed in Chapter 11, *Waterways*). Those constructed away from natural drainage lines are referred to as ‘perched’ waterways.

Another criterion is the safe length of contour banks. This is primarily governed by land slope. In each of the options, only key contour banks are shown. When implemented, there will be contour banks between the key banks with spacings according to land slope and other factors. Chapter 9, *Contour banks* provides detailed information on recommended bank length and spacings for different slopes.

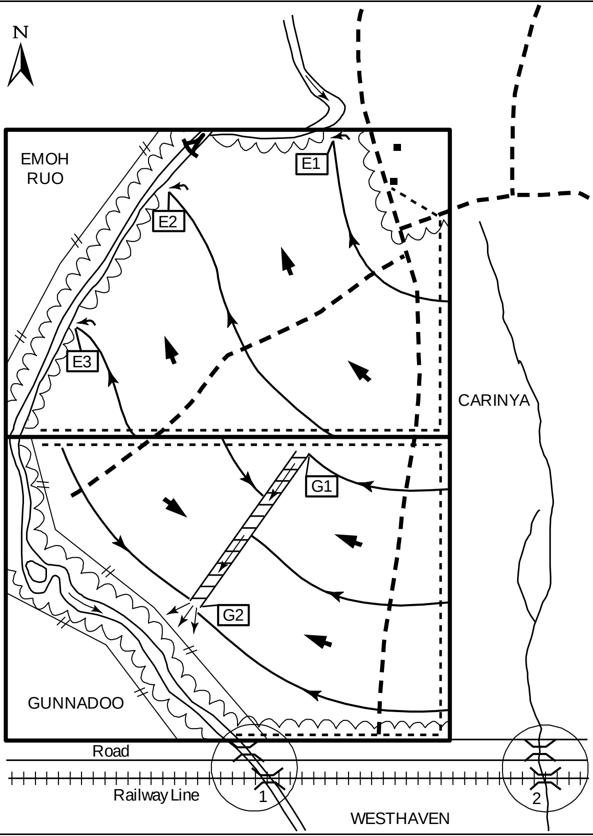
Figures 2.7 to 2.13 provide examples of how the area could be planned. Some discussion on the advantages and disadvantages of each option is included. The chosen option will be the one that the landholder considered to be most suitable for a chosen enterprise and which is technically and sustainably sound. Advice is provided as to when it would be advisable to seek the agreement of a neighbouring owner (refer also to Section 2.4, *Agreement to the plan*, in this chapter).

When comparing different options, it is useful to evaluate how each option meets the following criteria:

- Water disposal – do suitable locations exist or will it be necessary to wait until waterways have been constructed and stabilised? What is the likely cost of damage if there is a delay in implementing works?
- Construction and maintenance costs

- Workability – is the layout easy to manage in relation to on-farm equipment?
- Fences – will the layout accommodate the fencing needs of the property?
- Access tracks – are they in locations that best suit the needs of the property?
- Neighbours – are they in agreement with the proposed plan? Are there *alternatives that may be more suitable to the neighbour?*
- Road and rail cross-drainage – are any additional works required, and if so, how will they be funded and when can they be implemented?
- Watering points – if the property is used for grazing, are there sufficient watering points and does their location contribute to degradation problems?

Figure 2.7 Layout option 1



Emoh Ruo
Contour banks are the maximum length possible for this paddock.

Agreement to divert runoff out of its natural catchment should be sought from Gunnadoo’s owner.

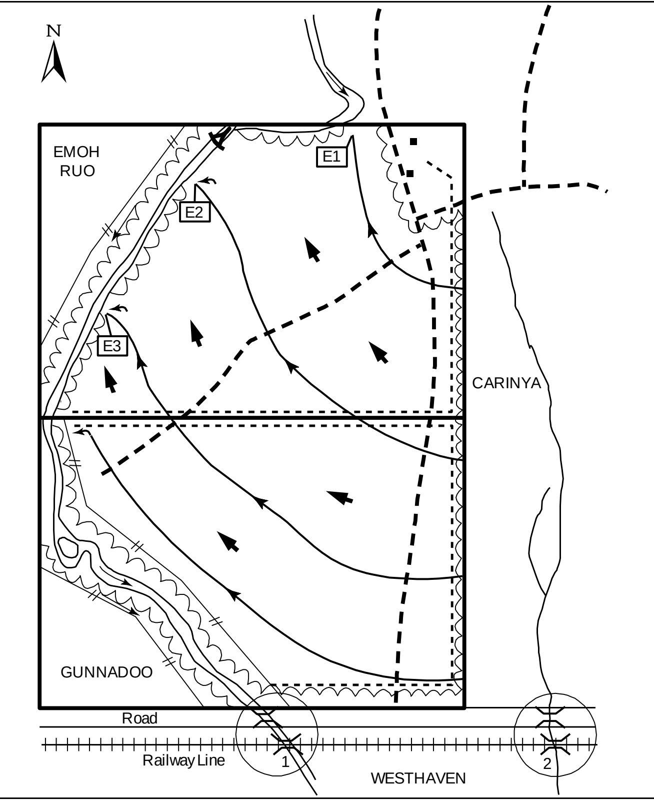
It will be necessary to check that the outlets E1, E2, E3 are suitable outlets for contour banks (including the banks between E1– E2 and E2– E3). Access tracks on the eastern and southern boundaries are well located at the top end of contour banks.

Gunnadoo
Waterway G1–G2 is located in what is a minor drainage line.

Access tracks are well located at the top end of contour banks on the northern and eastern boundaries.

There is a water spreading area into the pasture below G2. The entry point into the watercourse will need to be checked for stability.

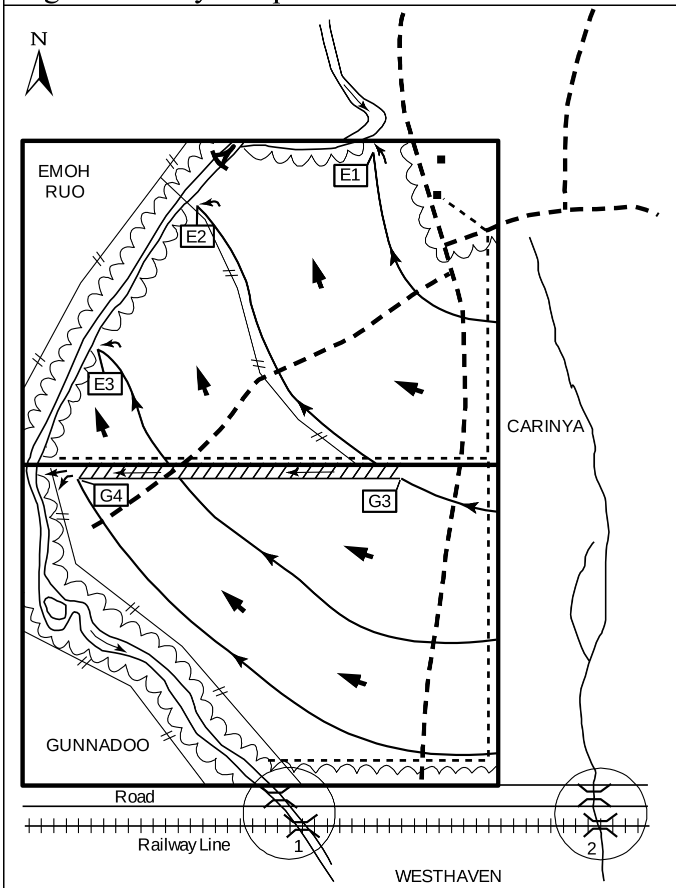
Figure 2.8 Layout option 2



A feature of this option is that contour banks cross the boundary between Gunnadoo and Emoh Ruo. It will be necessary to obtain the agreement of the owner of Emoh Ruo before implementing the plan. This practice is generally not recommended since contour bank maintenance on boundary fences can be an issue and they could be a source of future ill-feeling between neighbours. It will also mean that the access track on the northern boundary of Gunnadoo and the southern boundary of Emoh Ruo will need to cross over the contour banks. Ideally, contour banks should not be crossed by access tracks except at the top end.

This option could be suitable if both properties are under the same ownership and bank lengths are not excessive. Under this scenario, the fence between the two properties may be removed (taking care to ensure that the subdivision pegs are retained). If the properties are eventually sold as separate entities, it would be possible to modify the plan and construct a waterway along the northern boundary of Gunnadoo (as in Option 3).

Figure 2.9 Layout option 3



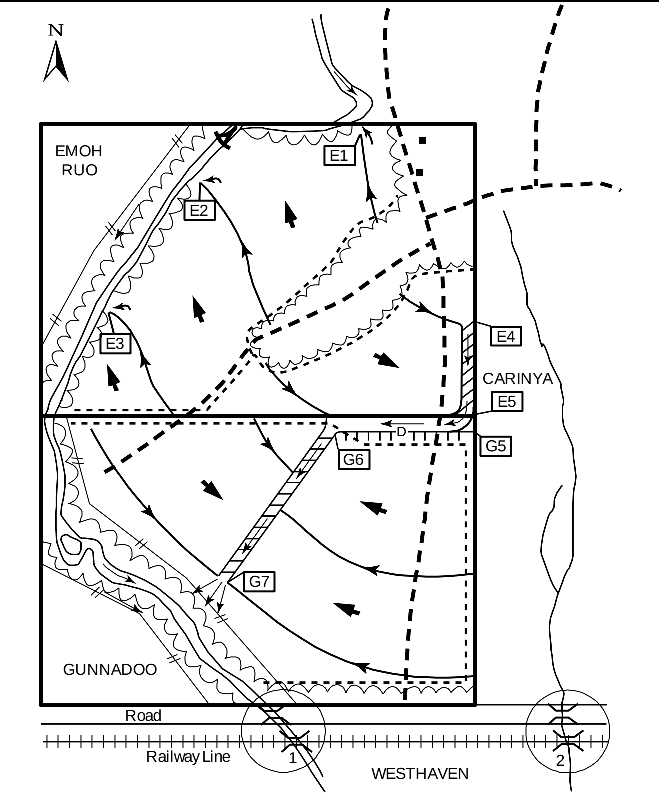
Emoh Ruo
Same layout as for Option 1 except that the paddock has been subdivided with a fence to be built below the contour bank leading to E2.

Gunnadoo
Provides maximum contour bank length for this paddock.

G3–G4 is a perched waterway (runs diagonal to the slope). Special construction techniques are required to ensure an adequate spread of runoff across the width of the waterway and additional contour bank capacity will be required where the banks enter the waterway. The suitability of the entry point into the watercourse at Point G4 will need to be checked.

For row crops there are difficulties in having rows discharge into the perched waterway, so a need for special care in maintaining the contour bank outlets, and removing any silt deposits near the outlets.

Figure 2.10 Layout option 4



Emoh Ruo

Contour banks are split on a vegetated ridge line. The ridge provides a suitable location for an access track. If required, a fence could be provided along the access track.

E4–E5 is a perched waterway virtually up and down slope.

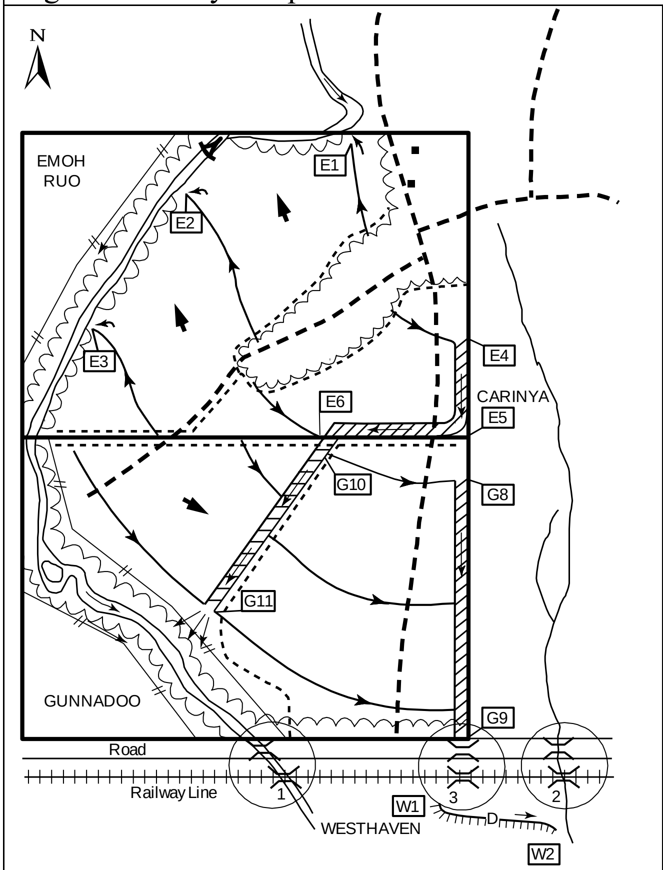
An undesirable feature of this plan is that contour banks below E5 would need to cross through a boundary fence.

Agreement to accept runoff at E5 and from the contour banks below E5 should be obtained from the owner of Gunnadoo.

Gunnadoo

The diversion bank G5–G6 accepts runoff from waterway E4–E5 as well as the contour banks below design point E5 and diverts it to waterway G6–G7. Some cut and fill may be required to ensure that the diversion bank has sufficient gradient to cross the ridge line.

Figure 2.11 Layout option 5



Emoh Ruo

As for Option 4 except that the contour banks below E5 discharge into the perched waterway E5–E6. The waterway has sufficient gradient to allow it to cross the ridge between E5 and E6 (if not, some cut and fill may be required).

Care would need to be taken with the construction of the right angle bend at point E5.

Gunnadoo

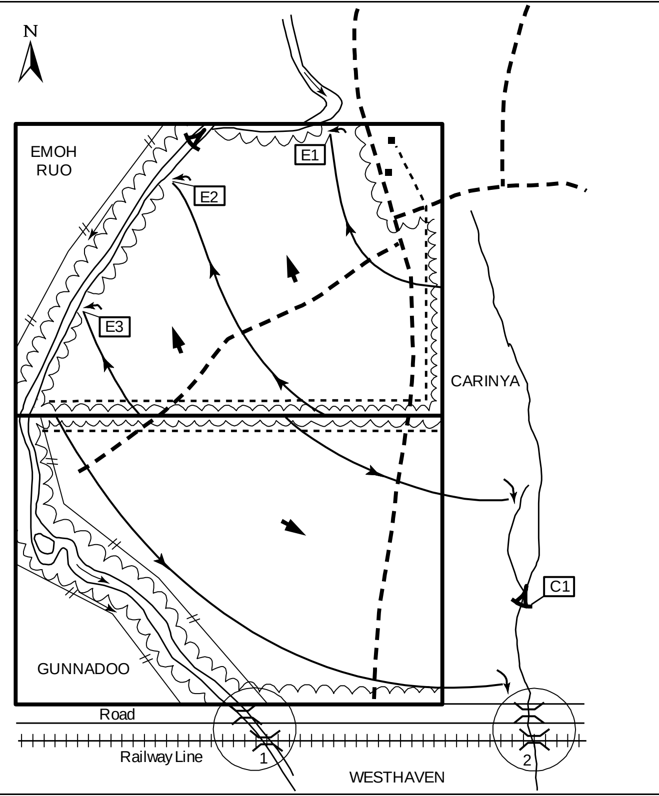
G8–G9 is a perched waterway running up and down slope.

The eastern side of waterway G10–G11 is a suitable location for an access track (and fence) as they are located at the top end of the contour banks.

Negotiations will be required with road and rail authorities to determine if cross-drainage may be provided at point 3.

Negotiations will also be required with the owners of Westhaven in relation to the need for them to construct diversion bank W1–W2 (they may prefer to deal with this runoff in other ways).

Figure 2.12 Layout option 6

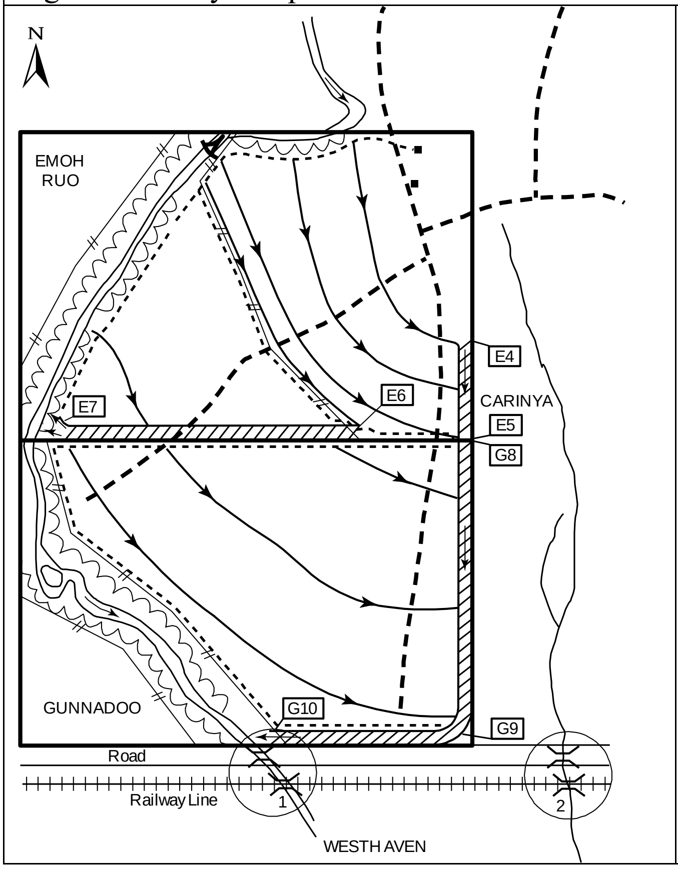


Emoh Ruo
As for Option 1.

Gunnadoo
Contour banks go across the fence between Gunnadoo and Carinya and discharge into a grazing paddock. This could be an acceptable option if both properties are under the same ownership and if the relevant agencies agreed to the additional runoff being received at the road and rail cross-drainage structures at point 2. However, the disadvantages of having contour banks cross boundary fences should be noted. It would also be undesirable for any access track that may be required on the Gunnadoo-Carinya boundary.

If the properties are under different ownership, then the agreement of the owner of Carinya will be required (additional runoff for the dam at C1 could be an incentive). A future alternative could be to construct a waterway G8–G9 (as in Option 7) if the land use in Carinya changed from grazing to cultivation — or G8–G9 as in Option 5.

Figure 2.13 Layout option 7



Emoh Ruo
This layout may be suitable if outlets E1–E3 in previous options are unsuitable discharge points. However it will require that point E7 is stable or that action can be taken to ensure stability.
The paddock has been subdivided by a fence under a contour bank.

Agreement will need to be obtained from the owner of Gunnadoo, recognising that waterway G8-10 will require a larger capacity..

Gunnadoo
Care will be required to ensure that the right angled bend at G9 has sufficient capacity or alternatively, this waterway could discharge across the road/rail, as in Option 5

2.3 Designing the structures

There are two stages in the design of soil conservation structures proposed in a soil conservation plan. Firstly, an estimate needs to be made of the peak rate of discharge that the structure will be required to accommodate and then the size of the structure needs to be determined. These issues are dealt with in Section B, *Runoff estimation* and Section C, *Channel design* of this manual.

2.3.1 Selection of design points

Care is required in the selection of design points as part of the planning process. Design points should be indicated on a property plan and provide essential information about the specifications of structures. This information is vital for the implementation and construction process. Design points also provide points of reference that are useful in any verbal or written communication about the plan.

The following features are recommended positions for design points:

- any locations in the runoff control network where a special design is required
- the commencement and outlet of waterways
- points where a waterway enters and exits a property, paddock or unfenced property lot
- points where there is a significant change in the specifications for a waterway such as:
  - at a change in gradient
  - where there has been a significant increase in the catchment area
  - where two waterways join
  - at a bend in a waterway
- diversion banks
- key contour banks requiring a specific design
- where key works are required for public utilities such as, road/rail culverts, access inverts
- spillways of dams.

When the designs have been completed, they should be documented for use by the landholder and subsequent owners of the property. An example of specifications provided to a landholder is available in Appendix 3.

2.4 Obtaining acceptance of a plan

During the preparation of the plan, it will normally be necessary to consult with neighbouring property owners and agencies responsible for roads and railways and other infrastructure that may be affected by the implementation of the plan (e.g.tramlines in cane growing areas, power lines, oil or gas pipelines and communication cables). Such communication is essential to ensure good co-operation between property owners and agencies.

As discussed previously, disputes between neighbouring landholders may make it difficult to reach consensus on a proposed plan. An option for resolving disputes between landholders is to use the mediation services provided by the Department of Justice and Attorney-General which has centres throughout the State. This service has trained mediators who bring the parties in a dispute together so that they can talk over their differences and reach a settlement that suits them both.

Once the preferred option for the plan has been selected and the necessary designs carried out, it will be necessary to carry out any final checks with third parties.

If the plan is to be approved as a property plan under the *Soil Conservation Act 1986,* signatures of approval will need to be obtained from the owner of the property as well as those 'affected' by the plan. 'Affected' landholders are defined in section 10(3) of the *Soil Conservation Act 1986* and include agencies responsible for road and rail reserves included in the plan. Such approval is normally obtained by the use of a 'signature block' on the face of the plan as shown in Table 2.1.

Table 2.1 Signature block for plan approval under the *Soil Conservation Act 1986*

I//we the undersigned owners of the specified land, have no objection to this plan and its approval under the *Soil Conservation Act 1986.*			
Specified land	Name of owner	Signature of owner	Date
Specifications for runoff control structures and/or essential management practices are contained in specification sheets identified by this plan number and form part of this plan for the purposes of the *Soil Conservation Act 1986.*			

If some affected parties are unwilling to indicate their agreement in writing, the *Soil Conservation Act 1986* has a process that enables a plan to be opened for public inspection and for objections to the plan to be submitted (refer to the section on *Legislative and regulatory requirements* in this chapter). Summarised information about this process is available in fact sheet L83 *Soil Conservation Planning in Cropping Lands* (available from the Queensland government webpages at www.qld.gov.au (enter the title in the search box)).

If it is not intended to have the plan approved under the *Soil Conservation Act 1986*, it would still be advisable to discuss the plan with neighbouring property owners as well as agencies responsible for road and rail reserves to consider obtaining their agreement as shown in Table 2.2. However, such agreement may not be binding on future owners.

Table 2.2 Signature block for use in indicating agreement by neighbours

I//we the undersigned owners of the specified land, have no objection to this plan			
Specified land	Name of owner	Signature of owner	Date
Specifications for runoff control structures and/or essential management practices are contained in specification sheets identified by this plan number and form part of this plan.			

2.5 Implementation

Part of the planning process should be the documentation of a schedule of events to be taken for the implementation of the plan including such issues as fence relocation, waterway construction and stabilisation, and contour bank construction. It may be necessary to delay the construction of contour banks for several years until suitable waterways have been constructed and stabilised.

This manual does not include information on the surveying of soil conservation measures and their construction. A Queensland publication relating to this issue is *Surveying for Soil*

Conservation – A Training Manual (Dickenson and Faulkner 1988).

The following fact sheets relate to the implementation of contour banks and waterways. They are available from the Queensland government webpages at www.qld.gov.au (search for the title in the search box).

- *L270 Soil conservation waterways - Construction and management*
- *L271 Soil conservation waterways - Plants for stabilisation*
- *L272 Soil conservation waterways - Planning and design*
- *L205 Contour bank specifications*.

The following publications relate to the construction of contour banks and waterways and are available in PDF format from the Department of Environment and Heritage protection library catalogue www.qld.gov.au/environment/library/.

- *Broad based bank construction with drawn graders* (Bass and Booth, 1995)
- *Build waterways with a farm dozer*, (Lehmann and Bartels , undated)
- *Contour bank construction using a bulldozer* (Marshall and Rowland , 1987).

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The *New South Wales Soil Conservation Service, Earth Movers Training Course* has information on the surveying, implementation and construction of soil conservation measures. It was produced in 1991 as a series of 21 booklets and is available from some libraries.

While some landholders carry out the necessary construction themselves, others choose to use a contractor. Works should be checked during and immediately after the construction to ensure that the works have been constructed to specifications. Special attention needs to be given to the following points:

- capacity of contour banks (especially where they cross old gully lines)
- contour bank outlets into waterways, watercourses or grassed areas
- capacity of waterways
- perched waterways (their profile and locations where contour banks enter them)
- steps taken to stabilise waterways with vegetation.

2.6 Management and maintenance

Erosion occurs spasmodically and it is easy to become complacent about the need to maintain soil conservation measures especially during extended periods of drought with minimal runoff. In fact these are the best times to monitor works and to carry out maintenance.

Poorly maintained contour banks and waterways are a liability and are likely to cause, rather than prevent erosion. When a contour bank breaks, the outflow may cause severe erosion in the contour bay below and contribute to the failure of subsequent contour banks.

The first point for failure to occur will be any low spots in the contour bank. The weakest link in a contour bank is often a point where the bank has been constructed across an old gully line. Higher rates of settlement can occur at this point and the effective height of the bank may be much less than the average bank height. Such low points can be observed visually by looking upwards at the bank from a suitable distance below it.

Sediment deposited in contour bank channels should be removed if the capacity of the contour bank is below specifications. This is normally achieved by earthmoving equipment which moves the sediment onto the contour bank thus increasing its capacity. Contour bank outlets should also be checked. Blockages caused by sediment deposition and prolific growth of vegetation may restrict flows at the outlet and lead to overtopping.

Waterways should be monitored to ensure that there is no evidence of anything that may lead to rill or gully development eg. a cattle pad or wheel tracks. Appropriate and early action may prevent a serious problem in the future. Slashing, grazing or burning a waterway and the control of woody weed growth should form part of a waterway maintenance program. Poor grass growth may indicate the need for the use of fertiliser.

Sediment removal may be necessary to ensure that waterways have adequate capacity. The overall goal should be to have minimal loss of soil from cultivated lands. However, even minor levels of sheet erosion occurring in the field over time, can contribute to reduced capacity of a waterway. This may periodically require stripping the waterway surface to restore capacity to its original design; or alternatively, increasing bank height to compensate for the reduced capacity. There may be a need to check that associated contour banks still have adequate outfall into a waterway.

Summarised information relating to specifications and maintenance of contour banks is contained in the fact sheets *L202 Maintaining contour banks* and *L205 Contour bank specifications*. They are available from the Queensland government webpages at www.qld.gov.au (enter the title in the search box).

2.7 Monitoring the plan

Periodically the plan should be reviewed to determine if any modifications are required .The following may need to be considered:

- Has a change in farming systems/machinery indicated a relocation of some works?
- Are implemented structures performing the way originally intended?
- Are bank spacings appropriate? Is there a need for some additional banks/waterways or can some be removed?
- Are the access tracks appropriately located?
- Will new fencing requirements necessitate modifications to the plan?
- Can additional land be brought into cropping or should some arable land be retired to pasture?
- Should some areas be established as permanent tree-crop areas or returned to ntive vegetation?
- Are runoff control works effectively co-ordinated with neighbouring properties/utilities.?
- Have changes in adjacent properties necessitated modifications to the plan or necessitated new agreements with neighbours?

■

Chapter 3

Runoff processes

To design a soil conservation structure, an estimate must first be made of the amount of runoff it will be required to carry. This requires an estimate of the *peak rate* of discharge usually expressed in cubic metres of runoff per second. An estimate of runoff *volumes* is not required unless a water storage structure such as a dam is being designed. This manual deals with estimates of peak rate of discharge.

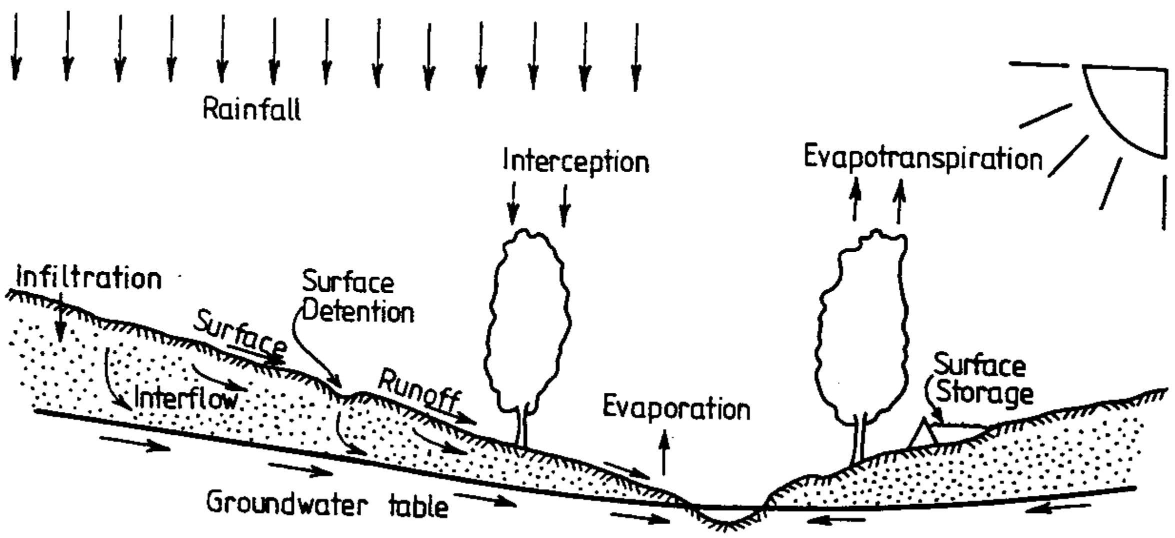
The majority of designs for soil conservation structures will be on catchments with areas less than 500 hectares. The methods described in this manual are satisfactory for catchments up to 2500 hectares in size. For larger catchments an alternative method of runoff estimation should be considered.

3.1 Factors affecting runoff

As the hydrologic cycle (Figure 3.1) indicates, rain falling on a catchment may return to the atmosphere, be stored above or below the soil surface or it may become runoff. Hydrologists refer to rainfall that does not appear as surface flow at the catchment outlet as a ‘loss’. Agriculturalists prefer to consider it as a ‘gain’ as much of this rainfall is stored in the soil for use by crops and pastures.

The proportion of annual rainfall that becomes runoff is generally smaller than most people would expect. A study carried out at the Brigalow Research Station found that under a Brigalow forest the average annual runoff represented only 3% of the total rainfall while the average annual runoff under pasture was 6% (Lawrence and Cowie 1992). Freebairn and Silburn (2004) reported that in southern Queensland, runoff occurs at the paddock scale on an average of 5 days a year, and significant soil movement about once every 2–4 years.

Figure 3.1 Hydrologic cycle



There are two sets of factors affecting the production of runoff:

- rainfall characteristics
- catchment characteristics.

3.11 Rainfall characteristics

Characteristics of rainfall that affect the amount and rate of runoff are:

- intensity
- depth
- distribution over an area (spatial)
- distribution over time (temporal).

3.111 Intensity

With high rainfall intensities there is a greater likelihood for runoff to occur. Very high rainfall intensities can occur in the Queensland environment especially in areas closer to the coast. The highest rates of runoff and soil erosion usually occur during the summer months. However significant runoff events may occur in other months especially in the southern half of the state where some areas receive between 30% and 40% of their annual average rainfall between April and September.

For any location, there is a general relationship between the duration and intensity of rainfall events. Longer events usually have greater total depths of rainfall, but are of lower average intensity than shorter events. Those long events may also contain short bursts of rain with high intensities.

Frequency distributions can be fitted to rainfall intensity/duration data to give an estimate of the probability of any intensity/duration combination occurring for any location. The resultant distributions are termed intensity–frequency–duration (IFD) curves. They are generated in Australia by the Bureau of Meteorology, based on an analysis of rainfall data from *Australian Rainfall and Runoff – A Guide to Flood Estimation* (Pilgrim 1987). Figure 3.2 gives an example of an IFD curve. Chapters 6 and 7 describe how IFD data is used to estimate peak rates of runoff for a specified return period.

Similar IFD curves can be obtained for any location in Australia. The curves may be purchased from the Bureau of Meteorology along with the necessary coefficients used to generate the curves. These coefficients are required for computer-based programs using IFD data. The formula used to determine the rainfall intensity for a specified return period is as follows:

$$\mathbf{ln(i) = a + b(lnT) + c(lnT)^2 + d(lnT)^3 + e(lnT)^4 + f(lnT)^5 + g(lnT)^6} \quad \text{..............................Equation 3.1}$$

Where

ln = natural logarithm
i = intensity in mm/hr
T = time in hours
a, b, c, d, e, f and g are coefficients

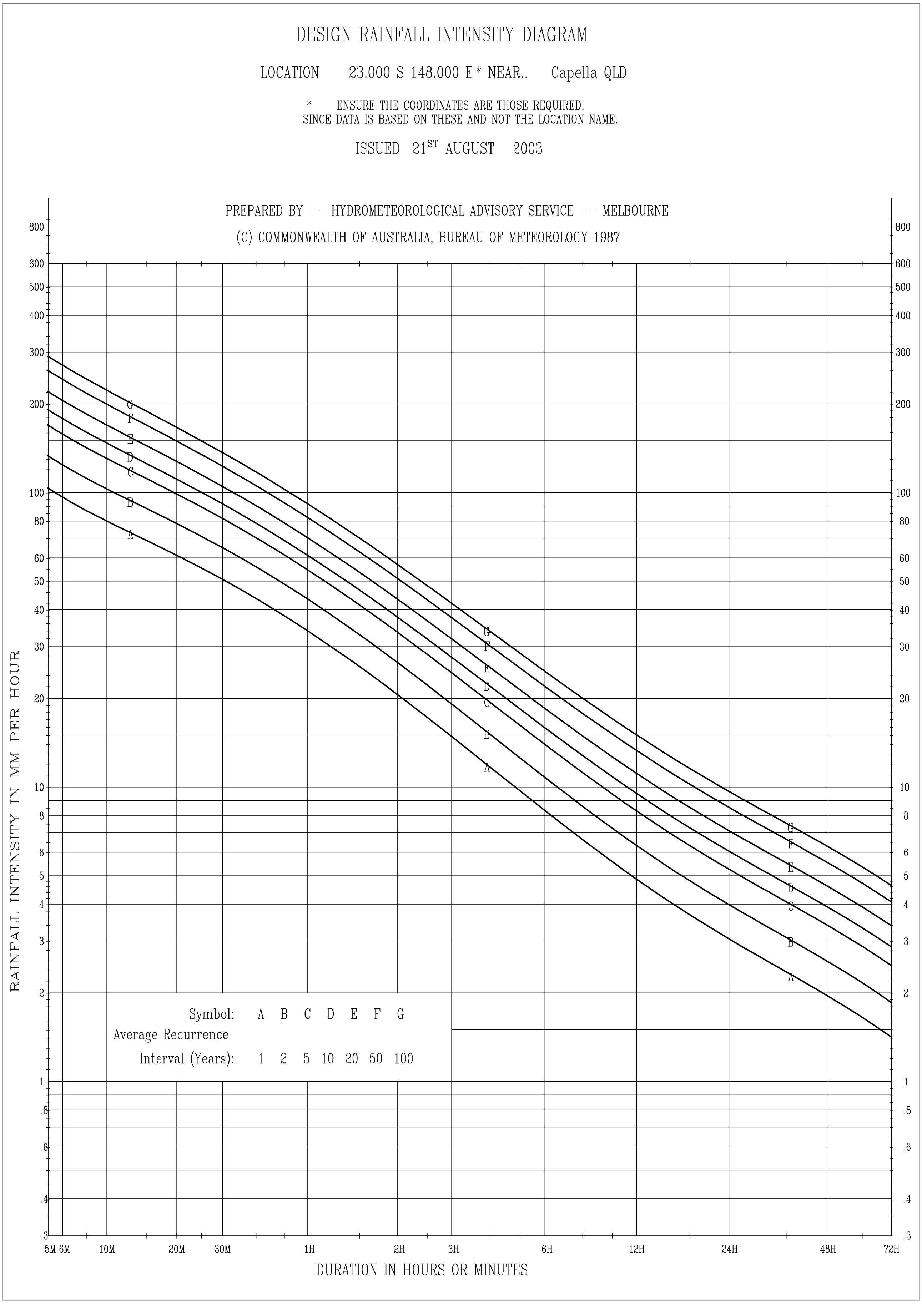
An example of the coefficients for a selection of return periods for the IFD curves in Figure 3.2 is shown in Table 3.1.

Table 3.1 Examples of coefficients for use in calculating rainfall intensities for selected ARI's for Capella

Return period (years)	a	b	c	d	e	f	g
1	3.2563	-0.6539	-0.1086	0.00838	0.007905	-0.0003447	-0.0001967
10	4.1171	-0.6419	-0.0929	0.00746	0.006617	-0.0002055	-0.0001838
50	4.4120	-0.6361	-0.0850	0.00721	0.005956	-0.0001617	-0.0001731

Source: Bureau of Meteorology

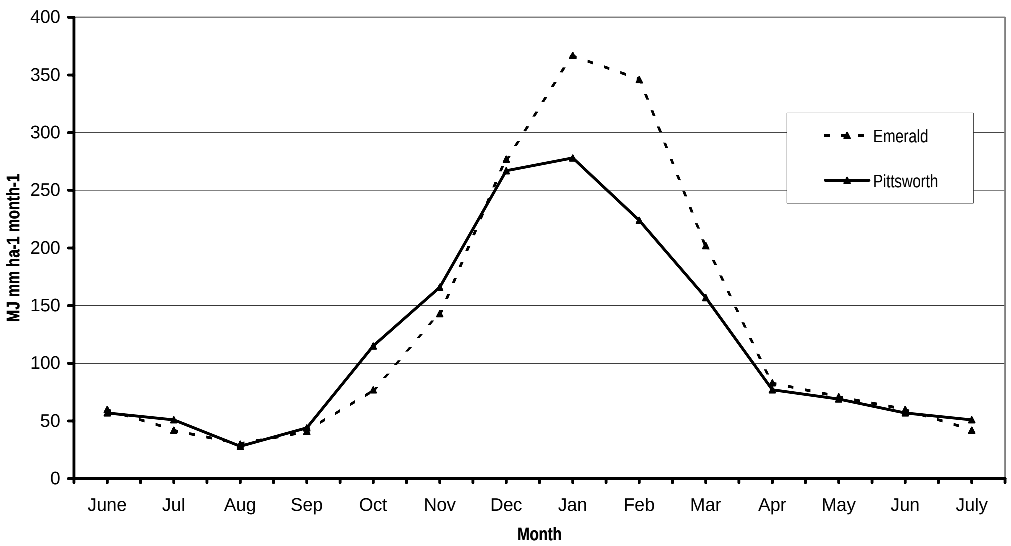
Figure 3.2 Rainfall intensity-frequency-duration curves for the location 23º S, 148º E near Capella as prepared by the Bureau of Meteorology



Where there is little variation in average annual rainfall totals throughout a district it would be acceptable to use just one IFD curve for a location that is representative of the district. However where average annual rainfall totals change significantly, then separate charts should be used for different rainfall zones. Areas where changes can occur over a short distance include the Gold Coast hinterland and areas between Cairns and Ingham.

Rainfall intensity is closely related to rainfall erosivity, which takes into account the combined effects of rainfall quantity and its kinetic energy. In most areas of Queensland, rainfall erosivity peaks in January–February and reaches a low point in August–September. Values of rainfall erosivity for specific centres are used in programs such as SOILLOSS (Rosewell 2001) which estimate rates of soil loss based on the Universal Soil Loss equation. Erosivity values for centres throughout Queensland are available in Rosenthal and White (1980). Figure 3.3 provides monthly rainfall erosivity values for Emerald and Pittsworth.

Figure 3.3 Monthly rainfall erosivity values for Emerald and Pittsworth



3.112 Depth

For rainfall events with the same average intensity, the longer the duration the greater the depth of rainfall. Longer events allow more opportunity for losses to be satisfied and more runoff to be produced. The discharge increases as losses are satisfied, until an equilibrium is reached, after which the peak discharge rate remains constant.

3.113 Spatial distribution

The variation of rainfall intensity and depth across a catchment is referred to as *spatial distribution*. A storm spread evenly across an entire catchment will yield runoff of a different magnitude compared to the runoff produced if the same volume of rainfall fell in only parts of that catchment. Similarly, runoff events will differ depending on where storms occur on a catchment. For example, a storm moving up a catchment is likely to produce a lower peak than a comparable storm moving down a catchment. In the former case, runoff produced in the lower part of the catchment will have left the catchment before the runoff from higher in the catchment arrives. In the latter case, the runoff rate is compounded because runoff from the top of the catchment may arrive at the same time as the storm has reached the lower catchment.

In some of the more complex runoff estimation models, an allowance can be made for spatial distribution. This is especially important in flood forecasting exercises, but when carrying out designs for soil conservation structures, it is generally assumed that the rain occurs evenly across the catchment.

3.114 Temporal distribution

Variation in intensity over time during a rainfall event is referred to as *temporal distribution*. The graphical representation of rainfall depth over time is called an hyetograph. A rainfall event with a large proportion of its volume at the start may produce a runoff event of different magnitude than if the same proportion occurred at the end or some other part of the event.

The Bureau of Meteorology has prepared a set of design temporal patterns from rainfall data for a range of durations (from 10 minutes to 72 hours) and Average Recurrence Interval (ARI's) (1 to 100 years), (Pilgrim 1987). Again, the more complex runoff estimation models use temporal patterns as part of their input data, both in design and flood forecasting exercises. The runoff estimation methods described in this manual assume that rainfall intensities are constant for the duration of the event.

3.12 Catchment characteristics

There are a number of physical characteristics of catchments that affect the amount and/or rate of runoff they generate. Some of these characteristics vary with the season and the type of management practices used. The impact of an individual characteristic depends on the size and shape of the catchment. For example, paddocks containing soils with high infiltration rates with consistently high levels of surface cover will have lower rates of runoff than paddocks containing soils with low infiltration rates and with low levels of surface cover. These characteristics should be taken into account when designing a waterway to accommodate the runoff from a paddock. However when preparing a design for a larger catchment containing a variety of soils and land uses, the effects of different characteristics will be averaged out and some representative parameter values for the whole catchment may be selected when calculating a runoff estimate.

3.121 Area and shape

In general, the volume and peak rate of runoff increases with catchment area. However, for the same rainfall event, a long narrow catchment would be expected to have a lower peak rate of runoff than a more compact or circular one of the same area. In the longer catchment, it takes more time for the runoff from the most remote part of the catchment to reach the outlet.

Contour bays represent an unnatural shape for a catchment. They have a relatively short length of overland flow with a contour bank that acts as a long detention basin especially when the channel flow is restricted by a crop or standing stubble. This shape needs to be taken into account when determining the peak discharge from a contour bay.

3.122 Topography

Catchments with low sloping terrain generally have a lower peak rate of runoff than those with steep terrain. This is because it takes longer for runoff to travel over lower sloping surfaces and the peak discharge will be both reduced and delayed. However, steep watercourses will often have a higher roughness which may offset any increase in flow velocity due to the higher slope.

3.123 Soil conditions

The rate of infiltration of rainfall into the soil affects the amount and rate of runoff. Infiltration rates vary with soil type. Soils with high infiltration rates include deep sands and ferrosols (krasnozems). Cracking clay soils have a variable infiltration rate—high when cracks are open and low when cracks are closed. Texture contrast soils often have subsoil layers with low infiltration rates. The term soil permeability is also used to express the rate at which water moves through a soil profile. The least permeable layer in the soil controls the rate of water transmission. Houghton and Charman (1986) describes three permeability rates as follows:

- slowly permeable – less than 10 mm per day
- moderately permeable – 10 mm to 1000 mm per day
- highly permeable – more than 1000 mm per day.

Soils with abundant biological life generally have high rates of infiltration. Earthworms and termites improve soil aeration and drainage through the construction of burrows and termite galleries. Tillage destroys these structures. Infiltration rates are also reduced by soil compaction and the formation of surface seals.

The amount of infiltration also depends on the antecedent moisture content of the soil. Catchments in a dry condition can absorb more rainfall then wet catchments before runoff commences. Major flood events (and soil erosion) can occur when heavy rain falls on an already wet catchment.

3.124 Storage

Runoff can be stored in depressions in the land surface, reducing the amount of surface runoff. Examples include roughly ploughed paddocks, hoof prints, melonholes or gilgais, sediment traps, dams, and wetlands. Some implements create storage in an attempt to encourage better utilisation of rainfall eg. tied-ridging implements. Constructed surface storages can be designed to empty over an extended period of time in order to reduce the flood peak downstream. These are termed detention storage structures.

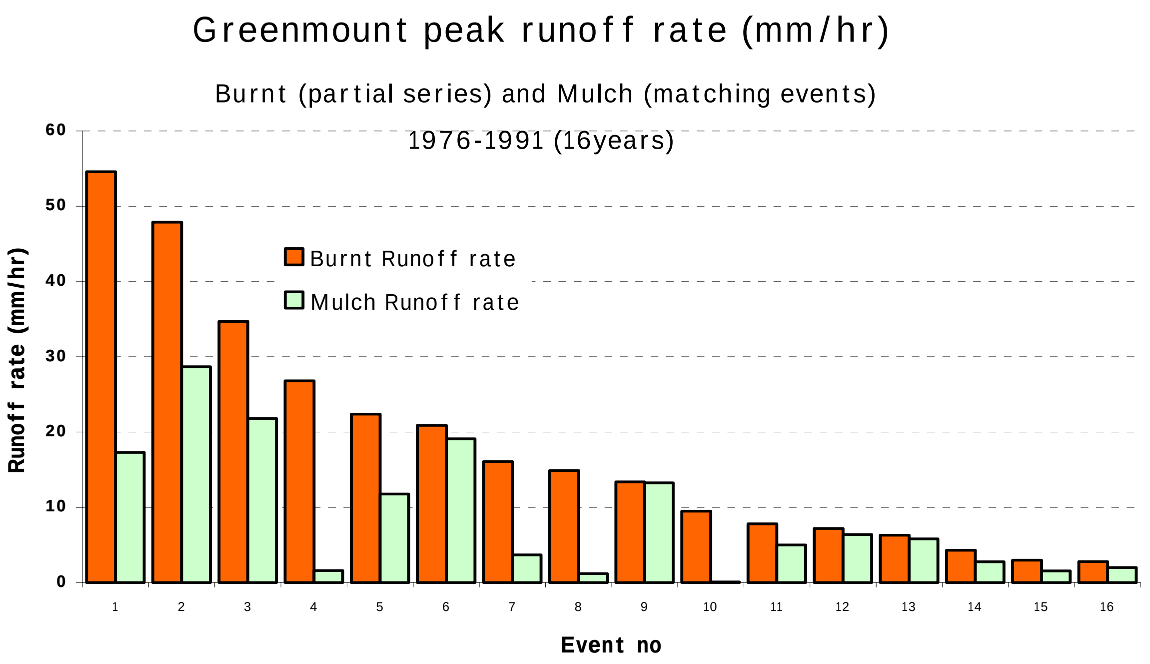
Contour banks can provide significant temporary storage. Contour banks of the same height will have much greater capacity on lower slopes than higher slopes because of the greater amounts of runoff stored behind the bank. Contour banks on lower slopes will also have lower gradients, which further increases the period of temporary pondage.

3.125 Land use and management

Generally, forested land will produce less runoff than cultivated or pasture land. As an example, Lawrence and Thorburn (1989) found that clearing brigalow forest at Theodore more than doubled the mean annual runoff depths. For one catchment, the mean annual runoff increased from 26 mm while under forest, to 56 mm when cultivated for the time period studied. The mean annual runoff for another catchment increased from 23 mm to 47 mm when the land use changed from forest to pasture.

The effect of soil surface management is also important. Higher rates of runoff will usually result from paddocks with low levels of surface cover compared to those with a crop or stubble from the previous crop. Surface vegetation helps maintain higher infiltration rates by reducing soil aggregate breakdown and surface sealing and it has an impeding effect on overland flows. Figure 3.4 shows peak runoff rates measured from two treatments in a paddock at Greenmount on the Darling Downs from 1976 to 1991. The peak runoff rates from treatments with high levels of surface cover were significantly lower than the rates from treatments with bare fallows in most years. There was a smaller difference in treatment effects when the storm event occurred late in the fallow (eg. events 6, 9, 12 and 13). Differences in surface cover levels are much higher at the beginning of a fallow than at the end when much of the stubble will have decomposed.

Figure 3.4 Peak runoff rates for the 16 largest events recorded at the Greenmount trial between 1976 and 1991



It is generally accepted that a minimum level of 30% stubble cover is required to provide a reasonable level of protection from erosion. Higher levels of cover will increase the protection provided. In drought conditions, crops may not be planted and cover levels will be minimal. This is more likely to happen in more marginal cropping areas where soils have lower moisture holding capacity and fertility levels. Cover levels are often lower in districts where farmers are struggling to maintain profitability because of small properties and limited opportunities to adopt new technology.

While zero tillage reduces soil erosion compared with conventional tillage techniques, sometimes it results in higher peak runoff rates than stubble mulched plots. This is due to the presence of higher antecedent moisture levels and smoother land surfaces (Sallaway *et al.* 1990, Freebairn and Wockner 1986).

Soil compaction can also inhibit infiltration. The wheels of tractors, harvesters and implements as well as farm animals may induce compaction. Highest rates of compaction occur when soil is sheared or compressed at the critical moisture content known as the ‘plastic limit’. The result is high soil strength and reduced porosity.

Severely eroded paddocks have a well-developed system of rills and gullies that rapidly generate runoff and deliver it to the lowest point in the paddock. A paddock protected with a contour bank and waterway system as well as stubble retention practices will have lower rates of runoff than an actively eroding paddock. Contour bank systems may store more than 50% of the runoff from a 50 mm to 70 mm storm (Sallaway *et al.* 1989). Galletly (1980) also referred to the considerable runoff detention capacity of contour bank channels. This is especially so when the paddock is under crop or standing stubble which significantly increase the time of concentration. A short storm of high intensity may have ceased before the whole of a contour bay is contributing to the waterway.

In urban and homestead areas, runoff volume and rate increases proportionally with the proportion of paved and roofed areas. ■

Chapter 4

Designing for risk

When designing a structure to carry or store runoff, it is necessary to consider how often it will be acceptable for the structure to fail or to surcharge.

The following terms, which refer to both rainfall and runoff, are used when discussing probability or risk:

- **Average Recurrence Interval (ARI)**, also referred to as average return period, is the average number of years (denoted as y years) within which an event will be equalled or exceeded.
- **Frequency** is an alternative way of expressing ARI. A frequency of 1 in y years means that the event will be equalled or exceeded once in y years on average.
- **Probability** is the inverse of frequency, that is, 1/y. It is often expressed as percentage probability, this being 100/y %.

If an event has an ARI of 10 years, it means that during a 100 year period, that event will be expected, on average, to be equalled or exceeded 100/10 or 10 times. The frequency of that event is 1 in 10 years, its probability is 0.1 (1/10) and its percentage probability is 10%. This also means that there is a 10% probability of that event being equalled or exceeded in each and every year. Such an event may occur more than once in any particular year.

It is important to understand that whatever terms are used, they all refer to *long-term averages* and that the periods between events are random. This means, that if an event with an ARI of 10 years occurred last year, the chances of a similar event occurring this year have not lengthened, they remain the same. That is, there is a 10% chance (or odds of 10 to 1) of it happening again. This concept should be fully explained to clients for whom designs are prepared.

For the design of soil conservation structures, the estimation of runoff usually relates only to very small areas such as a paddock or a small catchment on a farm. Extremely high rainfall events that are 'off the scale' of a district rainfall intensity chart can occur in very localised areas. So it is likely that in any district, at the paddock scale, rare events, such as those with an ARI of 100 years, will occur somewhere in a catchment on a much more frequent basis than 1 in 100 years.

It is generally accepted that soil conservation structures should be designed to handle a runoff event with an ARI of 10 years. However, as discussed later in this chapter, this concept is somewhat theoretical when applied to soil conservation structures since their ability to accommodate runoff is subject to considerable variation depending on the season and the stage of the cropping cycle.

A larger ARI should be used when designing soil conservation structures in situations where failure might threaten public safety or cause severe damage, for example, some diversion banks and perched waterways. The largest ARI used for the design of soil conservation works is seldom more than 50 years. On slopes below 1% where surcharging is unlikely to cause significant damage outside a waterway, designs with a lower ARI, for example, 5 years, may be considered.

Structures should be designed for 'average' conditions. Extreme values of the parameters of runoff estimation models are used by some operators to provide safety margins in design. This results in runoff estimates with unknown ARI's and increased construction costs. **If a more conservative design is required, it is better to design for a higher ARI.**

Unlike more permanent structures, the physical dimensions of contour banks are constantly changing. Contour bank capacity declines over time as the bank height reduces by settlement and use of tillage equipment. Channel capacity is also reduced by sediment deposition. For this reason contour banks are normally built to exceed specifications initially so that they will have an effective life of 5 to 10 years before requiring maintenance. In reality, the size of a structure is often determined by the construction technique used by a farmer rather than the theoretical specifications resulting from a design. For example, contour banks in some districts are constructed with one push of a large bulldozer.

For broad-based contour banks, 'failure' may only involve overtopping of the bank (surcharging). When narrow-based banks surcharge, the bank may be completely removed at the point of failure. Contour banks (especially those that are narrow-based) will also be susceptible to failure if preceding dry conditions have resulted in cracks developing across the bank or if animals have burrowed into the bank.

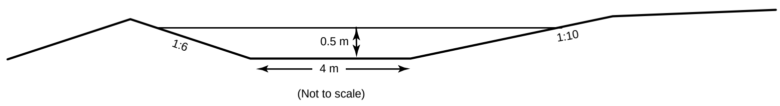
Contour bank failure may result in serious rill and gully erosion below the breakout and subsequent failure of lower contour banks. Such banks must attempt to accommodate the additional amounts of runoff for which they were not designed. Their capacity will have been greatly reduced as a result of sediment deposition resulting from the failure of the above bank. The amount of damage that occurs at the time of bank failure is dependent on the amount of protection provided by crops or stubble and the soil tilth in the contour bay at the time of the event.

In waterways, the depth of flow reached at the point of surcharging may lead to high velocities, which could erode the waterway. Runoff that escapes the confines of the waterway may also cause erosion as it flows parallel to the waterway or flows away from waterways that are not situated in a natural drainage line.

Soil conservation structures are subject to varying conditions in their channel, which adds an additional dimension to their design. Unlike structures made of concrete, soil conservation structures will have different degrees of 'roughness' in their channels depending on the cropping cycle in the case of contour banks, and the season in the case of waterways. This means that although a soil conservation structure may be designed to handle the 10 year ARI runoff event, its ability to handle such an event will vary considerably depending on the condition of the channel at the time of the event.

Table 4.1 shows that a typically shaped contour bank with a smooth bare channel (Mannings roughness coefficient, *n*, of 0.03) can carry five times as much runoff as a channel with a wheat crop or stubble from a previous crop where typical roughness coefficients may be around 0.15. This means that a contour bank designed for conditions when there is a sparse grass cover will be able to handle well in excess of the design storm when the channel is bare. However the bank will accommodate a runoff event with a much lower ARI if the channel flow is restricted by a crop or standing stubble. If the stubble in a contour bank channel is burnt, the bank will, within minutes, be able to handle an event with a much larger ARI.

Table 4.1 Broad-based contour bank discharges for three levels of Mannings *n*

Mannings *n*	Predicted velocity m/sec	Predicted capacity m^3/sec
0.03 (bare cultivated channel)	0.72	2.9
0.05 (sparse grass cover)	0.43	1.7
0.15 (standing wheat stubble)	0.14	0.6
Parameters: • Broad based contour bank with a trapezoidal shape • Bank batter 1:6 (V:H) and excavated batter 1:10 (V:H) • Bottom width of 4 metres • Flow depth of 0.5 metres • Gradient 0.2%		

Considering the example in Table 4.1, it would be reasonable to assume that contour banks should rarely surcharge when the contour bank channel is in a smooth and bare condition. In fact failures are common under these circumstances. Such failures can be attributed to ‘weak links’ at some points in the length of the contour bank. While 90% of the length of a contour bank may have sufficient capacity, the flow it can carry is determined by the capacity of the bank at its weakest point.

A common site for contour bank failure is where contour banks cross old gully lines. At these points contour banks need additional height to provide the gully crossing and to account for additional settlement. Such ‘crossings’ are effectively very small dams, which will in time silt up. Compounding the risk of failure is that these points are likely to have a rill above them which will lead to sediment deposition.

Research involving measurement of soil loss in cropping areas has shown that a large proportion of total soil loss results from a few large events. It would be reasonable to assume that since contour banks are ‘designed to fail’ in an event with an ARI in excess of 10 years, then their effectiveness in reducing soil loss in a paddock must be questioned. However, the data in Table 4.1 indicates that well maintained contour banks are most likely to fail when contour bays and channels are under crop or stubble. In such cases, soil loss will be reduced by the effects of the cover in the contour bay. Contour bank breakages under bare fallow conditions are only likely if contour banks have been poorly maintained and are not up to recommended specifications. In such situations, sediment ‘slugs’ deposited in bank channels below eroding rills will contribute to contour bank failure.

The ability of a grassed waterway to accommodate runoff will be very dependent on the density and length of grass in the channel as illustrated in Table 4.2. During a good season, grass growth may be prolific and will effectively choke the waterway resulting in reduced velocities and discharges. If waterways are heavily grazed or burnt there will be very little retardance to flow resulting in high (and erosive) velocities and high discharges. For this reason, in Chapter 11 *Waterways*, it is recommended that selection of a permissible velocity should be based on the seasonal condition when there is expected to be little retardance; and then depth of the channel based on the expected flow for a higher retardance.

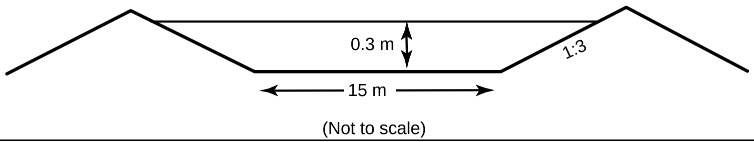
Vegetative condition is also sensitive to management actions such as slashing or periodic grazing and whether or not fertiliser is used to promote vigorous growth for more effective erosion control.

Table 4.2 Trapezoidal waterway discharges for three different levels of retardance

Retardance in waterway channel (Grass length in cm)	Mannings *n*	Predicted velocity m/sec	Predicted discharge m^3/sec
High retardance (A) >75 cm	0.3	0.2	1.0
Moderate retardance (C) 15–25 cm	0.04	1.5	7.3
Very low retardance (E) <5 cm	0.025	2.5	11.7

Parameters:

- Bottom width of 15 metres
- Batters (V:H) 1:3
- Depth of flow 0.3 m
- Slope 2%



■

Chapter 5

Peak discharge estimation

For the design of soil conservation structures it is necessary to estimate the peak discharge that will occur for a specified average recurrence interval. Such a discharge is often referred to as a 'design flood'. It should not be confused with the estimate of a flood height resulting from a specific rainfall event over a catchment. Such an estimate is referred to as a 'deterministic' design.

As can be seen from Chapter 3, *Runoff processes*, the peak rate of runoff produced by a catchment is dependent on many variables. If peak runoff rates from a catchment were measured over a long period of time, it would be possible to get a reasonable indication of the magnitude of the peak rates that could be expected for different ARI's from that catchment. However, runoff records are non-existent for the small agricultural catchments that are the subject of most soil conservation designs. For this reason it is necessary to use a method that provides an estimate of the peak rate of flow taking selected catchment characteristics into account.

Methods of estimating runoff vary in complexity depending on the hydrologic processes they attempt to simulate. The simulation of all runoff generation processes and relationships requires a high degree of expertise as well as sophisticated software and large amounts of data. Ideally, the method used should be developed using data from the catchment for which the design is required or from similar catchments. If this is not possible, the next best approach is to use methods developed elsewhere but having parameter values derived using local data.

Runoff estimation methods based on local hydrologic data are listed below. For more detailed information about the use of these methods refer to *Australian Rainfall and Runoff – A guide to flood estimation* (Pilgrim 1998).

- **Flood frequency analysis:** the flood peak discharge record of a catchment is analysed to provide a direct estimate of the desired design flood for that catchment.

- **Regional flood frequency models:** these models use relationships developed between runoff data and characteristics of catchments in the region. This approach was used to develop a version of the Rational Method for use in small catchments in the Darling Downs (the model is described in Chapter 7).

- **Runoff routing techniques:** runoff is followed from its point of origin to the design point using models which represent the runoff processes using storage routing concepts with a series of conceptual storages. The output represents the direct runoff hydrograph at the design point (a hydrograph being a graph showing discharge plotted against time). Examples of such techniques include the following:
  - Use of a single storage at the outlet, for example, synthetic unit hydrographs as described by Cordery and Webb (1974).
  - Use of a network of storages, for example, models such as RORB (Laurenson and Mein 1988) and WBNM (Boyd 1978).
  - Use of the continuity and Manning equations as in the ANSWERS model of Beasley *et al*. (1980).
  - Application of the differential equations of unsteady flow such as in the kinematic wave based model, KINCON (Connolly and Barton 1990) (not available for commercial use).

- **Water balance models:** these predict the hydrologic behaviour of a catchment by continuously simulating water movement through the hydrologic cycle.

The use of large amounts of resources in collecting data for calibration and/or use of sophisticated models is not warranted for the small catchments that are the basis of most soil conservation designs. Table 5.1 shows the results of a survey carried out by the Department of Primary Industries in 1988, which indicates the proportion of waterway designs carried out in catchments of different sizes in Queensland cropping areas. Scarborough *et al.* (1992) indicates that some 70% to 80% of catchment designs for the Coastal Burnett district are less than 50 ha.

Table 5.1 Proportion of waterway designs carried out in catchments of different sizes in Queensland

Catchment size	0–20 ha	20–50 ha	50–200 ha	200–500 ha	500–1000 ha	>1000 ha
Percentage of designs	33%	30%	25%	9%	2%	1%

In Queensland, the Rational Method of runoff estimation is normally used for the small catchments involved in most soil conservation designs. More sophisticated methods may be necessary for the design of soil conservation works in catchments exceeding 1000 ha. In the following chapters, two versions of the Rational Method are described—the **Empirical version** and the **Darling Downs Flood Frequency (DDFF) version.**

The Empirical version is considered to be an arbitrary method because it is based on estimated parameters rather than measured hydrologic data. However it is the preferred option for the design of small catchments dominated by paddocks with contour banks. The Darling Downs Flood Frequency version of the Rational Method is considered to have limitations when applied to a contour banked catchment. These limitations are described in Chapter 7. ■

Chapter 6

The Empirical version of the Rational Method

The Empirical version is named because the parameters it uses (apart from rainfall data) are arbitrary and are generally based on experience or observation rather than field measurements obtained over a long period of time. This version has been used in Queensland for many years and remains the accepted method for small catchments with a high proportion of contour banked paddocks.

6.1 Description

While there are few long-term records of runoff from small agricultural catchments there are reliable, long-term rainfall records for most parts of Queensland. The Rational Method uses this data to predict peak discharge for design purposes. The assumption is made that a rainfall event of a particular Annual Recurrence Interval (ARI) and duration will produce a runoff event of the same ARI. In practice, a specific rainfall event will produce varying amounts of runoff depending on the conditions of the catchment at the time that the event occurs. If the design rainfall occurs on a dry catchment the resulting peak runoff will be lower than that for the design; and higher than the design runoff if it was a wet catchment. A design method must therefore be based on 'average' catchment conditions.

To gain an appreciation of the basis of this method, consider the runoff that would occur from the tin roof of a building as a result of a storm in which the rate of rainfall was constant (Figure 6.1). The resultant hydrograph from such a storm is shown in Figure 6.2.

Figure 6.1 Direction of runoff from a tin roof

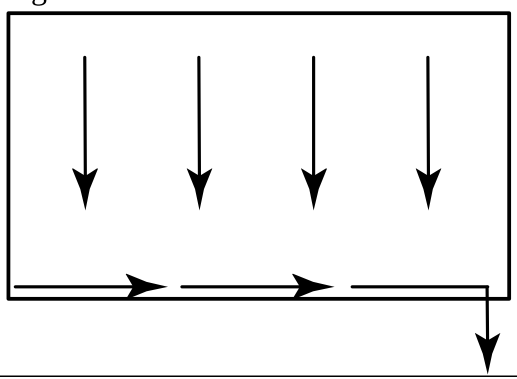
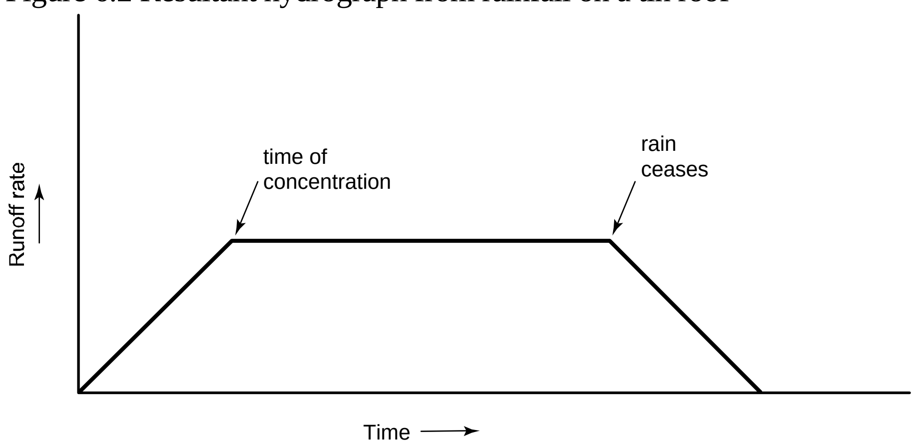


Figure 6.2 Resultant hydrograph from rainfall on a tin roof



After the commencement of rain, the rate of runoff would increase until it reached a peak. At this point the whole of the tin roof would be contributing to the outlet where the runoff was being measured. The period of time taken for the whole catchment to contribute is referred to as the *time of concentration* (tc). After this point has been reached, the constant rate of rainfall will ensure that the peak rate of runoff remains constant until such time as the rain ceases and the runoff rate will decline until no further runoff occurs.

To determine the peak rate of runoff for the tin roof, there are only two factors to consider:

- area of the roof
- rainfall intensity.

The formula used to determine the peak rate is:

Q = I A 0.00278

Where

Q = peak discharge in m^3/s
I = rainfall intensity in mm/hr
A = area in hectares
0.00278 is to balance the units. A uniform rainfall rate of 1mm/hr on 1ha would produce a peak discharge of $0.00278 m^3/s$ if all of the rain resulted in runoff.

To use this formula for design purposes to predict rates of runoff from tin roofs, an appropriate rainfall intensity would need to be determined. In doing this, it would be necessary to consider the ARI of the event for which a design is required. Rainfall intensity–frequency–duration charts could then be used to determine a rainfall intensity for the appropriate time of concentration and ARI.

The formula, Q = I A 0.00278 could be applied to any ‘catchment’ if it is assumed that all of the rainfall resulted in runoff. While this is almost true for a tin roof it does not apply to a natural catchment.

To account for all of the variables that reduce the rate of runoff from a catchment, the Rational Method uses a single factor known as the runoff coefficient (C). The C factor is an estimate of the proportion of rainfall that becomes runoff. The C factor for a tin roof would be very close to 1. The factor for a soil similar to a beach sand would be as low as 0.1 or 0.2 because of the very high infiltration rates.

Taking into account the C factor, the Rational formula then becomes:

$$\mathbf{Q_y = 0.00278\, C_y\, I_{tc,y}\, A} \qquad \text{.....Equation 6.1}$$

Where

Q_y = design peak runoff rate (m^3/s), for an ARI of y years
C_y = the runoff coefficient for an ARI of y years, (dimensionless)
I_{tcy} = average rainfall intensity (mm/h), for the design ARI and for a duration equal to the ‘time of concentration’ tc, (minutes) of the catchment
A = catchment area (ha)
0.00278 is to balance the units. A uniform rainfall rate of 1mm/hr on 1ha would produce a peak discharge of $0.00278 m^3/s$ if all of the rain resulted in runoff.

If the area is in square kilometres (km^2) instead of hectares, the conversion factor is 0.278 (or 1/3.6).

It is accepted that the Rational Method is an oversimplification of a complex process. However it is considered to be suitable for runoff estimation for the relatively small catchments in which designs for soil conservation measures are carried out. As discussed in Chapter 4, *Designing for Risk*, the ability of a soil conservation structure to convey the runoff for which it was designed can vary by a factor of 5 (or greater) depending on the season and the stage of the cropping cycle when the event occurs. For this reason there is limited benefit in using a more complex model in an attempt to further refine the method of runoff prediction.

6.2 Runoff coefficient

The runoff coefficient (C_y) is defined as the ratio of the flood peak runoff rate of a given ARI to the mean rate of rainfall for a duration equal to the catchment 'time of concentration' and of the same ARI. The runoff coefficient attempts to take into account all catchment characteristics that affect runoff. Runoff coefficient values for use in soil conservation designs in Queensland are based on a number of factors including the potential of the land management system to produce runoff. It should be noted that these are arbitrary values and are not based on hydrological data.

Three 'runoff potential' categories are listed in Table 6.1.

Table 6.1 Runoff potential categories for use in designs for soil conservation purposes

Runoff potential	Forest	Pasture	Cultivation
1	Dense forest in undisturbed condition	Not applicable	Not applicable
2	Medium density forest with moderate levels of surface cover in most seasons	Pasture with high levels of pasture density in most seasons	Zero tillage / opportunity cropping. Rotations with crops or pastures with high cover levels
3	Forested area subject to high pressure with compacted soils and no surface cover	Pasture with low levels of pasture density in most seasons	Predominantly bare fallows with a rotation giving moderate to low levels of cover

Table 6.2 provides 10 yr ARI values for runoff coefficients based on the runoff potential categories from Table 6.1 as well as soil permeability values and topography. Soil permeability ratings can be obtained from district Land Management Field Manuals.

Table 6.2 Runoff coefficients for use with the Empirical version of the Rational Method

Runoff potential based on topography and land slope		10 yr ARI runoff coefficients		
		Soil permeability		
		High	Medium	Low
Runoff potential 1				
Flat	0–2%	0.1	0.2	0.3
Rolling	2–10%	0.1	0.3	0.4
Hilly	10–30%	0.2	0.4	0.5
Runoff potential 2				
Flat	0–2%	0.15	0.3	0.4
Rolling	2–10%	0.2	0.4	0.5
Hilly	10–30%	0.3	0.5	0.6
Runoff potential 3				
Flat	0–2%	0.2	0.4	0.5
Rolling	2–10%	0.3	0.5	0.6
Hilly	0–30%	0.4	0.6	0.7

To estimate runoff coefficient values for ARI's other than 10 years, the 10 Year ARI should be multiplied by the factors in Table 6.3. For example, the ARI 50 runoff coefficient can be obtained by multiplying the ARI 10 coefficient by 1.5. The values in Table 6.3 are based on values obtained for the Darling Downs Flood Frequency Version of the Rational Method (see Chapter 7).

Table 6.3 Conversion factors to determine peak discharge for different ARI's

ARI (years)	Conversion factor
1	0.5
2	0.6
5	0.8
10	1.0
20	1.2
50	1.5
100	1.8

There are two methods of accounting for situations where runoff coefficients vary within a catchment:

- Equivalent Impervious Area
- Proportionality.

6.21 Equivalent Impervious Area

The *Equivalent Impervious Area* of a catchment is the area that would produce a design flood of the same size as that estimated for the catchment if that Equivalent Impervious Area has a runoff coefficient of 1; this means that all the rainfall falling on the Equivalent Impervious Area runs off.

It is calculated by dividing a catchment into components having similar runoff producing characteristics. The Equivalent Impervious Area for each component is then determined by multiplying its area by its runoff coefficient. The Equivalent Impervious Areas for each component are then added to determine the Equivalent Impervious Area for the total catchment.

Equivalent Impervious Areas within the one ARI are additive. If the ARI is changed it is necessary to calculate a new Equivalent Impervious Area based on the runoff coefficient applicable to the new ARI.

As Equivalent Impervious Area incorporates both the runoff coefficient and the catchment area, the Rational Method formula then becomes:

$$\mathbf{Q_y = 0.00278\, I_{tc,y}\, A_{ei,y}} \qquad \text{Equation 6.2}$$

Where

Q_y = design peak runoff rate (m^3/s), for an ARI of y years

$I_{tc,y}$ = average rainfall intensity (mm/h), for the design ARI and for a duration equal to the tc (minutes) of the catchment, and

$A_{ei,y}$ = Equivalent Impervious Area (ha) for the design ARI of y years

Example: Determine the Equivalent Impervious Area for a 90 ha catchment which consists of 20 ha of cultivation (C_y = 0.6), 30 ha of forest (C_y = 0.3) and 40 ha of pasture (C_y = 0.4).

Land use	Area (ha)	Runoff coefficient	Equivalent Impervious Area (ha)
Cultivation	20	0.6	12
Forest	30	0.3	9
Pasture	40	0.4	16
Total	**90**		**37**

6.22 Proportionality

The proportionality technique is used to provide a 'weighted' runoff coefficient for the catchment. For each component of the catchment having similar runoff producing characteristics, its assigned runoff coefficient value is multiplied by the ratio of its area to the total catchment area (Equation 6.3). These products are then summed to give a catchment proportional runoff coefficient.

$$\textbf{Component proportional } C_y = \frac{\textbf{component area x component } C_y}{\textbf{total catchment area}} \qquad \text{.......Equation 6.3}$$

Example: Using the same data as in the previous example.

Land use	Area (ha)	Runoff coefficient	Proportional runoff coefficient
Cultivation	20	0.6	0.13
Forest	30	0.3	0.10
Pasture	40	0.4	0.18
Total	**90**		**0.41**

Note: The catchment proportional runoff coefficient multiplied by the catchment area equals the catchment Equivalent Impervious Area ie. 90 x 0.41 = 36.9.

6.3 Rainfall intensity

The average rainfall intensity for a design storm of duration equal to the calculated 'time of concentration' (tc) of a catchment is estimated using IFD (intensity, frequency, duration) information for the catchment.

The catchment 'time of concentration' is the time estimated for water to flow from the most hydraulically remote point of the catchment to the outlet. The Rational Method assumes that the highest peak rate of runoff from the catchment will be caused by a storm of duration just long enough for runoff from all parts of the catchment to contribute simultaneously to the design point.

The 'time of concentration' is calculated by summing the travel times of flow in the different hydraulic components. Those components may include overland flow, stream flow and/or flow in structures. Several flow paths may need to be assessed to determine the longest estimated travel time, which is then used to determine rainfall intensity.

The following guidelines should be used when estimating the time of concentration.

6.31 Contoured catchments

6.311 Overland flow

Overland flow travel times can be determined for the most remote part of the contour bay. The formula used for calculating overland flow is as follows:

$$\mathbf{t = \frac{107\,n\ \sqrt[3]{L}}{5\sqrt{s}}} \qquad \text{.......Equation 6.4}$$

Where

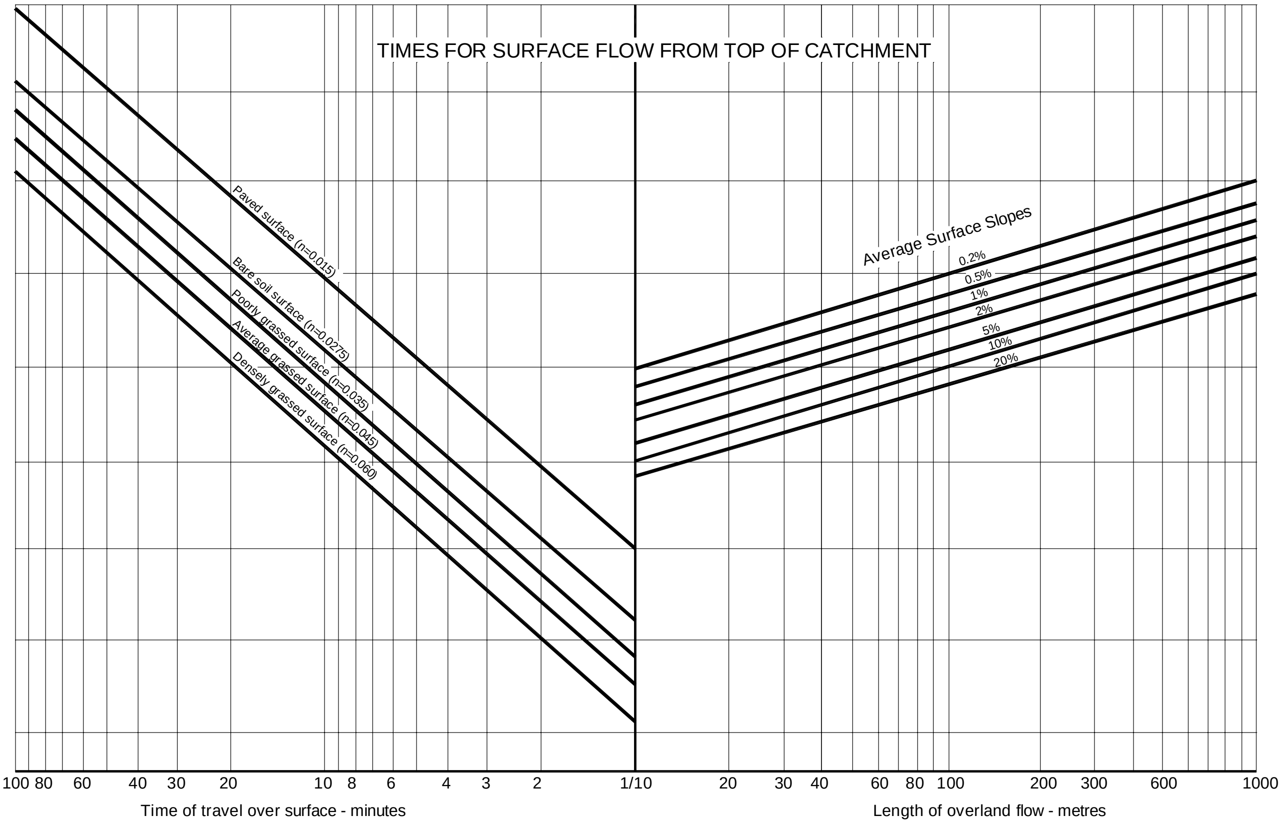
- t = time of travel over the surface (minutes)
- n = Hortons *n* values for the surface (Table 6.4)
- L = length of flow (metres)
- s = slope of surface (%)

Table 6.4 Hortons *n* values for different surface conditions

Surface condition	Hortons *n* value
Paved surface	0.015
Bare soil surface	0.0275
Poorly grassed surface	0.035
Average grassed surface	0.045
Densely grassed surface	0.060

The chart in Figure 6.3 is based on Equation 6.4. An average condition for the paddock surface should be chosen. Where stubble is normally retained on the soil surface, this would mean selecting for an average or poorly grassed surface. While Hortons *n* values are related to surface roughness, they should not be confused with the *n* values for roughness coefficients in the Manning equation (refer to Chapter 8, *Channel Design Principles*).

Figure 6.3 Travel time for overland flow



Formula $t = \frac{107\, n \sqrt[3]{L}}{5 \sqrt{s}}$

where
- t = time of travel over surface in minutes
- n = Horton's values for the surface
- L = Lenght of flow in metres
- s = slope of surface in %

Example

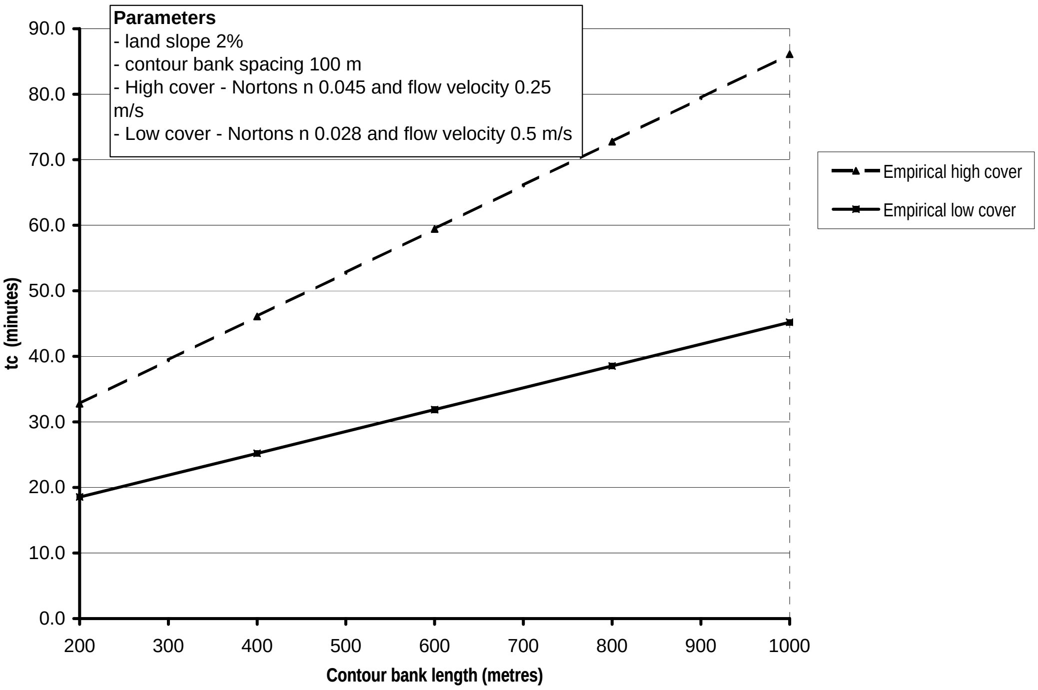
Length of overland flow 200m
Average slope of surface 5%
Densely grassed surface (n= 0.060)
Time of travel = 27.2 minutes

6.312 Interception structure flow

Travel times along interception structures (contour and diversion banks) are calculated by dividing the length of flow by the design velocity of the structure. Since it is recommended that designs should be based on average conditions, it is appropriate to select a velocity appropriate to the average condition of the channel. In a paddock where there would normally be either a crop or standing stubble in a paddock, then a velocity representative of that situation should be chosen. Where contour bank channels have either a crop or standing stubble, it is most unlikely that the average velocity in the contour bank channel will exceed 0.25 m/sec even though the maximum acceptable velocity may be 0.5 or 0.6 m/sec. Chapter 9, *Contour banks* has more information on this topic.

Figure 6.4 shows a comparison of times of concentration in a contour bay comparing a high cover farming system with a low cover system.

Figure 6.4 Comparison of times of concentration in a contour bay for a high and low cover farming system



6.313 Waterway flow

Similarly for waterways, a velocity based on the average condition in the waterway should be chosen rather than the maximum design velocity for the waterway.

6.32 Non-contoured catchments

6.321 Overland flow

The overland flow chart in Figure 6.3 provides distances for flows of up to 1000 metres. A guide to estimating the length of overland flow is to assume that flow would begin to concentrate at a distance appropriate to the recommended contour bank spacing for that slope (refer to Chapter 9, *Contour Banks*). This means that lengths of overland flow would rarely exceed 100 metres despite the fact that the chart provides values for up to 1000 metres.

6.322 Concentrated flow

A velocity of 1 m/s is considered to be an acceptable value to use until a well-defined drainage line is reached.

6.323 Stream flow

Travel time for stream flow would not normally be required for the estimation of runoff from cropping lands. However it may need to be considered when preparing a design for the construction of diversion banks and gully control structures.

Travel time for stream flow is calculated by dividing the length of the stream by an estimated average velocity of the flow. Chow (1959) describes a method of determining a Manning roughness coefficient for a stream reach. This requires a summation of values given to factors affecting the roughness coefficient. The Appendix provides a guide to velocities that can be expected for a range of situations and was developed using Chow’s method.

6.4 Applying the empirical method

The following procedure is used when determining the design peak discharge at a design point. The Waterway design proforma (Figure 6.6) is recommended when using the procedure and for providing a record of the calculations. The computer program RAMWADE (**Ra**tional **M**ethod **Wa**terway **De**sign) takes users through the same steps as provided in the proforma.

1. Decide on the design ARI.
2. Allocate locations on the plan for design points (refer to Chapter 2, *Soil Conservation Planning).*
3. Estimate the 'time of concentration' for the design point.
4. From the IFD diagram for the district, determine the design rainfall intensity relevant to the 'time of concentration' and the required ARI.
5. Identify and measure component areas within the catchment and assign a runoff coefficient to each.
6. Either a) calculate the Equivalent Impervious Area for the catchment or b) calculate the catchment proportional runoff coefficient.

Calculate the design peak discharge by substitution into Equations 6.1 or 6.2 as appropriate.

The procedure can be simplified by preparing a graph relating the catchment Equivalent Impervious Area and 'time of concentration' for a particular ARI and locality. This chart is often referred to as a constant discharge diagram. An example is given in Figure 6.5. Similar charts can be made for any district using the relevant IFD data to solve Equation 6.2 and plotting the results.

Figure 6.5 Relationship between Equivalent Impervious Area and 'time of concentration' for the Kingaroy district

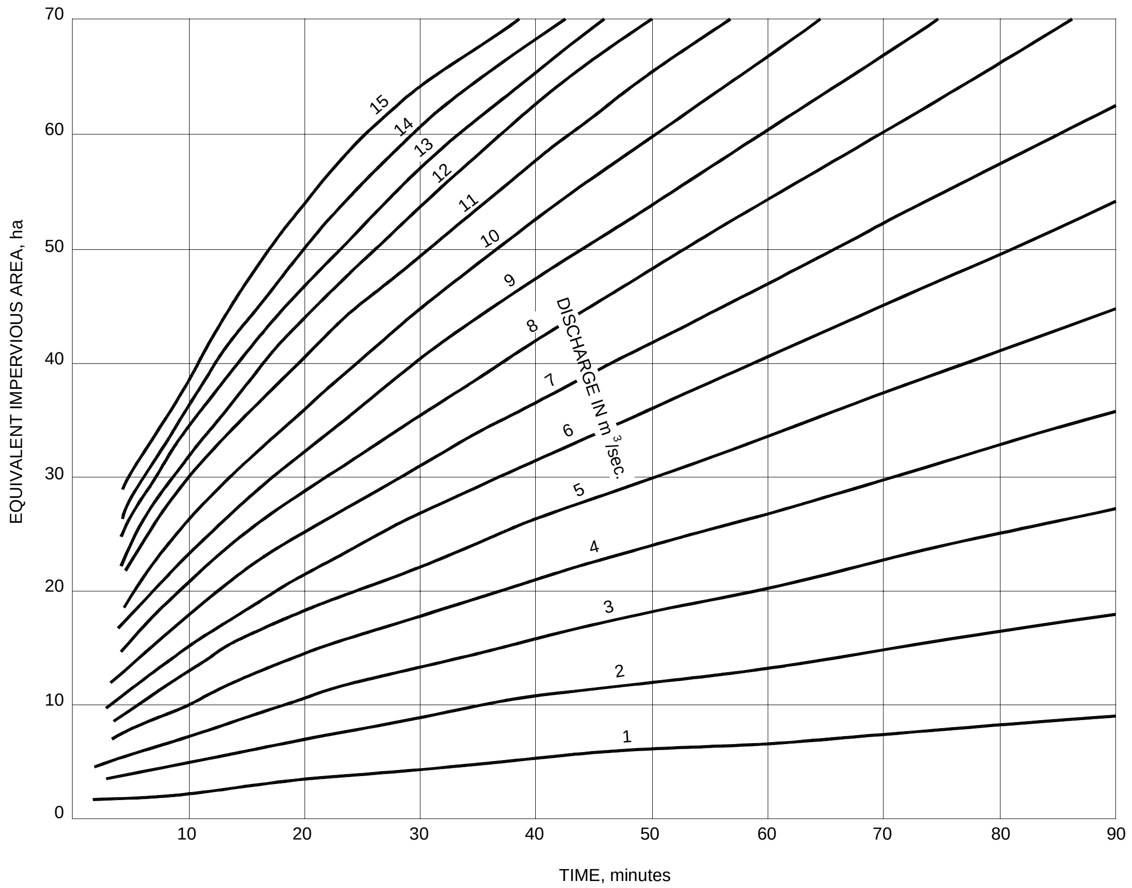


Figure 6.6 Waterway design proforma

Landholder			
Date	**Farm Code**	**Plan Number**	**Shire**
Contact details			
Property description			

1	Design Point							
2	Design ARI in years							
3	Length of overland flow (m)							
4	Average slope (%)	From survey or farm plan						
5	Time of travel for overland flow (min)							
6	Length of stream flow (m)							
7	Average slope of stream (%)							
8	Stream velocity (m/s)							
9	Time of travel in stream (minutes)	Row 6 / (Row 8 *60)						
10	Length of interception bank flow (m)							
11	Interception bank velocity (m/s)							
12	Time of travel in interception bank (min)	Row 10 / (Row 11 * 60)						
13	Tc previous design point (minutes)	Previous design point						
		Time						
14	Length of waterway flow (m)	Additional length if Row 13 is used						
15	Waterway velocity (m/s)	Estimated or previous design point						
16	Time of travel in waterway (minutes)	Row 14 / (Row 15 * 60)						
17	Time of concentration, tc, (minutes)	Total Rows 5,9,12, 13, 16 as applic						
18	**Rainfall Intensity, $I_{tc,y}$ (mm/h)**	**From IFD data for this location**						
19	Area at previous design point	Previous point						
		Total area						
		Equivalent Impervious Area (EIA)						
20	Area of pasture & average slope (ha)	Additional area if Row 19 is used						
21	Runoff co-efficient							
22	EIA, pasture (ha)	Row 20 x Row 21						
23	Area of cultivation & average slope (ha)	Additional area if Row 19 is used						
24	Runoff co-efficient							
25	EIA, cultivation (ha)	Row 23 x Row 24						
26	Other area & average slope (ha)	Additional area if Row 19 is used						
27	Runoff co-efficient							
28	EIA, other (ha)	Row 26 x Row 27						
29	Total area (ha)	Rows: 19+20+23+26						
30	**Total EIA, $A_{ei,y}$ (ha)**	**Rows: 19+22+25+28**						
31	**Peak discharge, Q_y (m^3/s)**	**$Q_y = 0.00278 \times I \times A_{ei,y}$**						
32	Design point slope (%)							
33	Retaining bank batters (1:Z (V:H))							
34	Minimum retardance value							
35	Design velocity, V (m/s)							
36	Bottom width, W (m)							
37	Maximum retardance value							
38	Flow depth, d (m)							
39	Settled bank height (m)	d + 0.15 m freeboard						

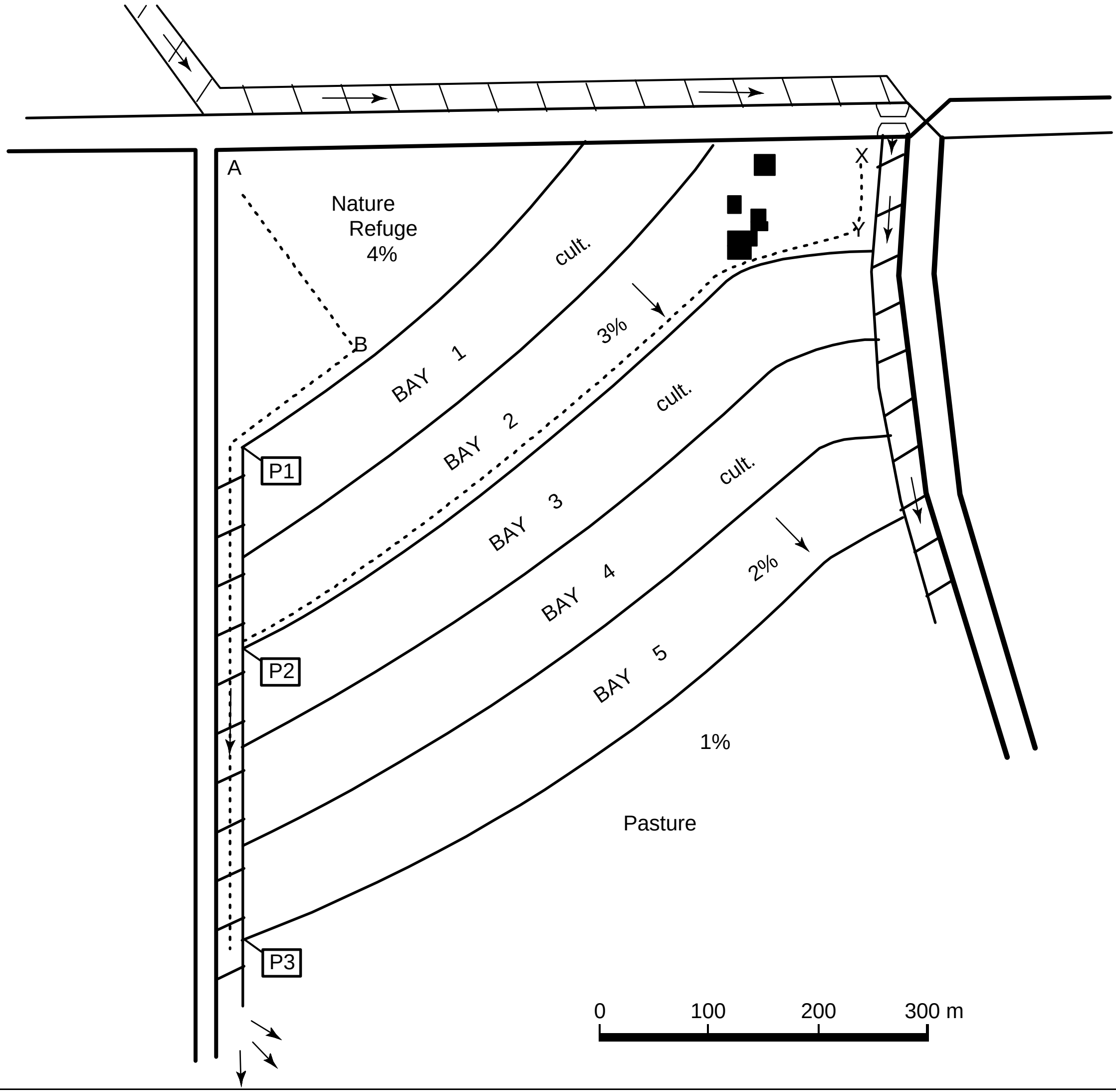
Comments

6.5 Example

Estimate the peak discharge for an ARI of 10 years for the waterway at design points, P1, P2 and P3 shown on the plan given in Figure 6.7. Assume the property is located in the Capella district, the soil is rated as being of low permeability and a farming system providing moderately low levels of cover is practiced. Use the waterway design proforma (Figure 6.6) and the information provided below:

Lengths		*Areas*	
A - B	290 m	Nature refuge	8 ha
B - P1	180 m	Contour bays 1+2	15 ha
X - Y	130 m	Contour bays 3+4+5	25 ha
P1 - P2	220 m		
P2 - P3	320 m		
Y - P2	820 m		
Design velocities		*Runoff coefficients (10 YR ARI)*	
Diversion bank	0.4 m/s	Nature refuge	0.4
Contour bank	0.3 m/s	Cultivation	0.6
Waterway	1.2 m/s		

Figure 6.7 Catchment for design example



Design point P1

Waterway design proforma row number	Design point P1	
3	Length of overland flow, A-B	290 m
4	Average slope, A-B	4%
5	Time of travel, overland flow, A-B *(Figure 6.3 assume average grassed surface)*	24 minutes
10	Length of diversion bank flow, B-P1	180 m
11	Design velocity, diversion bank	0.4 m/s
12	Time of travel, diversion bank (Row 10/(Row 11 x 60))	8 minutes
17	'Time of concentration' (Row 5 + Row 12)	32 minutes
18	Rainfall intensity, Capella (Figure 3.2)	88 mm/h
26	Area of nature refuge	8 ha
27	Runoff coefficient, nature reserve (Table 6.2 assume forest land use)	0.4
28	Equivalent Impervious Area (Row 26 x Row 27)	3.2
30	Total Equivalent Impervious Area	3.2
31	Peak discharge (0.00278 x Row 18 x Row 30)	0.8 m^3/s

Design Point P2

To determine the 'tc' for P2, it is necessary to compare the time of travel for flows along two different routes. Route A-B-P1-P2 should be compared with route X-Y-P2.

For route A-B-P1-P2, the travel time to P1 was calculated as 32 minutes (Row 17, previous chart). There is additional travel time along waterway P1-P2, 220 m at 1.2 m/s. This adds 3 minutes, giving a total time of travel of 35 minutes.

For route X-Y-P2, the time of travel is calculated below in the same order as previously for A-B-P1.

Waterway design proforma row number	Design point P2	
3	Length of overland flow, X-Y	130 m
4	Average slope, X-Y	3%
5	Time of travel, overland flow, X-Y. (Assume average grassed surface beside house and buildings, Figure 6.3)	20 minutes
10	Length of contour bank, Y-P2	820 m
11	Design velocity, contour bank	0.3 m/s
12	Time of travel, Y-P2 (Row 10/(Row 11 x 60))	46 minutes
17	Time of travel X-Y-P2 (Row 5 + Row 12)	66 minutes

Select the longest travel time to P2 (Here it is route X-Y-P2, being 66 minutes) and proceed.

Waterway design proforma row number	Design point P3	
17	'Time of concentration'	66 minutes
18	Rainfall intensity, Capella (Figure 3.2)	58 mm/h
19	Total area, previous design point, P1	8 ha
	Total Equivalent Impervious Area, previous design point, P1	3.2 ha
23	Area of cultivation (contour bays 1 + 2)	15 ha
24	Runoff coefficient, cultivation (Table 6.2)	0.6
25	Equivalent Impervious Area, cultivation (Row 23 x Row 24)	9 ha
29	Total area contributing to P2 (Row 19 + Row 23)	23 ha
30	Total Equivalent Impervious Area for P2 (Row 19 + Row 25)	12.2 ha
31	Peak discharge (0.00278 x Row 18 x Row 30)	2.0 m^3/s

Design point P3

The longest route for determining 'tc' is X-Y-P2-P3.

Waterway design proforma row number	Design point P3	
13	'Time of concentration' for previous design point, P2	66 minutes
14	Length of waterway, P2-P3	320 m
15	Design velocity, waterway	1.2 m/s
16	Time of travel, P2-P3 (Row 14/(Row 15 x 60))	4 minutes
17	'Time of concentration', P3 (Row 13 + Row 16)	70 minutes
18	Rainfall intensity, Capella (Figure 3.2)	55 mm/h
19	Total area, previous design point, P2	23 ha
	Total Equivalent Impervious Area, previous design point, P2	12.2 ha
23	Area of cultivation (contour bays 3, 4, 5)	25 ha
24	Runoff coefficient, cultivation (Table 6.2)	0.6
25	Equivalent Impervious Area, cultivation (Row 23 x Row 24)	15 ha
29	Total area contributing to P3 (Row 19 + Row 23)	48 ha
30	Total Equivalent Impervious Area for P3 (Row 19 + Row 25)	27.2 ha
31	Peak discharge (0.00278 x Row 18 x Row 30)	4.2 m^3/s

■

Chapter 7

Darling Downs Regional Flood Frequency version of the Rational Method

The Darling Downs Regional Flood Frequency Version of the Rational Method is considered suitable for runoff estimation in small catchments in the Darling Downs region where contour banked land represents a small component of the catchment. However for catchments dominated by contour banks, the Empirical version of the Rational Method as described in Chapter 6 is preferred.

7.1 Description

Runoff data was used to develop the Darling Downs Flood Frequency version of the Rational Method (Titmarsh 1989, 1994) for use in the area shown in Figure 7.1. This area is described as the area bounded to the south by the QLD/NSW border, to the west by the 151°E longitude, and to the north and east by the Great Dividing Range.

For most of Queensland, sufficient runoff data from small rural catchments are not available to carry out similar analyses. For instance, all runoff data for such catchments in the Burnett and Central Highlands region were collated and examined in an effort to develop a flood frequency version of the Rational Method for that region. No reliable relationship could be derived as there were too few gauging stations, many of which had short records.

Weeks (1991) has carried out a broad scale study of this type covering most of Queensland. However, the data used were very limited and were mainly from large catchments thus restricting the application and reliability of that version for soil conservation design.

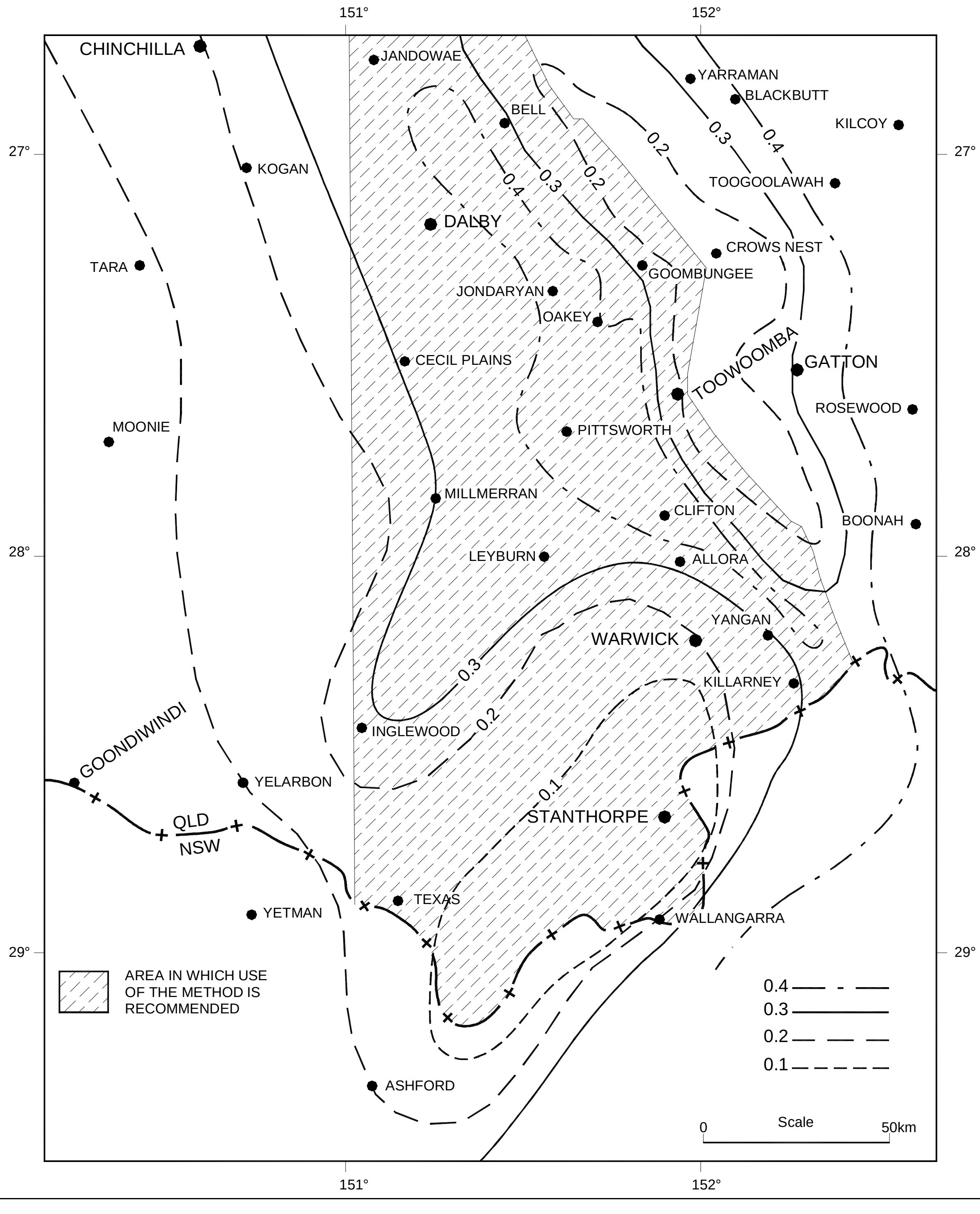
The formula for the DDFF version of the Rational Method is:

$$\mathbf{Q_y = 0.00278\, C_y\, I_{tr.y}\, A} \quad \text{.......... Equation 7.1}$$

Where

Q_y	=	design peak runoff rate for an ARI of y years (m^3/s)
C_y	=	runoff coefficient for the same ARI (dimensionless)
$I_{tr.y}$	=	average rainfall intensity (mm/h) for a design duration equal to a catchment response time tr (minutes) and the same ARI
A	=	area of catchment (ha)

Figure 7.1 Runoff coefficients for the Darling Downs Flood Frequency version of the Rational Method



7.2 Selection of a runoff coefficient

C_{10} values derived for the Darling Downs region are shown on the map in Figure 7.1. The runoff coefficients were also found to be dependent on the area of the catchment that is cultivated. If the catchment has some of its area cultivated, then C_{10} values should also be determined using Equation 7.2 or Table 7.1. The higher of the two C_{10} values (from either Table 7.1 or Equation 7.2) should then be used for the design.

$$\mathbf{C_{10} = 0.22 + 0.004\,\Phi} \quad \text{.......... Equation 7.2}$$

Where
C_{10} = runoff coefficient for the 10 year ARI
Φ = percentage of catchment area cultivated

Table 7.1 C_{10} runoff coefficients for the DDFF version of the Rational Method based on the percentage of cultivation in the catchment

Percentage cultivation	DDFF C_{10} value
10	0.3
20	0.3
30	0.3
40	0.4
50	0.4
60	0.5
70	0.5
80	0.5
90	0.6
100	0.6

Runoff coefficient values for ARI's other than 10 years can be estimated using Equation 7.3

$$\mathbf{C_y = FF_y\ C_{10}} \quad \text{.......... Equation 7.3}$$

Where
C_y = runoff coefficient for an ARI of y years
FF_y = frequency factor for an ARI of y years.
C_{10} = runoff coefficient for the 10 year ARI

The average frequency factors for ARI's of 1, 2, 5 and 20 years for use in Equation 7.3 are given in Table 7.2.

Table 7.2 Average frequency factors

ARI (years)	Average frequency factors (FF_y)
1	0.5
2	0.6
5	0.8
10	1.0
20	1.2

As an example, if the C_{10} runoff coefficient was 0.4 then the C_{20} runoff coefficient would be be determined as follows:

C_{20} = $FF_y\ C_{10}$
= 1.2 x 0.4
= 0.47

7.3 Catchment response time

The effect of catchment characteristics on the hydrologic behaviour of catchments was examined by Titmarsh (1989), in order to obtain a more objective method of determining a duration to use with IFD data. It was found that, for the catchments used, the average time from the start of the runoff to the time of peak discharge for large events was a good measure of that catchment's response time. A regression analysis between that time and many catchment characteristics determined that the catchment area alone gave a reliable estimate of that time. Use of catchment area has an advantage in that it is less affected by map scale than are measurements such as stream length.

The relationship used to calculate response time (tr) is:

tr = 7.8 $A^{0.36}$ minutes.. Equation 7.4

Where

tr = response time (minutes)
A = catchment area (ha).

This version of the Rational Method was developed using IFD information from Pilgrim (1987) and Equation 7.4. No other method of deriving a catchment response time or IFD data should be used with the C_{10} values shown in Figure 7.1.

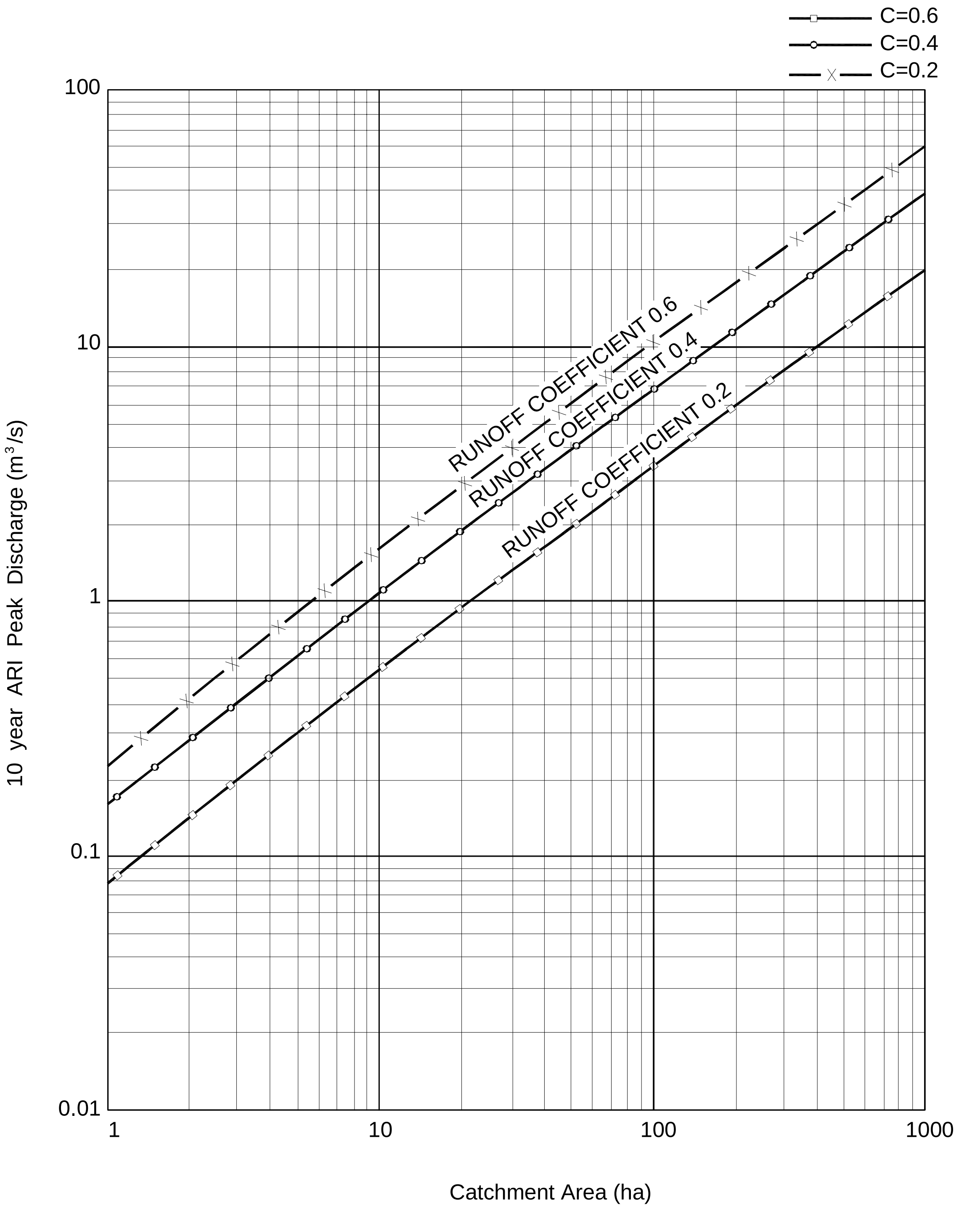
7.4 Applying the Darling Downs Flood Frequency version

The following procedure is used to determine the design peak discharge at a design point.

1. Decide on the design ARI.
2. Measure the area of cultivation and total catchment area to the design point.
3. Calculate the catchment response time using Equation 7.4.
4. From the IFD diagram for the district, determine the design rainfall intensity.
5. Determine a C_{10} value from Figure 7.1
6. Calculate the percentage of the catchment that is cultivated.
7. Calculate C_{10} value using Equation 7.2.
8. Select the higher of the C_{10} values from steps 5 and 7.
9. For ARI's other than 10 years, calculate a C_y value using Equation 7.3 and Table 7.2.
10. Calculate the design peak discharge using Equation 7.1.

A refinement of this procedure involves the use of a district specific chart as shown in Figure 7.2. With these charts, catchment area and runoff coefficient are the only variables to consider in determining the peak rate of runoff for a catchment in a specific district. It is not necessary to determine a rainfall intensity value when using this chart as rainfall intensity is directly related to response time, which is directly related to catchment area.

Figure 7.2 Catchment area - peak discharge relationship for the Oakey district



7.5 Example

Estimate the 10 year ARI peak discharge for a 120 hectare catchment at Oakey. Assume that 20 ha of the catchment is cultivated.

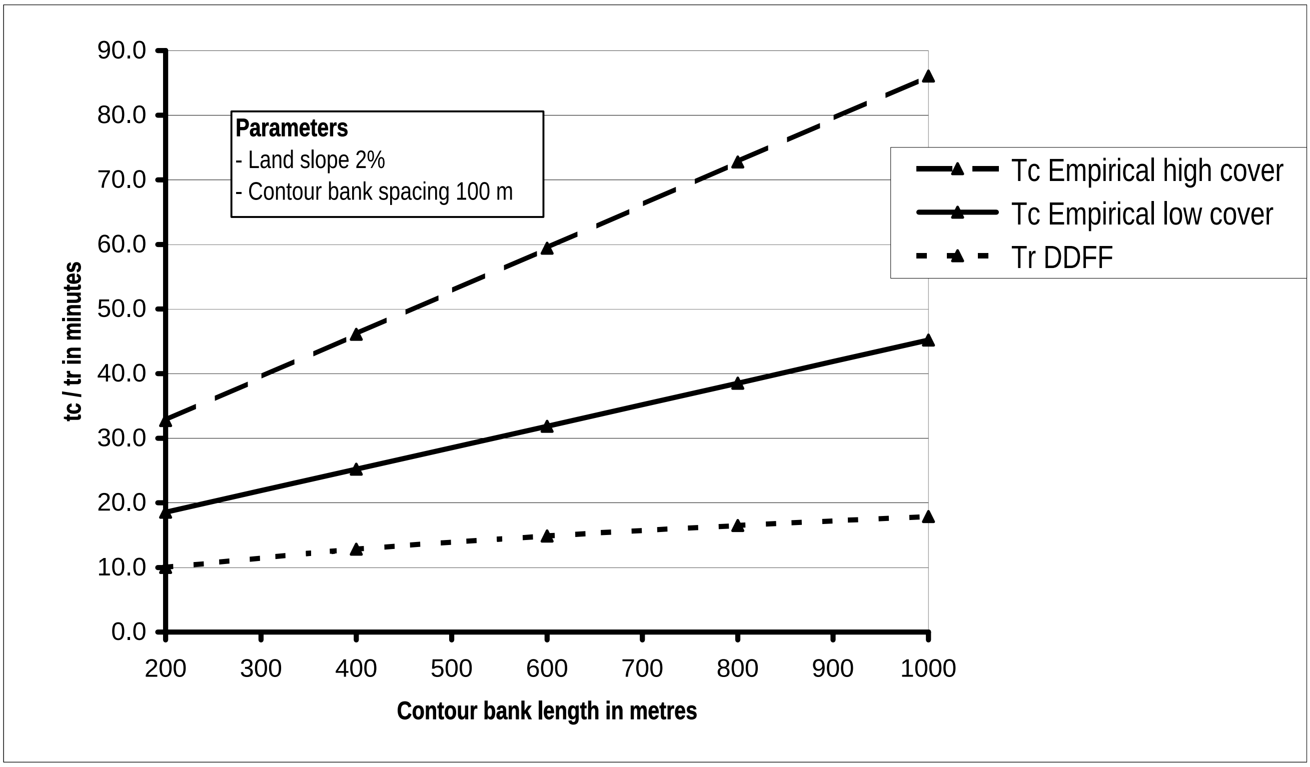
1. ***Calculate a design rainfall duration (tr) for the catchment***
   Tr = 7.8 A $^{0.36}$
   = 7.8 * 120 $^{0.36}$
   = 44 minutes
2. ***Determine the rainfall intensity from an IFD chart for Oakey for a 10 year ARI event of 44 minutes duration***
   55 mm/h
3. ***Determine a C_{10} value for Oakey from Figure 7.1***
   C_{10} = 0.4
4. ***Calculate the percentage of the catchment that is cultivated using Equation 7.2***
   Φ = (20/120) * 100
   = 17%
5. ***Calculate the C_{10} value using equation 7.2***
   C_{10} = 0.22 + 0.004 * 17
   = 0.3
6. ***Select the higher of the C_{10} values from steps 2 and 3 (0.4)***
7. ***Calculate the design peak discharge using Equation 7.1***
   Q_{10} = .00278 * 0.4 * 55 * 120
   = 7.3 m^3/s

7.6 Comparison with the Empirical version of the Rational Method

In comparing the Empirical and DDFF versions of the Rational Method, the DDFF version will provide higher estimates of peak discharge for contour bays. A contour bay represents an unnatural catchment with a long but relatively narrow rectangular shape. A contour bank has considerable storage capacity and has an attenuating affect on discharge from the contour bay. This is especially so when a contour channel has a crop or standing stubble which is likely to reduce flow velocity by a factor of 5 when compared to a bare channel. The longer the contour bank, the greater this effect will be. Because the time of return estimate for the DDFF is based only on the area of the catchment, this method assumes that all catchments have a similar shape and it cannot take into account the effect that contour banks have in retarding flows.

Figure 7.3 provides a comparison of time of response for the DDFF method compared to time of concentration for the Empirical version. It is considered that the method of calculating time of concentration gives a better reflection of the ability of contour banks to attenuate discharge rates than does the time of response value for the DDFF method.

Figure 7.3 Comparison of times of concentration and time of response for a contour bay



Values of the runoff coefficient derived from observed flood data in the DDFF version show no dependence on paddock characteristics such as soil type, slope or vegetation type and condition. One reason for this is that most runoff data used in the analysis of runoff estimation methods comes from catchments that are much larger than paddock size. Hence variation in runoff resulting from different attributes of the components of a catchment tends to average out. As discussed in Chapter 3, *Runoff Processes*, land management practices can have a significant effect on peak discharge at the paddock level. Even if the soil profile is full, stubble will retard overland flows and especially flow in contour bank channels.

The Empirical Version attempts to consider the impact of various paddock characteristics by using assumed values of the runoff coefficient as shown in Table 6.2 of Chapter 6. If the whole of a paddock is cultivated, as is the case in most soil conservation designs, the runoff coefficient for the DDFF method will be 0.6 irrespective of soil type or land management. With the estimated values of the runoff coefficient for the Empirical Method, it is common to use coefficient values ranging from 0.3 to 0.6 depending on the runoff potential of the landscape and the cropping system. Such values, while only estimates, are considered to reflect the situation occurring at the paddock level.

For the above reasons, use of the DDFF version of the Rational Method should be restricted to small non-contoured catchments in the area indicated in Figure 7.1. However it could be expected to give reasonable results for non-contoured catchments in other areas of Queensland that had comparable soils, topography and rainfall intensities to the area indicated in Figure 7.1. ■

Chapter 8

Channel design principles

The primary function of soil conservation structures is to control runoff water by intercepting it and transferring it safely into the local drainage network. Such structures are designed to carry the expected runoff discharge for an event with a chosen average recurrence interval.

Erosion in the structures themselves is controlled either by reducing the water velocity or by protecting the surface. Surfaces of soil conservation structures in cropping lands are usually protected with vegetation. Materials such as geotextiles, rock, gabions and concrete are commonly used in urban situations.

8.1 Channel flow concepts

8.11 Channel capacity

The hydraulic capacity of a channel can be determined by multiplying its cross-sectional area by the mean velocity as in the following formula:

Q = AV ....Equation 8.1

Where

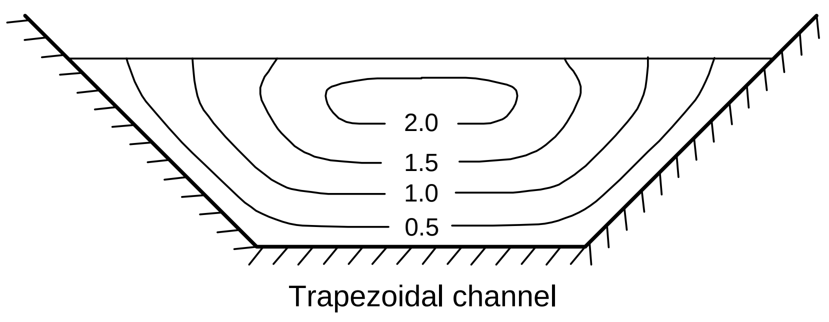
Q = the discharge or hydraulic capacity of the channel (m^3/s)
A = cross sectional area (m^2)
V = average velocity in (m/s)

8.12 The Manning Formula

The mean flow velocity in a channel can be calculated using the Manning Formula. The formula is applicable to steady uniform flow, which for design purposes assumes that flow is constant and uniform. Flow in channels can be described as critical, subcritical or supercritical. For definitions of these terms refer to the section on Froude number in this chapter.

Although it is assumed that the mean velocity is constant at each cross-section, there is variation in actual velocities at each cross-section. Frictional losses occur where the runoff comes in contact with the walls and the base of the channel. The greater the degree of roughness in the channel, the greater the amount of friction, which results in reduced velocities. Figure 8.1 shows an example of such variations in velocity.

Figure 8.1 Variation in flow velocities across a trapezoidal cross-section



The Manning Formula is expressed as follows:

$$V = \frac{R^{0.66} S^{0.5}}{n} \qquad \text{.......... Equation 8.2}$$

Where

V = mean velocity of flow (m/s)
n = Manning coefficient of roughness
S = channel slope (m/m)
R = hydraulic radius (m)

The hydraulic radius (R) is dependent on the cross-sectional area of flow and the wetted perimeter and is expressed by the formula:

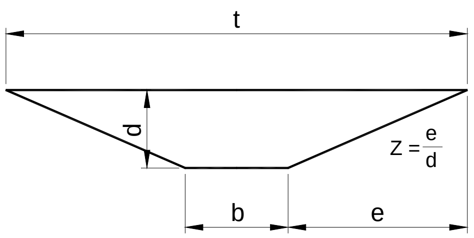
$$R = \frac{A}{P} \qquad \text{.......... Equation 8.3}$$

Where

A = the cross sectional area of flow (m^2)
P = the wetted perimeter ie. the length of the line of contact between the water and the channel boundary (m).

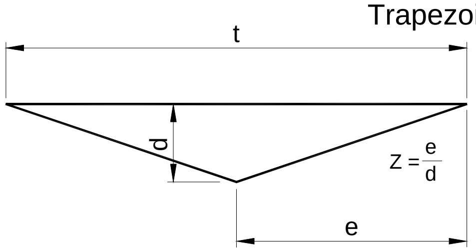
Figure 8.2 provides formulae relating to the hydraulic radius and wetted perimeter for trapezoidal, triangular and parabolic cross sections.

Figure 8.2 Formulae for dimensions relating to trapezoidal, triangular and parabolic cross-sections



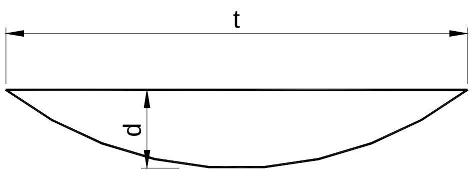
Cross - Sectional Area a	Wetted Perimeter	Hydraulic Radius R
$bd + Zd^2$	$b + 2d\sqrt{Z^2+1}$	$\frac{bd + Zd^2}{b + 2d\sqrt{Z^2+1}}$

Trapezoidal cross section



Zd^2	$2d\sqrt{Z^2+1}$	$\frac{Zd}{2\sqrt{Z^2+1}}$

Triangular cross section



$0.66td$	$t + \frac{8d^2}{3t}$	$\frac{t^2 d}{1.5t^2 + 4d^2}$

Parabolic cross section

8.121 The Manning roughness coefficient, n

The Mannings coefficient (*n*) is dependant on the roughness characteristics of the channel boundary surface. The characteristics relevant to the design of soil conservation structures include:

- the surface roughness or texture of the channel boundaries
- the presence and composition of vegetation – this effect can be complex and variable eg. grasses will offer significant resistance at low discharge but less resistance under high flows (see n-VR relationships below)
- discharge (or flow) depth – the value of *n* is likely to be high at shallow depths when much of the boundary to the flow consists of the coarse material of the channel bed
- the presence of bends, irregularities and obstructions.

Representative values of *n* are given in Table 8.1 for a range of conditions.

Table 8.1 Values of Mannings *n* coefficient of roughness

Channel/stream condition	Mannings *n*
Earth channels subject to intermittent flow and with vegetal lining	The n/VR relationship applies Refer to text in this chapter
Contour bank channels	
Smooth and bare	0.02-0.03
Roughly cultivated	0.04
Sparse grass cover	0.05
Wheat crop or standing wheat stubble	0.07-0.15
Sorghum (25 cm rows)	0.04-0.12
Lined Channels excavated in rock	
Smooth and uniform rock	0.025-0.040
Jagged and irregular rock	0.035-0.050
Concrete – smooth forms or trowelled	0.012
Small natural streams	
Straight, uniform and clean	0.025-0.033
Clean, winding, with some pools and shoals	0.033-0.045
Sluggish weedy reaches with deep pools	0.050-0.080
Very weedy reaches with deep pools	0.075-0.150

Source: Pilgrim (1987), Queensland Main Roads Department (1979), Ree (1954)

Estimates of the coefficient for a range of stream types are provided in the Appendix. These estimates were developed using a method described by Chow 1959.

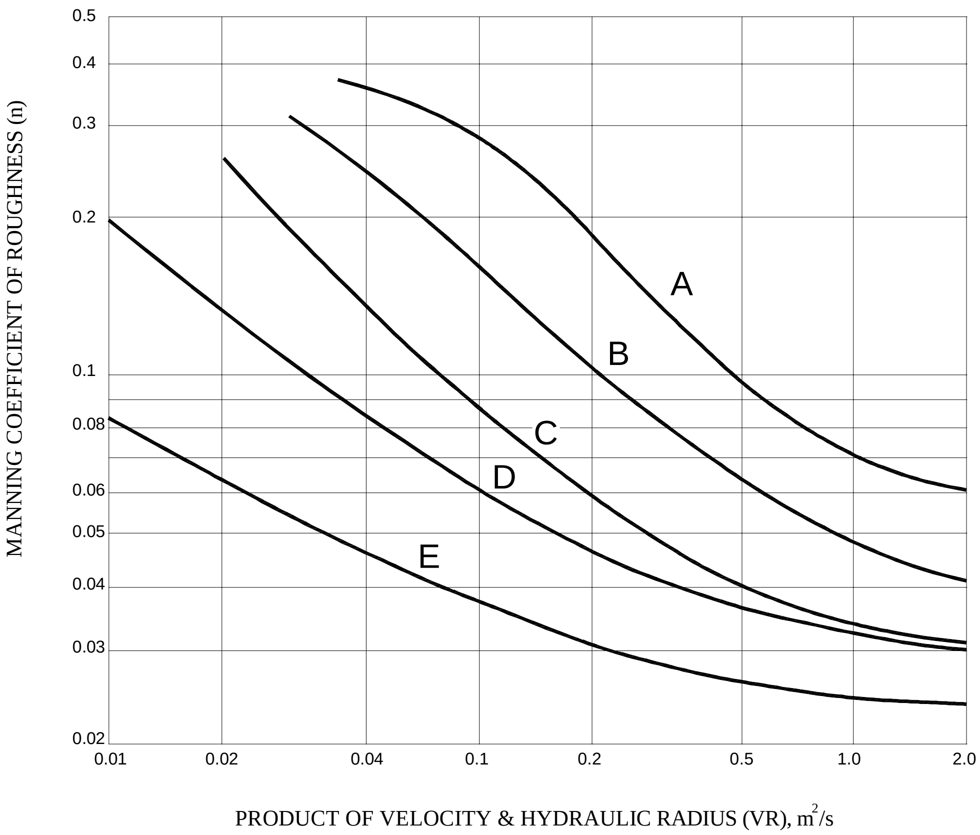
8.122 The n-VR relationship in channels lined with vegetation

Waterways used in soil conservation layouts usually depend on a well established vegetal cover for long-term stability. The nature of this cover can change significantly depending on the seasonal conditions and management practices. The Mannings ‘*n*’ factor in such waterways is greatly affected by the composition and depth of the vegetation, when the flow completely or nearly submerges the vegetation. Under the influence of velocity and depth of flow, vegetation tends to bend and oscillate continuously. Such conditions have an effect on the retarding of flows and the retardance varies as the velocity and depth of flow, changes. Ree (1954) points out that there is a common misconception that flowing water causes vegetation to bend over completely to shingle the bed and to form a protective shield. Observations through vertical glass walls in experimental channels lined with a range of vegetation species revealed that vegetation waved and moved back and forth during a flow.

The n-VR relationship refers to the fact that *n* varies with the product of velocity and hydraulic radius (VR). The design of vegetation-lined channels requires that *n* be compatible with the value of

VR. To aid in design, general n-VR curves for five degrees of vegetal retardance (A to E) have been developed (Figure 8.3). Figure 8.3 also includes the equations for the curves associated with each retardance. By using these equations, it is possible to apply the Manning formula by considering Mannings *n* to be a function of V and R for a specific retardance.

Figure 8.3 Graphical solution for five degrees of vegetal retardance for the Manning formula



Curve A $n = 0.440 - 1.674\,VR \quad VR < 0.1542$
$n = 0.046 + 0.0223/VR \quad VR > 0.1542$
Ref. Green, J.E.P. & Garton, J.E. (1983)

Curve B $n = 0.032 + 0.01545/(VR)^{7/8}$

Curve C $n = 0.030 + 0.00501/VR$

Curve D $n = 0.027 + 0.00534/(VR)^{3/4}$

Curve E $n = 0.022 + 0.003014/(VR)^{2/3}$

Ref. Findlay, G.H. & Ellul, G.A. (1976)

The n-VR curves together with other charts, can be used to provide graphical solutions of the Manning Formula. The graphical solution of the Manning Formula for vegetal retardances C is shown in Figure 8.4 (adapted from Ree 1954). Graphical solutions for all retardances are provided in the Appendix. Table 8.2 provides a guide to the selection of vegetal retardance.

Figure 8.4 Graphical solution to the Manning Formula for Retardance C

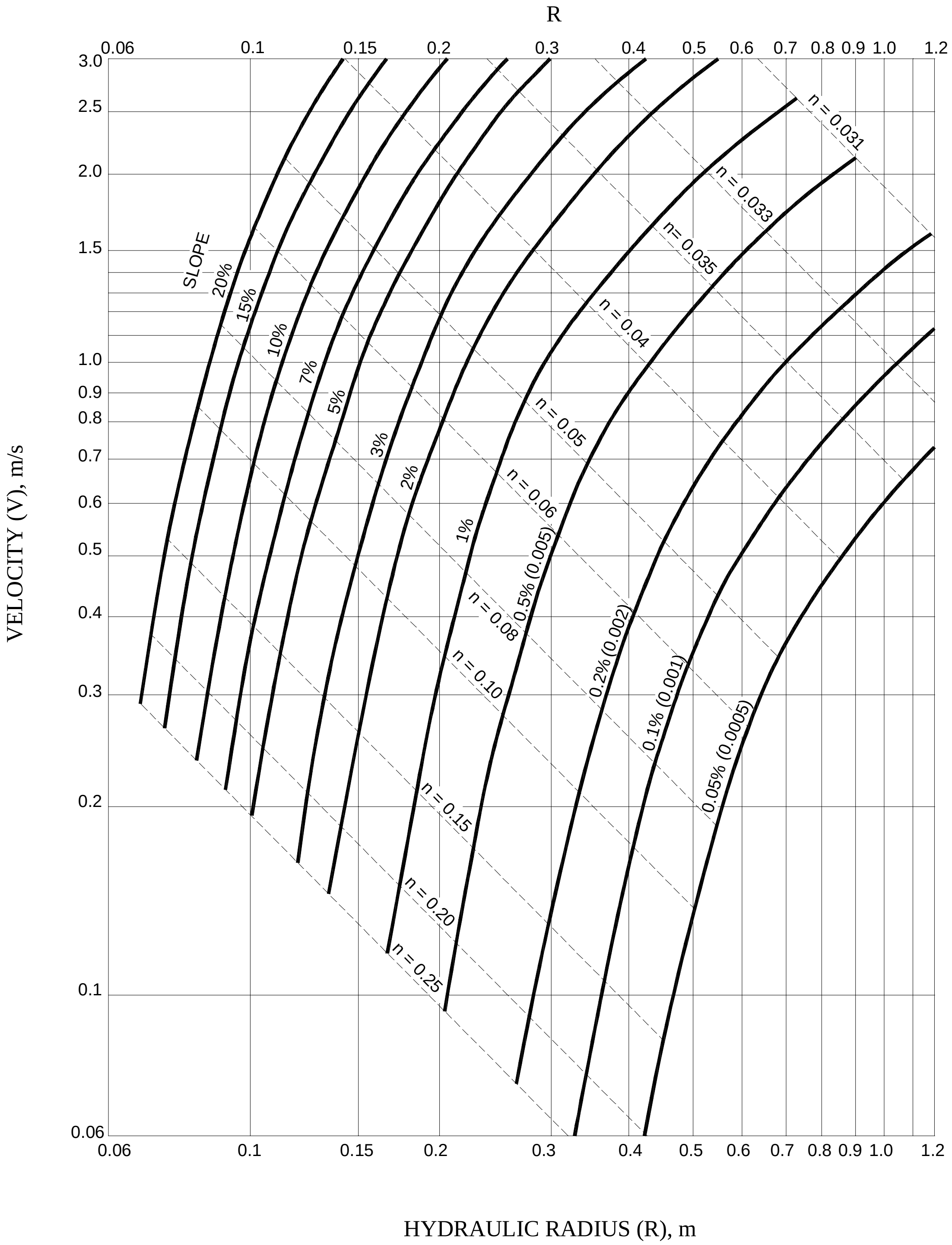


Table 8.2 Guide to selection of vegetal retardance

Average height of vegetation	Degree of retardance based on quality of vegetation	
	Good	Fair
Longer than 75 cm	A	B
30 cm to 60 cm	B	C
15 cm to 25 cm	C	D
5 cm to 15 cm	D	D
Less than 5 cm	E	E

Note that use of the A–E retardance charts apply to runoff flows with vegetation completely submerged or nearly so. For shallow flows through upright vegetation with no submergence, Mannings *n* ceases to be related to VR (Ree 1954) and the Manning formula can be solved with an appropriate selected value for *n* (Table 8.1).

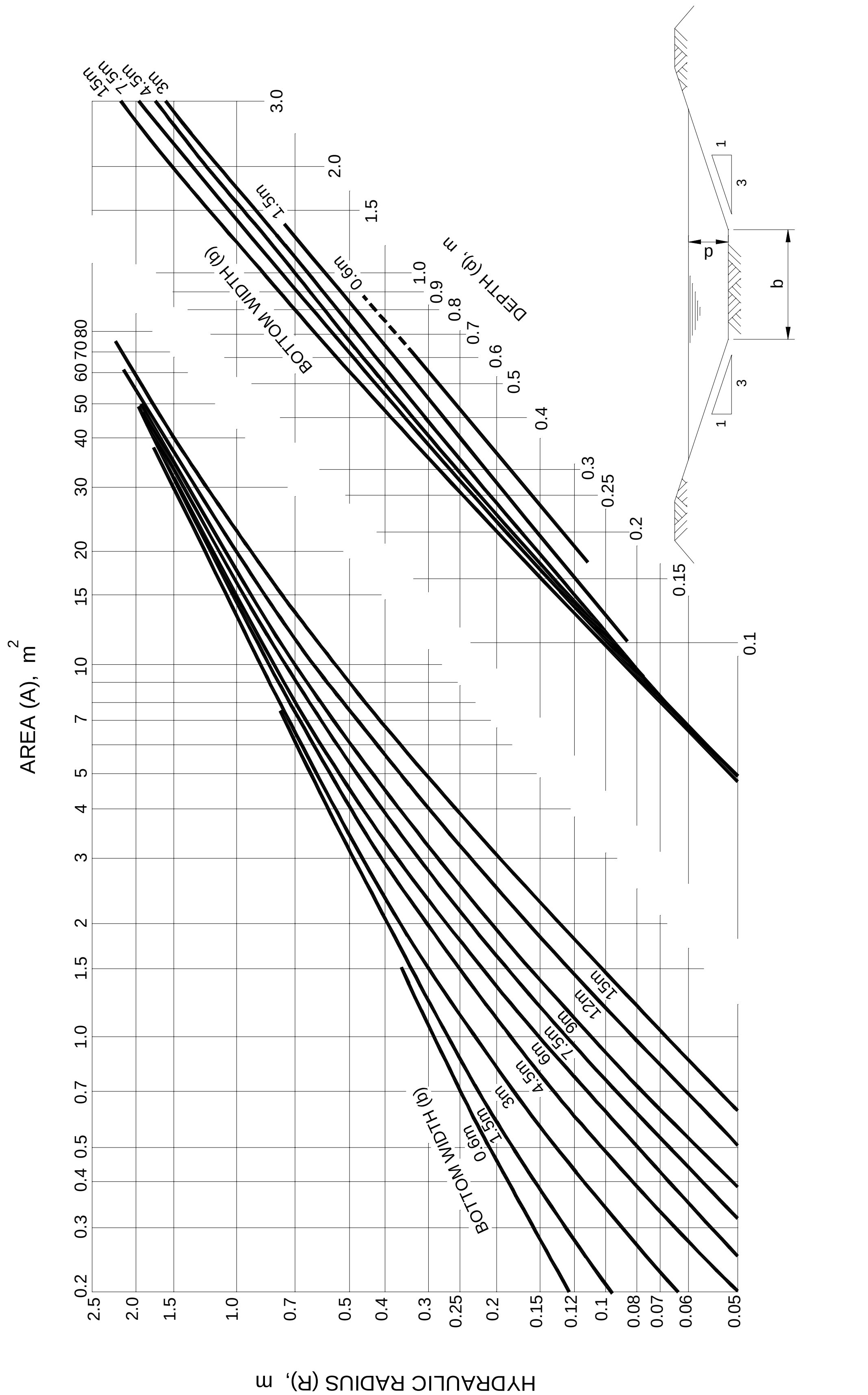
8.123 Hydraulic radius

For a given cross-sectional area, the shorter the wetted perimeter the greater will be the hydraulic radius and the greater the resulting velocity in the channel. The channel cross-section with the maximum hydraulic radius would be a semi circle. For a trapezoidal channel, the maximum hydraulic radius (and highest velocities) would result for a channel that most closely approximates a semi circle.

For triangular cross-sections, the hydraulic radius is approximately equal to half the depth. For waterways of width greater than 20 metres it is safe to assume that the depth of flow is equal to the hydraulic radius. For example, a trapezoidal waterway with 1:3 (V:H) side batters and a bottom width of 20 metres will have an hydraulic radius of 0.29 when carrying a depth of flow of 0.3 metres. This assumption can greatly simplify the task of designing wide waterways.

Charts showing dimensions for various shaped channels are included in the Appendix. An example of such a chart is shown in Figure 8.5 (Adapted from Ree 1954). For a trapezoidal channel with different inlet and outlet batters, it is possible to calculate the average batter dimension and then use the appropriate chart.

Figure 8.5 Dimensions of trapezoidal channels with 1:3 (V:H) side channels



8.2 Stability of channels

Earth channels, either bare or lined with vegetation, should carry the design discharge at non-erosive velocities. The following chapters on contour banks, diversion banks and waterways provide specific information on recommended velocities to ensure stability.

8.21 The Froude Number

The Froude Number (Fr) characterises the conditions in flowing water in terms of its velocity and depth. An understanding of critical flow conditions and the appreciation of Froude Numbers can assist in the design of channels, so that erosive damage to the channel does not occur.

The Froude Number provides a means for determining whether a given flow is subcritical, critical or supercritical. These terms are defined as follows:

- Critical flow is flow in which the Froude Number is equal to unity (Fr = 1) and surface disturbances (eg. the ripples caused when a rock is thrown into a stream) will not travel upstream
- Subcritical flow is flow in which the Froude Number is less than unity (Fr <1). For subcritical flow the depth tends to be relatively large and the velocity relatively low (ripples travel upstream)
- Supercritical flow is flow in which the Froude Number is greater than unity (Fr >1). For supercritical flow the depth tends to be relatively small and the velocity relatively high (all ripples resulting from a disturbance are downstream).

For safe design of vegetated channels, the Froude Number of the design flow should be between 0.8 and unity depending on the degree of erosion resistance provided by the vegetation. Where values exceed unity it would be necessary to ensure that the channel lining had a very high degree of erosion resistance.

The Froude Number is a dimensionless parameter expressing the ratio between the inertia and gravitational forces in a liquid and defined (in general) by the expression:

$$\mathbf{Fr = (\alpha Q^2 B / gA^3)^{0.5}} \qquad \text{Equation 8.4}$$

Where

Fr	=	Froude Number
Q	=	the discharge (m^3/s)
α	=	velocity head coefficient (commonly assumed as unity)
B	=	the surface width of flow (m)
A	=	the cross-sectional area (m^2)
g	=	the gravitational acceleration (9.8 m/s^2)

For the particular case of a channel of rectangular cross section, Equation 8.4 reduces to:

$$\mathbf{Fr = \frac{V}{(gd)^{0.5}}} \qquad \text{Equation 8.5}$$

Where

Fr	=	Froude Number
V	=	the mean flow velocity (m/s)
d	=	the flow depth (m)
g	=	gravitational acceleration (9.8 m/s^2)

For a trapezoidal channel, Equation 8.5 becomes

$$Fr = \left[\frac{V^2 (b + 2Zy)}{g \; y(b + Zy)} \right]^{0.5} \qquad \text{Equation 8.6}$$

Where

Fr	=	Froude Number
V	=	the mean flow velocity (m/s)
b	=	bottom width (m)
Z	=	side slope ratio (1 vertical : Z horizontal)
g	=	gravitational acceleration (9.8 m/s^2)
y	=	the flow depth (m)

8.22 Stream Power

Whether erosion or deposition occurs in a channel depends on the relativity between soil strength and discharge and the stream power or shear stress exerted by that discharge (Loch and Thomas 1987). More information on stream power is provided in the section on design velocity in Chapter 9, *Contour banks*.

Stream power is defined as the product of the shear stress exerted by the flow and average channel velocity and is expressed in the following formula:

w = TV .... Equation 8.7

Where

w	=	stream power in W/m^2 (Watts per square metre)
T	=	shear stress in Pa or N/m^2 (Pascals or Newtons per square metre)
V	=	average channel velocity in m/s

Shear stress is calculated from the formula:

T = ρ gRS .... Equation 8.8

Where

T	=	shear stress in Pa or N/m^2
ρ	=	density of the fluid, kg/m^3
g	=	gravitational acceleration, 9.8 m/s^2
R	=	channel hydraulic radius m
S	=	channel slope, m/m

8.3 General design approach

When carrying out a design for a soil conservation structure, it is useful to combine equations 8.1 and 8.2 as follows:

$$\frac{Q}{A} = V = \frac{R^{0.66}\,S^{0.5}}{n} \qquad \text{Equation 8.9}$$

Where

Q = the discharge or hydraulic capacity of the channel (m^3/s)
A = cross sectional area (m^2)
V = average velocity (m/s)
R = hydraulic radius (m)
S = channel slope (m/m)
n = Manning coefficient of roughness.

In a design exercise the following factors in the above equation would normally be known:

- discharge Q
- velocity V – it is normal to design for a selected velocity
- the channel slope S would be known in the case of a waterway design; however in the design of a contour or diversion bank it is a variable and different channel slopes (gradients) can be compared
- the Manning coefficient of roughness *n* would be selected as a fixed value (Table 8.1) or as a retardance value (Table 8.2) where n/VR relationships apply.

The design may however have other constraints. Examples are as follows:

- conditions in the channel are subject to considerable variation depending on seasonal and management conditions
- the top width for a waterway may be a limiting factor because a waterway needs to fit into a confined location
- the length of a contour bank batter may be set by the planting machinery used by a farmer.

By incorporating the known values of Q, V, S and *n* into the above equation it is possible to determine values for the cross-sectional area A, and the hydraulic radius R. This is a straightforward exercise if the value of Mannings *n* is constant but in the case where *n* varies with the product of V and R an iterative process is required to solve the equation. The value of *n* will also vary with seasonal and management conditions eg. a waterway can have abundant growth in a good season or be virtually bare during a drought. A contour bank channel may vary from a ploughed condition to an advanced crop or stubble depending on the cropping cycle. Examples of how this is taken into account are provided in Chapter 9, *Contour banks* and Chapter 11, *Waterways.*

The exercise then becomes a geometrical one in which it is necessary to determine which dimensions of the selected cross-section will give the required values for R and A. Charts similar to that in Figure 8.5 can be used for this purpose. Alternatively another iterative process is required to obtain the correct dimensions.

The computer program RAMWADE provides assistance in determining appropriate dimensions for soil conservation structures.

8.4 Freeboard and settlement

Freeboard and settlement should also be allowed for in the design. Freeboard is included to prevent overtopping due to surcharge or wave action. It also accounts for some irregularities in construction. Depending on factors such as operator skill, machinery used and soil properties at the time of construction, there will always be some irregularities in the height of a structure over its entire length. For most soil conservation structures with flow depths of 20–75 cm, a freeboard of 10–15 cm should be adequate.

An allowance should also be made for settlement of banks following initial construction. The amount of settlement depends on how well the structure was compacted during construction, and on soil type and soil moisture conditions at the time of construction. The degree of compaction is also related to the type of machinery used. Table 8.3 provides estimates of the amount of settlement likely to occur.

Table 8.3 Estimated settlement rates for bank construction

Construction equipment	Soil characteristics	
	Swelling clays e.g. black, cracking clays	Light textured soils
Bulldozer	50%	30%
Grader	30%	20%

Equation 8.10 can be used to calculate the constructed height of a bank (Hc) from the settled height (Hs) and the expected amount of settlement (y).

$$Hc = \frac{H_s}{1 - \frac{y}{100}} \quad \text{.......Equation 8.10}$$

Where

Hc = Constructed bank height

Hs = Settled bank height

y = % settlement

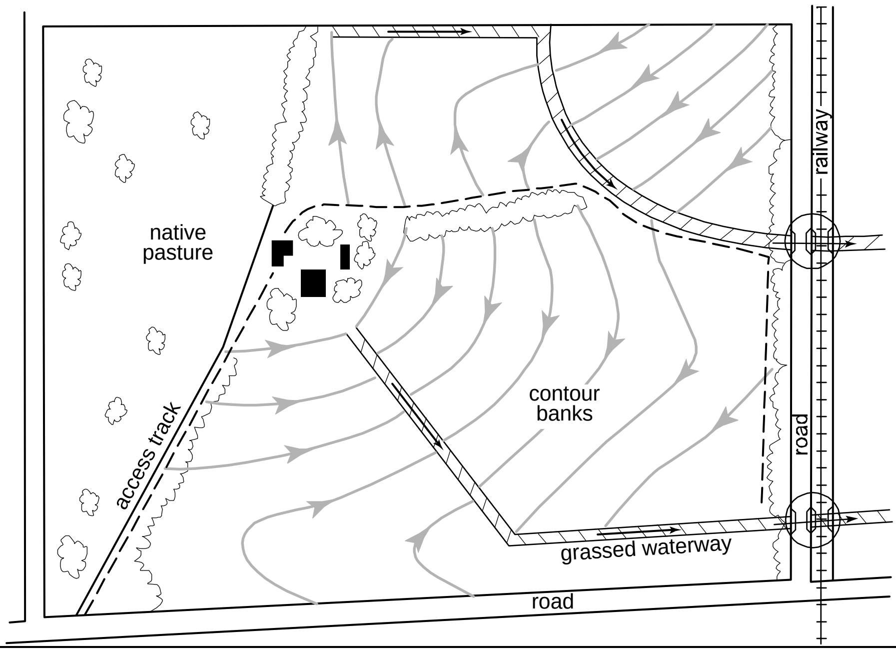
■

Chapter 9

Contour banks

Contour banks are earthen structures constructed across cultivated slopes, at intervals down the slope. In some countries and other Australian states contour banks are referred to as 'graded banks', 'terraces' or 'bunds'. They intercept run-off and safely channel it into stable grassed waterways, natural depressions or grassed areas adjacent to a paddock. Their function is to reduce slope length and to intercept runoff before it concentrates into an erosive force. They also trap much of the sediment from overland flow especially from rills and old gully lines. Any crop or stubble in a contour bank channel acts as a filter as runoff moves slowly along the contour bank channel.

Figure 9.1 Plan of a contour bank and waterway layout



Contour bank layouts require careful planning to ensure the satisfactory coordination of runoff between properties within a catchment and across public utilities such as roads and railway lines (Figure 9.1). More information on this topic is provided in Chapter 2, *Soil conservation planning.*

Contour banks are not strictly 'on the contour'. They have a low gradient (usually 0.1–0.4%) to minimise the chance of channel flow reaching erosive velocities when the channel is in a bare condition. In some intensive farming situations (eg. horticulture or sugar cane) where pondage must be avoided or where parallel layouts are required, steeper gradients are used for limited distances. If permanent cover is maintained in the channel, much steeper gradients can be utilised. The spacing of contour banks depends mainly on the slope of the land but is also influenced by soil type, cropping practices and previous erosion.

Theoretically, contour banks are usually designed to carry water resulting from a runoff event with a 10 year average recurrence interval. However, the ability of a contour bank to carry the estimated design runoff is very much dependent on the condition of the channel at the time the runoff event occurs. A contour bank with a smooth, bare channel can carry around five times more runoff than one with the channel covered with a close growing crop or dense stubble.

Crop management practices that maintain adequate levels of surface cover will greatly reduce the amount of erosion between contour banks. This will enhance the effectiveness of contour banks and greatly reduce their maintenance costs.

Contour banks play an important role in acting as sediment traps. Up to 80% of the soil moved from a contour bay may be deposited in the contour bank channel (Freebairn and Wockner 1986). Maximum rates of deposition and filtration of nutrients and pesticides are likely to occur when the channel contains a close growing crop or standing stubble.

In intensive cropping areas, as used for the production of horticulture crops or sugar cane, contour banks are usually constructed parallel to each other to facilitate inter-row cultivation, pesticide application, irrigation and harvesting practices. However contour bank layouts in extensive cropping areas are usually not parallel. The long contour banks in such systems provide limited opportunities for parallel layouts because of the irregular nature of the topography.

The introduction of controlled traffic farming has a number of implications for contour bank systems. These are discussed further in the Chapter 13, *Controlled traffic*.

Soils with dispersible subsoils at depths of less than 30 cm are limited in their suitability for bank construction and require special construction techniques. If the subsoils are exposed in the channel, the contour bank will be prone to failure by tunnel erosion.

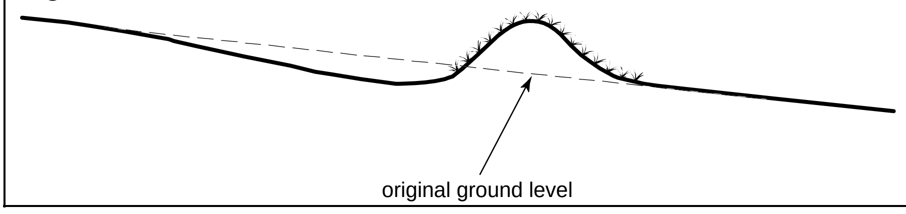
9.1 Contour bank types

The following types of contour bank cross-sections are used:

- narrow-based
- broad-based
- broad-based top side
- broad-based bottom side.

Narrow-based contour banks (Figure 9.2) have batters that are too steep to cultivate. They are normally planted to grass and require weed control especially during the first two years. The channels are usually treated as part of the contour bay, which means that they are cultivated and planted to crop. However some farmers choose to leave the channels grassed. Narrow-based banks may take up to 10% of total cultivated area.

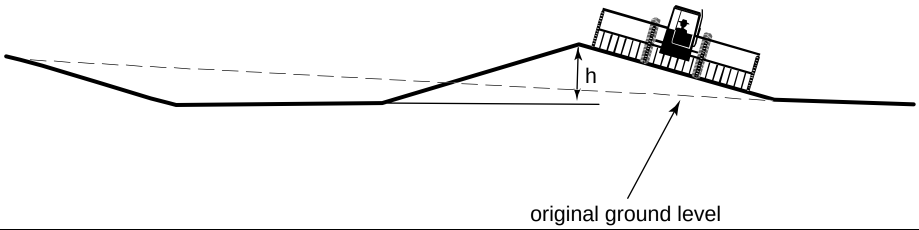
Figure 9.2 Narrow-based contour bank



They are commonly used on steeper cultivated slopes of 5–12% or on land that is only occasionally cultivated. They are not suited to cracking clay soils as they may fail following cracking in dry seasons. They are also susceptible to failures resulting from burrowing animals.

Broad-based contour banks (Figure 9.3) are built with batters that can easily be worked with tillage and planting machinery. They allow for the whole of the paddock to be cropped including the channel. Broad-based banks are generally used on deep soils and lower sloping land. They can be crossed at various angles by farming equipment under a controlled traffic system depending on the slopes of their batters.

Figure 9.3 Broad-based contour bank



Because the batters are cultivated, the risk of failure by cracking is reduced.

Broad-based banks are more costly to build and maintain than narrow-based banks and become impractical to construct as slopes exceed 5%. On steeper slopes on cracking clay soils, *semi-broad-based banks* may be implemented where the up-slope batter of the bank is broadened to suit the width of the most commonly used machinery. Such banks may have a broad base either on the top-side (Figure 9.4) or the bottom side (Figure 9.5).

Figure 9.4 Broad-based top side contour bank

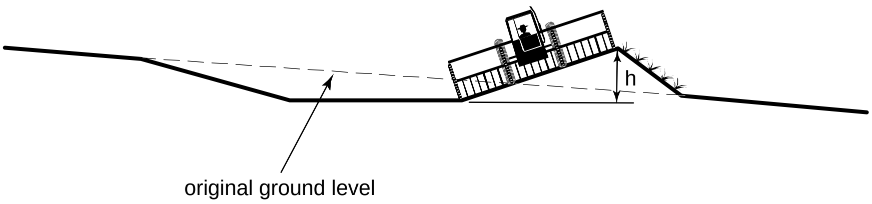
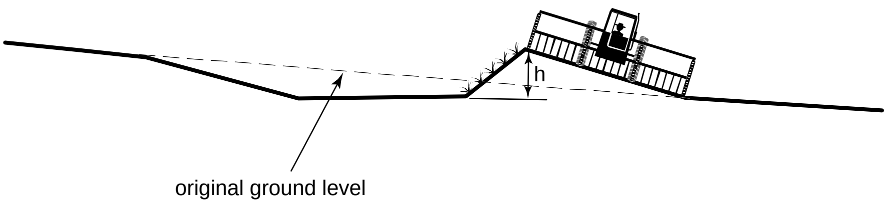


Figure 9.5 Broad-based bottom side contour bank



9.2 Design criteria

Contour banks are normally not individually designed. It is usual to develop specifications for particular situations in a district based on the following parameters:

- gradient
- length
- spacing
- cross-section and depth of flow.

Contour banks are subject to considerable variation in their capacity over time. Settlement will occur after construction. Banks may be worn down by tillage equipment. Sedimentation in the channel will also reduce capacity. Since maintenance of contour banks would normally be carried out on a 5–10 year cycle, it is desirable to carry out construction work so that banks are built or maintained to an above standard specification and then to maintain them once they are below specification.

The dimensions of a newly constructed contour bank are often governed by the construction technique rather than prescribed specifications. For example, contour banks may be constructed with one push of a large bulldozer, creating a structure that greatly exceeds the standard specifications.

9.21 Design velocity

Low velocities are desirable in a contour bank channel to avoid the chance of erosion in the channel and to ensure maximum deposition or trapping of sediment. Low velocities also reduce design peak discharges in waterways by lengthening the time of concentration.

The velocity of flow in a contour bank channel is very much dependent on the condition of the channel at the time that a runoff event occurs. If the channel is in a smooth and bare condition (Mannings *n* of 0.03) the bank will have maximum potential to discharge runoff. High velocities will occur if there is a significant depth of flow in a major runoff event. The aim of the design should be to keep velocities below 0.4 m/s for easily eroded soils and 0.6 m/s for erosion resistant soils.

However, if channel flow is restricted by a cereal crop such as wheat or standing stubble after harvest (where Mannings *n* may be 0.15) velocities are not likely to exceed 0.2 m/s. Contour banks must have sufficient capacity to accommodate the design event at these velocities.

In controlled traffic situations, crop direction may sometimes be at right angles to the direction of flow in the channel. Under these circumstances, Mannings *n* values could be expected to be greater than 0.15. Research is required to determine what Mannings *n* values are likely to occur under these circumstances.

The variable conditions that occur in a contour bank channel create some complexities in terms of the design. If a contour bank with a bare channel is flowing to capacity, it is likely to be handling an event much greater than that for which it was designed and erosive velocities will occur. This situation must be deliberately risked, as the only alternative is to build a smaller bank or to reduce the gradient. This would lead to regular failure if runoff events occur when the channel is restricted by crop or stubble.

If a design indicates that contour bank velocities will be too high, then the following options should be considered:

- use an alternative channel shape. The use of a flat-bottomed trapezoidal shape will convey flows more safely than a triangular cross-section.
- keep the channel permanently grassed
- use a lower gradient.

The stream power formula (Equation 8.7) may be used to determine the likelihood of erosion occurring in the channel. Table 9.1 provides values of stream power for a typical broad-based contour bank with a trapezoidal shape, a gradient of 0.2% and a Mannings *n* of 0.03 (bare soil). For cracking clay soils it is recommended that values of stream power be below 3 (W/m^2) (Titmarsh and

Loch 1993). (Values for other soils are not available.) The table indicates that this value will be exceeded for depths of flow of 0.4 metres or greater.

Table 9.1 Stream power values for a typical broad-based contour bank under bare soil conditions

Depth of flow (m)	Velocity (m/s)	Discharge (m^3/s)	Stream Power (W/m^2)
0.2	0.4	0.5	1.3
0.3	0.5	1.1	2.3
0.4	0.6	1.8	3.4
0.5	0.7	2.9	4.7
0.6	0.79	4.2	6.0
0.7	0.87	5.8	7.4

Based on the following parameters:
- Trapezoidal shape
- Gradient of 0.2%
- Mannings *n* of 0.3

9.22 Gradients

Contour bank gradients should be chosen to minimise the risk of erosion in the channel when it is in a bare condition but also ensure that the channel has adequate capacity to carry the design runoff when flow in the channel is restricted by crop or standing stubble. Such a compromise can be difficult to achieve in practice because of the five-fold differences that can apply in the values of Mannings *n* (0.03 to 0.15) for these two situations.

High gradients may lead to:
- erosion in the contour bank channel
- high runoff rates in waterways.

Low gradients may lead to:
- poor drainage—an important issue especially for many horticultural crops
- more low points in the bank that will pond runoff until they are filled with sediment
- ‘leakage’ into groundwater systems in locations where this is an issue
- failure by ‘piping’ (linked to tunnel erosion) where there are dispersible subsoils.

The impact of gradient on contour bank velocity and discharge is illustrated in Figures 9.6 and 9.7 respectively.

Figure 9.6 Effect of gradient on contour bank velocity for two flow depths

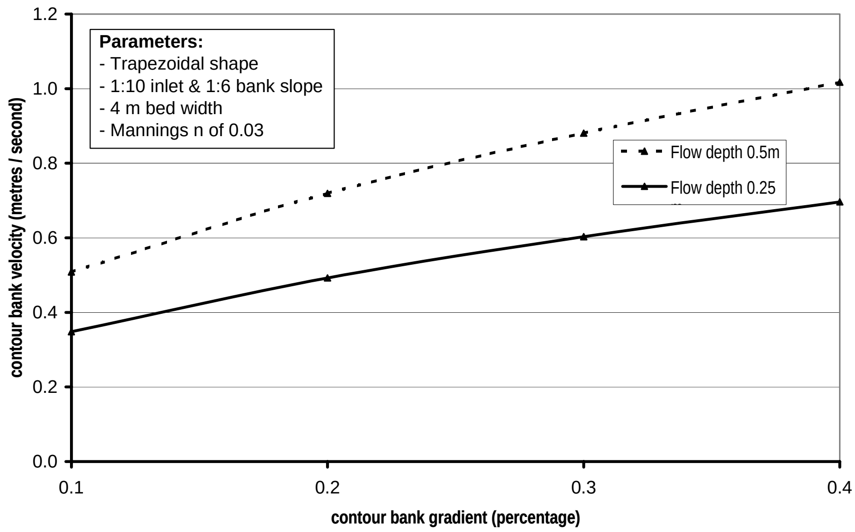
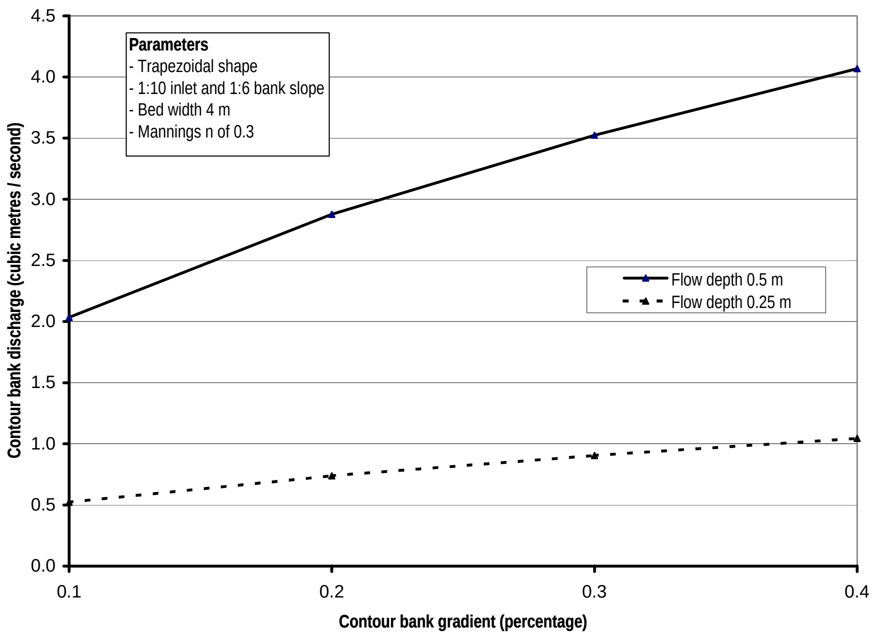


Figure 9.7 Effect of gradient on contour bank discharge for two flow depths



Recommended contour bank gradients are dependent on the steepness of the land and soil erodibility. The capacity of a contour bank of a given height depends on the land slope. The lower the land slope the greater the storage capacity of the bank. There is also a relationship between land slope and bank length. The steeper the landscape, the closer the distance between natural drainage lines. This means that average contour bank lengths on steep slopes are likely to be much shorter than the average bank lengths for low slopes.

Taking the above factors into account, there are good reasons for increasing contour bank gradients as land slope increases. Steeper gradients on higher slopes will compensate for the limited capacity of contour banks on such slopes. However shorter contour banks on steeper slopes means that they are required to handle less runoff than longer banks—and so there is less likelihood of erosion occurring in the channel.

In horticultural situations, higher gradients can be used where the channel is grassed or where it is bare but not cultivated. If contour banks are used for access and are not cultivated, the risk of erosion in the channel is greatly reduced.

In cane lands gradients as high as 4 % are used where green cane trash blanketing is used on erosion resistant soils eg. krasnozems. Contour bank channels in cane lands are only vulnerable to erosion for a relatively short period when a new crop is planted after the removal of the ratoon crop (every 4 to 8 years). The use of minimum tillage practices or a cover crop can reduce the risk of erosion during the fallow period. Further reference to gradients in cane lands is included in the section *Parallel layouts.*

It is normal practice for a contour bank to be constructed to the same capacity for its entire length. Since the amount of runoff to be carried increases with the length of the contour bank, *variable gradients* can be used along a contour bank channel. This will lengthen the time of concentration and reduce the peak discharge in the waterway.

In contour banks on low land slopes where the maximum gradients are less than 0.2%, there is limited opportunity to use variable gradients. However on steeper land slopes where the maximum gradient is higher, variable gradients as indicated in Table 9.2 can be used eg. for a land slope of 3% to 5%, the gradient in the top 33% of the bank would be 0.2%, changing to 0.25% in the middle 33% followed by 0.3% in the lower (outlet) 33% section of the bank.

Table 9.2 Gradients for contour banks with cultivated channels based on land slope

Land slope	Appropriate contour bank gradients (%) for average conditions		
	Top section	Middle section	Outlet section
1%	0.1	0.1	0.1
2%	0.1	0.15	0.2
3%–5%	0.2	0.25	0.3
5%–10%	0.3	0.4	0.5

In intensive cropping areas, parallel contour bank systems are often implemented. The implementation of such a system requires some flexibility in contour bank gradients but gradients should be managed to ensure that erosion in the channel is minimised (refer to the section on parallel layouts in this chapter).

Gradients can be modified over short distances to improve workability of the layout. At the high end of a contour bank, it is quite acceptable to improve workability by using a high or low gradient to ensure that the bank meets a fence line at close to a right angle rather than an acute angle.

It is normal practice to 'split' contour banks on well-defined ridgelines so that they direct runoff away from the ridge. This ensures that runoff remains in its natural catchment and also provides an ideal position for a road or track to cross over contour banks. The exact location of the 'split' should be prominently marked during the surveying process so that the farmer is aware of its location and the significance of this position. The splits on a ridge should be aligned. This may require a readjustment of some levels at the completion of the surveying task to obtain the best alignment.

It should be noted that if contour banks carry runoff across ridge lines that have low slopes or even a saddle, this may result in considerable variation in the contour bank spacing (referred to as the 'flat ridge syndrome'). This problem can be minimised by modifying the gradient where the bank crosses the ridge. Some zero grade sections in this situation would be acceptable as the low slope ensures maximum contour bank capacity and the convex nature of the topography ensures that there is less likelihood of concentrated flows discharging into this section of the contour bank.

Where contour banks cross 'sharp' depressions resulting in a sharp bend in the bank, the gradient can be modified to smooth out the shape of the bank to improve workability. However this will create a low point in the contour bank, which will detain runoff until sufficient sedimentation occurs to remove the pond. If this procedure is adopted, it is essential that the contour bank be given additional capacity where it crosses the drainage line and that such points are checked after construction to ensure they have adequate capacity.

Increased gradients should be considered in situations where contour banks are to be built in land with serious rilling and gullying. However an alternative consideration in such situations is to ensure that the contour bank has additional height where it crosses gully lines, bearing in mind that greater settlement of the bank is likely to occur at these points. The provision of additional height should obviate the need for increased gradient. Ideally, gullies will have been filled in during the construction process. However some form of a depression is likely to remain. This depression will be subject to sedimentation and will disappear over time. Levelling of the land between contour banks (the contour bay) is encouraged to remove the presence of old rill and gully lines. If levelling is not carried out, the rill will continue to concentrate runoff from the adjacent area leading to silt deposition where it meets the contour bank channel.

There is a case for using higher gradients for contour bays where zero tillage is adopted or where contour bank channels are not cultivated. As previously discussed, the highest velocity likely to be achieved in a standard size broad-based contour bank with a wheat crop or standing wheat stubble is 0.2 m/s. The risk associated with this approach is that it is possible that the property could change ownership and the new owner may adopt traditional cropping practices with lower levels of stubble. The preferred option therefore would be to use gradients applicable to a farming system that will have both bare and vegetated channels at different times.

From an hydraulic aspect, level (zero gradient) contour banks, especially on low slopes, could accommodate the runoff they receive, provided they were built to an adequate specification. However they are not recommended because such banks are subject to pondage at regular intervals along the bank. Such ponding can have an adverse effect on crop growth and restrict tillage, planting and harvesting activities.

9.221 Gradients at contour bank outlets

Problems can occur at the point where contour banks discharge into waterways. As well as the gradient in the bed of the contour bank channel, an important consideration is the gradient of the surface of the water in a channel (Stephens 1987). Two different situations may apply—where a bank discharges with a completely free outlet and where the outlet is obstructed in some way.

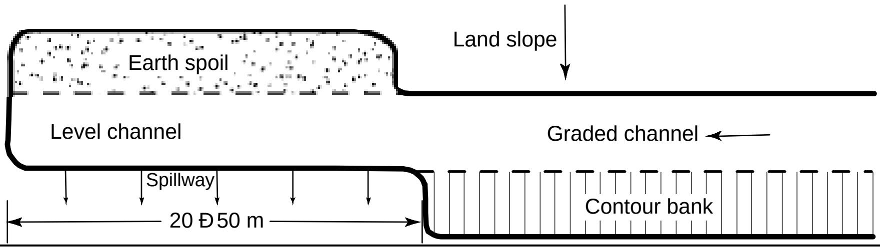
Examples of where a bank discharges with a completely free outlet include:

- a wide deep hollow
- an adjacent grass paddock
- a subsurface waterway
- an eroding waterway.

In the above cases the gradient of the water surface would be greater than that of the channel, and the velocity would increase. This can be the cause of erosion in bank outlets. In these situations there is no requirement for extra gradient at the bank outlet.

Where contour banks are discharging into a grassed area, it is advisable to construct a spreader channel (Figure 9.8) at the outlet to ensure that discharge occurs over a wide section of the bank. Spreader channels are level channels created by pushing soil uphill rather than downhill as with conventional contour banks. They are used to reduce the concentration of water discharging at the end of a diversion or contour bank into an area of pasture or a watercourse.

Figure 9.8 Plan view of a spreader channel at the outlet of a contour bank



A spreader channel would normally involve a level section for the last 20 to 50 metres of a contour bank. The section would have an excavated channel in which soil from the channel is pushed uphill. The use of a hedge incorporating a species such as Monto Vetiver grass along the spreading area would assist in ensuring that runoff exits the sill over the entire length of the spreading area.

Where there is an overfall at a bank outlet, some adjustment to contour bank spacings may be an option in order to find a more stable outlet for a contour bank. Normal gradients or even a level section should be used where there is an overfall. Such overfalls should be stabilised at the outlet by means of a structure such as a rock chute. Where there is instability at a contour bank outlet the last section of contour bank channel should be permanently grassed.

Examples of where the discharge is obstructed in some way include:

- where a bank outlet is too narrow or choked with grass or stubble
- where the bank discharges into a waterway that is flowing at a similar height to the water in the contour bank.

In the above cases the gradient of the water surface will be less than that of the channel bed and the velocity will decrease. This can be the cause of bank overflow near the outlet. Increased gradients will generally be required in these situations. The additional gradient should account for the estimated depth of excavation to construct the contour bank plus the design depth of flow above ground level in the waterway.

In low sloping situations it may not be possible to obtain sufficient additional fall at the bank outlet. In such situations bank height should be increased for at least the last 200 metres of the contour bank. As an additional measure, the contour bank may be constructed to discharge into a secondary waterway running adjacent to the main waterway for about half a contour bay interval.

9.23 Contour bank length

Farmers generally prefer contour banks to be as long as possible to maximise the length of run and to reduce the number of waterways required. However, as bank length increases, so does the risk of failure. The longest bank lengths are implemented on low sloping extensive cropping areas on the Western Downs and the Central Highlands.

On steeper landscapes, the distance between natural drainage lines decreases and normal contour bank lengths become shorter. Shorter contour banks are also associated with the more intensive cropping systems associated with the growing of sugar cane as well as horticulture.

Contour bank capacity is also related to land slope. A bank of a given height will have greater capacity on a low slope than it will on a steeper slope (refer to Figure 9.11 in the section on contour bank cross-sections). This enables the use of longer banks and lower gradients on low slopes.

The amount of runoff discharged from a contour bay will be proportional to the area of the bay. Figure 9.9 shows how the Empirical version of the Rational Method attempts to predict peak discharges for various contour bank lengths on a 2% slope with a 90 metre contour bank spacing at Pittsworth. The graph compares low and high cover farming systems. It shows significantly higher runoff rates under a bare fallow system due to the shorter time of concentration and the selection of a higher C value. However, a contour bank with bare soil in the channel will be able to accommodate considerably more runoff than a bank in which the channel is carrying a crop or standing stubble.

Figure 9.9 Peak discharge estimates based on contour bank length for Pittsworth

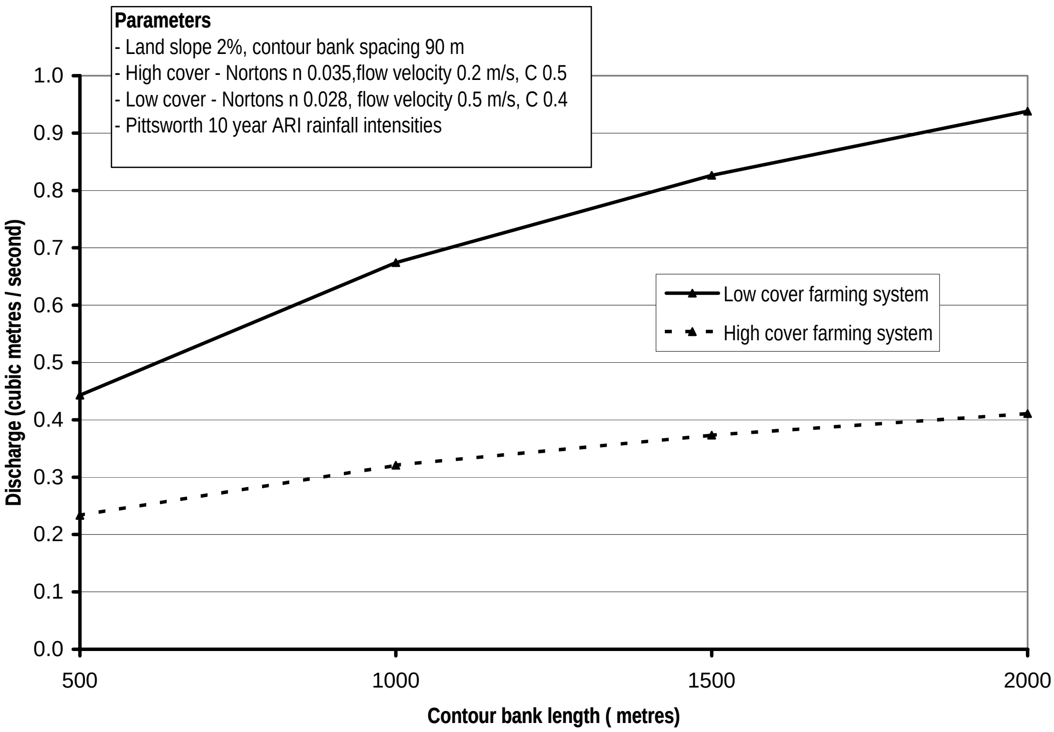


Table 9.3 provides a guide to recommended maximum bank lengths based on land slope. This table is based on contour bank capacities normally maintained by farmers on such slopes and the minimum contour bank spacings normally recommended on such slopes. It also assumes that the runoff is travelling in the one direction in the contour bank channel.

Table 9.3 Recommended maximum bank lengths for various land slopes

Land slope %	Recommended maximum bank length (metres)
1	2500
1.5	2000
2	1750
3	1500
4	1000
5	750
6	600
7	450
8	400
9	350
10	300

Based on the following parameters:
- Single spaced contour banks
- Use of cropping systems that provide high levels of cover
- High standard of contour bank maintenance

An alternative approach to the design of contour bank length using the KINCON model is provided in Connolly *et al*.1991. This program is not commercially available.

9.24 Bank spacing

Wide contour bank spacings facilitate the operation of farm machinery and reduce per hectare construction costs. However there are a number of factors that limit the spacing between contour banks:
- the increase in erosion for the wider spacings
- the tendency of overland flows to concentrate, forming gullies between the banks and building up deltas in the channel of the contour bank below
- the practical limit to bank size and the bank's ability to handle runoff.

Various formulae have been proposed for use in determining contour bank spacings based on land slope, soil erodibility, land use and rainfall erosivity. Examination of the Universal Soil Loss Equation has shown that steepness of slope has a much more significant impact on erosion than the length of the slope.

There are no strict rules that determine the 'correct' spacing for a particular situation. A concept of 'single' and 'double' spacings has been used to allow variations in contour bank spacings depending on the average conditions anticipated to be experienced in a paddock. Experience in Queensland has shown that the spacings provided in Table 9.4 are acceptable for most cropping situations.

Table 9.4 Recommended contour bank spacings

Average land slope (%)	Single spacing		Double spacing	
	Vertical Interval (VI) (metres)	Horizontal Interval (HI) (metres)	Vertical Interval (VI) (metres)	Horizontal Interval (HI) (metres)
1	0.9	90	1.8	180
2	1.2	60	2.4	120
3	1.5	45	3.0	90
4	1.6	40	3.2	80
5	1.8	36	3.6	72
6	1.9	32	3.8	64
7	2.1	30	4.2	60
8	2.4	30	4.8	60
9	2.7	30	5.4	60
10	3.0	30	6.0	60

‘Single spacings’ should be used where:

- bare fallow cropping systems are likely to be used
- a paddock is suffering from serious erosion
- soils are highly erodible
- contour bank length is close to the recommended maximum length
- farmers are likely to maintain their contour banks to a minimum standard
- parallel contour banks with higher than normal gradients are planned.

‘Double spacings’ may be used where:

- cropping systems that ensure high stubble levels during the fallow phase are used
- minimal erosion has occurred
- farmers are likely to build and maintain contour banks to a high standard.

Spacings between ‘single spaced’ and ‘double spaced’ may be chosen and are used in some districts. An argument against this practice is that the opportunity to later halve the spacing would result in spacings that were unacceptably close for most farmers. However experience has shown that the wider spacings are acceptable provided the conditions listed above are met.

Other factors may determine the spacings required for a particular situation eg. parallel contour banks in irrigated cane have traditionally had a spacing of 40 metres to match the spray width of water winches used for irrigation.

On irregular topography, the distance between banks will vary with the land slope. For this reason it is preferable to measure bank spacing using the vertical interval rather than the horizontal interval. To determine the appropriate vertical interval, a compromise is required. The recommended approach is to use the average VI for the contour bay.

9.25 Parallel layouts

Parallel layouts are a requirement for any situation where inter-row farming operations are practiced or where crops are irrigated. They have traditionally been used in more intensive cropping areas such as for sugar cane or horticulture.

The implementation of parallel layouts requires detailed topographic information and additional inputs are required to implement such systems. They are most readily applied where the topography is even (minimal variation in slope within each of the proposed contour bays). In intensive cropping areas, contour banks are short allowing for greater opportunities to alter gradients to ensure that the contour bank system is parallel.

The implementation of parallel layouts usually relies on the use of as many natural depressions as possible. This will result in short runs. However the use of subsurface waterways assists trafficability by allowing the tractor operator to lift an implement and travel across the waterway. Above ground waterways would reduce trafficability by requiring the operator to turn around at the waterway.

The use of single spacings in parallel layouts will reduce the amount of runoff that the contour banks need to accommodate and will provide more options for varying gradients to implement the parallel system. The spacing should be modified to match the implement widths or the irrigation system in use on the farm.

Where higher than normal gradients are required, consideration needs to given to the use of a parabolic or flat bottomed channel rather than a triangular one. The use of a grassed channel may also be necessary. Designs should be carried out to determine if the expected velocities are likely to cause erosion when the channels are in a bare condition.

A steep gradient of say 3–4% will usually be acceptable over a short distance eg. 50 metres at the high end of a contour bank channel because minimal flow is being carried in this section. Table 9.5 (Scarborough *et al*. 1992) provides examples of gradients recommended for use in parallel layouts in the Coastal Burnett. This table applies to situations where contour bank channels are cultivated and could be used as a general guide for the whole of Queensland. If green cane trash blanketing is used and measures are taken to provide erosion protection after the removal of the ratoon crop, (every 4 to 8 years) then higher gradients than that shown in Table 9.5 could be used.

Table 9.5 Recommended gradients for contour banks in parallel layouts where channels are cultivated

Soil erodibility	Average grade %	Maximum grade for 50 m %
Low	1.5	3.0
Medium	1.0	2.0
High	0.5	1.0

Especially in vineyards but also in trellised tree crops, it is of great advantage if rows are not only parallel to each other but also straight. It is difficult and more expensive to build trellises on curved lines. Water winches used to irrigate sugar cane generally require straight rows to operate effectively.

Some reverse grade sections may be unavoidable in a parallel system. Such sections will result in ponding. Cropping systems and soil types will determine if such ponding can be tolerated. A reverse grade may be avoided by an additional cut in the elevated section of the channel. Another method of correcting the low section leading to a reverse gradient would be to construct this section of the bank from the lower side. This will result in the channel at this point being higher than adjacent sections of the channel.

Parallel layouts have seldom been implemented on broadacre farming systems. The implementation of parallel layouts in such areas would be difficult because there is generally a considerable amount of variation in slopes within contour bays in the rolling landscapes that are a feature of these areas. The lowest slopes are usually found on ridge lines while the maximum slopes occur between the ridge line and the drainage line.

The long contour banks used in broadacre cropping have low gradients and there is limited opportunity to use higher gradients unless the contour bank channel was to be permanently grassed.

The introduction of controlled traffic farming systems requires that land be cultivated in parallel blocks. In broad acre systems this has generally been achieved by cultivating the whole paddock, usually in one direction and passing up and over contour banks (Refer to Chapter 13, *Controlled traffic farming).*

In the South Burnett, some farmers have achieved parallel farming with non-parallel broad-based contour banks by selecting a key bank and working parallel to it. Contour banks above and below the key bank are then crossed at a slight angle. This systems results in furrows that are close to the contour but which drain either into a waterway or a contour bank.

9.26 Contour bank cross-sections

The different types of contour banks were discussed at the beginning of this chapter. While contour banks are often constructed with a trapezoidal shape, the cross-section usually reverts to a triangular shape after a few years of tillage operations.

Two factors with a significant influence on the cross-sectional area of a contour bank are bank height and land slope. Figure 9.10 illustrates the effect of bank height on the cross-sectional area of flow. The data is based on a triangular shaped broad-based contour bank on a 2% land slope and with a bank batter of 1:6. It assumes that the excavated batter conforms to normal land slope.

Figure 9.10 Effect of bank height on the cross-sectional area of a contour bank

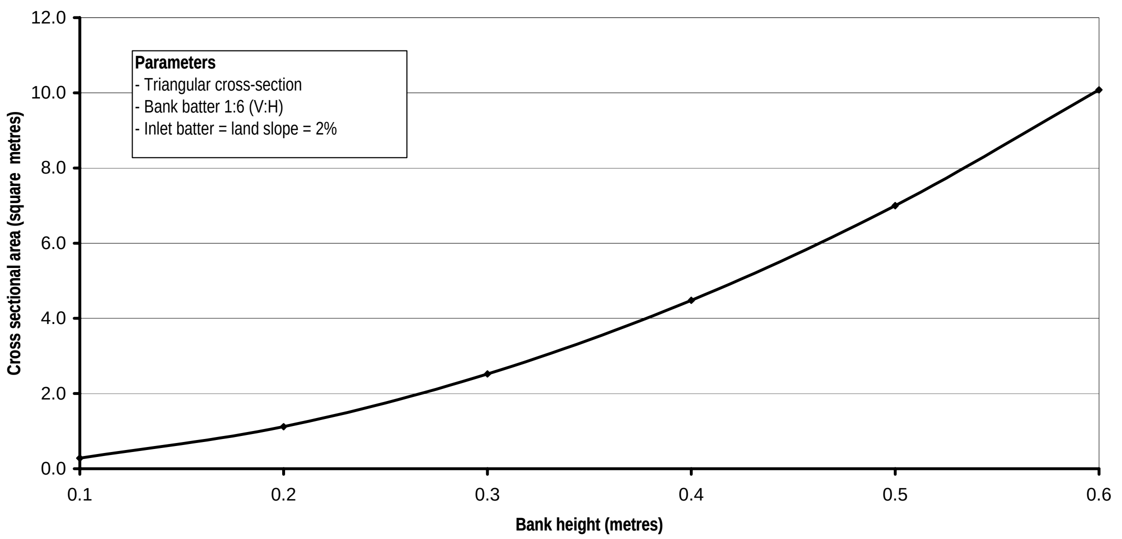
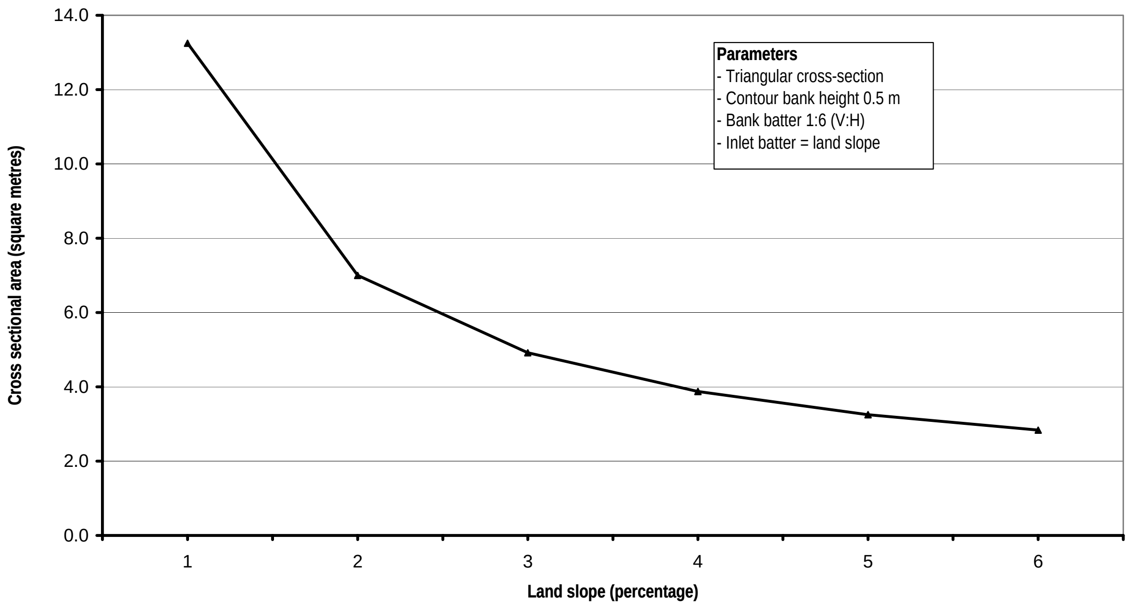


Figure 9.11 illustrates the effect that land slope has on contour bank capacity. The data is based on a triangular shaped broad-based bank with a flow depth of 0.5 metres and a bank batter of 1:6. It also assumes that the excavated batter conforms to normal land slope. On a land slope of 1% where a contour bank interval of 0.9 metres is used, half the contour bay would be under water if there was a flow depth of 0.45 metres. This illustrates the enormous amount of storage that contour banks can have on very low slopes.

Figure 9.11 Effect of land slope on contour bank cross-sectional area



Where land slopes are low, the excavated batter will often conform with the normal land slope after a few years of tillage operations. If the bank has been constructed with a bulldozer using a long length of travel in pushing up the bank then the excavated bank batter will almost conform with normal land slope after construction is complete.

Figure 9.12 also illustrates how land slope impacts on the cross- sectional area of contour banks. It illsustrates how 5% is the normally accepted limit for the construction of broad based contour banks with 1:4 batters.

Figure 9.12 Broad based contour banks with 1:4 batters on land slopes of 1%, 2% and 5%

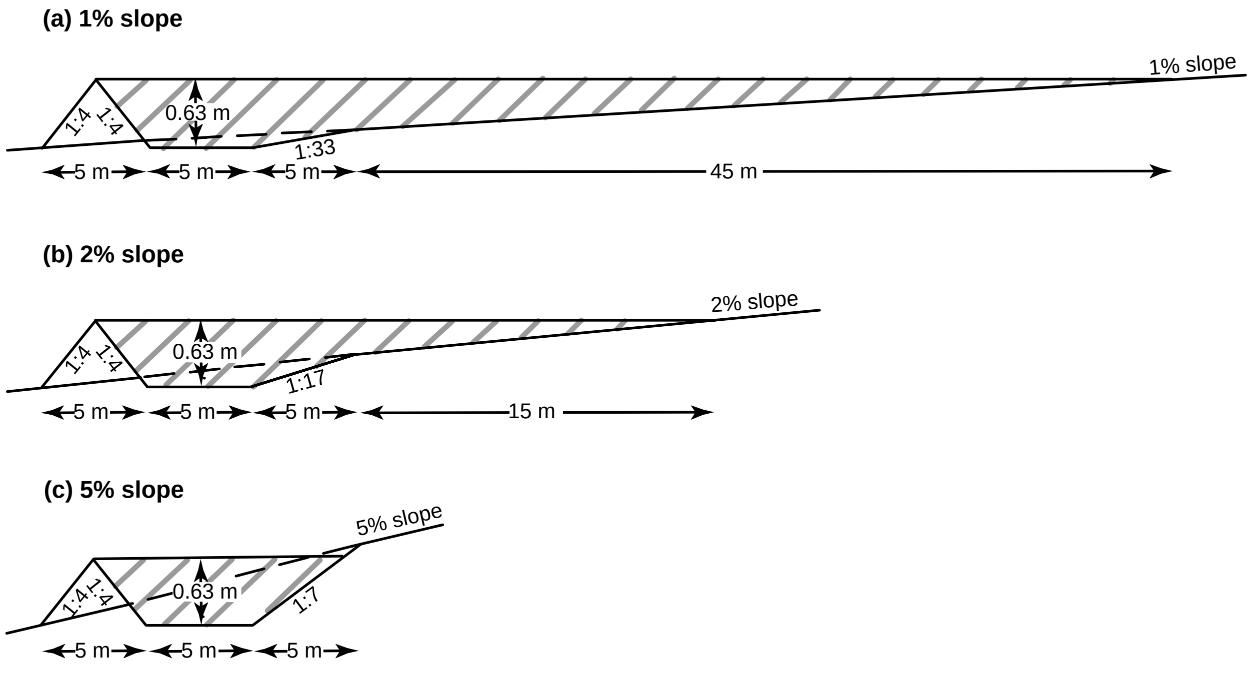
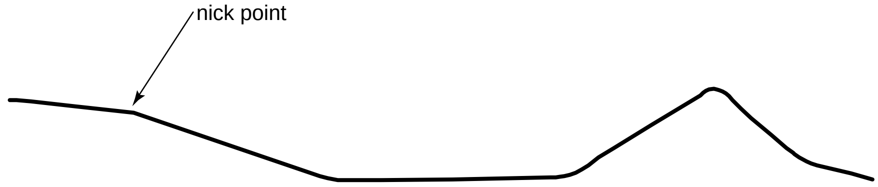


Figure 9.13 Contour bank cross-section illustrating the nick point



To provide protection against erosion of contour bank channels on steeper slopes, it is best to aim for a flat-bottomed channel (trapezoidal or parabolic). However, on steeper slopes there will be a distinct change in slope where the excavated batter meets the normal land slope. This point is referred to as the 'nick point' (Figure 9.13). It can contribute to rill erosion as overland flows meet the increased slope as they flow into the channel.

Machinery needs must be taken into consideration when determining contour bank cross-sections. The length and grade of the batters of contour banks should be constructed to suit the equipment used to operate on them (especially planting machinery). For cultivated banks, batters flatter than 1:4 (V:H) are recommended. Chapter 13 on *Controlled traffic farming* provides information on contour bank shapes suitable for traversing by machinery.

If a trapezoidal channel is constructed then the base must also conform with machinery needs. Tow paths for travelling irrigators require a trapezoidal shape with at least a 2.0 metre bottom width to help tracking of the irrigator.

9.27 Freeboard and settlement

Refer to the section on freeboard and settlement in Chapter 8, *Channel design principles*.

After construction, contour bank capacities need to be checked to ensure they have adequate capacity. Points for special attention are where contour banks cross old gully lines. Additional bank height is required at these locations to ensure the bank has adequate capacity to accommodate the design flow as it crosses the old gully line.

9.3 Design approach

As stated at the beginning of this chapter, contour banks are normally constructed according to general specifications that may apply to a particular situation in a district. Some land management field manuals provide such specifications which have been developed after numerous field observations over many years.

When it is necessary to carry out an individual design for a contour bank or to prepare or modify specifications for use in a district, the following approach is recommended.

In Chapter 8 the concept of combining equations 8.1 (Q=AV) and 8.2 (the Manning formula) was discussed. The resulting formula is as follows:

$$\frac{\mathbf{Q}}{\mathbf{A}} = \mathbf{V} = \frac{\mathbf{R^{0.66}\ S^{0.5}}}{\mathbf{n}} \quad \text{.......Equation 9.1}$$

Where

Q	=	the discharge or hydraulic capacity of the channel (m^3/s)
A	=	cross-sectional area (m^2)
V	=	average velocity (m/s)
R	=	hydraulic radius (m)
S	=	channel slope (m/m)
n	=	Manning coefficient of roughness

Because the channel in a contour bank may have surface conditions varying from a bare condition (Mannings *n* of 0.03) to a crop or standing stubble (Mannings *n* of 0.15 in the case of a wheat crop or standing wheat stubble), it is necessary to consider both conditions in the design. This requires the estimation of two design discharges. Figure 9.9 illustrates how the design peak discharge for a contour bank varies considerably for a high and low cover farming system. All paddocks are subject to varying amounts of cover. A low cover farming system refers to the management of the fallow but such a paddock will have a high cover level when it is growing a crop. A paddock where a high level of stubble management is used may have low cover during a period of drought when no crop is planted.

Since crop or standing stubble restricts flows in contour banks it is best to design initially for this condition and then check to see what happens when the design discharge occurs when the channel is bare. A limitation of this method of design, is that it does not take the temporary storage capacity of the contour bank channel into account. The method therefore provides an over-estimation of the actual capacity required. Galletly (1980) refers to the role of contour banks as temporary storage structures. Further research is required to develop a design method that incorporates storage capacity.

From substitution in the above formula the known factors will be the following:

- discharge Q
- gradient s
- roughness coefficient n.

Since we are initially designing for a high level of channel roughness, it can be assumed that the flow will be well below erosive velocities. Therefore we do not need to input a value of V into the above equation. The problem now comes down to finding a depth of flow in the contour bank channel that will give a hydraulic radius R and cross-sectional area A that will accommodate the required value of Q for a given gradient and value of Mannings *n*. This would require an iterative procedure.

A suitable design can be obtained by preparing a spreadsheet based on the required cross-sectional shape incorporating trial depths of flow and a high and low value of Mannings n. Table 9.6 provides an example of such a table. The table shows how erodible velocities (>0.5 m/s) will occur once the depth of flow in a bare channel exceeds 0.25 m depth of flow. However when the channel is protected by standing stubble, a flow depth of 0.7 m will only be flowing at 0.17m/s.

Table 9.6 Discharges and velocities for a range of flow depths for a trapezoidal shaped contour bank with a gradient of 0.2%

Depth (m)	Cross-sectional area (m^2)	Hydraulic Radius (m)	Mannings *n* = 0.15 eg. standing wheat stubble		Mannings *n* = 0.03 eg. bare cultivated channel	
			Velocity (m/s)	Discharge (m^3/s)	Velocity (m/s)	Discharge (m^3/s)
0.10	0.48	0.09	0.06	0.03	0.29	0.14
0.15	0.78	0.12	0.07	0.06	0.37	0.29
0.20	1.12	0.15	0.09	0.10	0.44	0.49
0.25	1.50	0.19	0.10	0.15	0.49	0.74
0.30	1.92	0.22	0.11	0.21	0.54	1.04
0.35	2.38	0.25	0.12	0.28	0.59	1.41
0.40	2.88	0.28	0.13	0.37	0.64	1.83
0.45	3.42	0.30	0.14	0.46	0.68	2.32
0.50	4.00	0.33	0.14	0.58	0.72	2.88
0.55	4.62	0.36	0.15	0.70	0.76	3.50
0.60	5.28	0.39	0.16	0.84	0.80	4.20
0.65	5.98	0.41	0.17	0.99	0.83	4.97
0.70	6.72	0.44	0.17	1.16	0.87	5.82

Shaded area indicates erosive velocities (> 0.5 m/s)
Parameters:
- Trapezoidal cross-section with inlet slope of 1:10, bank slope of 1:6 and bed width of 4 metres
- Contour bank gradient of 0.2%

9.31 Example

Determine the constructed height for a contour bank to accommodate discharges of 0.4 m^3/sec when a contour bay has a mature wheat crop (n = 0.15) and a discharge of 0.9 m^3/sec when the contour bay is under bare fallow (n = 0.03). The contour bank is to have a trapezoidal cross-section with inlet batters of inlet slope of 1:10, bank slope of 1:6 and bed width of 4 metres and a gradient of 0.2%. Assume that the bank will be built by a bulldozer and that it will settle by 50% after construction.

Solution

1. Use a spreadsheet to prepare a table similar to Table 9.6 showing velocities and discharges for the two values of *n* for a range of trial depths and for an acceptable gradient.
2. From Table 9.6 when *n* = 0.15 a flow depth of 0.4 m will have a discharge of 0.37 m^3/sec with a velocity of 0.13 m/sec.
3. From Table 9.6 when *n* = .03 a flow depth of 0.3 m will have a discharge of 1.04 m^3/sec with a velocity of 0.54 m/sec.
4. The depth of flow obtained in step 1 shows that a depth of flow of 0.4 m would be sufficient to accommodate the required flow. (If an alternative design was required an additional spreadsheet could be prepared based on a different gradient.)
5. An allowance of 0.15 m for freeboard would give a recommended settled bank height of 0.55 metres.
6. An additional 50% should be added to allow for settlement giving a constructed height of 1.1 metres (using equation 8.10).

Note that should the bank carry the design depth of flow of 0.4 m in a bare fallow condition, Table 9.6 shows that it would be carrying a discharge of 1.83 m^3/sec at a velocity of 0.64 m/sec. Such a velocity is likely to be erosive but such an event would be rare as it is double the design discharge for bare fallow. Since bare fallow farming systems contribute to high rates of soil erosion in a contour bay, it is most desirable that a high cover farming system is adopted rather than one that has bare fallows.

9.32 Contour bank design charts

Design charts can be prepared to show how contour banks with a specified cross-section perform under a range of values of Mannings *n*, gradient and flow depth. Figure 9.14 is an example of a contour bank design chart for a broad-based contour bank with a bottom width of 4 metres and batters of 1:6 and 1:10. The three graphs illustrate the dramatic affect that surface roughness in the channel has on both velocity and discharge.

Figure 9.14 Contour bank design chart for a trapezoidal shape and a range of values for Mannings *n*, channel gradient and flow depth

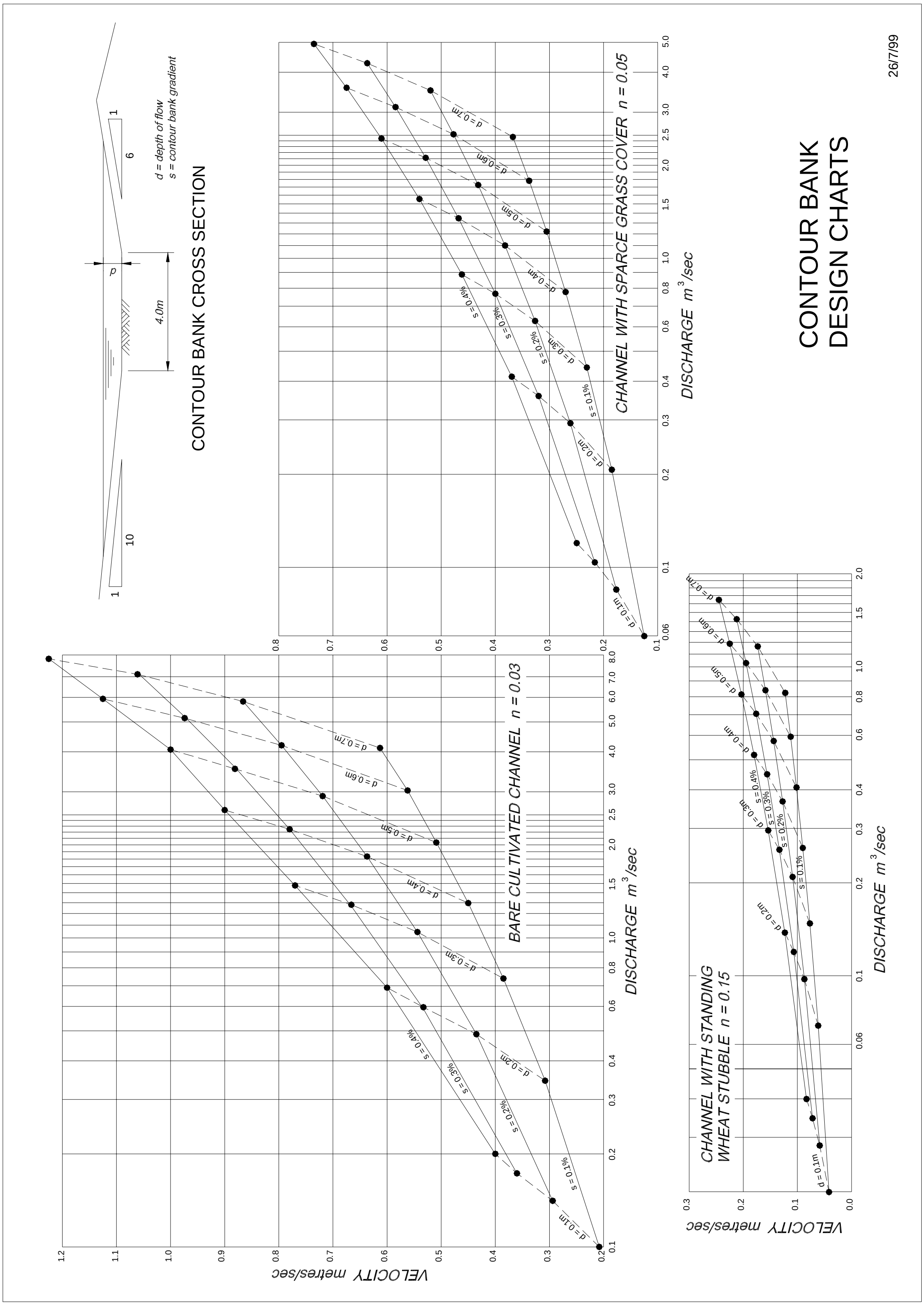
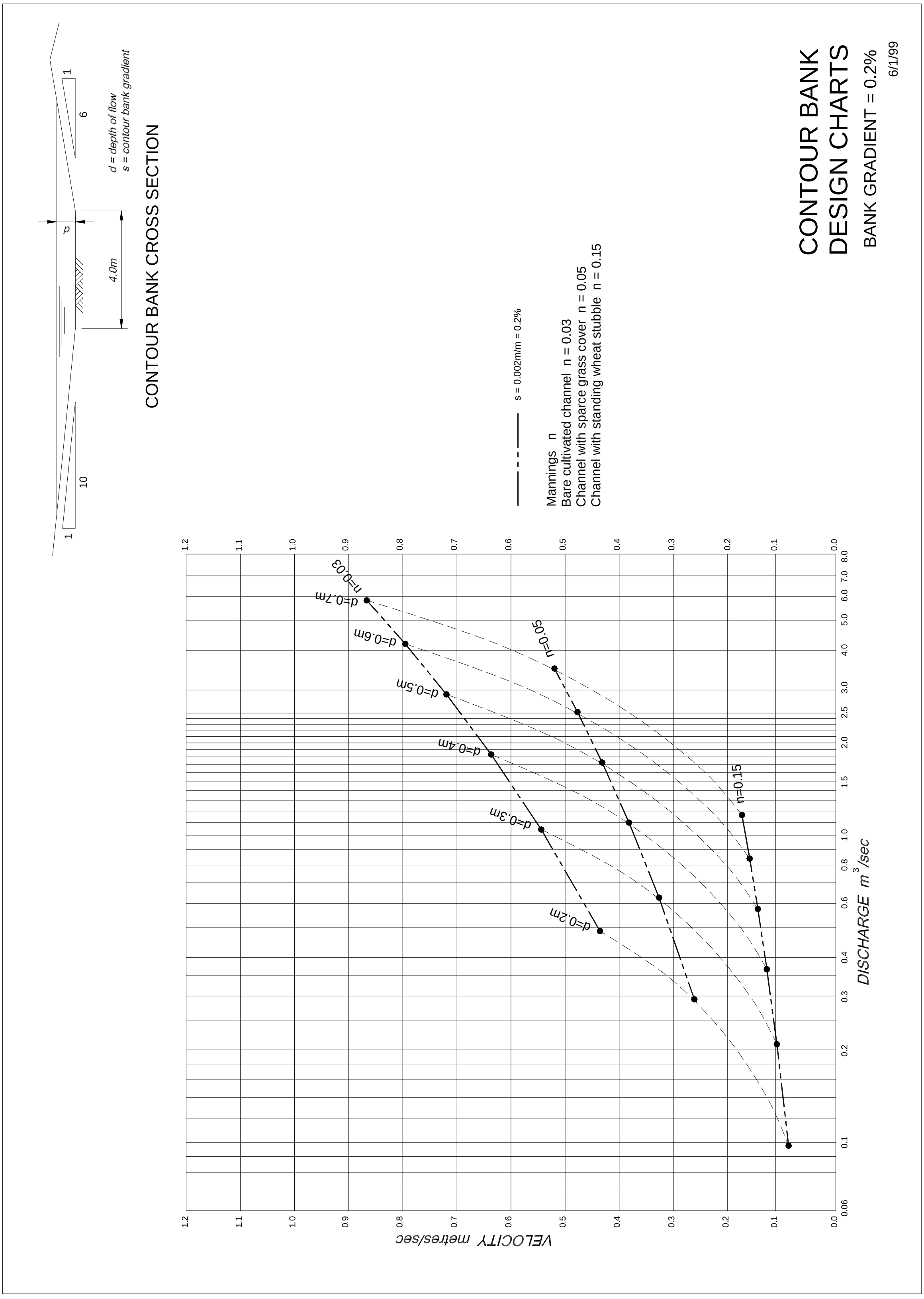


Figure 9.15 shows a graph for the same cross-section as Figure 9.14 but for a constant gradient of 0.2% and three values of Mannings *n*.

Figure 9.15 Contour bank design chart for a trapezoidal shape and a range of values for Mannings *n* and flow depth



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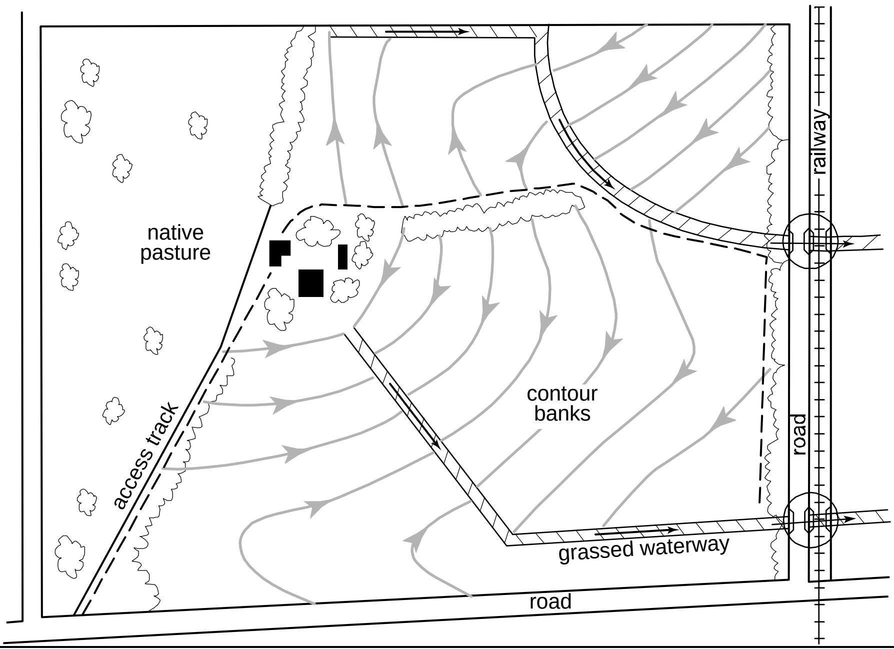
Chapter 9

Contour banks

Contour banks are earthen structures constructed across cultivated slopes, at intervals down the slope. In some countries and other Australian states contour banks are referred to as ‘graded banks’, ‘terraces’ or ‘bunds’. They intercept run-off and safely channel it into stable grassed waterways, natural depressions or grassed areas adjacent to a paddock. Their function is to reduce slope length and to intercept runoff before it concentrates into an erosive force. They also trap much of the sediment from overland flow especially from rills and old gully lines. Any crop or stubble in a contour bank channel acts as a filter as runoff moves slowly along the contour bank channel.

Figure 9.1 Plan of a contour bank and waterway layout



Contour bank layouts require careful planning to ensure the satisfactory coordination of runoff between properties within a catchment and across public utilities such as roads and railway lines (Figure 9.1). More information on this topic is provided in Chapter 2, *Soil conservation planning*.

Contour banks are not strictly ‘on the contour’. They have a low gradient (usually 0.1–0.4%) to minimise the chance of channel flow reaching erosive velocities when the channel is in a bare condition. In some intensive farming situations (eg. horticulture or sugar cane) where pondage must be avoided or where parallel layouts are required, steeper gradients are used for limited distances. If permanent cover is maintained in the channel, much steeper gradients can be utilised. The spacing of contour banks depends mainly on the slope of the land but is also influenced by soil type, cropping practices and previous erosion.

Theoretically, contour banks are usually designed to carry water resulting from a runoff event with a 10 year average recurrence interval. However, the ability of a contour bank to carry the estimated design runoff is very much dependent on the condition of the channel at the time the runoff event occurs. A contour bank with a smooth, bare channel can carry around five times more runoff than one with the channel covered with a close growing crop or dense stubble.

Crop management practices that maintain adequate levels of surface cover will greatly reduce the amount of erosion between contour banks. This will enhance the effectiveness of contour banks and greatly reduce their maintenance costs.

Contour banks play an important role in acting as sediment traps. Up to 80% of the soil moved from a contour bay may be deposited in the contour bank channel (Freebairn and Wockner 1986). Maximum rates of deposition and filtration of nutrients and pesticides are likely to occur when the channel contains a close growing crop or standing stubble.

In intensive cropping areas, as used for the production of horticulture crops or sugar cane, contour banks are usually constructed parallel to each other to facilitate inter-row cultivation, pesticide application, irrigation and harvesting practices. However contour bank layouts in extensive cropping areas are usually not parallel. The long contour banks in such systems provide limited opportunities for parallel layouts because of the irregular nature of the topography.

The introduction of controlled traffic farming has a number of implications for contour bank systems. These are discussed further in the Chapter 13, *Controlled traffic*.

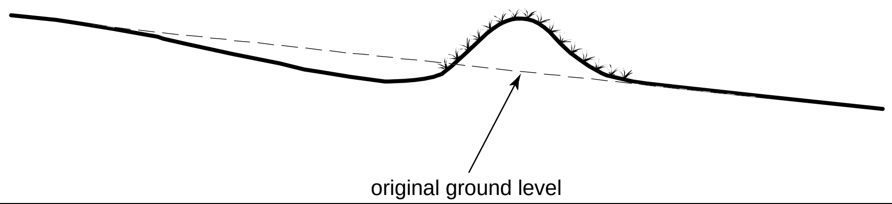
Soils with dispersible subsoils at depths of less than 30 cm are limited in their suitability for bank construction and require special construction techniques. If the subsoils are exposed in the channel, the contour bank will be prone to failure by tunnel erosion.

9.1 Contour bank types

The following types of contour bank cross-sections are used:
- narrow-based
- broad-based
- broad-based top side
- broad-based bottom side.

Narrow-based contour banks (Figure 9.2) have batters that are too steep to cultivate. They are normally planted to grass and require weed control especially during the first two years. The channels are usually treated as part of the contour bay, which means that they are cultivated and planted to crop. However some farmers choose to leave the channels grassed. Narrow-based banks may take up to 10% of total cultivated area.

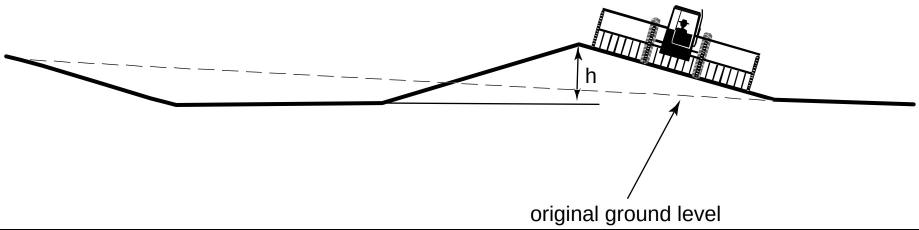
Figure 9.2 Narrow-based contour bank



They are commonly used on steeper cultivated slopes of 5–12% or on land that is only occasionally cultivated. They are not suited to cracking clay soils as they may fail following cracking in dry seasons. They are also susceptible to failures resulting from burrowing animals.

Broad-based contour banks (Figure 9.3) are built with batters that can easily be worked with tillage and planting machinery. They allow for the whole of the paddock to be cropped including the channel. Broad-based banks are generally used on deep soils and lower sloping land. They can be crossed at various angles by farming equipment under a controlled traffic system depending on the slopes of their batters.

Figure 9.3 Broad-based contour bank



Because the batters are cultivated, the risk of failure by cracking is reduced.

Broad-based banks are more costly to build and maintain than narrow-based banks and become impractical to construct as slopes exceed 5%. On steeper slopes on cracking clay soils, *semi-broad-based banks* may be implemented where the up-slope batter of the bank is broadened to suit the width of the most commonly used machinery. Such banks may have a broad base either on the top-side (Figure 9.4) or the bottom side (Figure 9.5).

Figure 9.4 Broad-based top side contour bank

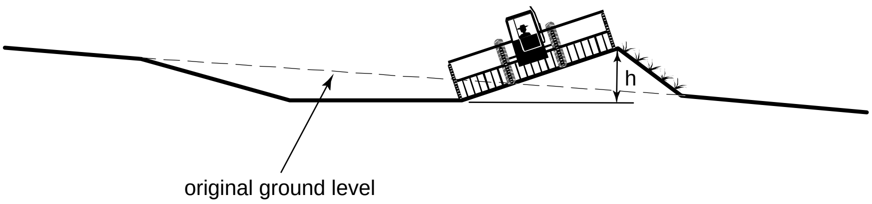
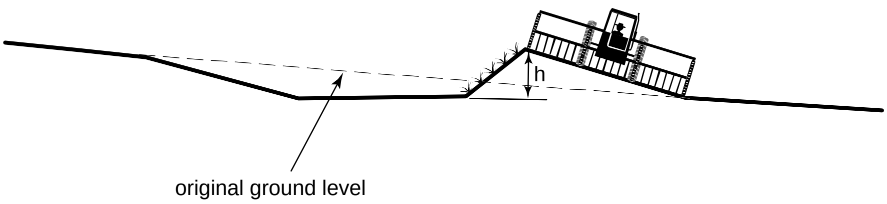


Figure 9.5 Broad-based bottom side contour bank



9.2 Design criteria

Contour banks are normally not individually designed. It is usual to develop specifications for particular situations in a district based on the following parameters:

- gradient
- length
- spacing
- cross-section and depth of flow.

Contour banks are subject to considerable variation in their capacity over time. Settlement will occur after construction. Banks may be worn down by tillage equipment. Sedimentation in the channel will also reduce capacity. Since maintenance of contour banks would normally be carried out on a 5–10 year cycle, it is desirable to carry out construction work so that banks are built or maintained to an above standard specification and then to maintain them once they are below specification.

The dimensions of a newly constructed contour bank are often governed by the construction technique rather than prescribed specifications. For example, contour banks may be constructed with one push of a large bulldozer, creating a structure that greatly exceeds the standard specifications.

9.21 Design velocity

Low velocities are desirable in a contour bank channel to avoid the chance of erosion in the channel and to ensure maximum deposition or trapping of sediment. Low velocities also reduce design peak discharges in waterways by lengthening the time of concentration.

The velocity of flow in a contour bank channel is very much dependent on the condition of the channel at the time that a runoff event occurs. If the channel is in a smooth and bare condition (Mannings *n* of 0.03) the bank will have maximum potential to discharge runoff. High velocities will occur if there is a significant depth of flow in a major runoff event. The aim of the design should be to keep velocities below 0.4 m/s for easily eroded soils and 0.6 m/s for erosion resistant soils.

However, if channel flow is restricted by a cereal crop such as wheat or standing stubble after harvest (where Mannings *n* may be 0.15) velocities are not likely to exceed 0.2 m/s. Contour banks must have sufficient capacity to accommodate the design event at these velocities.

In controlled traffic situations, crop direction may sometimes be at right angles to the direction of flow in the channel. Under these circumstances, Mannings *n* values could be expected to be greater than 0.15. Research is required to determine what Mannings *n* values are likely to occur under these circumstances.

The variable conditions that occur in a contour bank channel create some complexities in terms of the design. If a contour bank with a bare channel is flowing to capacity, it is likely to be handling an event much greater than that for which it was designed and erosive velocities will occur. This situation must be deliberately risked, as the only alternative is to build a smaller bank or to reduce the gradient. This would lead to regular failure if runoff events occur when the channel is restricted by crop or stubble.

If a design indicates that contour bank velocities will be too high, then the following options should be considered:

- use an alternative channel shape. The use of a flat-bottomed trapezoidal shape will convey flows more safely than a triangular cross-section.
- keep the channel permanently grassed
- use a lower gradient.

The stream power formula (Equation 8.7) may be used to determine the likelihood of erosion occurring in the channel. Table 9.1 provides values of stream power for a typical broad-based contour bank with a trapezoidal shape, a gradient of 0.2% and a Mannings *n* of 0.03 (bare soil). For cracking clay soils it is recommended that values of stream power be below 3 (W/m^2) (Titmarsh and

Loch 1993). (Values for other soils are not available.) The table indicates that this value will be exceeded for depths of flow of 0.4 metres or greater.

Table 9.1 Stream power values for a typical broad-based contour bank under bare soil conditions

Depth of flow (m)	Velocity (m/s)	Discharge (m^3/s)	Stream Power (W/m^2)
0.2	0.4	0.5	1.3
0.3	0.5	1.1	2.3
0.4	0.6	1.8	3.4
0.5	0.7	2.9	4.7
0.6	0.79	4.2	6.0
0.7	0.87	5.8	7.4

Based on the following parameters:

- Trapezoidal shape
- Gradient of 0.2%
- Mannings *n* of 0.3

9.22 Gradients

Contour bank gradients should be chosen to minimise the risk of erosion in the channel when it is in a bare condition but also ensure that the channel has adequate capacity to carry the design runoff when flow in the channel is restricted by crop or standing stubble. Such a compromise can be difficult to achieve in practice because of the five-fold differences that can apply in the values of Mannings *n* (0.03 to 0.15) for these two situations.

High gradients may lead to:

- erosion in the contour bank channel
- high runoff rates in waterways.

Low gradients may lead to:

- poor drainage—an important issue especially for many horticultural crops
- more low points in the bank that will pond runoff until they are filled with sediment
- 'leakage' into groundwater systems in locations where this is an issue
- failure by 'piping' (linked to tunnel erosion) where there are dispersible subsoils.

The impact of gradient on contour bank velocity and discharge is illustrated in Figures 9.6 and 9.7 respectively.

Figure 9.6 Effect of gradient on contour bank velocity for two flow depths

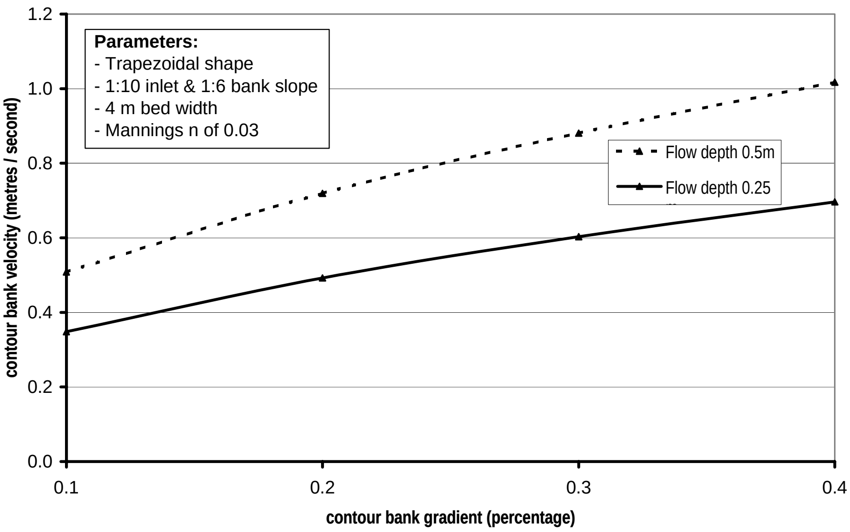
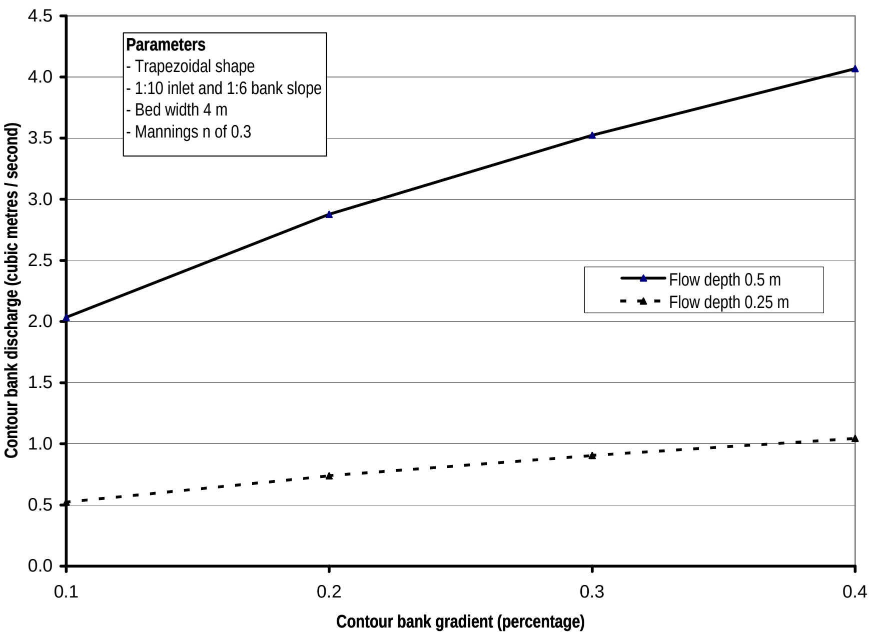


Figure 9.7 Effect of gradient on contour bank discharge for two flow depths



Recommended contour bank gradients are dependent on the steepness of the land and soil erodibility. The capacity of a contour bank of a given height depends on the land slope. The lower the land slope the greater the storage capacity of the bank. There is also a relationship between land slope and bank length. The steeper the landscape, the closer the distance between natural drainage lines. This means that average contour bank lengths on steep slopes are likely to be much shorter than the average bank lengths for low slopes.

Taking the above factors into account, there are good reasons for increasing contour bank gradients as land slope increases. Steeper gradients on higher slopes will compensate for the limited capacity of contour banks on such slopes. However shorter contour banks on steeper slopes means that they are required to handle less runoff than longer banks—and so there is less likelihood of erosion occurring in the channel.

In horticultural situations, higher gradients can be used where the channel is grassed or where it is bare but not cultivated. If contour banks are used for access and are not cultivated, the risk of erosion in the channel is greatly reduced.

In cane lands gradients as high as 4 % are used where green cane trash blanketing is used on erosion resistant soils eg. krasnozems. Contour bank channels in cane lands are only vulnerable to erosion for a relatively short period when a new crop is planted after the removal of the ratoon crop (every 4 to 8 years). The use of minimum tillage practices or a cover crop can reduce the risk of erosion during the fallow period. Further reference to gradients in cane lands is included in the section *Parallel layouts.*

It is normal practice for a contour bank to be constructed to the same capacity for its entire length. Since the amount of runoff to be carried increases with the length of the contour bank, *variable gradients* can be used along a contour bank channel. This will lengthen the time of concentration and reduce the peak discharge in the waterway.

In contour banks on low land slopes where the maximum gradients are less than 0.2%, there is limited opportunity to use variable gradients. However on steeper land slopes where the maximum gradient is higher, variable gradients as indicated in Table 9.2 can be used eg. for a land slope of 3% to 5%, the gradient in the top 33% of the bank would be 0.2%, changing to 0.25% in the middle 33% followed by 0.3% in the lower (outlet) 33% section of the bank.

Table 9.2 Gradients for contour banks with cultivated channels based on land slope

Land slope	Appropriate contour bank gradients (%) for average conditions		
	Top section	Middle section	Outlet section
1%	0.1	0.1	0.1
2%	0.1	0.15	0.2
3%–5%	0.2	0.25	0.3
5%–10%	0.3	0.4	0.5

In intensive cropping areas, parallel contour bank systems are often implemented. The implementation of such a system requires some flexibility in contour bank gradients but gradients should be managed to ensure that erosion in the channel is minimised (refer to the section on parallel layouts in this chapter).

Gradients can be modified over short distances to improve workability of the layout. At the high end of a contour bank, it is quite acceptable to improve workability by using a high or low gradient to ensure that the bank meets a fence line at close to a right angle rather than an acute angle.

It is normal practice to 'split' contour banks on well-defined ridgelines so that they direct runoff away from the ridge. This ensures that runoff remains in its natural catchment and also provides an ideal position for a road or track to cross over contour banks. The exact location of the 'split' should be prominently marked during the surveying process so that the farmer is aware of its location and the significance of this position. The splits on a ridge should be aligned. This may require a readjustment of some levels at the completion of the surveying task to obtain the best alignment.

It should be noted that if contour banks carry runoff across ridge lines that have low slopes or even a saddle, this may result in considerable variation in the contour bank spacing (referred to as the 'flat ridge syndrome'). This problem can be minimised by modifying the gradient where the bank crosses the ridge. Some zero grade sections in this situation would be acceptable as the low slope ensures maximum contour bank capacity and the convex nature of the topography ensures that there is less likelihood of concentrated flows discharging into this section of the contour bank.

Where contour banks cross 'sharp' depressions resulting in a sharp bend in the bank, the gradient can be modified to smooth out the shape of the bank to improve workability. However this will create a low point in the contour bank, which will detain runoff until sufficient sedimentation occurs to remove the pond. If this procedure is adopted, it is essential that the contour bank be given additional capacity where it crosses the drainage line and that such points are checked after construction to ensure they have adequate capacity.

Increased gradients should be considered in situations where contour banks are to be built in land with serious rilling and gullying. However an alternative consideration in such situations is to ensure that the contour bank has additional height where it crosses gully lines, bearing in mind that greater settlement of the bank is likely to occur at these points. The provision of additional height should obviate the need for increased gradient. Ideally, gullies will have been filled in during the construction process. However some form of a depression is likely to remain. This depression will be subject to sedimentation and will disappear over time. Levelling of the land between contour banks (the contour bay) is encouraged to remove the presence of old rill and gully lines. If levelling is not carried out, the rill will continue to concentrate runoff from the adjacent area leading to silt deposition where it meets the contour bank channel.

There is a case for using higher gradients for contour bays where zero tillage is adopted or where contour bank channels are not cultivated. As previously discussed, the highest velocity likely to be achieved in a standard size broad-based contour bank with a wheat crop or standing wheat stubble is 0.2 m/s. The risk associated with this approach is that it is possible that the property could change ownership and the new owner may adopt traditional cropping practices with lower levels of stubble. The preferred option therefore would be to use gradients applicable to a farming system that will have both bare and vegetated channels at different times.

From an hydraulic aspect, level (zero gradient) contour banks, especially on low slopes, could accommodate the runoff they receive, provided they were built to an adequate specification. However they are not recommended because such banks are subject to pondage at regular intervals along the bank. Such ponding can have an adverse effect on crop growth and restrict tillage, planting and harvesting activities.

9.221 Gradients at contour bank outlets

Problems can occur at the point where contour banks discharge into waterways. As well as the gradient in the bed of the contour bank channel, an important consideration is the gradient of the surface of the water in a channel (Stephens 1987). Two different situations may apply—where a bank discharges with a completely free outlet and where the outlet is obstructed in some way.

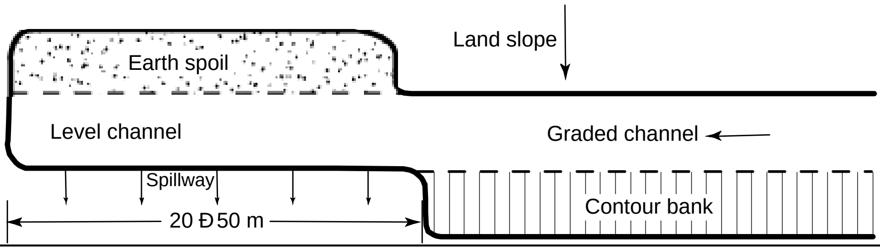
Examples of where a bank discharges with a completely free outlet include:

- a wide deep hollow
- an adjacent grass paddock
- a subsurface waterway
- an eroding waterway.

In the above cases the gradient of the water surface would be greater than that of the channel, and the velocity would increase. This can be the cause of erosion in bank outlets. In these situations there is no requirement for extra gradient at the bank outlet.

Where contour banks are discharging into a grassed area, it is advisable to construct a spreader channel (Figure 9.8) at the outlet to ensure that discharge occurs over a wide section of the bank. Spreader channels are level channels created by pushing soil uphill rather than downhill as with conventional contour banks. They are used to reduce the concentration of water discharging at the end of a diversion or contour bank into an area of pasture or a watercourse.

Figure 9.8 Plan view of a spreader channel at the outlet of a contour bank



A spreader channel would normally involve a level section for the last 20 to 50 metres of a contour bank. The section would have an excavated channel in which soil from the channel is pushed uphill. The use of a hedge incorporating a species such as Monto Vetiver grass along the spreading area would assist in ensuring that runoff exits the sill over the entire length of the spreading area.

Where there is an overfall at a bank outlet, some adjustment to contour bank spacings may be an option in order to find a more stable outlet for a contour bank. Normal gradients or even a level section should be used where there is an overfall. Such overfalls should be stabilised at the outlet by means of a structure such as a rock chute. Where there is instability at a contour bank outlet the last section of contour bank channel should be permanently grassed.

Examples of where the discharge is obstructed in some way include:

- where a bank outlet is too narrow or choked with grass or stubble
- where the bank discharges into a waterway that is flowing at a similar height to the water in the contour bank.

In the above cases the gradient of the water surface will be less than that of the channel bed and the velocity will decrease. This can be the cause of bank overflow near the outlet. Increased gradients will generally be required in these situations. The additional gradient should account for the estimated depth of excavation to construct the contour bank plus the design depth of flow above ground level in the waterway.

In low sloping situations it may not be possible to obtain sufficient additional fall at the bank outlet. In such situations bank height should be increased for at least the last 200 metres of the contour bank. As an additional measure, the contour bank may be constructed to discharge into a secondary waterway running adjacent to the main waterway for about half a contour bay interval.

9.23 Contour bank length

Farmers generally prefer contour banks to be as long as possible to maximise the length of run and to reduce the number of waterways required. However, as bank length increases, so does the risk of failure. The longest bank lengths are implemented on low sloping extensive cropping areas on the Western Downs and the Central Highlands.

On steeper landscapes, the distance between natural drainage lines decreases and normal contour bank lengths become shorter. Shorter contour banks are also associated with the more intensive cropping systems associated with the growing of sugar cane as well as horticulture.

Contour bank capacity is also related to land slope. A bank of a given height will have greater capacity on a low slope than it will on a steeper slope (refer to Figure 9.11 in the section on contour bank cross-sections). This enables the use of longer banks and lower gradients on low slopes.

The amount of runoff discharged from a contour bay will be proportional to the area of the bay. Figure 9.9 shows how the Empirical version of the Rational Method attempts to predict peak discharges for various contour bank lengths on a 2% slope with a 90 metre contour bank spacing at Pittsworth. The graph compares low and high cover farming systems. It shows significantly higher runoff rates under a bare fallow system due to the shorter time of concentration and the selection of a higher C value. However, a contour bank with bare soil in the channel will be able to accommodate considerably more runoff than a bank in which the channel is carrying a crop or standing stubble.

Figure 9.9 Peak discharge estimates based on contour bank length for Pittsworth

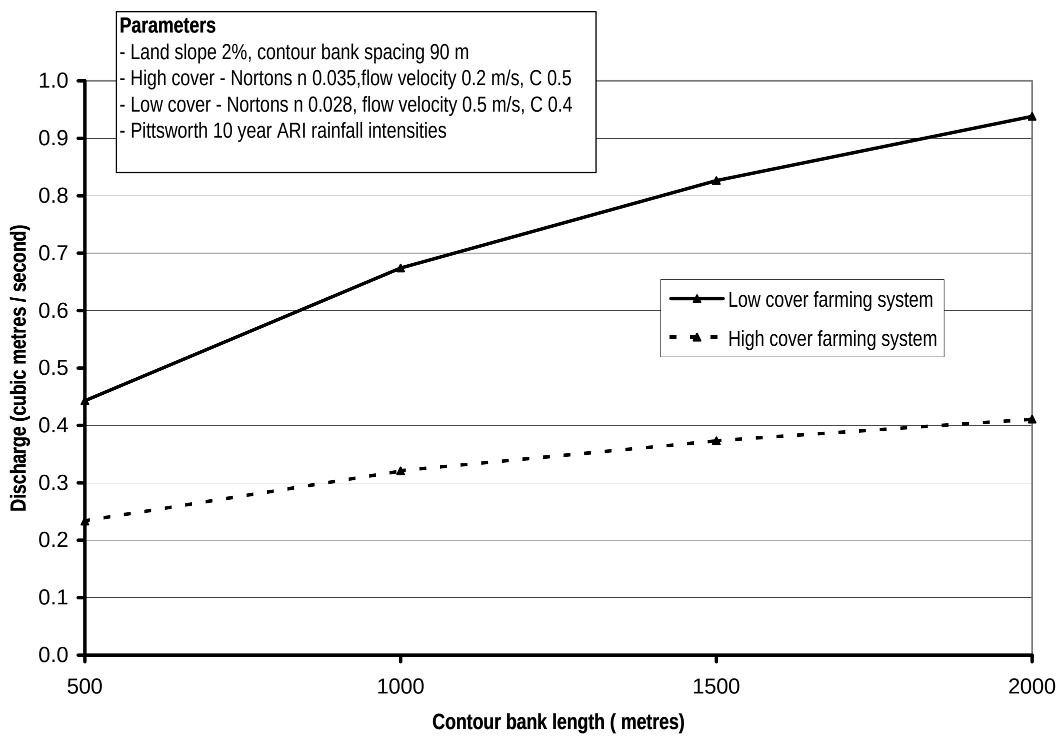


Table 9.3 provides a guide to recommended maximum bank lengths based on land slope. This table is based on contour bank capacities normally maintained by farmers on such slopes and the minimum contour bank spacings normally recommended on such slopes. It also assumes that the runoff is travelling in the one direction in the contour bank channel.

Table 9.3 Recommended maximum bank lengths for various land slopes

Land slope %	Recommended maximum bank length (metres)
1	2500
1.5	2000
2	1750
3	1500
4	1000
5	750
6	600
7	450
8	400
9	350
10	300

Based on the following parameters:
- Single spaced contour banks
- Use of cropping systems that provide high levels of cover
- High standard of contour bank maintenance

An alternative approach to the design of contour bank length using the KINCON model is provided in Connolly *et al*.1991. This program is not commercially available.

9.24 Bank spacing

Wide contour bank spacings facilitate the operation of farm machinery and reduce per hectare construction costs. However there are a number of factors that limit the spacing between contour banks:
- the increase in erosion for the wider spacings
- the tendency of overland flows to concentrate, forming gullies between the banks and building up deltas in the channel of the contour bank below
- the practical limit to bank size and the bank's ability to handle runoff.

Various formulae have been proposed for use in determining contour bank spacings based on land slope, soil erodibility, land use and rainfall erosivity. Examination of the Universal Soil Loss Equation has shown that steepness of slope has a much more significant impact on erosion than the length of the slope.

There are no strict rules that determine the 'correct' spacing for a particular situation. A concept of 'single' and 'double' spacings has been used to allow variations in contour bank spacings depending on the average conditions anticipated to be experienced in a paddock. Experience in Queensland has shown that the spacings provided in Table 9.4 are acceptable for most cropping situations.

Table 9.4 Recommended contour bank spacings

Average land slope (%)	Single spacing		Double spacing	
	Vertical Interval (VI) (metres)	Horizontal Interval (HI) (metres)	Vertical Interval (VI) (metres)	Horizontal Interval (HI) (metres)
1	0.9	90	1.8	180
2	1.2	60	2.4	120
3	1.5	45	3.0	90
4	1.6	40	3.2	80
5	1.8	36	3.6	72
6	1.9	32	3.8	64
7	2.1	30	4.2	60
8	2.4	30	4.8	60
9	2.7	30	5.4	60
10	3.0	30	6.0	60

'Single spacings' should be used where:

- bare fallow cropping systems are likely to be used
- a paddock is suffering from serious erosion
- soils are highly erodible
- contour bank length is close to the recommended maximum length
- farmers are likely to maintain their contour banks to a minimum standard
- parallel contour banks with higher than normal gradients are planned.

'Double spacings' may be used where:

- cropping systems that ensure high stubble levels during the fallow phase are used
- minimal erosion has occurred
- farmers are likely to build and maintain contour banks to a high standard.

Spacings between 'single spaced' and 'double spaced' may be chosen and are used in some districts. An argument against this practice is that the opportunity to later halve the spacing would result in spacings that were unacceptably close for most farmers. However experience has shown that the wider spacings are acceptable provided the conditions listed above are met.

Other factors may determine the spacings required for a particular situation eg. parallel contour banks in irrigated cane have traditionally had a spacing of 40 metres to match the spray width of water winches used for irrigation.

On irregular topography, the distance between banks will vary with the land slope. For this reason it is preferable to measure bank spacing using the vertical interval rather than the horizontal interval. To determine the appropriate vertical interval, a compromise is required. The recommended approach is to use the average VI for the contour bay.

9.25 Parallel layouts

Parallel layouts are a requirement for any situation where inter-row farming operations are practiced or where crops are irrigated. They have traditionally been used in more intensive cropping areas such as for sugar cane or horticulture.

The implementation of parallel layouts requires detailed topographic information and additional inputs are required to implement such systems. They are most readily applied where the topography is even (minimal variation in slope within each of the proposed contour bays). In intensive cropping areas, contour banks are short allowing for greater opportunities to alter gradients to ensure that the contour bank system is parallel.

The implementation of parallel layouts usually relies on the use of as many natural depressions as possible. This will result in short runs. However the use of subsurface waterways assists trafficability by allowing the tractor operator to lift an implement and travel across the waterway. Above ground waterways would reduce trafficability by requiring the operator to turn around at the waterway.

The use of single spacings in parallel layouts will reduce the amount of runoff that the contour banks need to accommodate and will provide more options for varying gradients to implement the parallel system. The spacing should be modified to match the implement widths or the irrigation system in use on the farm.

Where higher than normal gradients are required, consideration needs to given to the use of a parabolic or flat bottomed channel rather than a triangular one. The use of a grassed channel may also be necessary. Designs should be carried out to determine if the expected velocities are likely to cause erosion when the channels are in a bare condition.

A steep gradient of say 3–4% will usually be acceptable over a short distance eg. 50 metres at the high end of a contour bank channel because minimal flow is being carried in this section. Table 9.5 (Scarborough *et al*. 1992) provides examples of gradients recommended for use in parallel layouts in the Coastal Burnett. This table applies to situations where contour bank channels are cultivated and could be used as a general guide for the whole of Queensland. If green cane trash blanketing is used and measures are taken to provide erosion protection after the removal of the ratoon crop, (every 4 to 8 years) then higher gradients than that shown in Table 9.5 could be used.

Table 9.5 Recommended gradients for contour banks in parallel layouts where channels are cultivated

Soil erodibility	Average grade %	Maximum grade for 50 m %
Low	1.5	3.0
Medium	1.0	2.0
High	0.5	1.0

Especially in vineyards but also in trellised tree crops, it is of great advantage if rows are not only parallel to each other but also straight. It is difficult and more expensive to build trellises on curved lines. Water winches used to irrigate sugar cane generally require straight rows to operate effectively.

Some reverse grade sections may be unavoidable in a parallel system. Such sections will result in ponding. Cropping systems and soil types will determine if such ponding can be tolerated. A reverse grade may be avoided by an additional cut in the elevated section of the channel. Another method of correcting the low section leading to a reverse gradient would be to construct this section of the bank from the lower side. This will result in the channel at this point being higher than adjacent sections of the channel.

Parallel layouts have seldom been implemented on broadacre farming systems. The implementation of parallel layouts in such areas would be difficult because there is generally a considerable amount of variation in slopes within contour bays in the rolling landscapes that are a feature of these areas. The lowest slopes are usually found on ridge lines while the maximum slopes occur between the ridge line and the drainage line.

The long contour banks used in broadacre cropping have low gradients and there is limited opportunity to use higher gradients unless the contour bank channel was to be permanently grassed.

The introduction of controlled traffic farming systems requires that land be cultivated in parallel blocks. In broad acre systems this has generally been achieved by cultivating the whole paddock, usually in one direction and passing up and over contour banks (Refer to Chapter 13, *Controlled traffic farming).*

In the South Burnett, some farmers have achieved parallel farming with non-parallel broad-based contour banks by selecting a key bank and working parallel to it. Contour banks above and below the key bank are then crossed at a slight angle. This systems results in furrows that are close to the contour but which drain either into a waterway or a contour bank.

9.26 Contour bank cross-sections

The different types of contour banks were discussed at the beginning of this chapter. While contour banks are often constructed with a trapezoidal shape, the cross-section usually reverts to a triangular shape after a few years of tillage operations.

Two factors with a significant influence on the cross-sectional area of a contour bank are bank height and land slope. Figure 9.10 illustrates the effect of bank height on the cross-sectional area of flow. The data is based on a triangular shaped broad-based contour bank on a 2% land slope and with a bank batter of 1:6. It assumes that the excavated batter conforms to normal land slope.

Figure 9.10 Effect of bank height on the cross-sectional area of a contour bank

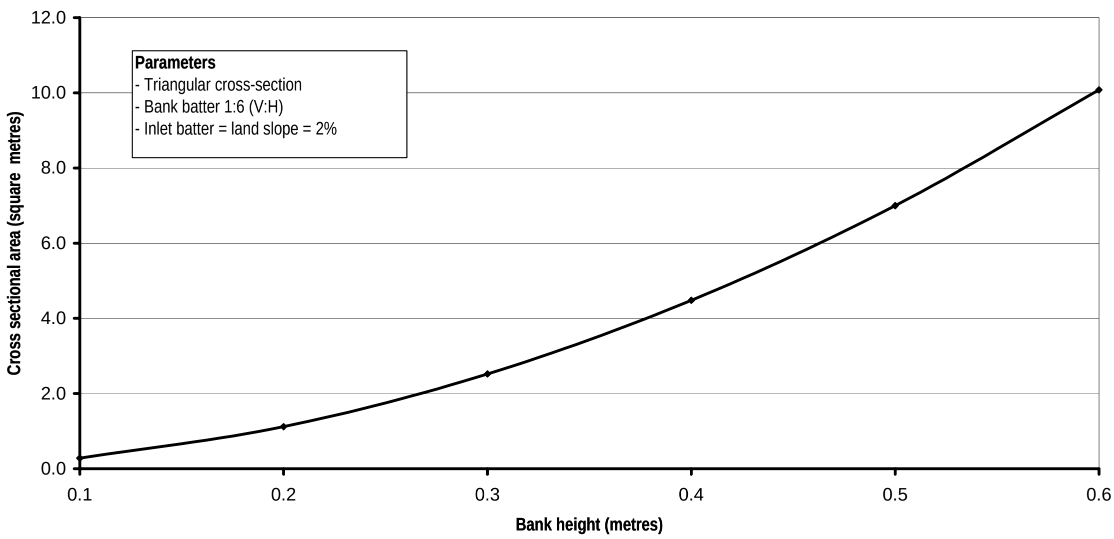
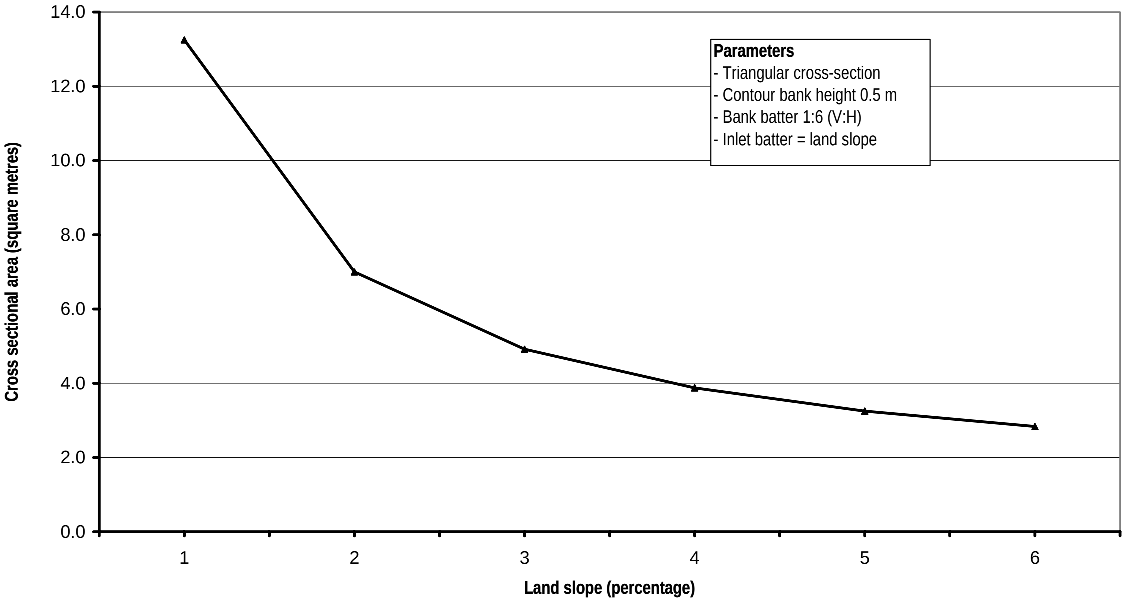


Figure 9.11 illustrates the effect that land slope has on contour bank capacity. The data is based on a triangular shaped broad-based bank with a flow depth of 0.5 metres and a bank batter of 1:6. It also assumes that the excavated batter conforms to normal land slope. On a land slope of 1% where a contour bank interval of 0.9 metres is used, half the contour bay would be under water if there was a flow depth of 0.45 metres. This illustrates the enormous amount of storage that contour banks can have on very low slopes.

Figure 9.11 Effect of land slope on contour bank cross-sectional area



Where land slopes are low, the excavated batter will often conform with the normal land slope after a few years of tillage operations. If the bank has been constructed with a bulldozer using a long length of travel in pushing up the bank then the excavated bank batter will almost conform with normal land slope after construction is complete.

Figure 9.12 also illustrates how land slope impacts on the cross- sectional area of contour banks. It illsustrates how 5% is the normally accepted limit for the construction of broad based contour banks with 1:4 batters.

Figure 9.12 Broad based contour banks with 1:4 batters on land slopes of 1%, 2% and 5%

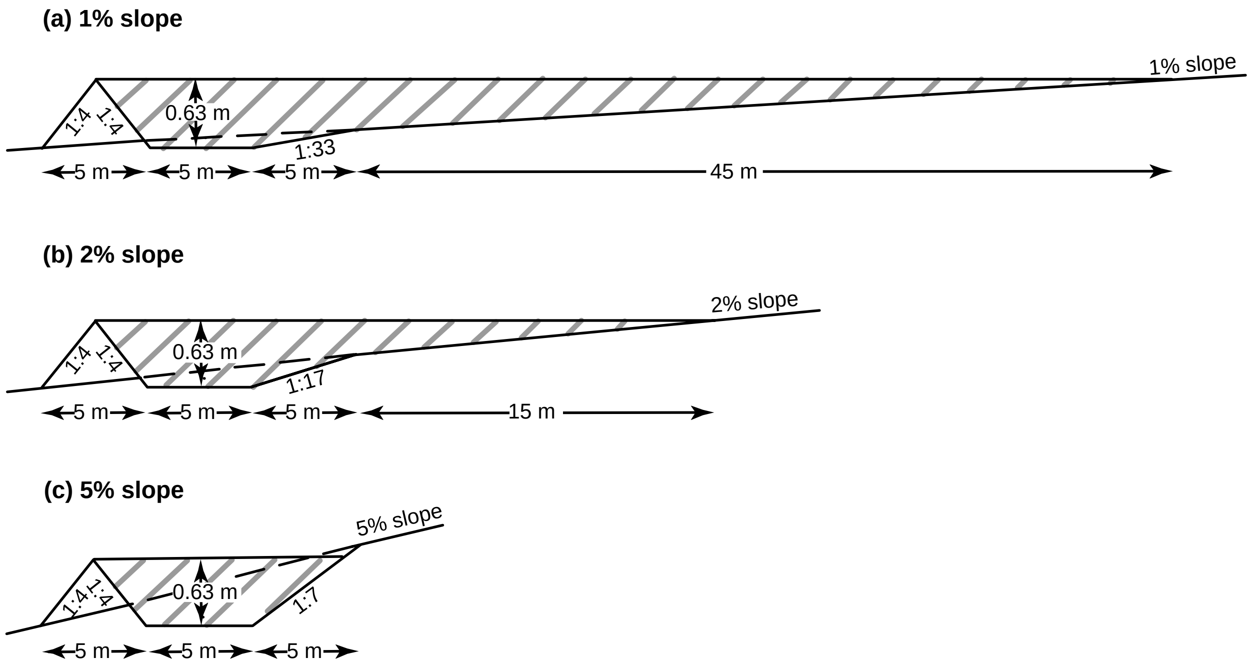
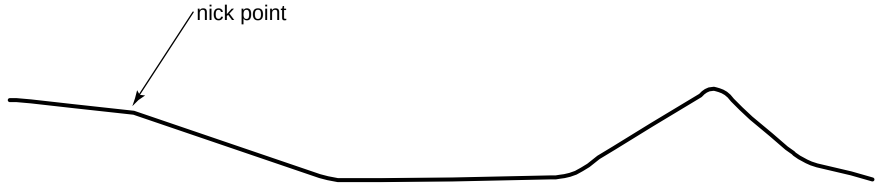


Figure 9.13 Contour bank cross-section illustrating the nick point



To provide protection against erosion of contour bank channels on steeper slopes, it is best to aim for a flat-bottomed channel (trapezoidal or parabolic). However, on steeper slopes there will be a distinct change in slope where the excavated batter meets the normal land slope. This point is referred to as the 'nick point' (Figure 9.13). It can contribute to rill erosion as overland flows meet the increased slope as they flow into the channel.

Machinery needs must be taken into consideration when determining contour bank cross-sections. The length and grade of the batters of contour banks should be constructed to suit the equipment used to operate on them (especially planting machinery). For cultivated banks, batters flatter than 1:4 (V:H) are recommended. Chapter 13 on *Controlled traffic farming* provides information on contour bank shapes suitable for traversing by machinery.

If a trapezoidal channel is constructed then the base must also conform with machinery needs. Tow paths for travelling irrigators require a trapezoidal shape with at least a 2.0 metre bottom width to help tracking of the irrigator.

9.27 Freeboard and settlement

Refer to the section on freeboard and settlement in Chapter 8, *Channel design principles*.

After construction, contour bank capacities need to be checked to ensure they have adequate capacity. Points for special attention are where contour banks cross old gully lines. Additional bank height is required at these locations to ensure the bank has adequate capacity to accommodate the design flow as it crosses the old gully line.

9.3 Design approach

As stated at the beginning of this chapter, contour banks are normally constructed according to general specifications that may apply to a particular situation in a district. Some land management field manuals provide such specifications which have been developed after numerous field observations over many years.

When it is necessary to carry out an individual design for a contour bank or to prepare or modify specifications for use in a district, the following approach is recommended.

In Chapter 8 the concept of combining equations 8.1 (Q=AV) and 8.2 (the Manning formula) was discussed. The resulting formula is as follows:

$$\frac{\mathbf{Q}}{\mathbf{A}} = \mathbf{V} = \frac{\mathbf{R^{0.66}\ S^{0.5}}}{\mathbf{n}} \quad \text{..........Equation 9.1}$$

Where

Q	=	the discharge or hydraulic capacity of the channel (m^3/s)
A	=	cross-sectional area (m^2)
V	=	average velocity (m/s)
R	=	hydraulic radius (m)
S	=	channel slope (m/m)
n	=	Manning coefficient of roughness

Because the channel in a contour bank may have surface conditions varying from a bare condition (Mannings *n* of 0.03) to a crop or standing stubble (Mannings *n* of 0.15 in the case of a wheat crop or standing wheat stubble), it is necessary to consider both conditions in the design. This requires the estimation of two design discharges. Figure 9.9 illustrates how the design peak discharge for a contour bank varies considerably for a high and low cover farming system. All paddocks are subject to varying amounts of cover. A low cover farming system refers to the management of the fallow but such a paddock will have a high cover level when it is growing a crop. A paddock where a high level of stubble management is used may have low cover during a period of drought when no crop is planted.

Since crop or standing stubble restricts flows in contour banks it is best to design initially for this condition and then check to see what happens when the design discharge occurs when the channel is bare. A limitation of this method of design, is that it does not take the temporary storage capacity of the contour bank channel into account. The method therefore provides an over-estimation of the actual capacity required. Galletly (1980) refers to the role of contour banks as temporary storage structures. Further research is required to develop a design method that incorporates storage capacity.

From substitution in the above formula the known factors will be the following:

- discharge Q
- gradient s
- roughness coefficient n.

Since we are initially designing for a high level of channel roughness, it can be assumed that the flow will be well below erosive velocities. Therefore we do not need to input a value of V into the above equation. The problem now comes down to finding a depth of flow in the contour bank channel that will give a hydraulic radius R and cross-sectional area A that will accommodate the required value of Q for a given gradient and value of Mannings *n*. This would require an iterative procedure.

A suitable design can be obtained by preparing a spreadsheet based on the required cross-sectional shape incorporating trial depths of flow and a high and low value of Mannings n. Table 9.6 provides an example of such a table. The table shows how erodible velocities (>0.5 m/s) will occur once the depth of flow in a bare channel exceeds 0.25 m depth of flow. However when the channel is protected by standing stubble, a flow depth of 0.7 m will only be flowing at 0.17m/s.

Table 9.6 Discharges and velocities for a range of flow depths for a trapezoidal shaped contour bank with a gradient of 0.2%

Depth (m)	Cross-sectional area (m^2)	Hydraulic Radius (m)	Mannings *n* = 0.15 eg. standing wheat stubble		Mannings *n* = 0.03 eg. bare cultivated channel	
			Velocity (m/s)	Discharge (m^3/s)	Velocity (m/s)	Discharge (m^3/s)
0.10	0.48	0.09	0.06	0.03	0.29	0.14
0.15	0.78	0.12	0.07	0.06	0.37	0.29
0.20	1.12	0.15	0.09	0.10	0.44	0.49
0.25	1.50	0.19	0.10	0.15	0.49	0.74
0.30	1.92	0.22	0.11	0.21	0.54	1.04
0.35	2.38	0.25	0.12	0.28	0.59	1.41
0.40	2.88	0.28	0.13	0.37	0.64	1.83
0.45	3.42	0.30	0.14	0.46	0.68	2.32
0.50	4.00	0.33	0.14	0.58	0.72	2.88
0.55	4.62	0.36	0.15	0.70	0.76	3.50
0.60	5.28	0.39	0.16	0.84	0.80	4.20
0.65	5.98	0.41	0.17	0.99	0.83	4.97
0.70	6.72	0.44	0.17	1.16	0.87	5.82

Shaded area indicates erosive velocities (> 0.5 m/s)
Parameters:

- Trapezoidal cross-section with inlet slope of 1:10, bank slope of 1:6 and bed width of 4 metres
- Contour bank gradient of 0.2%

9.31 Example

Determine the constructed height for a contour bank to accommodate discharges of 0.4 m^3/sec when a contour bay has a mature wheat crop (n = 0.15) and a discharge of 0.9 m^3/sec when the contour bay is under bare fallow (n = 0.03). The contour bank is to have a trapezoidal cross-section with inlet batters of inlet slope of 1:10, bank slope of 1:6 and bed width of 4 metres and a gradient of 0.2%. Assume that the bank will be built by a bulldozer and that it will settle by 50% after construction.

Solution

1. Use a spreadsheet to prepare a table similar to Table 9.6 showing velocities and discharges for the two values of *n* for a range of trial depths and for an acceptable gradient.
2. From Table 9.6 when *n* = 0.15 a flow depth of 0.4 m will have a discharge of 0.37 m^3/sec with a velocity of 0.13 m/sec.
3. From Table 9.6 when *n* = .03 a flow depth of 0.3 m will have a discharge of 1.04 m^3/sec with a velocity of 0.54 m/sec.
4. The depth of flow obtained in step 1 shows that a depth of flow of 0.4 m would be sufficient to accommodate the required flow. (If an alternative design was required an additional spreadsheet could be prepared based on a different gradient.)
5. An allowance of 0.15 m for freeboard would give a recommended settled bank height of 0.55 metres.
6. An additional 50% should be added to allow for settlement giving a constructed height of 1.1 metres (using equation 8.10).

Note that should the bank carry the design depth of flow of 0.4 m in a bare fallow condition, Table 9.6 shows that it would be carrying a discharge of 1.83 m^3/sec at a velocity of 0.64 m/sec. Such a velocity is likely to be erosive but such an event would be rare as it is double the design discharge for bare fallow. Since bare fallow farming systems contribute to high rates of soil erosion in a contour bay, it is most desirable that a high cover farming system is adopted rather than one that has bare fallows.

9.32 Contour bank design charts

Design charts can be prepared to show how contour banks with a specified cross-section perform under a range of values of Mannings *n*, gradient and flow depth. Figure 9.14 is an example of a contour bank design chart for a broad-based contour bank with a bottom width of 4 metres and batters of 1:6 and 1:10. The three graphs illustrate the dramatic affect that surface roughness in the channel has on both velocity and discharge.

Figure 9.14 Contour bank design chart for a trapezoidal shape and a range of values for Mannings *n*, channel gradient and flow depth

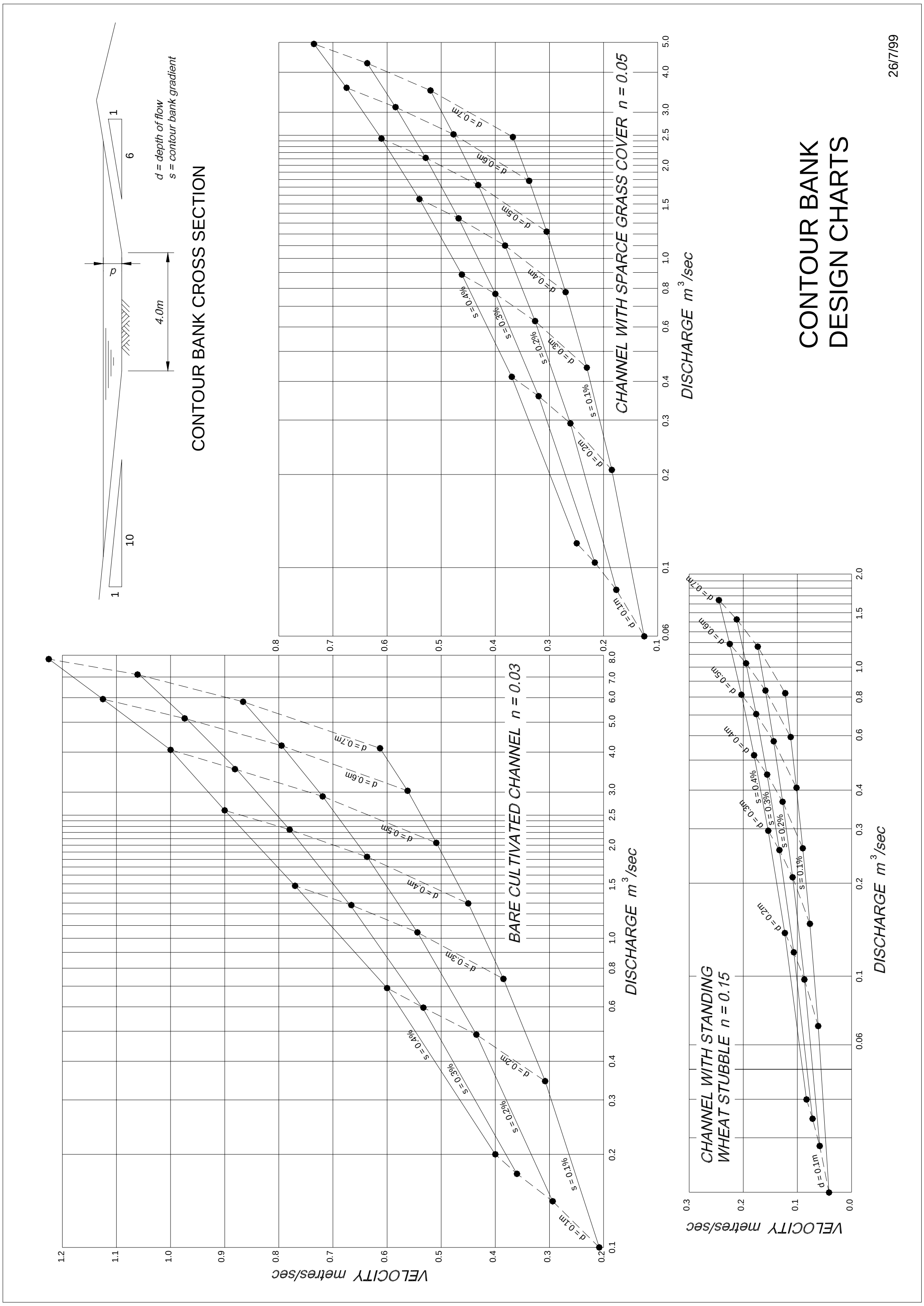
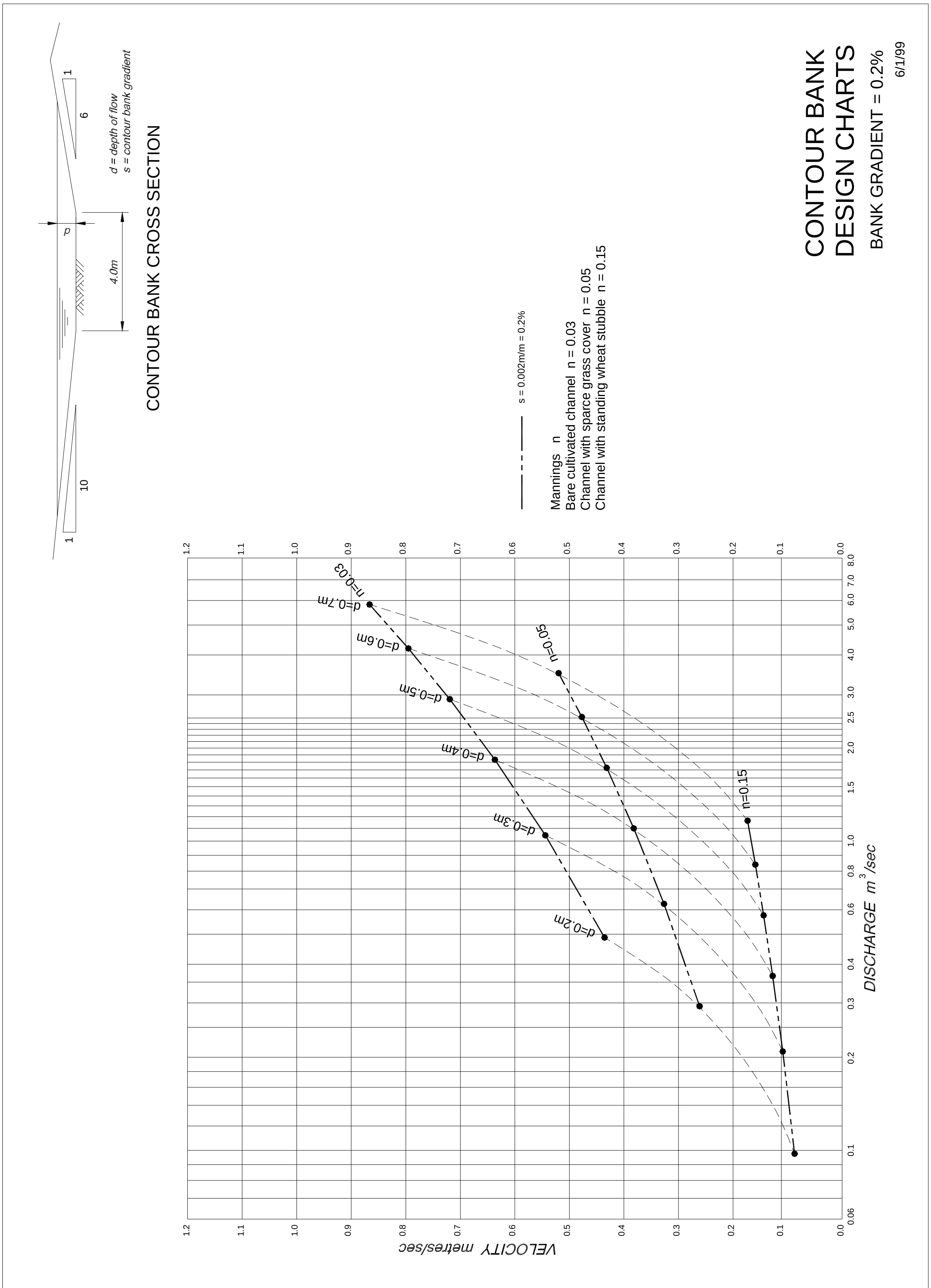


Figure 9.15 shows a graph for the same cross-section as Figure 9.14 but for a constant gradient of 0.2% and three values of Mannings *n*.

Figure 9.15 Contour bank design chart for a trapezoidal shape and a range of values for Mannings *n* and flow depth



Chapter 10

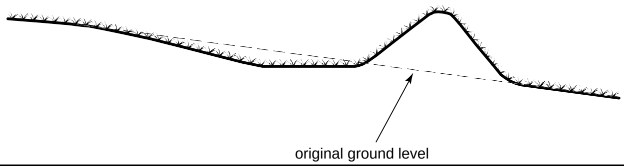
Diversion banks

Diversion banks (Figure 10.1) divert runoff away from cultivation or buildings into stable waterways, natural depressions or water storages. They are usually constructed using a bulldozer to a height of at least 1 metre. Diversion banks are similar in many respects to perched waterways (refer to Chapter 11, *Waterways*). Where the failure of a diversion bank would have serious consequences, its design should be based on an increased ARI eg. 20 to 50 years.

Typical uses for diversion banks are as follows:

- above contour bank systems to intercept runoff from areas above cropping land
- in strategic locations within cultivated paddocks where they may be required to carry more runoff than a normal contour bank
- to divert runoff away from unstable areas (this option is only viable if there is a suitable disposal area for the runoff).
- to collect runoff from cross road drainage points and direct it to a waterway
- to collect runoff from small constructed or natural waterways and divert it into a larger waterway.

Figure 10.1 Diversion bank cross-section



10 .1 Cross-sections

Diversion banks usually have a trapezoidal shape as shown in Figure 10.1. On slopes of above 2%, runoff will usually be contained entirely within the excavation. The excavated batter slope will increase as land slope increases and will be at risk from erosion until it is stabilised with vegetation.

However, on slopes of less than 2%, diversion bank cross-sections may approximate to a triangular shape where the upstream batter conforms to normal land slope. In such cases, the storage capacity of the structure will extend up-slope depending on the slope of the land.

10.2 Gradients

There is considerable scope for varying the gradients of diversion banks provided they have grassed channels. When constructed as the top bank of a contour bank system, a gradient that is slightly steeper than contour bank gradient would normally be used. Most diversion banks above contour bank systems have gradients of around 0.5%. This means that the diversion bank tends to follow the same direction as the contour bank below it, resulting in a contour bay that is reasonably easy to work.

Because the channel is grassed, gradients higher than 0.5% can be used. In horticultural situations it is common for diversion banks to have gradients from 1% to 3%. In such circumstances the diversion bank virtually becomes a perched waterway.

10.3 Stabilisation

It is desirable that the diversion bank channel and batters should be stabilised with vegetation as soon as possible after construction. Species used for stabilising waterways or any pasture species suited to the local area can be used. If gradients exceed 0.5% and the diversion bank becomes a perched waterway then erosion resistant species as recommended for waterways should be used.

Annual species such as millet (summer) or oats (winter) are suitable for providing rapid, temporary protection from erosion until perennial species become established.

10.4 Freeboard and settlement

Refer to the section on freeboard and settlement in Chapter 8 for information about this topic.

10.5 Design approach

As in the design of contour banks and waterways the following formula needs to be considered:

$$\frac{Q}{A} = V = \frac{R^{0.66}\, S^{0.5}}{n}$$

Where

Q	=	the discharge or hydraulic capacity of the channel (m^3/s)
A	=	cross sectional area (m^2)
V	=	average velocity (m/s)
R	=	hydraulic radius (m)
S	=	channel slope (m/m)
n	=	Manning coefficient of roughness.

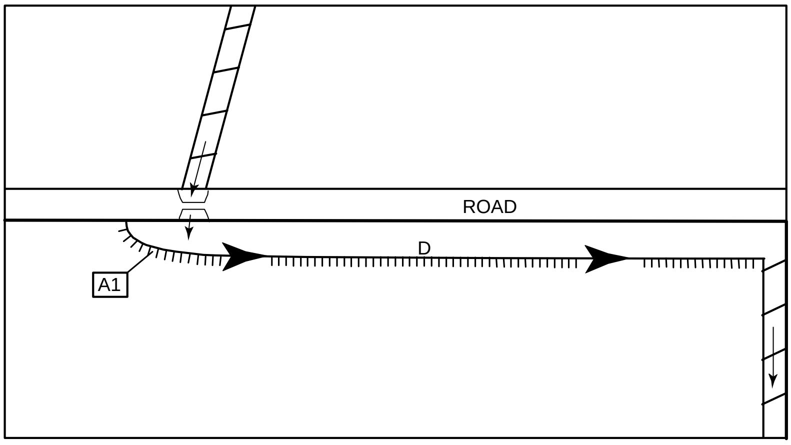
In estimating the design discharge, consideration should be given to the consequences of the diversion bank failing. It may be appropriate to design a diversion bank for an ARI as high as 50 years or even higher if the circumstances permit (refer to Chapter 4, *Designing for risk*).

If the channel is grassed, then it is appropriate to apply the n-VR relationship rather than using a fixed n value (refer to Chapter 8, *Channel design principles*).

The approach to designing a diversion bank will vary with the following situations:
- slopes exceeding 2% (grassed channel)
- slopes less than 1% (grassed channel)
- cultivated channel.

Where a diversion bank intercepts runoff from a concentrated flow such as the discharge from a road culvert, additional capacity should be provided at the point of receival (Design point A1 in Figure 10.2). An additional bank height of 0.3 metres is provided as a general guide in such situations.

Figure 10.2 Diversion bank receiving runoff below a road culvert



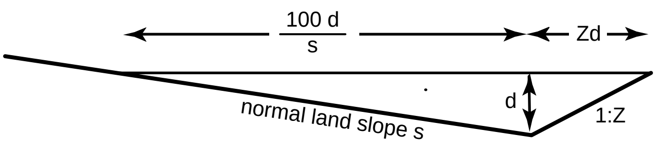
10.51 Slopes exceeding 2%

Where slopes exceed 2% and most of the runoff will be contained in the excavated channel of the diversion bank, the design of the diversion bank can be considered to be the same as that used for designing a waterway and Chapter 11 should be referred to. As the batter slopes on the bank and on the excavated slope are likely to differ, an average slope can be chosen and used in the design exercise.

10.52 Slopes less than 2%

Where slopes are less than 2%, diversion bank cross-sections may approximate to a triangular shape where the upstream batter conforms to normal land slope (Figure 10.3).

Figure 10.3 Diversion bank cross-section on a land slope below 2%



The formula used for the cross-section of such a channel is as follows:

$$\mathbf{A = \frac{d^2(100/s + z)}{2}}$$ .... Equation 10.1

The following formula is used to obtain an adequate approximation of the wetted perimeter:

P = d(100/s + z) .... Equation 10.2

Where

A = Cross-sectional area (m^2)
P = wetted perimeter (m)
d = depth of flow (m)
s = land slope (m)
z = bank batter (1:Z) (V:H)

To assist with design, a spreadsheet can be prepared in a similar manner to the approach used in contour bank design. Table 10.1 is an example of such a table based on a triangular cross-section, a bank batter of 1:3, an up-slope batter that conforms to the land slope of 2% and a gradient of 0.5%.

Table 10.1 Example of a spreadsheet prepared for diversion bank design

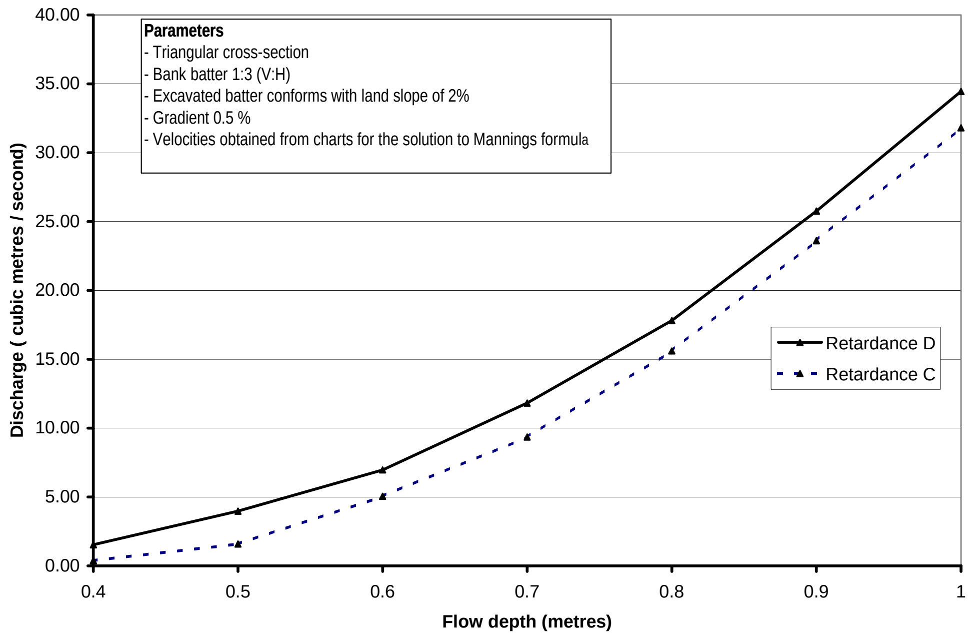
Depth of flow (m)	Cross sectional area (m^2)	Wetted permitter (m)	Hydraulic radius (m)	Retardance C		Retardance D	
				Velocity m/s	Flow m^3/s	Velocity m/s	Flow m^3/s
0.3	2.4	15.9	0.15	na	na	0.18	0.43
0.4	4.2	21.2	0.20	0.09	0.38	0.36	1.53
0.5	6.6	26.5	0.25	0.24	1.59	0.63	4.17
0.6	9.5	31.8	0.30	0.53	5.06	0.73	6.96
0.7	13.0	37.1	0.35	0.72	9.35	0.94	12.21
0.8	17.0	42.4	0.40	0.90	15.26	1.00	16.96
0.9	21.5	47.7	0.45	1.10	23.61	1.20	25.76
1.0	26.5	53.0	0.50	1.20	31.80	1.30	34.45

Parameters:
- Triangular cross-section
- Bank batter 1:3
- Land slope 2% (upper batter conforms with land slope)
- Gradient 0.5%

Velocities obtained from charts for the solution to the Manning formula (eg. Figure 8.4)

The results obtained in Table 10.1 are shown graphically in Figure 10.4

Figure 10.4 Diversion bank discharges based on flow depth and Retardances C and D



10.53 Diversion banks with cultivated channels

If a diversion bank within a cultivated area was to have a channel that was cultivated as part of the cropping cycle, then it is virtually a large contour bank. In such situations, Chapter 9, *Contour banks* should be referred to in relation to their design. ■

Chapter 11

Waterways

In soil conservation terminology, the term 'waterway' has a different meaning from the more conventional use of the term. Waterways for soil conservation purposes collect runoff from contour bank systems and convey it at a safe velocity to a drainage line or creek system. Waterways are especially vulnerable to erosion because of the concentrated flows they need to accommodate. They should be carefully designed, constructed, stabilised and maintained to reduce the risk of failure by gullying or by overtopping. Where the failure of a waterway would have serious consequences, its design should be based on an increased ARI of 20 to 50 years.

Waterways are designed by taking into account the size of the catchment area, soil type, land slope, land use, and expected grass cover in the channel. They are constructed with farm dozers, bulldozers, graders or self-loading scrapers and are usually constructed from the inside.

There is a tendency for many farmers to consider the land occupied by waterways to be a loss of valuable land. This can lead to the construction of waterways that are too narrow, leading to high runoff velocities and gullying within the waterway. The area of land occupied by a waterway is often less than people imagine. A 1 km long waterway with a 20 m width would occupy only 2 ha of land. Waterways can be used for strategic grazing but if stock have regular access to waterways, erosion is likely to occur.

Waterways can be a neglected component of a soil conservation system. Insufficient attention is often given to their stabilisation and maintenance. The fact that it may take 2 to 3 years for a waterway to have enough grass growth to safely accept runoff can disillusion farmers who are keen to implement soil conservation measures to control erosion in their paddocks. Farmers may be willing to accept an eroding waterway at the side or the middle of a paddock provided the erosion within a paddock is under control. However this can lead to considerable soil loss within the waterway with impacts on downstream water quality. It may also lead to erosion at the outlets of contour banks flowing into the waterway.

Where possible, waterways should be located in natural drainage lines. Here the slopes are usually lower than adjacent parts of the catchment, and the topography tends to confine the flow to the waterway. Soils and moisture levels are usually more favourable to vegetative growth in natural drainage lines.

Ideally, waterways should conform with natural meanders in a drainage line. It is generally not desirable to 'straighten' watercourses by removal of the natural meanders. Such action leads to higher construction costs and inhibits the natural inclination for water to flow in a meandering pattern. However there are many situations, especially in small paddocks, where there is no natural drainage line. In these cases a straight waterway, often following a fence line, will usually be the best option. Such waterways are referred to as 'perched waterways'.

Waterways are generally not recommended for construction on floodplains. In these situations the aim is to ensure that flood flows spread across the floodplain as they would under natural conditions. Such spreading can be facilitated by the use of strip cropping practices. Small subsurface waterways may be required to accommodate residual flows. As these waterways have no above ground banks, flood flows are not diverted.

Prolonged flows in waterways may occur during low intensity rainfall events that occur over several days on saturated catchments. Such flows will be more pronounced where there are long contour banks and zero tillage farming systems. Soils and grass cover that are capable of withstanding a short duration flood peak above that which they were designed for, may fail when subjected to a prolonged low flow when soils are super saturated with greatly reduced cohesive strength. Such conditions may also have a negative impact on vegetative growth in the waterway.

The installation of sub-surface drainage systems in waterways has rarely been implemented in Queensland. However such a system could greatly improve the stability of waterways by minimising the damage resulting from small trickle flows.

The widespread adoption of zero tillage systems means that runoff with low turbidity will usually be exiting from contour bank outlets. Such runoff has a greater potential to cause erosion in a waterway than turbid runoff.

While trees are a natural feature of riparian zones and provide many benefits including the stabilisation of creek banks, they are not considered to play a beneficial role in the stabilisation of waterways constructed for soil conservation purposes. Tree roots provide stability to steep creek banks but this function is not required in a constructed waterway. In waterways for soil conservation purposes, stability is provided by close growing swards of vegetation on the soil surface. The presence of trees in such systems can inhibit grass growth by competition for water and nutrients and by shading out the grass species. Grazing animals are attracted to the shade provided by trees and such areas are usually devoid of surface cover. It is desirable to have clumps and corridors of trees in a cultivation paddock but it is considered that there are risks associated with locating them in and immediately adjacent to constructed waterways.

11.1 Waterway cross-sections

Waterways for soil conservation purposes are normally constructed to a trapezoidal (Figure 11.1), parabolic (Figure 11.2) or a triangular shape.

Figure 11.1 Trapezoidal waterway

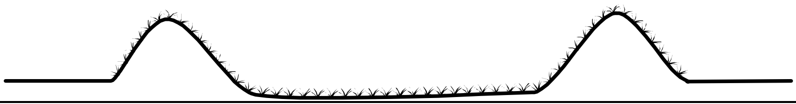
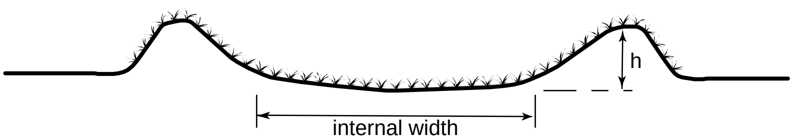


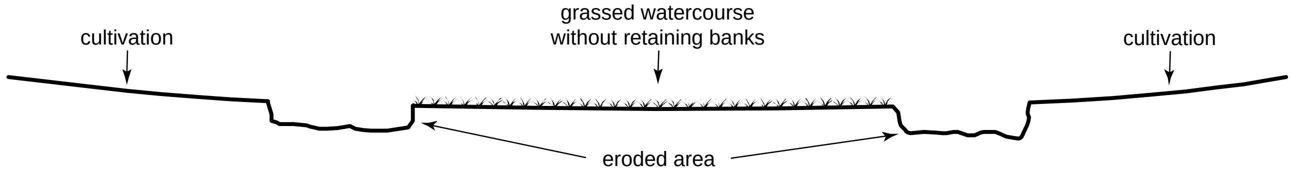
Figure 11.2 Parabolic or dish-shaped waterway



Parabolic cross-sections (or trapezoidal waterways constructed with a slight 'dish') most closely resemble those found in natural waterways and small flows will be carried with less meandering than a flat-bottomed channel. Providing soil depth is not limiting, the 'dish' can be constructed to provide a 10 cm additional depth. A flat-bottomed waterway is recommended on land slopes over 5% where a shallow depth of flow is required to prevent excessive velocities.

Retaining banks are essential to ensure that the flow remains in the waterway. If they are not constructed, runoff will have a strong tendency to flow along the cultivation on either side of the grassed drainage line (Figure11.3). This leads to gullying on one or both sides of the grassed drainage line. Retaining banks also define the exact area of land occupied by the waterway. This prevents a farmer from gradually expanding the cultivated land into the waterway.

Figure 11.3 Cross-sectional view of a watercourse with erosion in the adjacent cultivation



Triangular shaped channels are generally avoided, as they are more likely to erode because of the higher velocities in the 'V' of the channel.

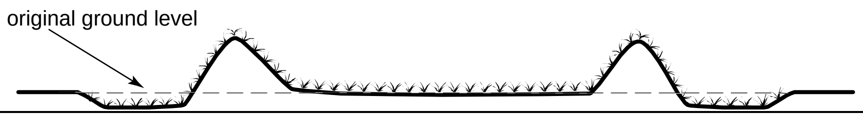
Graders and scrapers are suitable for constructing trapezoidal shaped channels. Parabolic channels are more difficult to construct than flat-bottomed channels and are usually constructed with bulldozers or ploughs.

Soil type may control the maximum depth of excavation. Stability problems may be encountered if infertile, or unstable subsoils are involved. Whenever possible, topsoil should be spread over excavated channels as part of the construction process. One way to achieve this is to construct the first 20 metres of the waterway deeper than it needs to be. Topsoil can then be moved in from the 20 metre section below and the process continued.

A minimum excavation depth may be required where drainage is important, for example, where deep furrows are required to discharge directly into waterways.

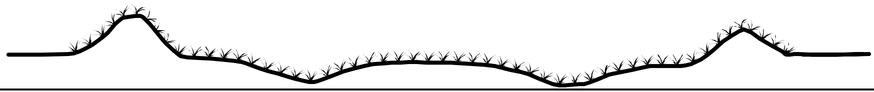
In situations with highly erodible subsoils, it is desirable to avoid disturbing the area where concentrated flow will occur. In such cases, the waterways are constructed by excavating the retaining bank from the outside so that the section for water flow is left undisturbed (Figure 11.4). Another approach on low sloping situations is to obtain soil for use in the banks from a series of excavations in the centre of the waterway. Such an operation requires the use of a scraper.

Figure 11.4 Waterway with banks built from the outside



A double-dished bottom can be used in low sloping situations on waterways wider than 30 metres (Figure 11.5). This type of construction allows the central area of the waterway to remain undisturbed.

Figure 11.5 Waterway with a double-dished bottom



11.11 Perched waterways

In some paddocks there may be no suitable natural depression available and it can be convenient to construct a waterway adjacent to a fence. Such waterways will have some degree of side slope unless the fence runs directly up and down the slope. As these waterways are elevated in comparison to any adjacent natural watercourses they are referred to as 'perched' waterways

(Figure 11.6). They may only need a bank on one side depending on the amount of side-slope involved. Perched waterways generally require a significant amount of excavation across the waterway to produce a relatively flat channel. Such construction requires a higher level of skill than that required for a conventional waterway. Perched waterways should be avoided where subsoils have high levels of sodicity.

In the event of a perched waterway overflowing, damage to adjacent areas is likely to be greater than with waterways located in natural depressions.

An advantage of perched waterways is that they do not receive runoff until diversion and contour banks are constructed into them. This means that they can be constructed and planted to vegetation several years prior to the construction of contour banks. Where waterways are constructed in natural depressions they are referred to as ‘live’ waterways and must accept runoff as soon as it occurs. This creates a period of risk until the waterway has stabilised with vegetation.

Figure 11.6 Perched waterway

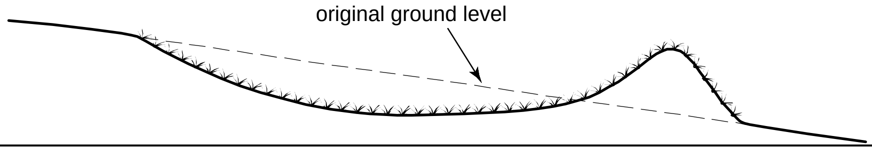
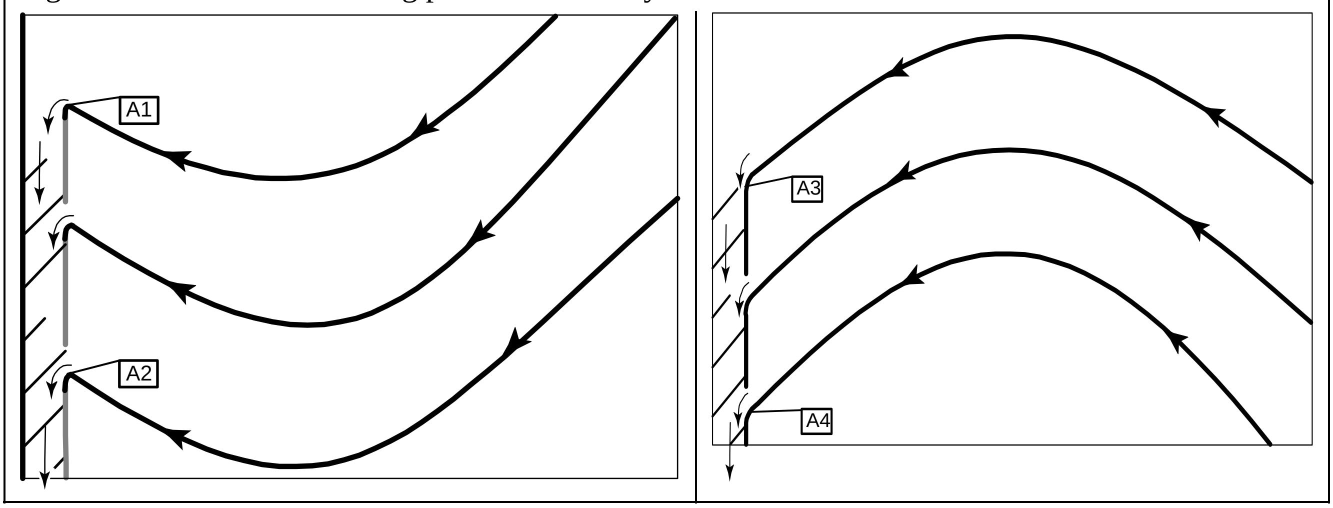


Figure 11.7 is a plan view showing two perched waterways in fenced paddocks. For waterway A1–A2 the orientation of the contours means that there is a natural tendency for runoff to flow against the waterway bank adjacent to the fence. Failure of this waterway would mean that runoff would enter the neighbouring property (if the fence was a property boundary). In such situations it would be advisable to design for a higher than normal return period. In waterway A3–A4 the tendency is for runoff to flow against the bank furthest from the fence. Care needs to be taken to ensure that there is adequate capacity at the point where the contour bank enters the waterway (eg. design points A3 and A4) as this can be a common point for structure failure through overtopping. Other examples of perched waterways are provided in Chapter 2, *Soil conservation planning*.

Figure 11.7 Plan view showing perched waterways



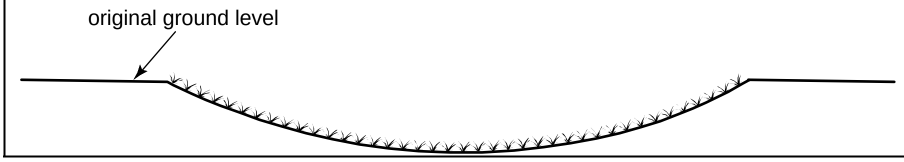
11.12 Subsurface waterways

In horticultural situations, subsurface waterways are often constructed (Figure 11.8). They can be crossed by tractors and machinery to improve workability of the paddock. They also have an application in catchment outlets where they may be used in conjunction with strip cropping.

Batter slopes should be 1:4 or flatter. Waterways that are maintained by slashing should have batters flatter than 1:3 and the dimensions of the waterway should ideally be multiples of the width of the slashing equipment.

When crossing subsurface waterways with implements, they must be lifted so that the grass lining of the channel is not damaged. The waterway channel should be deeper than the channel of adjacent structures so runoff from these structures can flow freely into the channel.

Figure 11.8 Subsurface waterway



11.2 Design velocity

Recommended maximum velocities vary for different types of cover and soil types. Issues to consider are:

- physical nature of the vegetation (type and distribution of root growth, and density and physical condition of top growth)
- erodibility of soil
- channel shape
- degree and uniformity of cover
- bed slope.

A guide to maximum recommended permissible velocities for use in design is provided in Table 11.1, which incorporates the effects of waterway slope, fraction of cover and soil erodibility.

Table 11.1 Recommended maximum velocities for consolidated, bare and vegetated channels

Channel gradient %	Recommended maximum velocities (m/s) related to percentage of anchored surface cover			
	0% cover	50% cover	75% cover	100% cover
	Bare surfaces which are consolidated but not cultivated	Tussocky species (includes most native grasses)	Rhodes grass and creeping species such as couch grass in moderate condition	Creeping species such as kikuyu that can be maintained as a permanent dense sod
	A. Erosion resistant soils (eg. Krasnozems)			
1	0.7	1.6	2.1	2.8
2	0.6	1.4	1.8	2.5
3	0.5	1.3	1.7	2.4
4		1.3	1.6	2.3
5		1.2	1.6	2.2
6			1.5	2.1
8			1.5	2.0
10			1.4	1.9
15			1.3	1.8
20			1.3	1.7
	B. Easily eroded soils (eg. Black earths, fine surface texture-contrast soils)			
1	0.5	1.2	1.5	2.1
2	0.5	1.1	1.4	1.9
3	0.4	1.0	1.3	1.8
4		1.0	1.2	1.7
5		0.9	1.2	1.6
6			1.1	1.6
8			1.1	1.5
10			1.1	1.5
15			1.0	1.4
20			0.9	1.3

Adapted from Gregory and McCarthy (1985)

The Froude Number (Equations 8.4 to 8.6) can be used to determine the susceptibility of a waterway to erosion. For safe design of vegetated channels, the Froude Number of the design flow should be between 0.8 and unity depending on the degree of erosion resistance provided by the vegetation. Where values exceed unity it would be necessary to ensure that the channel lining had a very high degree of erosion resistance. Table 11.2 provides values of Froude numbers for a trapezoidal waterway with a bottom width of 7 m, side slopes of 1:3, slope of 6% and retardance C.

Table 11.2 Froude Number values for a trapezoidal waterway

Flow depth	Velocity	Froude No
0.14	0.9	0.8
0.16	1.2	1.0
0.18	1.6	1.2
0.20	1.9	1.4

Parameters:

- bottom width of 7m
- bed slope 6%
- side slopes of 1:3
- retardance C

Froude numbers can be reduced by adopting a design with a lower velocity. This can be best achieved by using a cross-section incorporating shallower flows. If the Froude Number was to exceed unity, the vegetation in the waterway would have to be selected and managed so that it provides a high degree of erosion resistance.

11.3 Waterway stabilisation

Soil conservation waterways usually rely on a lining of vegetation to give protection from erosion. Vegetation protects the channel by reducing the velocity near the bed and covering and binding the soil together.

A uniform sod-forming grass having a dense relatively deep root system will offer the best protection against erosion. Species commonly used in Queensland are kikuyu, couch, African star grass, Rhodes, pangola, *Bothriochloa pertusa* and *Bothriochloa insculpta*. All of these species are exotics but are commonly found in agricultural areas. Local advice should be obtained to determine if a proposed species has weed potential in a particular area.

The small seeds that are a feature of most grass species lead to germination difficulties on cracking clay soils and this is a significant reason why farmers have difficulties in establishing stable waterways. Sods can be planted as an alternative to planting seed but this process is labour intensive, suitable planting material may not be readily available, and watering may be necessary until the sods become established.

Most native species grow in tussocks and have much less resistance to erosion than special purpose vegetation normally used in waterways. However native species are the best option where suitable stands already exist. It may be possible to construct waterway banks from the outside to ensure that the grass in the waterway is not disturbed.

Tussocky species will have lower recommended maximum velocities and will require a wider waterway than sod-forming species. Recommended maximum velocities for tussock grasses are lower than where sod-forming species are used, because:

- areas bare of vegetation exist thereby reducing the surface cover fraction
- tussock grasses generally produce the effect of very rough beds that disturb the smoothness of flow
- tussock grasses lack a dense, uniform root system.

11.31 Non-vegetative options for stabilisation

Bare soil waterways have been used on relatively flat irrigation land (<1%) in Coastal Burnett cane growing areas where a surface drainage function is required as well as runoff control. On such low slopes, grassed waterways may have widths that farmers consider to be excessive. Table 11.1 shows that bare, consolidated waterways (i.e. not cultivated) can have permissible velocities at 0.5 m/s on 1% slopes on easily erodible soils. Where slopes are less than 1%, experience has shown that design velocities were much lower than 0.5 m/s unless depths were so great that the waterway would be impractical to construct.

In urban situations, a wide variety of options are used for lining waterways. Although more costly than the use of vegetation, they offer advantages such as stability under higher velocities and they can accept runoff immediately after construction. Such options have rarely been used in agricultural applications. However they would be worthy of consideration in high value horticultural applications and chutes used in gully stabilisation. Specifications provided by suppliers should be checked to determine recommended maximum velocities for these surfaces. Examples of such options include:

- *Reinforced turf*. Greater protection from erosion can be obtained by using specially grown turf reinforced with a UV stabilised mesh. This turf can withstand much higher runoff velocities than normal turf and is available from commercial suppliers.

- *Turf reinforcement mats*. These consist of various products woven into a three dimensional web. They provide good initial ground coverage while allowing the growth of vegetation through the mat. Sediment is trapped in the three dimensional mat and provides additional stability to the system.

- *Rock*. Rocks may be set in cement or contained by wire netting

- *Concrete*. Not recommended in clay soils subject to cracking.

- *Geocells or cellular confinement systems*. Honeycombed shaped cells made of polyethelene that are filled with topsoil and turfed or filled with gravel and covered with a close weave wire netting.

- *Butyl rubber or UV resistant PVC sheets*. Useful for providing immediate protection to relatively small areas with minimal need for preparation of the surface to be covered.

11.4 Freeboard and settlement

Refer to the section on freeboard and settlement in Chapter 8, *Channel design principles.*

11.5 Bends in waterways

Soil conservation layouts occasionally require the use of a 90º bend in a waterway to direct runoff around a corner of a rectangular paddock. Bends in waterways should have as large a radius as possible and as a general guide, the outside bank on the curve should be given an additional height of 0.2 metres to 0.3 metres. An alternative is to construct a small dam with the spillway coming off at 90° to the inlet waterway.

11.6 Design approach

Consideration should be given to the locations in which specific designs are required. Refer to the section *Selection of design points* in Chapter 2, *Soil conservation planning*.

As discussed in the chapter on channel design principles, it is useful to use Equation 8.9 when determining the approach to waterway design.

$$\frac{\mathbf{Q}}{\mathbf{A}} = \mathbf{V} = \frac{\mathbf{R}^{0.66}\ \mathbf{S}^{0.5}}{\mathbf{n}}$$

Where:

Q	=	the discharge or hydraulic capacity of the channel (m^3/s)
A	=	cross-sectional area ($m^{2)}$
V	=	average velocity (m/s)
R	=	hydraulic radius (m)
S	=	channel slope (m/m)
n	=	Manning coefficient of roughness.

In the following sections, examples are provided for the design of waterways. Since the design runoff event may occur when the waterway condition varies from low levels of cover (eg. retardance E) to high levels of cover (eg. retardance B), a decision must be made on whether the design will be based on a single retardance or a high and low value for retardance.

If the design is based on two levels of retardance, the width of a waterway would be based on the velocity related to a low retardance value (eg. retardance D) and the depth based on a higher retardance value (eg. retardance B) where velocity will not be a limiting factor.

An example is provided on how to design a waterway from first principles. To simplify the task, charts are available based on a trapezoidal shape with 1:3 (V:H) batters, retardances of C and D and a range of slopes from 0.2% to 10%. Examples of such charts are provided in Figures 11.9 (slope 2% and retardance C) and Figure 11.10 (slope 2% and retardance D). Copies of all of the charts are provided in the *Appendix*. The computer program RAMWADE (**Ra**tional **M**ethod **Wa**terway **De**sign) can also be used to design waterways. The program can design for a range of retardances from B to D.

Figure 11.9 Waterway design chart for retardance C and land slope of 2%

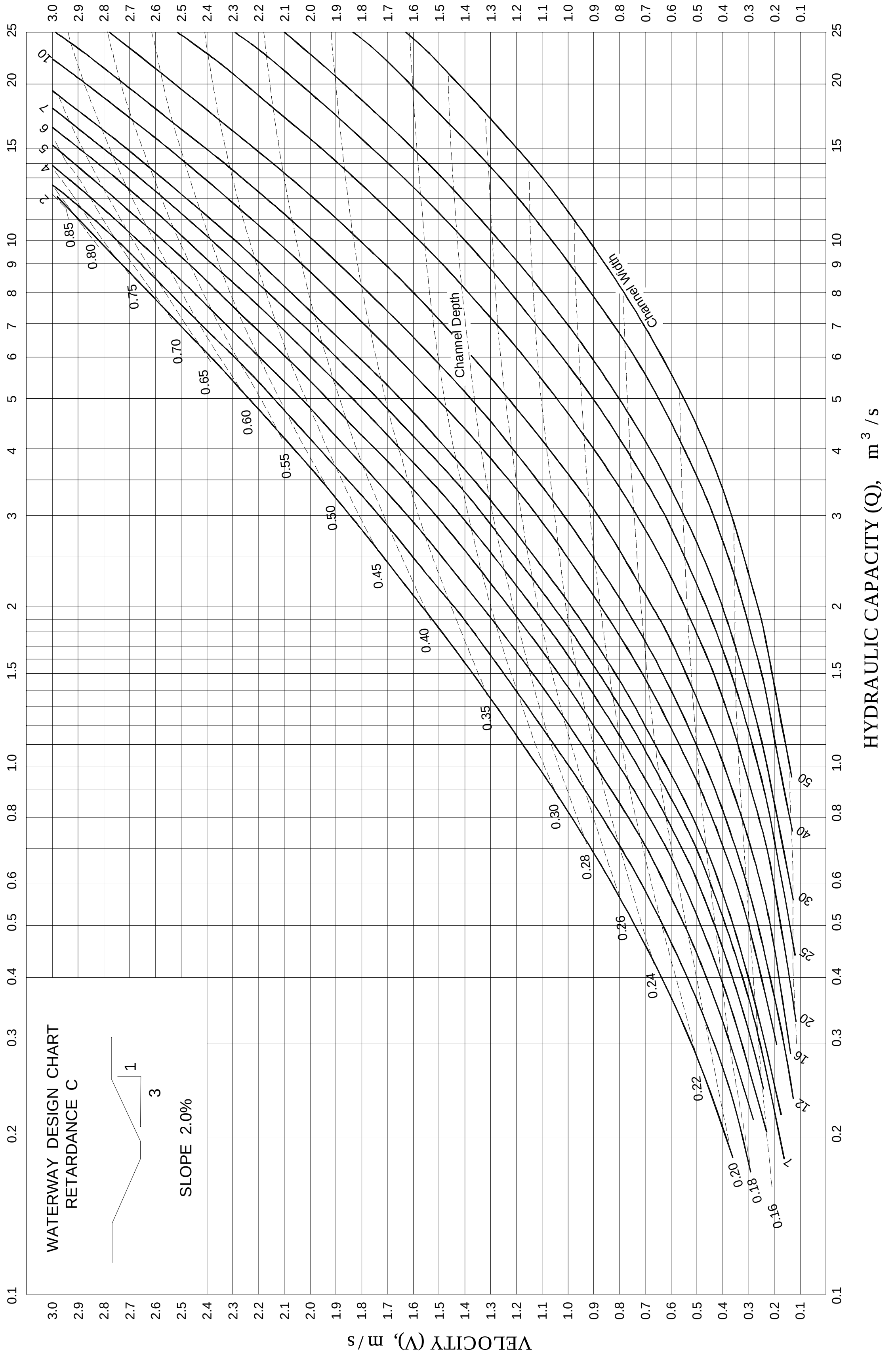
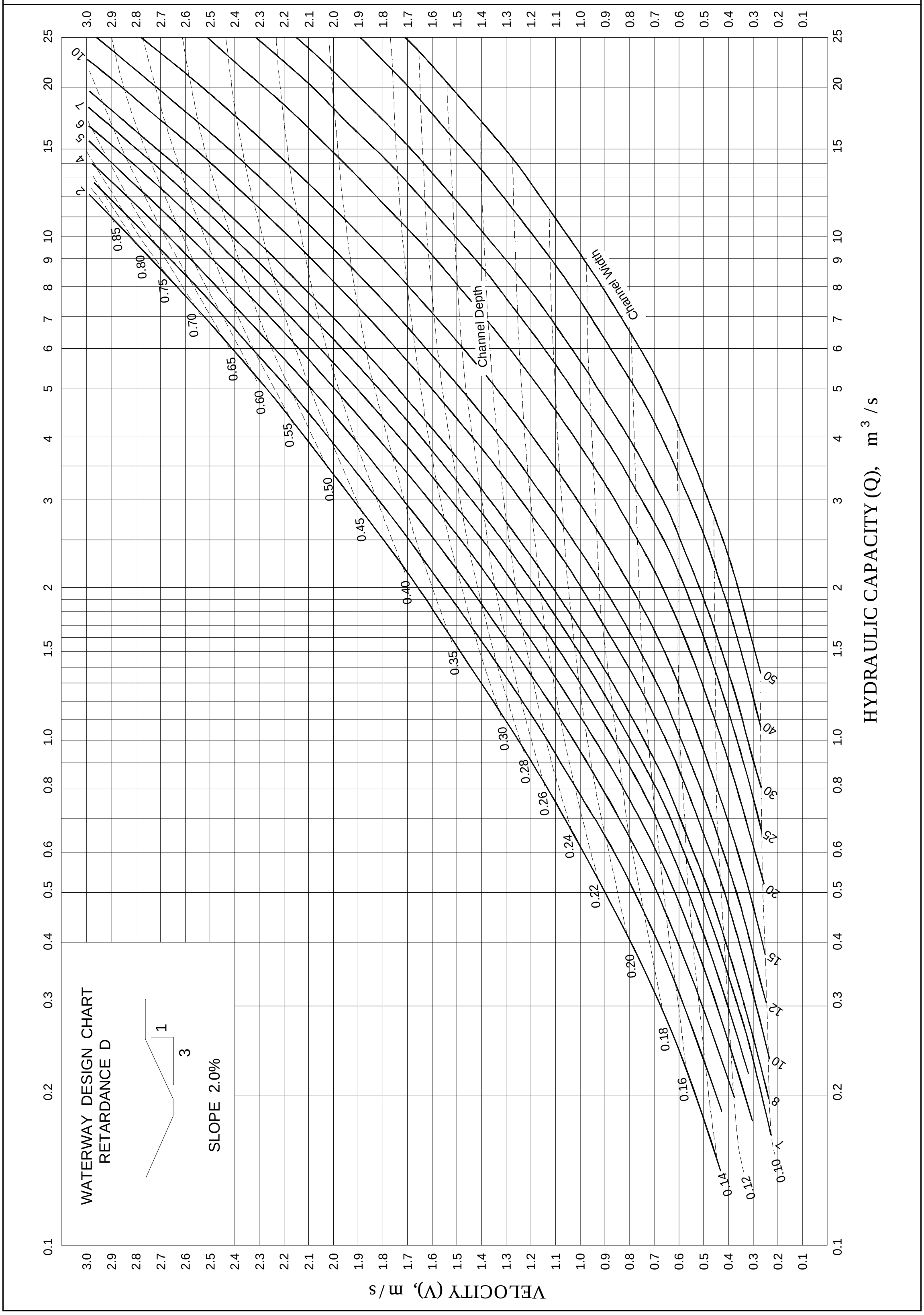


Figure 11.10 Waterway design chart for retardance D and land slope of 2%



The high end of a waterway which carries runoff from only one bank is usually not designed but a minimum top width of about 6 metres (from bank centre to bank centre) is used to enable entry by farm machinery such as mowing equipment.

11.61 Design of a waterway based on one level of retardance

The following steps explain how to design a waterway from first principles for a single retardance value.

A Determine the required cross-sectional area of the waterway

1. Calculate the discharge Q.
2. Estimate a safe design velocity appropriate to the slope, vegetation type and soil erodibility (refer to Table 11.1 *Recommended velocities for consolidated, bare channels and vegetated channels*).
3. Calculate the required cross-sectional area (A= Q/V).

B Determine the required hydraulic radius of the waterway

1. Select the level of retardance eg retardance C.
2. Measure the slope at the design point.
3. Using the solution to the Manning formula for the selected retardance, calculate the hydraulic radius for the specified velocity and slope (Figure 8.4 *Solution of the Manning formula for retardance C* or refer to the *Appendix* for other values of retardance. Note that you do not require a value of *n* to use this graph).

C Select a cross-sectional shape for the waterway

Normal waterway shapes are trapezoidal, parabolic or triangular.

D Determine the appropriate dimensions for the waterway

Use an appropriate chart to determine the dimensions for a specified waterway shape when the cross-sectional area and hydraulic radius are known. Figure 8.4 *Dimensions of trapezoidal channels with 1:3 side channels* is an example of such a chart. Other charts are available in the *Appendix*.

E Calculate constructed bank height

Add 0.15 m to the depth of flow to allow for freeboard. Add an additional amount to account for settlement of the bank after construction. Refer to Table 8.3 and Equation 8.10

F Calculate the Froude number to ensure that the value is less than unity

Refer to Equation 8.6.

Waterway design example 1

Design a trapezoidal shaped waterway with batters of 1:3 (V:H) to accommodate a discharge of 3 m^3/s on a land slope of 2%. Assume that the vegetation in the waterway will be maintained at a constant retardance of C and the design velocity is 1.2 m/s. (Note that the following example shows how to design a waterway from first principles. Since the required design is a trapezoidal shape with 1:3 (V:H) batters and a retardance of C, Figure 11.9 can also be used to obtain a solution.)

A Determine the required cross-sectional area of the waterway

A = Q/V = 3/1.2 = 2.5 m^2

B Determine the required hydraulic radius of the waterway

Using the *Solution to the Manning formula for retardance C* (Figure 8.4), calculate the hydraulic radius for the specified velocity of 1.2 m/s.
The value of the hydraulic radius is 0.25.

C Select a cross-sectional shape for the waterway

A trapezoidal shape has been specified.

D Determine the appropriate dimensions for the waterway

Using Figure 8.5 (*Dimensions of trapezoidal channels with 1:3 (V:H) side slopes*) and the values of 0.25 for R and 2.5 for A, determine the required bottom width of 9 m and depth of flow of 0.27 m

E Calculate constructed bank height

Add a value of 0.15m to the depth of flow to account for freeboard
0.27 + 0.15 = 0.42

Assuming settlement of 30%, calculate constructed height of 0.6 m (Equation 8.10)

F Calculate top width

Top width = Bottom width + (Batter slope *(flow depth + freeboard))

= 9 + (3*0.42)

= 10.3m

G Calculate the Froude Number

Using equation 8.6 a value of 0.85 is obtained which is acceptable.

11.62 Design of waterways based on two levels of retardance

The above example indicates how to determine the dimensions of a trapezoidal shaped waterway based on a single retardance. To design the same waterway for a higher level of retardance it is necessary to determine the depth required for that retardance. The waterway width will be the same as that calculated for the lower retardance. Velocity will not be a constraint as it will be lower than the permissible velocity used in the design for the low retardance.

Equation 8.8 can be used to determine this depth.

$$\frac{Q}{A} = \frac{R^{0.66} S^{0.5}}{n}$$

The table below gives a guide to determining the values in the above equation.

Q = value is known

A = $bd + Zd^2$

R = $\frac{bd + Zd^2}{b + 2d\sqrt{(Z^2 + 1)}}$

S = Value is known

n = 0.030 + 0.00501/VR (From Figure 8.3, for V substitute the value Q/A)

Where

- b is the width of the waterway calculated for the lower retardance
- d is the depth of flow
- Z is the batter slope 1:Z (V:H)

As depth is the only unknown in the above equation it can be determined using an iterative approach. The velocity at which the flow will be occurring can then be determined from the formula V = Q/A.

An alternative to the above approach is to use the waterway design charts as shown in the following example. The computer program RAMWADE can also be used.

Waterway design example 2

Use waterway design charts to determine the specifications for a trapezoidal shaped waterway with batters of 1:3 to accommodate a discharge of 4 m^3/s on a land slope of 2% at a maximum velocity of 1.2 m/s. Determine the width of the waterway based on retardance D and the depth based on retardance C.

Solution
1. From Figure 11.10 (*Waterway design chart for Retardance D and land slope of 2.0%*) determine the width of waterway required to accommodate the flow of 4 m^3/sec on a 2% slope at a velocity of 1.4 m/s
Answer: Bottom width is 15 metres (the depth of flow is 0.22 m)

2. Assuming a bottom width of 15 metres, determine from Figure 11.9 (*Waterway design chart for Retardance C* and land slope of 2.0%) the depth of flow required to accommodate the 4 m^3/sec flow at a retardance of C
Answer: Depth of flow is 0.24m (note that the velocity at the higher retardance would be 1.1 m/s (Note that in this example there is minimal difference in flow depths. There would be a more significant difference if a wider range of retardances was used eg. B and D)

3. Calculate constructed bank height and waterway top width using the procedure in Waterway design example 1.

11.7 Determining the capacity of natural grassed drainage lines

If a natural grassed hollow is to be used instead of a constructed waterway, the capacity should be checked. It may be necessary to check the capacity in several locations if there are changes in the shape or land slope. The procedure is as follows:

- Estimate the retardance value (Table 8.2, Guide to selection of vegetal retardance)
- Measure the slope
- Take measurements to determine the cross-section for the waterway
- Determine the wetted perimeter
- Calculate the area in the waterway cross-section
- Calculate the hydraulic radius
- Determine velocity from a graph showing solutions to Mannings formula for a specified retardance (eg. Figure 8.4 Solution of the Manning formula for retardance C)
- Multiply the velocity by the cross-sectional area to determine the discharge capacity of the drainage line. ■

Chapter 12

Floodplain applications

The strategy for controlling erosion on floodplains is to ensure that floods are encouraged to spread out as much as possible thus reducing their velocity. In areas where both winter and summer crops can be grown reliably, strip cropping (Figure 12.1) is a successful solution. Crops are grown in alternating strips that are perpendicular, or close to perpendicular, to the direction of flow of water. Strip cropping should be combined with conservation cropping and crop rotation techniques to ensure that there is always a crop or standing stubble in every strip to help spread water and reduce flow velocity. Stubble needs to be anchored to avoid its floating and subsequent deposition where it may cause problems such as the blocking of road cross-drainage structures.

Incorporating opportunity cropping into a strip cropping system provides greater protection from erosive flooding. Opportunity cropping is the practice of planting a crop whenever soil moisture reserves are considered sufficient, rather than according to a rigid rotational pattern. This leads to an increase in cropping frequency (eg. two crops in three years) and greater levels of surface cover.

Figure 12.1 Strip cropping on the Darling Downs floodplain

As well as controlling soil erosion, strip cropping improves water quality by assisting in filtering out sediment, nutrients and pesticides.

For more detailed information about strip cropping, the following publication is recommended: *Better Management Practices – Floodplain Management on the Darling Downs*, published in 1999 by what was then the Queensland Department of Natural Resources.

The use of strip cropping in Queensland has been pioneered on the floodplains of the Darling Downs. While flooding is most common in summer, winter floods also occur in this area. The geomorphology of a number of creeks flowing out of the upland areas of the Eastern Darling Downs is a well-defined watercourse in the upland area, spreading onto ill-defined flow paths on the Condamine River floodplain. Flow velocities, and consequent erosion risk, depend on the land slope, cover levels and proximity to channels where flows are deeper than the adjacent areas. Overland flow velocities generally decrease, as the flows get closer to the Condamine River. This is because slopes are lower and the floods have had an opportunity to spread over a vast area. Many parts of the Darling Downs floodplain are regularly inundated but are not at risk of erosive flooding. There are also large areas with soils and topography that are characteristic of the floodplain but are rarely flooded.

The risk of erosive flooding in the Brigalow floodplains between Dalby, Jandowae and Chinchilla is lower than that for the creek outlets on the eastern Darling Downs. However, the levelling of melonholes to make the land more suitable for cropping has reduced the amount of rainfall that is retained on the surface and increased the rates and volumes of flood flows (McLatchey and Watts 1985).

Strip cropping layouts need to be designed and implemented in a co-ordinated manner. The adoption of strip cropping practices on a single property will have limited overall benefit. All affected landholders, including farmers, local and state governments must work together to ensure that floodwater is spread over the entire floodplain. Co-ordinated planning of the whole floodplain is required to minimise the effects of structures such as roads, railway lines, irrigation infrastructure and levee banks that may divert and concentrate flood flows.

Strip cropping is generally not suited to narrow floodplains associated with creeks and rivers. In these situations the strip length is too short, leading to inefficiencies in crop production. Narrow floodplains subject to regular erosive flooding (eg. less than once in five years) should have permanent cover such as that provided by a pasture.

12.1 Design of strip cropping systems

12.11 Strip width

A number of formulae have been developed to determine recommended strip widths based on criteria such as land slope, flow rates, soil erodibility, crop rotations and management. Most of these formulae were developed from practical experience. However Smith, Hancock and Ruffini (1988) developed more technically rigorous design procedures from experimental work.

Many of these formulae were developed when bare fallows were normal practice. The widespread adoption of zero tillage has meant that entire properties may be protected by crop or standing stubble at the one time. If such a cropping system could be guaranteed, irrespective of seasonal conditions, then strip cropping would not be necessary, provided the crop rows were at right angles to flood flows. However the following factors create a need for strip cropping:

- The use of erosion inducing row crops such as sunflower and cotton that give inadequate protection
- In periods of drought it is likely that parts of a property will not be protected from erosive flooding by adequate levels of cover.

Table 12.1 is a guide to strip cropping widths based on the topographic situation and the level of protective cover provided by the crop rotation and management system. The determination of the level of protective cover is somewhat subjective but some guidance can be obtained from Tables 12.2 and 12.3.

It is necessary to refine the width of the strip to achieve compatibility with the various widths of the commonly used machinery on the property.

Table 12.1 Recommended strip cropping widths for floodplains subject to erosive flooding

Level of protective cover provided by the crop management system	Recommended strip cropping width (metres)		
	Slopes of 0.4% to 0.5%	Slopes of 0.2% to 0.3%	Slopes of 0.1% and less
	Creek outlets and narrow valley floors	Plains – upland flow	Plains in lower areas subject to widespread inundation
High	50	80	100
Moderate	25	40	50
Low	Not recommended	Not recommended	30

Table 12.2 Guide to determining the level of protective cover provided by a crop management system

Level of protective cover provided by the crop management system	Stubble management	Cropping system
High	Zero tillage	High proportion of crops providing high cover levels. Opportunity cropping whenever possible.
Moderate	Reduced tillage	A moderate proportion of crops providing high cover levels. Low levels of opportunity cropping.
Low	Bare fallow	One crop per year with a high proportion of crops providing low levels of cover.

Table 12.3 Level of protective cover provided by crop type.

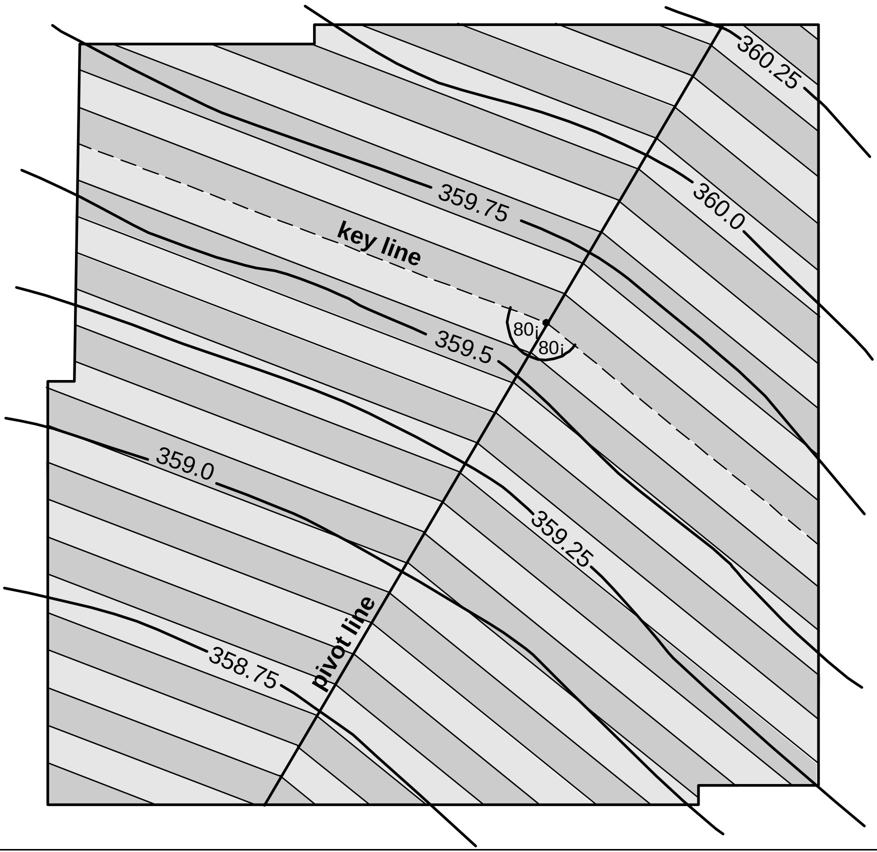
Level of protective cover	Crops	Comment
High	wheat, barley, sorghum, maize	Crops grown in wide rows provide less protection
Low	sunflowers, chick peas, cotton, mung beans	Legume crops leave little or no stubble after harvest. Cotton is an effective crop at slowing floodwaters during active growth but the stubble provides little protection after harvest.

12.12 Strip direction

Detailed topographic and flood flow path information is necessary in order to determine the most appropriate direction for strips on floodplains. Ideally, topographic information should have an interval of 0.25 m or less for slopes of less than 0.5%.

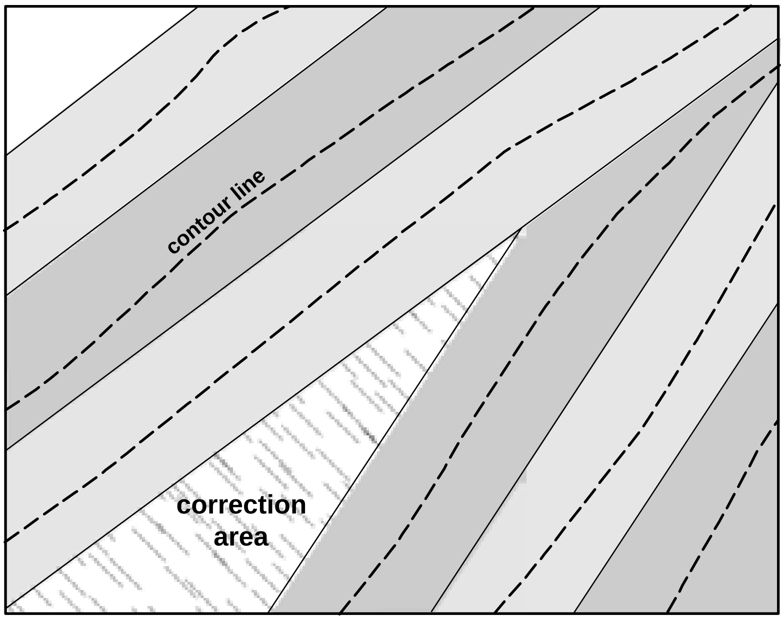
If it is necessary to locate strips in different directions due to a change in the direction of flow/slope, then a pivot line is required at the change in direction (Figure 12.2) For the width of strips on either side of the pivot line to be equal, the angles at which the strips deviate from the pivot line must also be equal. If the pivot angles are unequal it will be necessary to manage the strips on either side of the pivot line as separate blocks. The minimum angle for a pivot is generally about 70° as sharper angles will leave unplanted headlands especially when multiple-hitch machinery is used.

Figure 12.2 Strip cropping layout showing a pivot to provide for change in strip direction. (Eacott 1979)



In order to improve workability and ensure that strips are located on the contour, it may be necessary to insert a correction strip as shown in Figure 12.3

Figure 12.3 Correction area in a strip cropping layout (Macnish 1980)



Since strip cropping is carried out in parallel lands it is compatible with controlled traffic farming. There have been suggestions that controlled traffic on floodplains should be implemented with strips running up and down the slope. While this practice may be acceptable in a section of a floodplain where erosive flooding is not an issue or where drainage is necessary, it is considered to be most inappropriate on floodplains at risk of erosive flooding. Such a system may divert flood flows down the strips that had the least retardance to flows. High velocities and associated gullying would be a likely result with deep wheel tracks being especially vulnerable.

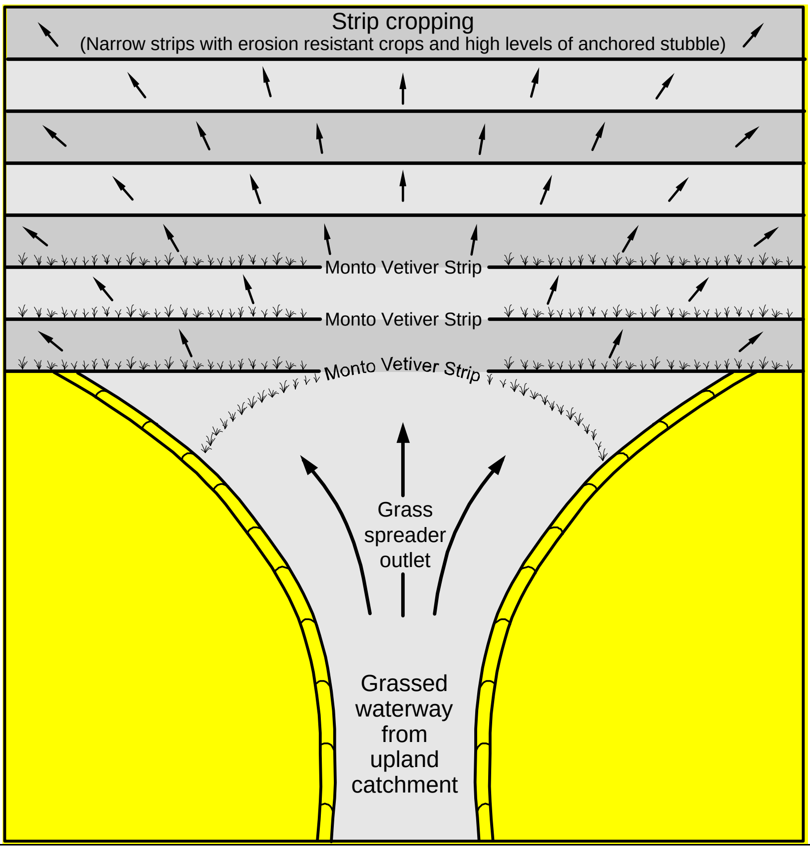
In Queensland, it is generally not practical to use strip cropping directions that would provide protection from erosive winds. The heavy texture of most cropping soils in Queensland means that they are not susceptible to wind erosion. Such layouts would need to be at right angles to erosive winds (generally from the south-west) and would not be compatible with any strips or runoff control measures that may be required for control of erosion by water. The adoption of conservation cropping measures should be sufficient to provide protection against wind erosion in the Queensland environment where wind erosion is not considered to be a serious problem in cropping lands

12.13 Dealing with concentrated runoff flowing onto floodplains

There are a number of options for dealing with the situation where concentrated flows spill onto floodplains. A grass spreader outlet (Figure 12.4) may be used at the point where a waterway meets a strip cropping area. Another option is to design and build a dam with provision for bywashes on either side discharging into a subsurface channel or sill. Maintenance of these outlet areas is critical. They are subject to high rates of sedimentation, which may direct flows away from the grassed area and onto adjacent areas that will be vulnerable to erosion.

Relatively narrow strip widths are required immediately below any spreading devices to accommodate the high velocity flows. The waterway delivering the runoff to the grass spreader requires regular maintenance including slashing, strategic grazing and desilting.

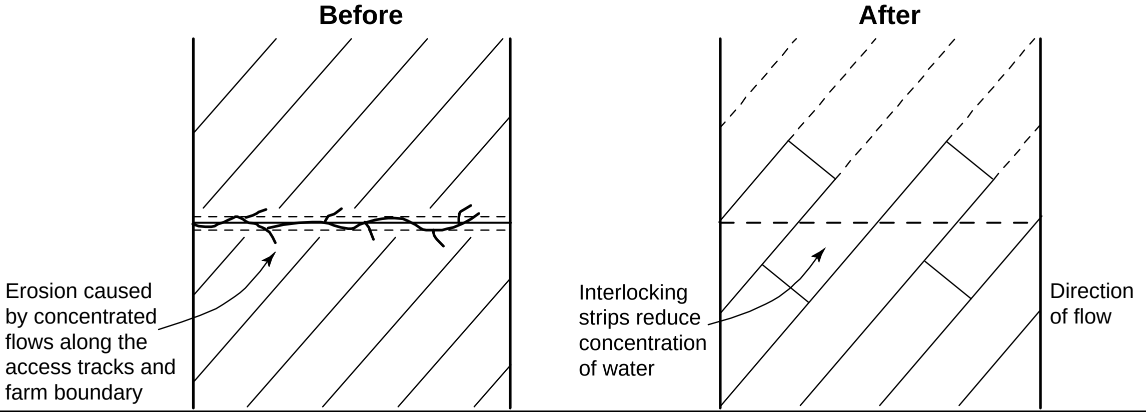
Figure 12.4 Grass spreader at a waterway outlet



12.14 Give-and-take

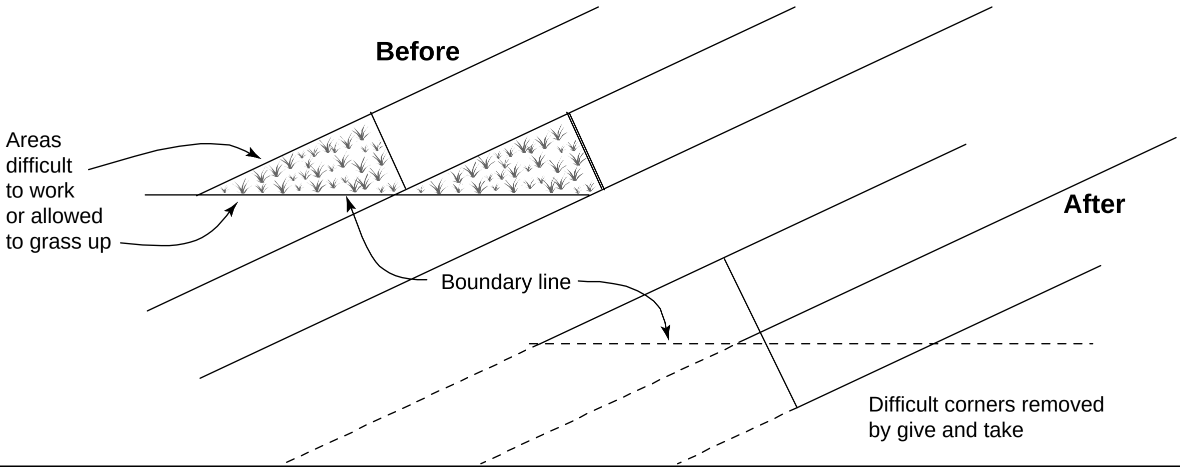
'Give-and-take' refers to an exchange of land between neighbours to help keep floodwaters spread. Problems often arise where two strip cropping layouts meet at a boundary line. There is usually an access track on both sides of the boundary where water tends to concentrate, causing washouts. This can be overcome by neighbours interlocking their strip cropping layouts and each landholder farming some of their neighbour's land as shown in Figure 12.5. Alternative means of access in strip cropping layouts is described in a later section.

Figure 12.5 'Give and take' to overcome concentrated flows along fencelines



In some strip cropping layouts, the strip will meet the fence line at very sharp angles creating corners that are difficult to work. These corners are often left to grass up, creating potential weed problems. By the use of 'give-and-take' with a neighbour, these problems are overcome (Figure 12.6)

Figure 12.6 'Give and take' to avoid difficult corners



12.15 Land levelling

The presence of rills and gullies in a paddock can make it difficult to achieve an effective spread of flood flows and make crop management more difficult. They are also susceptible to further erosion during a flooding event. Runoff flowing in such depressions may result in poor crop establishment or even the need to replant a crop.

Land levelling combined with strip cropping can assist in achieving a more effective spread of floodwaters. It may be carried out with the use of a land plane drawn behind a tractor, scraper or tractor drawn bucket. The use of laser equipment assists the process.

To have minimal impact on natural flow paths, all land levelling should be carried out in such a way that the down-field and cross-field slopes align with the natural slope of the land. Land levelling should be designed to blend with natural surface profiles both within and surrounding the block. This will avoid significant differences in finished heights on the block boundaries, which can promote erosion and consequent concentration of flows.

12.16 Use of Monto Vetiver Grass on floodplains

The Monto strain of Vetiver grass (*Vetiveria zizanioides* L) is being evaluated on the Darling Downs floodplain to stabilise and silt up active gullies. The grass is established in rows across gully floors. The rows act as barriers to flood flows and silt is deposited against and in front of the rows. Unlike earth structures, which often fail due to cracking or undermining, Vetiver weirs will not easily wash away. At the same time as water flows over the top of the grass 'weirs', water also flows through them, minimising turbulence and undermining. Vetiver grass has a very dense, deep root system (another reason why it is not easily undermined and washed out). The Vetiver rows should extend out onto the shoulders of the gully to prevent water from cutting around the ends.

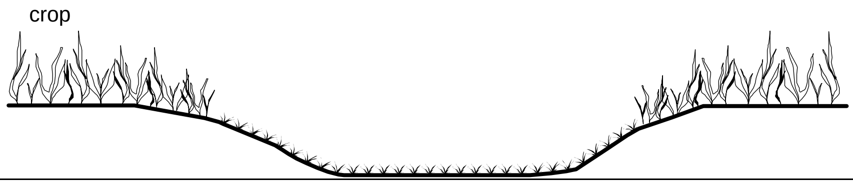
In a field trial on a floodplain at Jondaryan, Monto Vetiver hedges have also been used between crop strips to provide additional protection (Truong and Loch 2004). Such a system would be advantageous when some strips remain in fallow because of drought conditions.

12.2 Residual flow drains

On the floodplains of the Darling Downs, a residual flow may persist for several weeks after a major flooding event or prolonged wet period. Residual flows within cultivated lands have the potential to interrupt farming operations and cause waterlogging.

Residual flow drains (Figure 12.7) may be used to remove residual flows from cultivation allowing for more timely access after floods and to even out moisture conditions over the cultivated area (Begbie 1977, Cummins and Bass 1978). The restriction of saline trickle flows to a residual flow drain will protect agricultural land from contamination.

Figure 12.7 Residual flow drain



12.21 Planning

Residual flow drains should be co-ordinated from property to property and should be subsurface so that they do not interfere with flood flows. Historically, they have been located along the length of the main flowpaths of some of the floodplain catchments. Their location and effectiveness has been totally reliant on the goodwill and co-operation between the floodplain stakeholders across whose land the residual flow drain has been constructed.

In general, residual flow drains should be located so as to run parallel to the natural flow path as closely as possible. This minimises earthworks and decreases the potential for diversion of flows. Changes of direction should be accomplished with gentle curves rather than sharp bends to avoid erosion-inducing turbulence. The risk of erosion in a residual flow drain can be minimised if the drain is not located in the deepest section of the flood flow where high velocities may occur during floods. With approval and co-operation from Local Government, residual flow drains may be constructed along roadsides. However, they should remain separate from road table-drains to avoid destabilising the road as a result of long-term saturation of foundations associated with residual flows.

Residual flow drains may be subject to Local Authority by-laws pertaining to levee banks. In catchments where Water Resource Plans have been approved under the provisions of the Water Resources Act 2000, there may be controls on new works requiring approval as assessable development if such works are likely to increase the 'take' of overland flow wate12.2

12.22 Design

Residual flow drains should be subsurface without any banks above normal ground level that would divert flood flows. They are at risk of erosion during flood events especially when they flow between well advanced crops which have a high retardance to flood flows.

There are no hard and fast rules for determining the capacity of a residual flow drain. If possible, observations of the trickle flow should be made to determine the required capacity. Bass and Cummins (1978) based designs for drains in the Pittsworth Plains on 0.21 m^3/1000ha for upland catchments plus 0.07 m^3/1000 ha for plains catchments.

Residual flow drains can be stabilised using species such as kikuyu and African star grass. In wetter areas, water couch and salt tolerant couch grasses could be considered (Bass 1984). Where spring flows persist, it may not be possible to maintain a permanent vegetation cover and designing the drain for bare soil conditions may be the only option.

Residual flow drains with a bare channel are vulnerable to erosion especially considering the saturated soil conditions that would exist during flooding. Because they are located on flood plains where slopes would normally be less than 0.3%, it is possible to ensure that shallower flows can be kept below a velocity of 0.3 to 0.4 m/s. Additional protection could be provided with drop structures or sod chutes with energy dissipaters.

Outfalls are one of the most important sections of a drain. They allow water to free-flow from the drain into a disposal area. Outfall into deeper drains, pump sumps, etc, need to be rock protected to prevent erosion or other suitable stabilisation measurers. Structures similar to that used on drain entries can be used.

12.23 Construction

Drains should be constructed with very broad-sided batters that can be cropped part way down the channel sides to avoid scours developing from the channel sides back into the cultivation.

Drains generally produce significant amounts of spoil because they are constructed below normal ground level. This spoil should be placed so as not to interfere with overland flow paths. It should be spread as shallow fill on adjacent cultivation, placed as spoil banks aligned with the direction of flow, or removed totally from the area. It is inadvisable to construct a raised road parallel to the drain as this can interrupt or divert flow, or induce erosive flow velocities as a consequence of increased depth of flow.

Crossings over residual drains should be constructed so as not to affect flows in the drain. Ideally, crossings should be constructed as gravel inverts either at or slightly above (max. 100 mm) bed level of the drain. The thickness of gravel required will depend on the weight and frequency of traffic; a minimum of 200 mm depth of gravel is necessary, but for heavy traffic loading, a thickness of up to 300 mm over a suitable geofabric would be required. Culverts require sufficient cross-sectional area to pass flow with minimal surcharge level upstream of the structure. Box-shaped culverts are preferable. Professional design will often be necessary.

12.24 Maintenance

Drains need to be well maintained to retain their function. Vegetation should be managed by slashing, spraying, or occasional grazing. Silt deposits should be removed. In many cases, it will be necessary to virtually reform the drain at regular intervals. Ancillary structures such as inlet works, outfalls and drop structures also require ongoing maintenance. Access for maintenance is not possible until the drain has dried out.

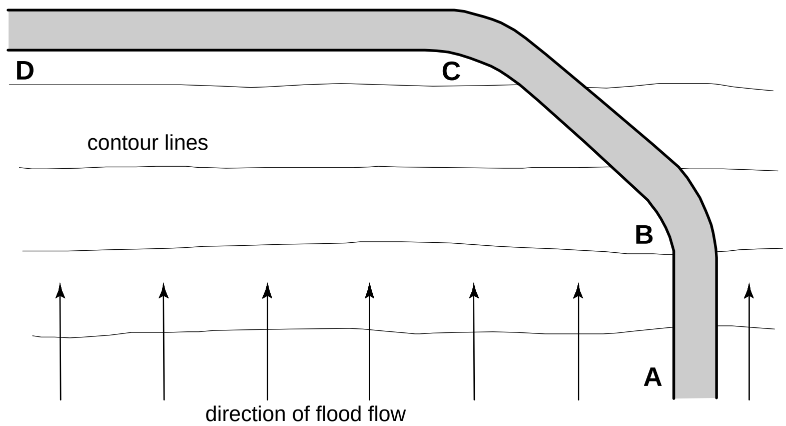
12.3 Infrastructure effects

On floodplains, roads, railway lines, fences, levee banks and irrigation structures can significantly interfere with the natural spread of floodwaters. They can concentrate flows that would normally spread and greatly increase the risk of erosive flooding in affected parts of the landscape.

12.31 Public roads

Conventional roads are generally raised 300 mm to 600 mm above natural ground level, however this is not recommended for most situations on the floodplains. The impact that formed roads have on flood flows depends on their orientation towards the natural flow direction. Figure 12.8 shows how the direction of a road may be orientated within a floodplain landscape. The section of the road A—B is running directly up and down slope and would cause no diversion of floods no matter how elevated it was. The section B—C is running diagonal to the slope and may cause significant diversion. The section C—D is on the contour and can act like a weir. High flow velocities could be experienced downstream from any floodways or culverts located on roadways that are perpendicular to the natural flowpath.

Figure 12.8 The orientation of a road to the contour affects its impact on flood flows (Marshall (1988)



Where a road runs across the flowpath of floods, lowering the formation to no more than 100—200 mm above natural ground level will overcome most erosion problems on surrounding land. Such a road acts as a long floodway and creates much less backup of water than a raised road. Floodwaters flow over its full length in a shallow controlled flow. As the overfall below such a road is small, turbulence is minimal and little damage will be experienced on the cultivated land below.

Low roads are generally considered unacceptable by constructing authorities for major highways because they will flood too frequently. People unfamiliar with the area and unaware of driving requirements during flood times frequently use highways, so for safety reasons, raised formations are preferred. However, safety problems are less likely on low secondary roads. Provided low sections are well marked with depth indicators and built with adequate cross fall to prevent water lying on the road, they will create few problems for local residents and will contribute substantially towards reducing erosion problems.

In cases where drainage is provided under roads, it is preferable to use box culverts rather than pipes in order to achieve a better spread of flood flows, and to help in keeping the road formation to a low profile.

12.32 Farm roads

The same issues that apply to shire roads also apply to farm roads and access tracks. Where such roads cross-flood flow areas they should be constructed no more than 100 mm above natural ground level. A formed road may be prone to damage because of high moisture content after flooding, so it should be built at least 5 m wide with a solid foundation.

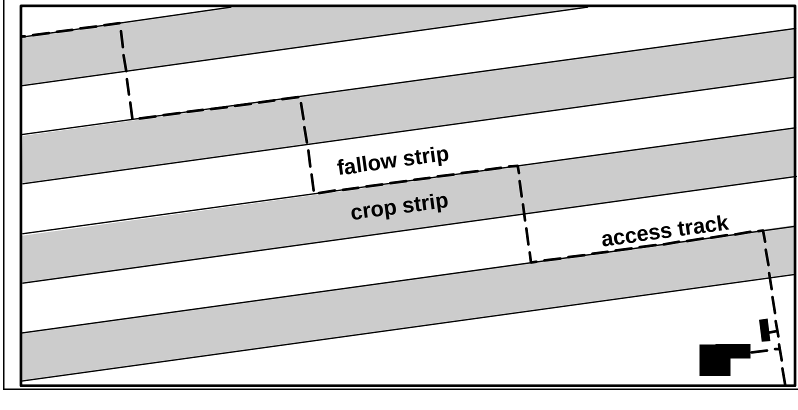
Where a road already exists across a flood-flow area, floodway sections should be installed at intervals to reduce flow diversion and concentration. The width and frequency of these floodway sections is dependant on the intensity of the flooding. Where a road is causing major erosion or pondage problems, serious consideration should be given to relocating the road so that it does not affect flood flows.

On unformed roads and access tracks, water can run along and damage the road surface. Low banks, or ‘whoa-boys’, placed at intervals across such roads and extending into adjoining cultivation will minimise this problem. ‘Whoa-boys’ should be no more than 200 m apart so that runoff is released in small quantities onto adjoining land.

12.33 Access tracks

Access tracks through cultivated paddocks should be relocated regularly as they are very prone to erosion damage. Crops should be planted across tracks and right up to paddock boundaries so that the whole paddock is protected from erosion by a growing crop. Tracks through a strip cropped area can be zigzagged to reduce the possibility of flow concentrating along the track and causing erosion (Figure 12.9)

Figure 12.9 Zigzagged track through a strip cropping layout



12.34 Railway lines

Railway embankments are typically raised at least 500 mm above normal ground level and hence have potential to cause considerable impediment and diversion of flood flows. The loose stone ballast supporting railway sleepers is easily removed by floods leaving the rails and sleepers unsupported. For this reason, railway lines are always constructed on embankments to raise the railway above expected flood levels.

Railway lines on the Darling Downs were constructed in the late 1800s or early 1900s when there was little cultivation on the floodplain. Since then there has been considerable change in the patterns of overland flow resulting in inadequate railway cross-drainage at many locations. Subject to budget restraints, Queensland Rail is willing to consider suggestions for improving cross-rail drainage.

12.35 Fencelines

Floodwater is often diverted and concentrated along fencelines, not necessarily because of the fence itself but because of the vegetation growing along the fenceline or a build-up of soil or silt deposits along the fence.

In many parts of the Darling Downs floodplain where there are no stock on farms and no stock routes, fences have been removed. Removal of fences must be accompanied by levelling of soil build-up and erosion scours along them. Where fences have been removed, corner posts should be retained along portion boundaries to prevent the need for a re-survey on the sale of the property and avoid encroachment of cultivation onto road reserves.

Where occasional fencing is required for stock control, electric fencing is ideal. If this is impractical, suspension fencing will cause fewer problems than conventional fencing because of the lower number of posts to collect debris and interfere with under-fence maintenance.

12.36 Levee banks

Levee banks are often constructed in an attempt to control flooding on floodplains. In attempting to achieve this, they may concentrate flows, which can lead to higher velocities, more erosion and may have adverse effects on downstream properties.

Levee banks counter the basic principle of spreading flood flows. Levees along a watercourse can increase the discharge downstream and thus increase flooding problems for lower landholders. Serious scouring and gully erosion can also result if a levee bank is breached and water rushes through in a confined flow.

Levee banks constructed to protect residential areas from flooding may cause major problems for surrounding cultivated land. However, a levee bank surrounding isolated homes and buildings in the middle of a floodplain should have minimal impact on flood flows.

Some Local Authorities with floodplains have established Local Laws under the *Local Government Act 1993* to give them control over levee bank constructions. Construction of levee banks may also be controlled under the provisions of a Water Resource Plan approved under the Water Act 2000, relating to control of overland flows.

12.37 Irrigation structures

Any above–ground structures associated with irrigation such as ring tanks, diversion banks and head ditches may interfere with flood flows. Most infrastructure for irrigation on the Darling Downs floodplain has been constructed on sections of the floodplain that are less vulnerable to erosive flooding. However in recent years there has been an expansion of the irrigated area in areas subject to erosive flooding.

Irrigation infrastructure may also be subject to development controls by Local Government Levee Bank Local Laws, or Water Resource Plans. ■

Bibliography

2013 Addendum: Many of the publications in this bibliography that were produced by the Queensland government can be downloaded as a PDF file from the Queensland Department Of Environment and Heritage Protection library catalogue.

Aveyard JM (Ed) (undated). *Design Manual for Soil Conservation Works*, Technical Handbook No. 5, Soil Conservation Service of New South Wales.

Bass GA (1985). Residual flow drains on the Darling Downs. In *Proceedings of the Fourth Australian Soil Conservation,* Maroochydore, Queensland.

Bass GA (1984). *The use of residual flow drains on the Darling Downs.* Department of Primary Industries, Queensland, Internal report.

Beasley DB, Huggins LF and Monke EJ (1980). ANSWERS: A model for watershed planning. *Transactions of the American Society of Agricultural Engineers* **23**, 935–944.

Begbie DK (1977). *Report on the study of the Linthorpe and Aubigny Catchments, Darling Downs, Qld.* A report prepared for Linthorpe No. 5 Soil Conservation Group and the Central Darling Downs Advisory Group Committee, Queensland Department of Primary Industries, Brisbane.

Benjamin C (2002). *Rural Life–Is it for you*, Queensland Department of Primary Industries, Publication number QI 02053.

Bierenbroodspot J and Thew RK (1980). *The use of solodic soils on the Eastern and Western Downs of Queensland*, Division of Land Utilisation Information Booklet 80/1, Department of Primary Industries.

Bierenbroodspot J (1985). *Design of runoff control structures for horticultural and other intensive cropping areas*. Queensland Department of Primary Industries Training Series QE85008.

Booth N and Bourne G (1989). *Gindie Soil Conservation Project Central Queensland*, Soil Conservation Services Branch, Department of Primary Industries Project Report QO89015.

Boughton WC (1993). A hydrograph-based model for estimating the water yield of ungauged catchments. *Hydrology and Water Resources Symposium, 1993,* Institution of Engineers, Australia, National Conference Publication No. 93/14, pp 317–324.

Bourne GF and Booth N (1986). The Use of Laser Systems in the Surveying of Graded Banks in the Central Highlands of Queensland. *Journal of Soil Conservation New South Wales* Vol. 42 No. 2 1986.

Bourne G (1986). *Property development guidelines for the Central Highlands*, Queensland Department of Primary Industries, Information Series QI 86021.

Bourne GF and Herbert JG (1993). *Orion Group Scheme Land Conservation Project Report*, Project Report Series QO92018, Department of Primary Industries.

Bourne GF and Tuck GA (1993). Resource Information. *In:* Thwaites RN and Maher JM (eds.) Understanding and Managing Soils in the Central Highlands, Queensland Department of Primary Industries Training Series QE93002.

Boyd MJ (1978). A storage routing model relating drainage basin hydrology and geomorphology. *Water Resources Research* **14 (5)**, 921–923.

Brough D, Lawrence P, Fraser G, Rayner D and Le Grand J (2004) Improved inputs for prediction of regional-scale soil erosion potential for Queensland, Proceedings 13th International Soil Conservation Organisation Conference, Brisbane.

Burnash RJC, Ferral RL and McGuire RA (1973). *A generalised streamflow simulation system and conceptual modelling for digital computers*. Joint Federal State River Forecast Centre, US National Weather Service and California, Department Water Resources, Sacramento, California.

Capelin MA (1985). A survey of soil erosion on horticultural farms on the Sunshine Coast of south-east Queensland. *Proceedings of the Fourth Australian Soil Conservation Conference*, Maroochydore, Queensland.

Carey B and Stone B (2001). *Soil conservation planning*. NRM Facts series No L83, Department of Natural Resources and Mines, Queensland.

Carey B (1995). Parallel strip cropping between non-parallel contour banks. *In*: Yule DF and Tullberg JN (eds.) Proceedings of the National Controlled Traffic Conference, September 1995, Rockhampton.

Carey B (2002). Degraded land – a liability we can ill afford. In: Franks AJ, Playford JP and Shapcott A (eds) Landscape Health of Queensland, The Royal Society of Queensland.

Carey B, Gray J and Seagrave C (2001). *Gully erosion*. NRM Facts Series No. L81, Department of Natural Resources and Mines, Queensland.

Carey BW, Leach GJ and Venz B (2004). Soil erosion in Queensland cropping lands – an historical perspective and new challenges. Proceedings 13th International Soil Conservation Organisation Conference, Brisbane.

Carey B (1997). Erosion control in rural areas of Queensland. Proceedings of the Stormwater and Soil Erosion 1997 Conference convened by the International Erosion Control Association and the Stormwater Industry Association, Brisbane.

Chapman W, Spackman GB, Yule DF, and Cannon RS (1995). Controlled traffic development on dryland broadacre farms in Central Queensland. Proceedings National Controlled Traffic Conference, Rockhampton.

Chapman D (1986). *A notched weir structure at Rockhampton – an application of the weir formula.* Land Utilisation Technical News, Vol. 8 No. 1, Queensland Department of Primary Industries.

Chow VT (1959). *Open channel hydraulics*. McGraw-Hill Kogakusha Ltd, Publication.

Chow Ven Te (1959). Open Channel Hydraulics, McGraw-Hill.

Clarke AL and Wylie PB (Eds) (1997). *Sustainable crop production in the sub tropics – an Australian perspective.* Department of Primary Industries, Queensland.

Connolly RD and Barton N (1990). *KINCON Version 1.1 Users Manual*, Queensland Department of Primary Industries, Internal Report.

Connolly RD, Ruffini JL and Smith RJ (1985). Design of structural soil conservation measures using kinematic wave theory, In Conference papers Agricultural Engineering, Sydney, 25-30 Sept. Inst of Engineers (Aust), National Conference Publication No 88/12 178-181.

Connolly RD, Silburn DM and Barton N (1991). *Design of long contour banks in south-west Queensland.* Queensland Department of Primary Industries, Information series, QI91014.

Conservation Farmers Inc. (2003). *Controlled Traffic Farming Guide*. Conservation Farmers Inc., Toowoomba, Queensland.

Cordery I and Webb SN (1974). Flood estimation in eastern New South Wales - A design method. *Civil Engineering Transactions, Institution of Engineers, Australia,* Vol. CE16, pp 87–93.

Crawford KL (1975). Report on strip cropping techniques in the Darling Downs area of Queensland. Soil Conservation Service of New South Wales HO Papers 75/107.

Crothers RB (1991). *Rural subdivision planning – Guidelines for subdivision design.* Queensland Department of Primary Industries, Information Series QI91008.

Crothers RB, Wilkinson WF, Gray HJ and McLatchey JF (1990). *Gully stabilisation techniques used by the Soil Conservation Service of New South Wales.* Queensland Department of Primary Industries, Study Tour Report QS 90002.

Crouch JA, Henry RA, O'Brien WJ and Sherlock VG (1984). Small weirs for gully control. *Journal of the Soil Conservation Service of New South Wales* **40**(2), 88–93.

Cummins VG and Bass GA (1978). *Report on a study of the Pittsworth Plains and associated upland catchments, Darling Downs, Queensland.* Queensland Department of Primary Industries, Brisbane.

Department of Primary Industries (1978). *Soil Conservation Handbook*, Soil Conservation Branch, Queensland Department of Primary Industries.

Department of Primary Industries (1990). *Guidelines for Agricultural Land Evaluation in Queensland.* Land Resources Branch, Queensland Department of Primary Industries. Information Series QI90005.

Department of Primary Industries and Department of Housing, Local Government and Planning (1993). *Planning guidelines: The Identification of Good Quality Agricultural Land*.

Department of Primary Industries (1994). *RUSTIC: Runoff Storage Irrigation Calculation* Version 1.1.

Dickenson J and Faulkner G (1988). *Surveying for soil conservation – A training manual.* Queensland Department of Primary Industries, Training series QE88002.

Dwyer G (1994). *Sustainable Vegetable Production in South-East Queensland — Managing for erosion control*, Department of Primary Industries Information Series Q194024

Dwyer GT (1990). *Gympie/Nambour Soil Conservation Project Report.* National Soil Conservation Program Project Report QO90032, Queensland Department of Primary Industries.

Dwyer GT and Page R (1988). *Land Use and Erosion Control Practices in Horticultural Crops of the Far North Coast of New South Wales.* Queensland Department of Primary Industries, Study Tour Report QS88016.

Eacott LS (1979). *Practical aspects of planning and implementing strip cropping systems on very low gradient land.* Division of Land Utilisation Report 79/4, Queensland Department of Primary Industries.

Eastgate WI, Swartz GL and Briggs HS (1979). *Estimation of runoff rates from small Queensland catchments.* Division of Land Utilisation, Queensland Department of Primary Industries, Technical Bulletin. No. 15.

Evans D and Daniells J (2001). Erosion control for bananas. NRM Facts Number L43, Department of Natural Resources and Mines, Queensland.

Evans DS (1996). *Vetiver grass for erosion control and land stabilization in the wet tropics.* Paper presented to workshop on Research, Development and Application of Vetiver Grass for Erosion and Sediment Control in Queensland, Toowoomba.

Farr EJ (1979). Report on Pittsworth Plains drainage. Unpublished report and maps prepared for Pittsworth Shire Council. JE Farr, Toowoomba.

Findlay GH and Ellul GA (1976). *The application of computers to prepare design tables for grasses waterways and flumes.* Agricultural Engineering, Aust. Vol 5: 20-24.

Finlayson B and Silburn M (1996). Soil, Nutrient and Pesticide Movements from Different Land Use Practices and Subsequent Transport by Rivers and Streams *In*:, H.M. Hunter, A.G. Eyles & G.E.Rayment (eds), *Downstream Effects of Land Use*, pp. 129-140. Department of Natural Resources, Queensland.

Freebairn D (2004). *Some observations on the role of soil conservation structures and conservation.* Natural Resource Management, Vol. 7, No. 1.

Freebairn DM and Silburn DM (2004). Soil Conservation in Australia's semi arid tropics: Pathways to success and new challenges. Proceedings 13th International Soil Conservation Organisation Conference, Brisbane.

Freebairn DM and Wockner GH (1986). A study of soil erosion on vertisols of the eastern Darling Downs, Queensland. I. Effects of surface conditions on soil movement within contour bay catchments. *Australian Soil Research* **24**, 135–158.

Freebairn DM, Truong P, Miles RL, Ciesolka CCA, Titmarsh G and Norrish S (1996). Practical measures to counter soil erosion *In*:, H.M. Hunter, A.G. Eyles & G.E.Rayment (eds), *Downstream Effects of Land Use*, pp. 213-219. Department of Natural Resources, Queensland.

French RH (1986). *Open Channel Hydraulics.* McGraw-Hill Book Co, Singapore.

Galletly JC (1980). *Design and efficiency of contour banks.* Agricultural Engineering Conference, Geelong, 1980.

Garton JE and Green JE. (1981). *Improved design procedures for vegetation- lined channels.* Research Report P-814, Agricultural Experiment Station, Division of Agriculture, Oklahoma State University.

Genrich M and Lesleighter L (1995). *Cultivating between contour banks in broadacre areas.* DNR Land Facts, Queensland Department of Natural Resources.

Glanville TJ, Macnish SE and Scarborough RC (1991). *Land Management Manual – Coastal Burnett Districts.* Queensland Department of Primary Industries Training Series QE91004.

Gordon MA and Booth NJ (1990). *Kilcummin Group Scheme Final Project Report*, Queensland Department of Primary Industries.

Gray HJ (1990). *African Star Grass – Its history, uses and distribution in Queensland.* Project Report QO90009. Queensland Department of Primary Industries.

Gray HJ and Macnish SE (1985). *Land Management Field Manual Wandoan District.* Training Series QE85006. Queensland Department of Primary Industries.

Green JEP and Garton JE (1983). *Vegetation lined channel design procedures.* Transactions ASAE, Vol 26: 436-439.

Gregory JM and McCarthy TR (1985). *Maximum allowable velocity prediction for vegetated waterways.* Paper No. MCR-85-109, American Society of Agricultural Engineers, St Joseph, Michigan.

Haan CT, Barfield BJ and Hayes JC (1994). *Design hydrology and sedimentology for small catchments.* Academic Press.

Harris PS, Biggs AJW, Stone BJ, Crane LN and Douglas NJ (Eds) (1999). *Central Darling Downs Land Management Manual*, Queensland Department of Natural Resources Publication No. DNRQ990102.

Heijnen EAH (1996). Land Degradation. In: *Understanding and Managing Soils in the Stanthorpe-Rosenthal Region*, Queensland Department of Natural Resources DNRQ96001.

Henderson FM (1970). *Open Channel Flow*, The MacMillan Co, New York.

Hindle DR (1982). Flood detention structures for soil conservation. *Journal of the Soil Conservation Service of New South Wales* **38**(1), 23–30.

Hoogvliet W (1966). *Strip cropping and crop rotation.* Queensland Agricultural Journal, March 1966.

Houghton D (1986.) *Mounds for permanent tree crops – Which way?* Technical News, Vol. 8 No. 1, Division of Land Utilisation, Queensland Department of Primary Industries.

Houghton PD and Charman PEV (1986). Glossary of terms used in soil conservation. Soil Conservation Service of NSW, Government Printer, NSW.

Hunter HM and Hairsine PB (2002). Riparian and wetland buffers for water quality protection, *Proc. 2nd national conference on Aquatic Environments: Sustaining Our Aquatic Environments - Implementing Solutions, Townsville, Australia, 20-23 November, 2001.*

Institution of Engineers Australia, Queensland Division (1996). *Soil Erosion and Sediment control – Engineering Guidelines for Queensland Construction Sites.*

Jordan AT, Dwyer GT, and Eldershaw VJ (1993). *Self Help Landcare for New Farmers*, Publication No. QI93050, Queensland Department of Primary Industries.

Kamel T and Robotham B (1980). *Land levelling for soil erosion control.* Technical News, Vol. 4, No. 2, Division of Land Utilisation, Queensland Department of Primary Industries.

Karsees L and Prosser I (2001). The Application of the RUSLE as a Risk Assessment Tool in Site Specific Projects. In *Proceedings of the 9th Annual Conference on Soil and Water Management, 20–23 November 2001.* Australasian Chapter of the International Erosion Control Association, Picton, New South Wales.

Koch AJ, Bryant WJ, Herbert JG, Muller AD and Gray HJ (1996). *Guidelines for the Rehabilitation of Degraded Native Pastures Using Shallow Ponds and Water Spreading Techniques.* Project Report Series QS96002, Queensland Department of Primary Industries.

Ladewig JE and Skinner AF (1950). Soil Conservation in Queensland — General Aspects. *Queensland Agricultural Journal* **70**, 14–24.

Laurenson EM and Mein RC (1988). *RORB: Version 4, runoff routing program, user manual*. Published in conjunction with ACADS and Montech Pty Ltd by Department of Civil Engineering, Monash University, Melbourne.

Lavercombe DP and Stone BJ (1986). *Soil conservation for cassava in coastal southern Queensland.* Project Report Q086010, Queensland Department of Primary Industries.

Lawrence P and Cowie B (1992). *Water balance and decline in soil fertility of brigalow pastures: Outcomes and lessons from the Brigalow catchment study.* Report number RQR92007, Queensland Department of Primary Industries.

Lawrence PA and Key A (1993). Water conservation for ponded pasture in central Queensland. *Australian Journal of Soil and Water Conservation* **6(2)**, 42–48.

Lawrence PA and Thorburn PJ (1989). *Changes in hydrology, soil fertility and productivity of brigalow catchments following clearing*. Queensland Department of Primary Industries, RQR 89002.

Littleboy M, Silburn DM, Freebairn DM, Woodruff DR and Hammer GL (1989). *PERFECT. A computer simulation model of Productivity, Erosion, Runoff Functions, to Evaluate Conservation Techniques*. Queensland Department of Primary Industries Publication.

Loch RJ and Thomas EC (1987). Resistance to rill erosion: Observations on the efficiency of rill erosion on a tilled clay soil under simulated rain and run-on water. Catena Supplement No. 8, pp 71–83.

Loch RJ and Silburn DM (1997). Soil erosion. In *Sustainable crop production in the sub tropics – an Australian perspective.* Clarke AL and Wylie PB (eds), Department of Primary Industries, Queensland.

Macnish S (1980). A review of strip cropping practices on the eastern Darling Downs. Division of Land Utilisation 80/1, Queensland Department of Primary Industries.

Macnish SE (Ed) (1987). Land Management Field Manual Roma District Queensland Department of Primary Industries, Training Series QE87001.

Marshall J, Mullins J, Freebairn D, Donnollan T, Glanville S and Crothers R (1980). *Erosion survey for the Clifton, Cambooya and Pittsworth Shires, Eastern Darling Downs after the storm events of the 26/1/80 and 5/2/80*, Division of Land Utilisation Report 80/15, Queensland Department of Primary Industries.

Marshall JP (1988). Floodplain Management for Erosion Control and High Productivity on the Darling Downs. Division of Land Utilisation, Queensland Department of Primary Industries.

Marshall JP, Crothers RB, Macnish SE and Mullins JA (1988). *Land Management Manual South-East Darling Downs Districts*, Queensland Department of Primary Industries, Training Series QE88001.

Mason RM, Titmarsh GW and Sallaway MM (1995). Making controlled traffic work in non parallel contour banks. In Yule DF and Tullberg JN (eds.) *Proceedings of the National Controlled Traffic Conference*, September 1995, Rockhampton.

McLatchey JF (1992). Planning For Floodplain Management. Unpublished handout for the Brigalow Floodplain Project.

McLatchey JF and Watts TR (1985). The implications of levelling gilgais in southern inland Queensland. Proceedings Australian Soil Conservation Conference, October 1985, Maroochydore, Queensland.

Mijnarends RJ (1985). The integration of rural and urban drainage at Kingsthorpe – a case study. Proceedings Australian Soil Conservation Conference, October 1985, Maroochydore, Queensland.

Muller AD (1991). Soil conservation management and planning. *In*: Part A of Thwaites, R.N. & Macnish, S.E. (eds.) Land Management Manual Waggamba Shire, Queensland Department of Primary Industries and Waggamba Conservation Committee, Queensland Department of Primary Industries Training Series QE90014.

Osmond M (1971). Multiple strip cropping. *Queensland Agricultural Journal*, April 1971.

Pilgrim DH (Ed) (1987). 3rd edition, *Australian rainfall and runoff, a guide to flood estimation, Vol. 1.* The Institution of Engineers, Australia.

Pilgrim DH (Ed) (1998). 4th edition, *Australian rainfall and runoff, a guide to flood estimation, Vol. 1.* The Institution of Engineers, Australia.

Pyper W and Hunter H (2003). *Stream-side studies focus on improving waterway health*. QNRM03379, Queensland Department of Natural Resources and Mines, Brisbane.

Queensland Fruit and Vegetable Growers (1998). *Farmcare: Cultivating a better future – Code of Practice for Sustainable Fruit and Vegetable Production in Queensland*, Queensland Fruit and Vegetable Growers.

Queensland Main Roads Department (1979). Urban main roads design manual, Volume 2.

Queensland State Government, Department of Natural Resources (1999). *Better Management Practices – Floodplain Management on the Darling Downs*.

Queensland Water Resources Commission (1984). *Farm Water Supplies Design Manual, 2nd Ed., Vol.1, Farm storages*. Queensland Department of Primary Industries Publication.

Ree WO (1954). *Handbook of channel design for soil and water conservation.* The Soil Conservation Service of the United States Department of Agriculture, SCS-TP-61.

Rose C (2004). *An introduction to the environmental physics of soil, water and watersheds.* Cambridge University Press.

Rosenthal KM and White BJ (1980). *Distribution of a Rainfall Erosion Index in Queensland.* Division of Land Utilisation Report 80/8. Queensland Department of Primary Industries.

Rosewell CJ (2001). *SOILOSS – A program to assist in the selection of management practices to reduce erosion.* New South Wales Department of Conservation and Land Management.

Rosser J (1964). Flow of water in a channel lined with kikuyu grass. *Queensland Journal of Agricultural Science* **21**, 1.

Rosser J, Swartz GL, Dawson NM and Briggs HS (1974). A Land Capability Classification for Agricultural Purposes. Division of Land Utilization Technical Bulletin No 14. Queensland Department of Primary Industries.

Rowland P (1987). Property facilities need careful planning. *Queensland Agricultural Journal*, January-February.1987.

Ruffini J, Smith R, Hancock N and Glasby T (1988). *Flood Strip Cropping, Guidelines for Selection of Strip Widths.* Darling Downs Institute of Advanced Education, School of Engineering, Centre for Engineering in Agriculture. Technical Report No 11/88.

Sallaway MM, et al (1988). *Runoff and soil loss study, Capella, Central Queensland.* Queensland Department of Primary Industries Monographic Series. Project Report Q088012 (referred to in Sallaway 1989)

Sallaway M.M (1987). Assessment of waterway suitability in the Central Highlands. Queensland Department of Primary Industries.

Sallaway MM, Connolly RD and Barton N (1989). Runoff estimation for agricultural catchments. *Hydrology and Water Resources Symposium, 1989.* Institution of Engineers, Australia, National Conference Publication.

Sallaway MM, Yule DF and Ladewig JH (1983). *Read Effect of agricultural management on catchment runoff and soil loss in a semi-arid tropical environment.* Hydrology and Water Resources Symposium, Hobart, the Institution of Engineers Australia.

Sallaway MM, Yule DF, Mayer D and Berger PW (1990). Effects of surface management on the hydrology of a vertisol in semi-arid Australia. *Soil & Tillage Research* **15**, 227–245.

Sallaway MM, Yule DF, Lawson D, Carroll C, Fossett G, Burger P and Nickson D (1988). *Runoff and Soil Loss Study, Capella, Central Queensland.* Queensland Department of Primary Industries, Project Report Q088012.

Scarborough RC, Stone BJ and Glanville TJ (1992). Specifications for erosion control measures. Land Management Manual Coastal Burnett Districts. QE 92008, Department of Primary Industries, Queensland.

Shaw JH (1967). Grass strips for erosion control. *Queensland Agricultural Journal* **93**, 586–8.

Shields PG and Gillespie RL (1991). *Land Management Manual – Dawson/Callide Districts.* Queensland Department of Primary Industries, Training Series QE91003.

Skurlow J (1975). Metric versions of some formulae used in hydraulic design. *Journal of the Soil Conservation Service of New South Wales* **31**(1), 66–77.

Soil Conservation Service of New South Wales (1991). Earthmovers Training Course Units 1 to 21. Soil Conservation Service of New South Wales.

Stephens RM (1987). *Water flow at the outlets of contour banks.* Division of Land Utilisation, Department of Primary Industries, Volume 9, Number 1.

Stephens RM (1987). *Review of Soil Conservation Design Procedures in Queensland*, Queensland Department of Primary Industries, unpublished.

Stone BJ and Titmarsh GW (1997). Farm and catchment planning. In *Sustainable crop production in the sub tropics — an Australian perspective.* A.L. Clarke & P.B. Wylie (eds), Department of Primary Industries, Queensland.

Titmarsh G and Loch R (1993). *Towards more efficient soil conservation layouts.* Report to the Cotton Research and Development Corporation, Department of Primary Industries, Queensland.

Titmarsh G, Wockner G and Waters D (2004). Controlled traffic farming and soil erosion considerations. *Proceedings 13th International Soil Conservation Organisation Conference, Brisbane.*

Titmarsh GW (1989). *A flood estimation for small agricultural catchments in the Darling Downs region, Queensland*. Unpublished, ME Thesis, University of New South Wales, Sydney.

Titmarsh GW (1994). *A field manual for design peak discharge estimation on the Darling Downs using a probabilistic version of the Rational Method*. Queensland Department of Primary Industries Publication.

Titmarsh GW and Stone BJ (1997). Runoff management: techniques and structures. In *Sustainable crop production in the sub tropics — an Australian perspective.* A.L. Clarke & P.B. Wylie (eds), Department of Primary Industries, Queensland.

Titmarsh GW and Cordery I (1990). Estimation of floods on small agricultural catchments using the Unit Hydrograph approach. *Agricultural Engineering Conference, 1990,* Institution of Engineers, Australia, National Conference Publication.

Titmarsh GW, Cordery I and Ciesiolka CAA (1989b). Application for nonlinear runoff routing model to catchments modified by soil conservation structures. *Hydrology and Water Resources Symposium, 1989.* Institution of Engineers, Australia, National Conference Publication No. 89/19, pp 166-170.

Titmarsh GW, Cordery I, Pilgrim DH, Marschke GW and Freebairn DM (1989). Design flood estimation for agricultural catchments in south east Queensland using the Rational Method. *Hydrology and Water Resources Symposium 1989.* Institution of Engineers, Australia, National Conference Publication No. 89/19, pp 237–241.

Titmarsh GW, Pilgrim DH, Cordery I and Hoesein AA (1989). An examination of design flood estimation using the US Soil Conservation Services Method. *Hydrology and Water Resources Symposium, 1989*. Institution of Engineers, Australia, National Conference Publication No. 89/19, pp 247–251.

Thwaites R and Lloyd P (1995). Evaluating Queensland—Fifty years of land resource assessment, *Australian Journal of Soil and Water Conservation,* Vol 8 No 2.

Truong P (2002). Monto vetiver grass for soil and water conservation. NRM Facts Number L34, Department of Natural Resources and Mines, Queensland.

Truong PN (1983). Erosion in farm waterways in Queensland. Division of Land Utilisation Report 81/4.

Truong PNV and Loch R (2004). Vetiver systems for erosion and sediment control. *Proceedings of the 13th International Soil Conservation Organisation Conference, Brisbane.*

Tullberg JN and Yule DF (1998). Second National Controlled Traffic Conference Proceedings, Gatton College. Published by Department of Primary Industries, Department of Natural Resources and Mines, University of Queensland.

United States Department of Agriculture (1971). *National engineering handbook, section 4, hydrology.* United States Department of Agriculture Publication.

United States Soil Conservation Service (1985). *National engineering handbook, section 4, hydrology.* United States Soil Conservation Service Publication.

Van Putten J (1985). The effect of contour banks on frost. Division of Land Utilisation, Technical News, Vol. 7 No. 2, Queensland Department of Primary Industries.

Van Putten JH (1985). Soil conservation in coffee plantations in the Mareeba district. *Queensland Agricultural Journal,* January-February, 1985.

Vock N and Chapman L (Eds) (1994). 'Agrilink - Queensland Information Kit for Looking after Horticultural Land. Number 18 in a series.

Waldron RD (1994). RAMWADE: A program for using the Rational Method for Waterway Design, Department of Primary Industries, Queensland, unpub.

Watt MO (1984). *Waterway design tables.* Queensland Department of Primary Industries, Miscellaneous Publication Series QM 84010.

Weeks W (1991). Design floods for small rural catchments in Queensland. *Australian Civil Engineering Transactions, Institution of Engineers, Australia* **33(4)**, 249–261.

Yule DF and Tullberg JN (1995). National Controlled Traffic Conference, Rockhampton, Queensland, Department of Primary Industries and University of Queensland. ■

Appendix 1 Aerial photo interpretation

A stereoscope enables the images of overlapping parts of a stereoscopic pair of photos to be optically fused into a single three-dimensional image. It is useful to use clear overlay sheets and different coloured marking pens, to record information from the photographs.

An approximate scale is provided on aerial photographs. However there will be some variation in the scale depending on the height of the land at any point and the distance of the point from the centre of the photograph. A perfectly vertical photograph of flat, level land will have a reasonably constant scale over the whole photo, although some distortion towards the edges.

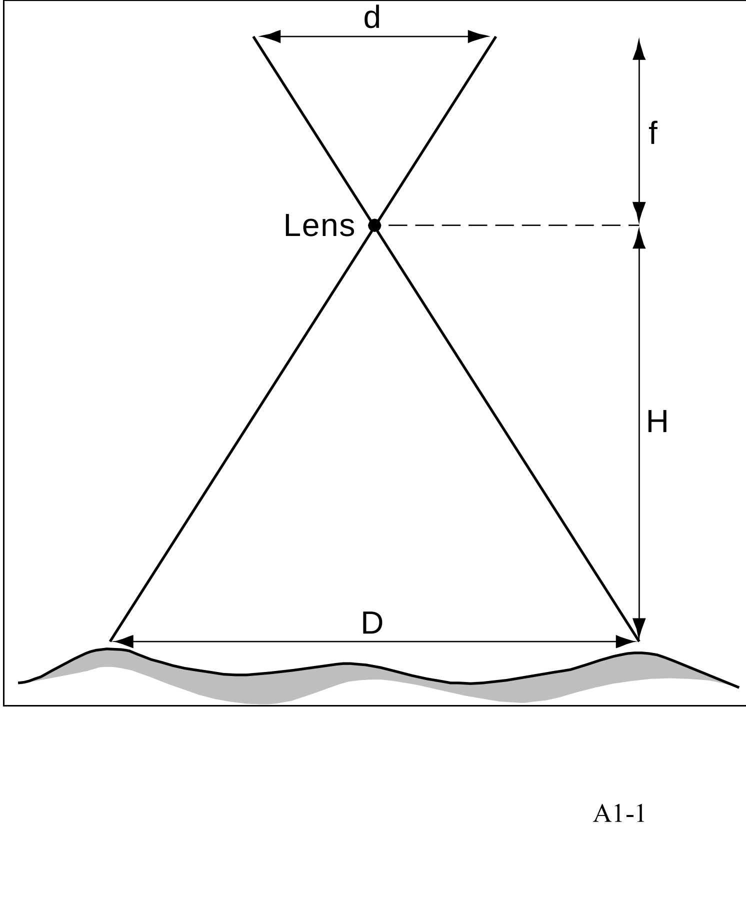
For aerial photography, the following equation applies:

$$\frac{d}{D} = \frac{f}{H} \quad \text{..........Equation 2.1}$$

Where
d = distance between two points on a photograph
D = the distance between the same two points on the ground
f = the focal length of the camera lens
H = the height above sea level of the aeroplane minus the height above sea level of the land surface, i.e the vertical distance from the plane to ground level

The lengths used in the above ratios must be in the same units. Figure 2.14 shows a sketch of the distances referred to in the equation. The distance D can be obtained by field measurement or from a cadastral map or survey plan.

Figure 2.14 Relationship between lengths appropriate to the calculation of the scale of an aerial photograph



From equation 2.1, the scale of the photograph can be calculated by either of the following:

$1:\ \frac{H}{f}$ ……………………………………………………………………Equation 2.2 or

$1:\ \frac{D}{d}$ …………………………………………………………………… Equation 2.3

The following information can be interpreted from aerial photography (or satellite imagery) and later verified by field inspection:

Land related factors

- land use — pasture, intensive/extensive cultivation,industrial, urban
- variation in soils
- topography and land slopes (refer to the section *Collection of data and information* in this chapter)
- infrastructure
    - roads
    - railways
    - air strips
    - buildings
    - fence lines
    - stock yards
    - power lines
- areas of degradation
    - erosion patterns
    - saline areas
    - scalded areas
    - landslips.

Water related factors

- catchment boundaries (ridges)
- rilling and gullying
- drainage lines
- wetlands
- flood prone areas
- dams and possible dam sites.

Vegetation related factors

- vegetation, types, condition and extent
- weed infestation.

Examples

- A radial pattern of converging cattle tracks usually indicates the presence of a stock watering point.
- If tracks converge to a point on a fence line, the presence of a gate is indicated.

- Fence locations are often made obvious by the variations in land use between paddocks. Paddock appearances in cultivated areas will vary according to crop type, stubble management, ploughing patterns, contour bank location. In grazing lands, different grazing pressures will often be apparent. Fencelines can also be observed if they have strips of vegetation along them.
- Orchards may have a distinctive 'checker-board' appearance.
- Railway lines can be distinguished from roads by the greater length of straights, long uniform curves and the presence of stations or sidings. In hilly country, there may be tunnels.
- Outcrops of rocks may be suspected if irregular margins are observed around cultivated land or if 'islands' of uncultivated land occur within cultivated areas.
- Different vegetation types may be indicated by factors such as height, density, tone and location in the landscape. Patches of vegetation with similar characteristics can be defined on the photos and sample areas identified by ground traversing eg.
    - Most eucalypts grow in fairly open communities, are of light tones and have fairly open canopies of foliage. This may be indicated by their shadows.
    - Brigalow, belah and wilga trees grow together in dense and extensive communities and melon holes may be evident
    - Some acacias such as wattles, bendee and lancewood are usually found on steep and stony scarps or on the tops of mesas; or may indicate degraded land. They grow in dense communities and have a very dark tone.
    - Rainforests usually occur on the eastern slopes of coastal ranges and on south facing aspects and are unmistakable because of the large size and density of canopies
    - False sandalwood and bull-oak usually grow on very dispersible soils with a high content of sodium salts which makes such soils vulnerable to gully erosion.
- Erosion
    - Rill erosion is often visible
    - Gully erosion is relatively easy to identify especially in cleared country. Tree canopy may conceal gullies in forested lands.
    - Areas that have lost significant quantities of topsoil can usually be identified by the presence of soils with a lighter colour.

■

Appendix 2 Land capability/suitability/use

A number of systems of classifying land have been used in Queensland. Since soil conservation planners may come across all of these systems when checking existing soil conservation plans and other resource information, they have been included here for reference purposes.
The following systems for classifying land are described:

- The eight class land capability classification for agricultural purposes
- The seven class land zoning system used in the Area of Erosion Hazard Program in the 1970s and 1980s
- The five land suitability classes for agricultural land evaluation for assessing the suitability of a land for growing a specified crop
- The four land suitability class system for assessment of good quality agricultural land

A recommended reference on this topic is *Guidelines for Agricultural Land Evaluation in Queensland,* (Department of Primary Industries, 1990). It includes a good coverage of the philosophies relating to land capability and land suitability. In general, the term *'land capability'* refers to the capability of land to support a broad range of land uses. The term *'land suitability'* is used to determine the suitability of land for a specified purpose such as a specific crop.

It is difficult to make generalisations about the value of different Queensland soils. As an example, the black Vertosols (cracking clays) on the floodplains of the Darling Downs are very suitable for cereal cropping because of their high fertility and moisture holding capacity. However these soils are generally unsuitable for growing trees for forestry and in their natural state were grasslands with no trees. Many Sodosols (shallow and sodic, duplex soils) are unsuitable for cropping because of limitations such as low fertility and moisture holding capacity as well as sodicity. However these soils are capable of supporting native woodlands and forests with very large trees such as eucalypts.

A2.2.1 The eight class Land Capability Classification for agricultural purposes

This system identifies eight classes of land for different agricultural uses as described in Table 2.2 (Rosser *et al.*1974). The level of management needed, in particular that for soil conservation, increases from Class 1 to 4. Note that classes 3 and 4 state the need for a period under pasture to provide extra protection from erosion but a pasture rotation would be desirable for all classes in order to increase soil organic matter levels and the overall health of the soil. The three classes that are suitable only for pastoral or forestry uses (Class 5 to 7) also have different limitations and require different levels of conservation management. Class 8 land is not suitable for agriculture.

Table 2.2 Land classes for the eight class, land capability classification (Rosser *et al.* 1974).

Land class	Limitations
Land suitable for cropping and grazing	
1	Suited to a wide range of agricultural crops and is highly productive. It presents no limitations to the use of machinery or choice of implements Wind and water erosion hazard is low.
2	Land with some limitation to the choice of crops and/or slight restrictions to productivity. Land with some impediment to the use of cultivation machinery which limits the choice of implement or restricts the conditions for successful operation. Land which under cultivation requires simple conservation practices to reduce soil loss. to an acceptable level. (Simple practices include contour working, strip cropping and stubble mulching).
3	Land with moderate limitations to the choice of crops and/or moderate restrictions to productivity Land with moderate impediments to the use of cultivation machinery which limits the choice of implement or restricts the conditions for successful operation Land, which under cultivation, requires intensive conservation practices to reduce soil loss to an acceptable level. Such practices include the retention of high levels of stubble cover, the use of crops that provide high levels of surface cover, pasture rotations and the use of contour banks and waterways for runoff management.
4	Land on which the choice of crops is severely restricted and/or conditions are such that productivity under cropping is severely limited Land with severe impediments to the use of cultivation machinery which limits the choice of implement or severely restricts the conditions for successful operation Land, which cannot be used safely for permanent cultivation; if cropped a pasture phase must be the major component in the cropping programme to limit soil loss to an acceptable level.
Land suitable for grazing	
5	Land which has limitations which, unless removed, make cultivation impractical and/or uneconomic (such limitations include rocks or stones, gilgai (melonhole) microrelief, wetness or waterlogging or subject to regular flooding
6	Land which is not suitable for cultivation but is well suited to pastoral use and which pasture improvement involving the use of machinery is practicable
7	Land which is not suitable for cultivation but on which pastoral use is possible only with careful management; pasture improvement involving the use of machinery is not practicable.
Land not suitable for any agricultural purpose	
8	Land with limitations that would preclude its use for any form of agriculture

The following attributes are considered in determining the appropriate land classificiation and are considered further in Table 2.3. A detailed description of these limiting factors, as well as a number of others, are described in *Guidelines for Agricultural Land Evaluation in Queensland,* (Department of Primary Industries, 1990).

- climate (c)
- soil moisture availability (m)
- effective soil depth (d)
- soil physical factors (p)
- soil nutrient fertility (n)
- soil salinity or sodicity (s)
- topography (t)
- soil workability (k)
- rockiness (r)
- surface microrelief (gilgai or gullying) (g)
- wetness (w)
- water erosion hazard (e)
- susceptibility to flooding (f)
- susceptibility to wind erosion (a).

Table 2.3 Factors for determining classes in the Land Capability Classification

Limiting or controlling factors	Degree of limitation or special measures required		Sub-class
Factors limiting choice of crops or crop productivity			
Climatic limitation other than rainfall, c	Affects crop choice or restricts production potential	Slight. Moderate Severe Cropping not possible	c2 c3 c4 c6
Moisture availability for crop growth, m	Occasional limitation Regular limitation Frequent limitation Moisture availability too unreliable for cropping	(7-8 crops possible /10 years) (5-7 crops possible /10 years) (<5 crops possible /10 years)	m2 m3 m4 m6
Effective soil depth, d	Exerts influence on the ‘m' factor	>60 cm 45-60 cm 25-45 cm <25 cm	d2 d3 d4 d6
Soil physical factors affecting crop growth, p	Crusting, sub-surface compaction, etc.	Slight restriction Moderate restriction Severe restriction	p2 p3 p4
Soil nutrient fertility, n	Nutrient requirement	Replacement of removed N and/or P only N/P/micro-nutrients need supplementing Deficiencies preclude regular cropping	n2 n3 n4
Soil salinity or sodicity, s	Affects crops through: loss of soil water availability loss of structure toxicity	Slight effect on crops Moderate effect on crops Severe effect on crops Tolerant pasture/herbage species only Salt pan	s2 s3 s4 s6/7 s8
Factors limiting the use of agricultural machinery or accessibility			
Topography, t	Severe relief or gullies preclude contour cultivation	Occasional cropping possible. Slopes 15-20% or severe relief prevent cultivation. Slopes 20-45% or extreme gullying, accessible for grazing Slopes or topography too severe for grazing animals.	t4 t6 t7 t8
Soil workability, k	Soil properties restricting machinery and reduce production potential, eg. stiff clay, columnar structure, compaction, narrow moisture range for working	Slight restriction Moderate restriction Severe restriction	k2 k3 k4
Rockiness or stoniness, r	Effects on degree of restriction of tillage machinery Use of all machinery for cropping impractical		r2-4 r5
Surface micro-relief, gilgai and gullying, g	Effects on degree of restriction of tillage machinery Use of all machinery for cropping impractical		g2-4 g5
Wetness, w	Effects on delay in implement use and reduction of production potential Permanently wet; cultivation impractical		w2-4 w5
Factors controlling land deterioration			
Susceptibility to water erosion, e	Cropping – increasing intensity of erosion control measures Erosion risk precludes cropping; continuous pasture required Erosion risk precludes grazing		e2-4 e6-7 e8
Susceptibility to flooding, f	Occasional overflow flooding Regular overflow flooding Severe overflow flooding; permanent cultivation not possible Flood frequency and/or severity precludes any cropping		f2 f3 f4 f5
Susceptibility to wind erosion, a	Erosion risk requires increasing level of control measures for cropping Erosion risk precludes cropping; restricted grazing only		a2-4 a6-8

A2.2.2 Land zoning under past legislative programs

Soil conservation plans prepared under the Areas of Soil Erosion Hazard Program in the 1970s and 1980s had land zones based on the degree of erosion hazard and limitation. These zones formed the basis for establishing land use and management practices that would reduce soil erosion to acceptable levels.

The Erosion Hazard Zoning system, was generally applicable to arable land and it allowed for only two primary limitations relative to specific soil types, ie. land slope and soil depth. Susceptibility to flooding in the alluvial areas of the Darling Downs was an additional limitation taken into account.

Table 2.4 provides a synopsis of the descriptions that applied to each zone. Some of the terms used in the 1970s have been modified to match the terminology used in this manual eg. 'Standard' spaced contour banks are now referred to as 'single' spaced.

Table 2.4 Land zoning system used for the Areas of Soil Erosion Hazard program in the 1970s and 1980s

Zone	Land slope and depth criteria	Land management requirements
0	0 to 1%	Land with no significant hazard or limitation under normally accepted farming methods Generally no soil conservation measures are required. However some situations may require: Protection from local catchment runoff by runoff control structures Conservation tillage practices to minimise soil surface sealing and soil structure deterioration which is likely to result in unacceptable soil loss
1	1 to 3%	Land of low erosion hazard and limitation Cultivated land requires: Contour banks at single spacing if erosion inducing cropping systems are used Contour banks at double spacing if cropping systems achieving high levels of cover are used Pasture land should be managed to provide adequate levels of cover to reduce erosion to acceptable levels
1f	0 to 1%	Low sloping land which has varying degrees of erosive flooding hazard No specific requirements are specified but they would include strip cropping with rotations and stubble management practices appropriate to the risk of erosive flooding
2	3 to 5%, depth >45cm	Land of moderate erosion hazard and limitation As for zone 1 (as land slopes would normally be steeper, contour banks would be more closely spaced); and adoption of conservation tillage practices
3	3 to 5%, depth <45cm 5 to 8%, depth >45cm	Land of high erosion hazard and limitation As for Zones 1 and 2 (steep slopes would require more closely spaced contour banks) Will require adoption of conservation tillage practices, and Use of a pasture phase in a crop rotation system
4a	8 to 12%, depth >45cm	Land of severe erosion hazard and limitation. Although this land is arable, it is considered to be unsuitable for long term cropping. (While significant areas of such land were cultivated in the 1970s, most of this land has been returned to pastures because it is generally uneconomic to use these areas for cropping)
4b	Not applicable	Land that has limitations other than, or in addition to, erosion hazard that make it unsuitable for agriculture eg. stoniness, salinity, waterlogging.

A2.2.3 Land suitability classes

The publication *Guidelines for Agricultural Land Evaluation in Queensland,* (Department of Primary Industries,1990), describes five land suitability classes that have been defined for use in Queensland, with land suitability for agricultural uses decreasing progressively from Class 1 to Class 5 (Table 2.5). Land is classified on the basis of its suitability for the use of land for growing specific crops.

Table 2.5 Five land suitability classes for the use of land for a specific purpose eg. the growth of a specified crop

Class	Description
Class 1	Suitable land with negligible limitations. This is highly productive land requiring only simple management practices to maintain economic production.
Class 2	Suitable land with minor limitations which either reduce production or require more than the simple management practices of class 1 land to maintain economic production.
Class 3	Suitable land with moderate limitations which further lower production or require additional management practices than described for class 2 land in order to maintain economic production.
Class 4	Marginal land which is presently considered unsuitable due to severe limitations. The long term significance of these limitations on the proposed land use is unknown. The use of this land is dependent upon undertaking additional studies to determine whether the effects of the limitation(s) can be reduced to achieve sustained economic production.
Class 5	Unsuitable land with extreme limitations that preclude its use for the specified purpose.

A2.2.4 Agricultural Land Classes

Based on the assessment of the suitability of land for agriculture, four agricultural land classes are recognised (Table 2.6) (from Department of Primary Industries and Department of Housing, Local Government and Planning (1993). *Planning guidelines: The Identification of Good Quality Agricultural Land*.)

Table 2.6 Land classes to assess the suitability of land for agriculture

Class	Description
Class A	Crop land – Land suitable for current and potential crops with limitations to production which range from none to moderate levels.
Class B	Limited crop land – Land that is marginal for current and potential crops due to severe limitations; and suitable for pastures. Engineering and/or agronomic improvement may be required before the land is considered suitable for cropping.
Class C	Pasture land – Land suitable only for improved or native pastures due to limitations which preclude continuous cultivation for crop production; but some areas may tolerate a short period of ground disturbance for pasture establishment.
Class D	Non-agricultural land – Land not suitable for agricultural uses due to extreme limitations. This may be undisturbed land with significant habitat, conservation and/or catchment values or land that may be unsuitable because of very steep slopes, shallow soils, rock outcrops or poor drainage.

In some regions of Queensland, the above classes have been further subdivided to suit local needs eg. Class B has been subdivided into B1 and B2 depending on whether suitable techniques are currently available. Class C has been subdivided into C1 and C2 depending on the suitability of the land for sown pastures, or only for native pastures.

■

Appendix 3 – Design aids for soil conservation measures

Waterway design charts

A series of waterway design charts for trapezoidal channels for Retardance C and Retardance D for a range of slopes from 0.2% to 10% are available in the publication *Waterway design tables* produced by Queensland Department of Primary Industries (Watt M 1984). Examples of these charts are provided in Figure 11.9 and 11.10 in Chapter 11 *Waterways.* The publication can be downloaded as a PDF file from the *Queensland Department of Environment and Heritage Protection library catalogue.*

Figure A3.1 Proforma for soil conservation specifications

No…. of …………sheets

Landholder:			
Date:	Farm Code:	Plan Number:	Local authority:
Contact details:			
Property description:			
Designed by:			

Waterway specifications

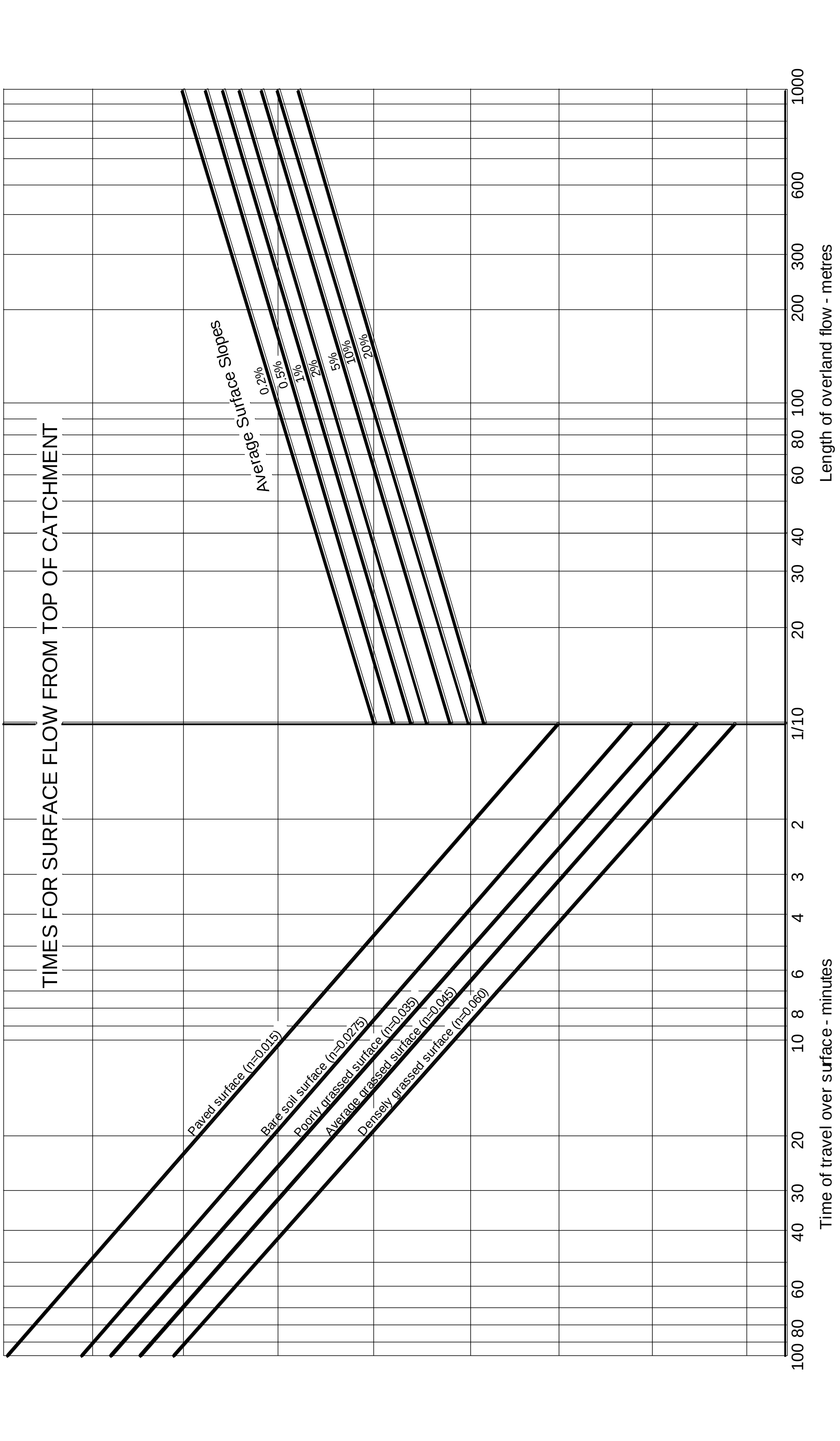
Design point on plan	Type of cross-section (Note A)	Bank height m		Design flow depth m	Width m		Bank batters (V:H)		Comments
		Unsettled	Settled		Bottom	Top	Inside	Outside	

Contour and diversion bank specifications

Location on plan	Type of cross-section (Note B)	Bank height (settled) m	Cross-sectional area (settled) m^2	Bank batters (V:H)		Comments
				Upslope	Downslope	

Notes A: See Chapter 11, *Waterways* for types of cross-sections
B: See Chapter 9, *Contour Banks* and Chapter 10, *Diversion Banks*

Figure A3.2 Travel time for overland flow



Formula $t = \frac{107\, n \sqrt[3]{L}}{\sqrt[5]{s}}$

where
t = time of travel over surface in minutes
n = Norton's values for the surface
L = Lenght of flow in metres
s = slope of surface in %

Example

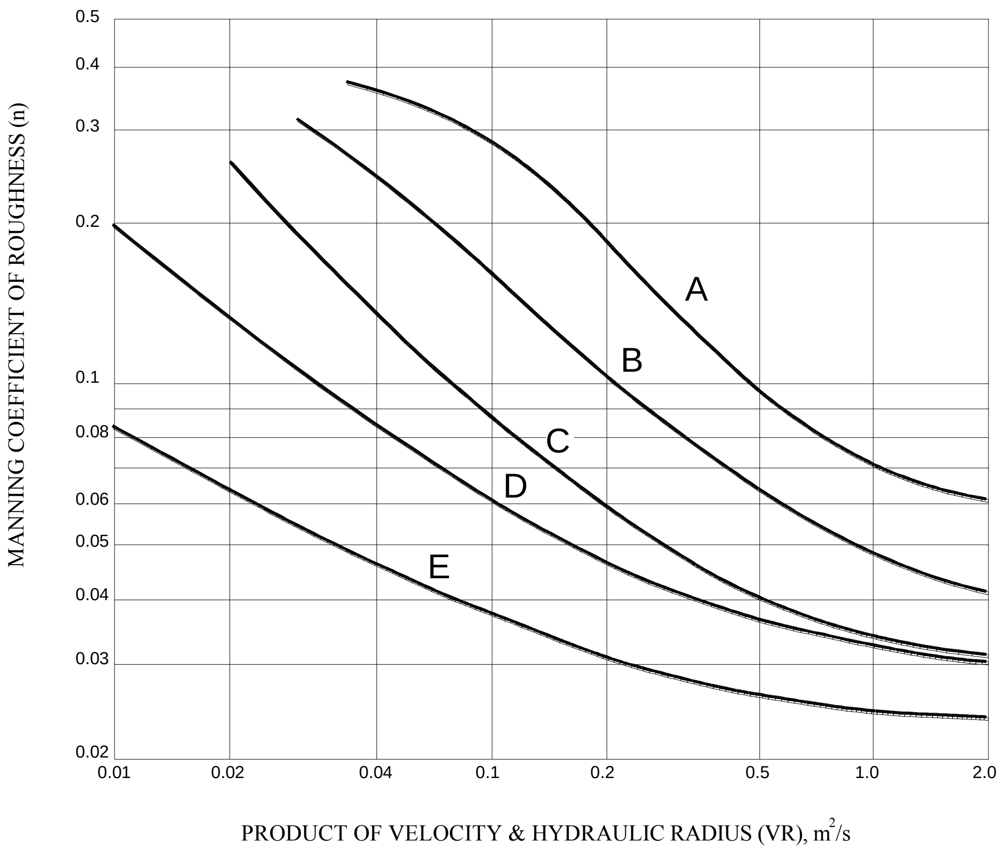
Length of overland flow 200m
Average slope of surface 5%
Densely grassed surface (n= 0.060)
Time of travel = 27.2 minutes

Table A3.1 Values of Mannings *n* coefficient of roughness

Channel/stream condition	Mannings *n*
Earth channels subject to intermittent flow and with vegetal lining	The n/VR relationship applies Refer to text in this chapter
Contour bank channels	
Smooth and bare	0.02-0.03
Roughly cultivated	0.04
Sparse grass cover	0.05
Wheat crop or standing wheat stubble	0.07-0.15
Sorghum (25 cm rows)	0.04-0.12
Lined Channels excavated in rock	
Smooth and uniform rock	0.025-0.040
Jagged and irregular rock	0.035-0.050
Concrete – smooth forms or trowelled	0.012
Small natural streams	
Straight, uniform and clean	0.025-0.033
Clean, winding, with some pools and shoals	0.033-0.045
Sluggish weedy reaches with deep pools	0.050-0.080
Very weedy reaches with deep pools	0.075-0.150

Source: Pilgrim (1987), Queensland Main Roads Department (1979), Ree (1954)

Figure A3.3 n/VR relationship for five degrees of vegetal retardance



Curve A $n = 0.440 - 1.674\ VR \quad VR < 0.1542$
$n = 0.046 + 0.0223/VR \quad VR > 0.1542$
Ref. Green, J.E.P. & Garton, J.E. (1983)

Curve B $n = 0.032 + 0.01545/(VR)^{7/8}$

Curve C $n = 0.030 + 0.00501/VR$

Curve D $n = 0.027 + 0.00534/(VR)^{3/4}$

Curve E $n = 0.022 + 0.003014/(VR)^{2/3}$

Ref. Findlay, G.H. & Ellul, G.A. (1976)

Figure A3.4 Graphical solution to the Manning formula for Retardance A

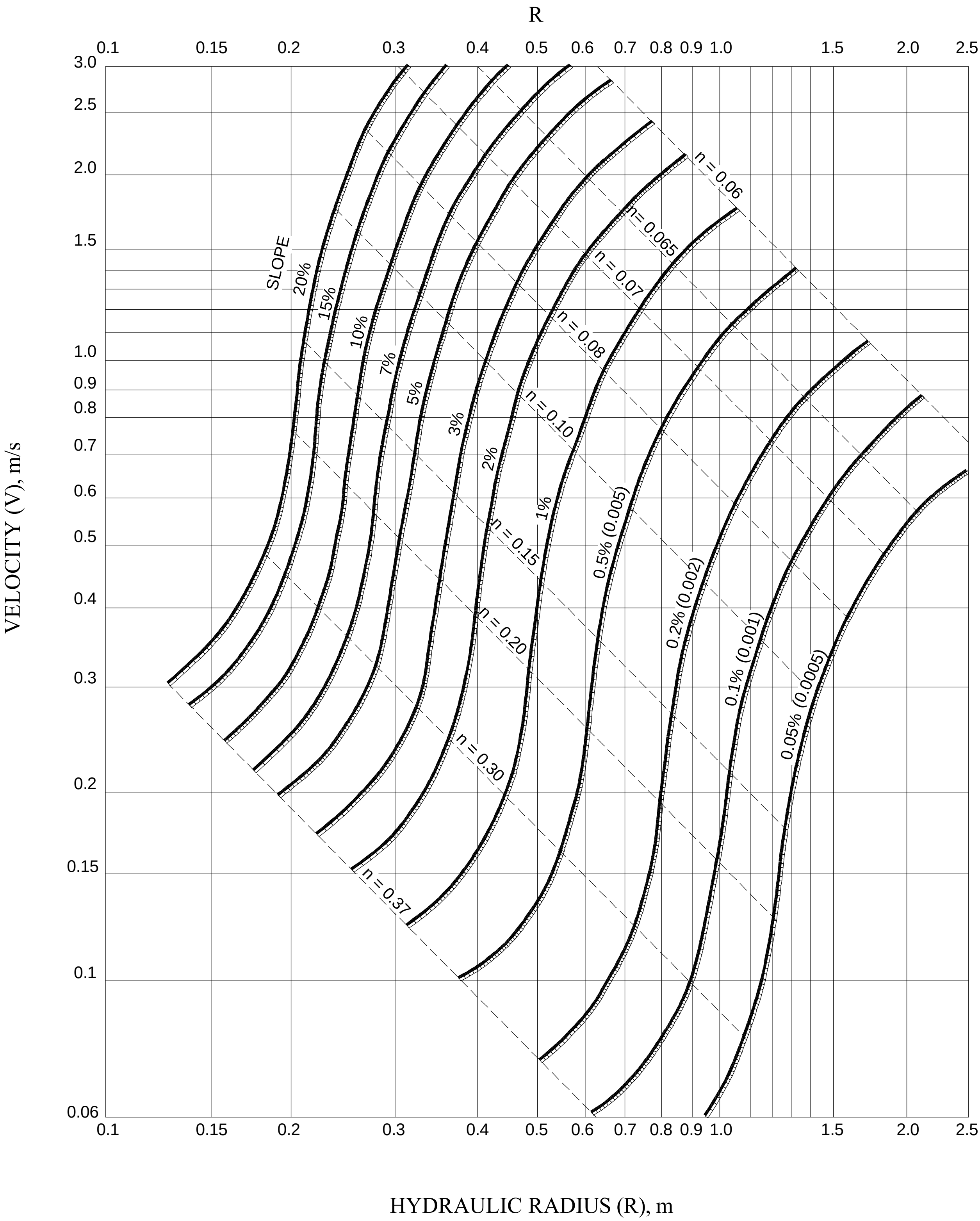


Figure A.3.5 Graphical solution to the Manning formula for Retardance B

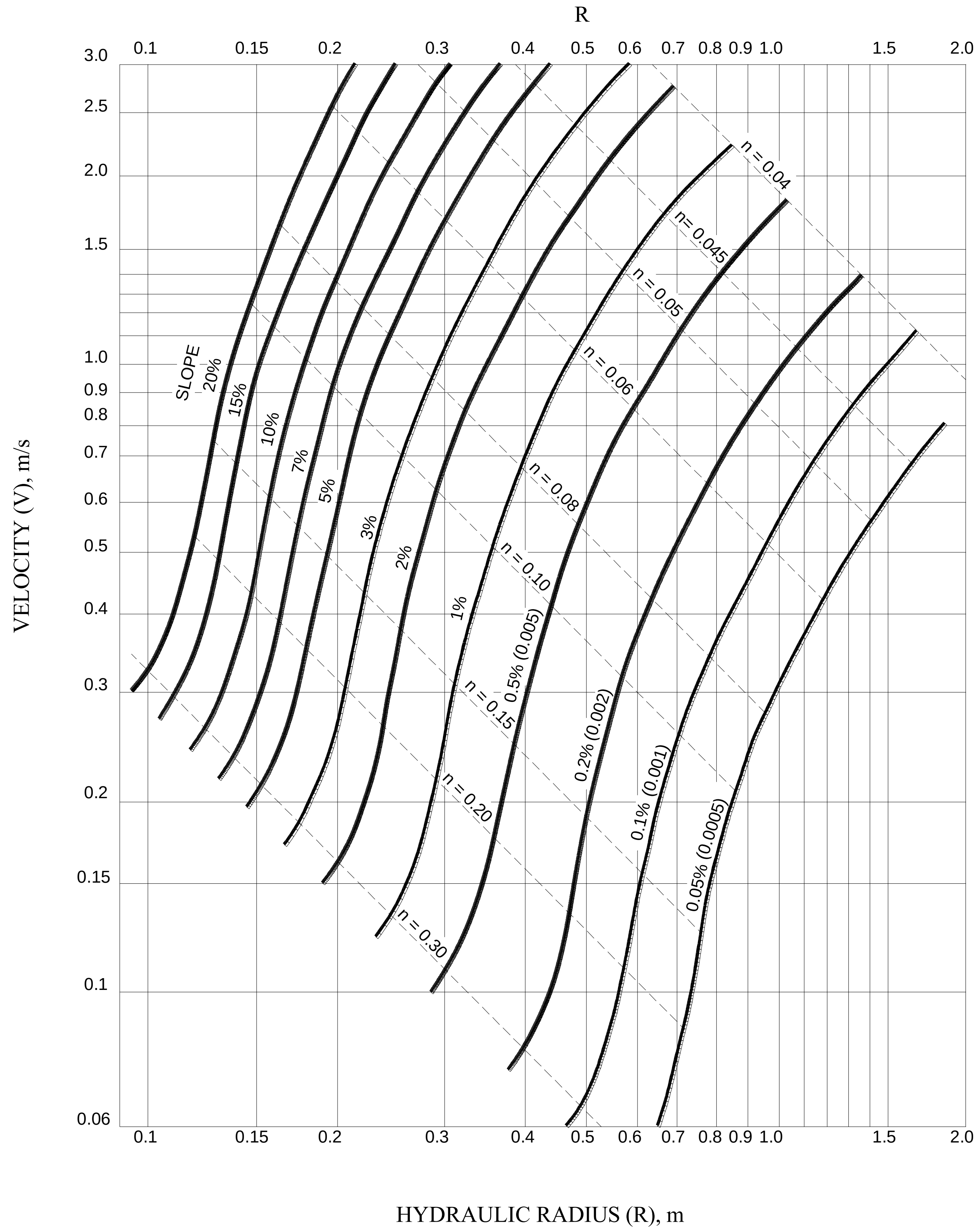


Figure A3.6 Graphical solution to the Manning formula for Retardance C

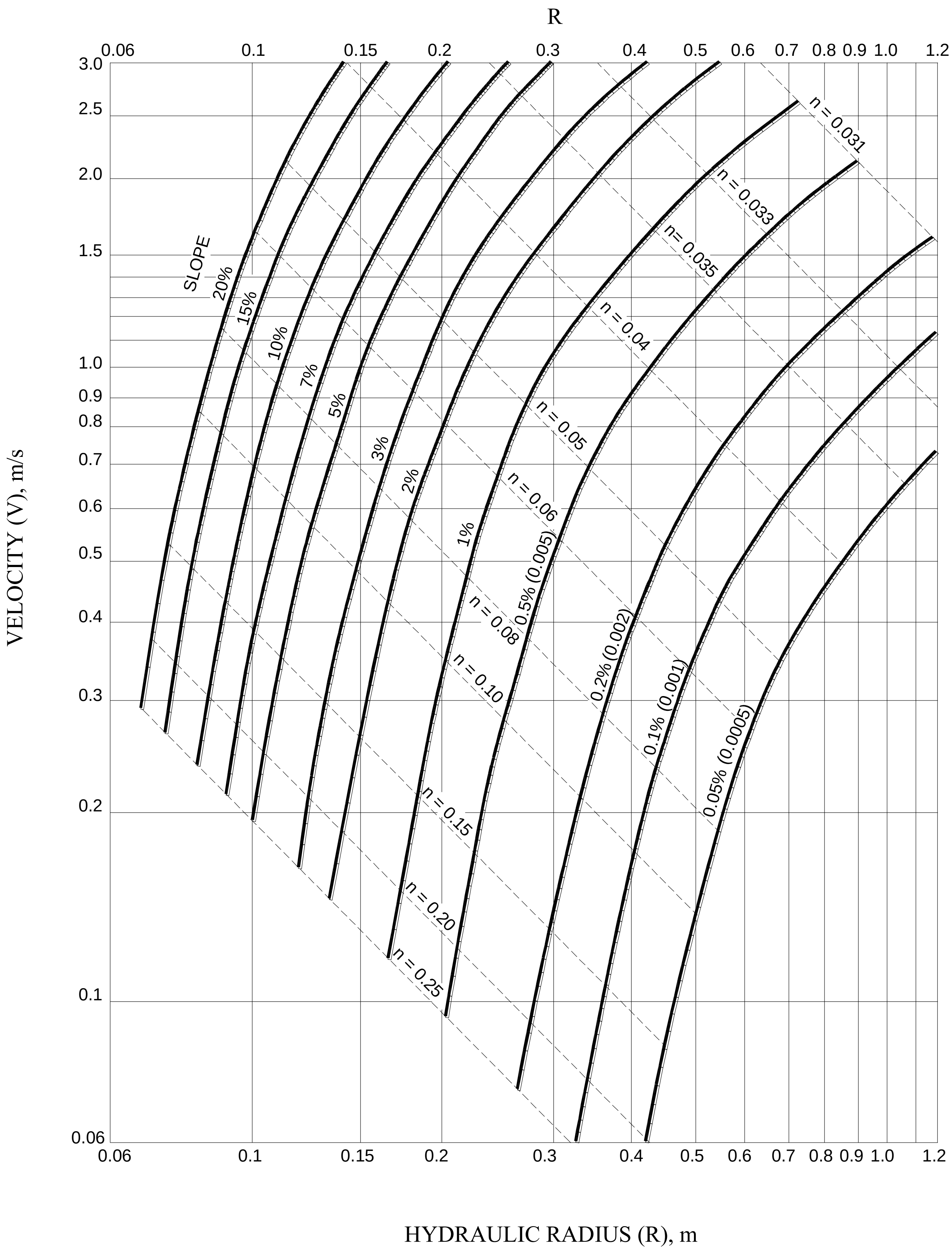


Figure A3.7 Graphical solution to the Manning formula for Retardance D

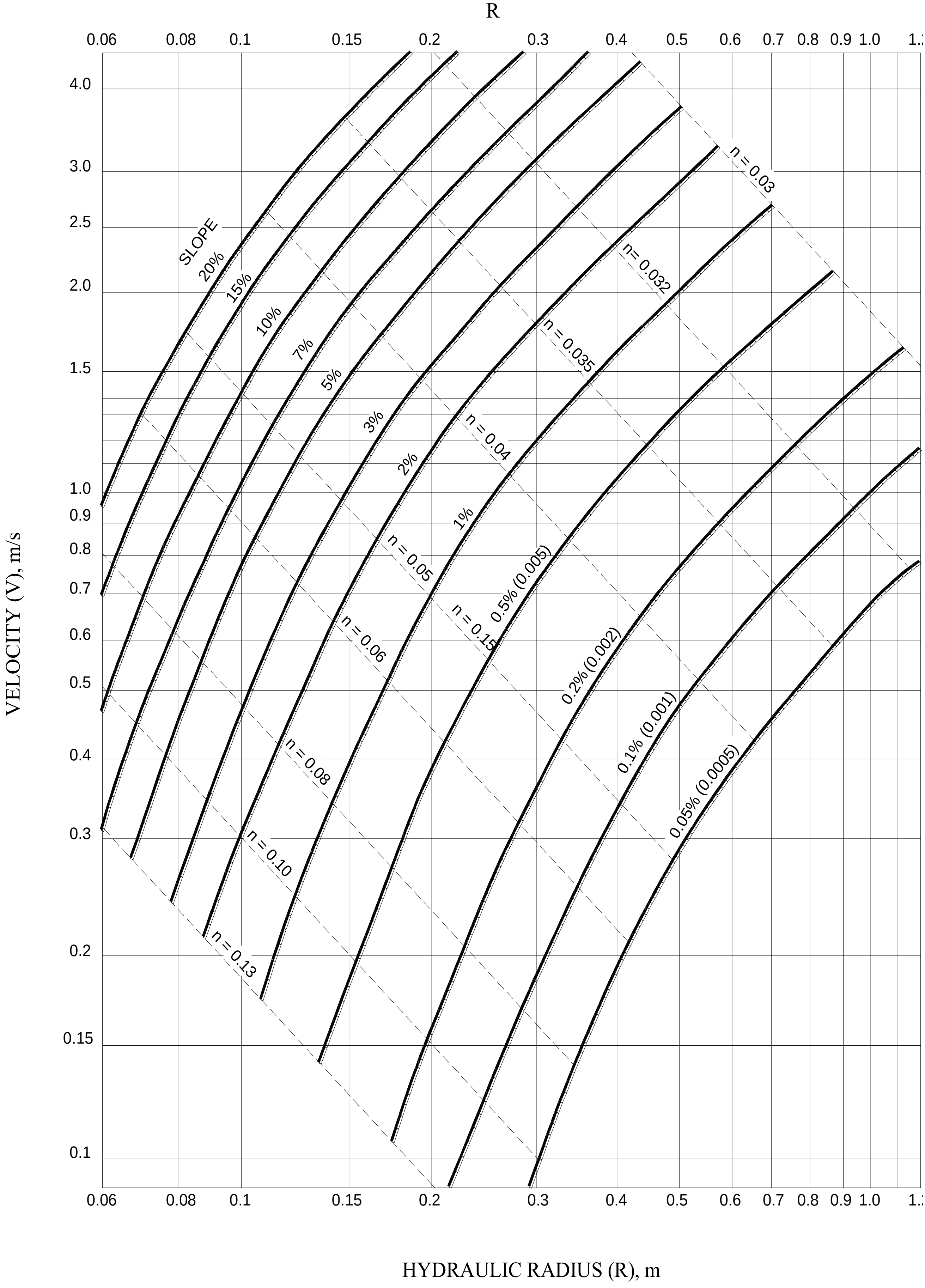


Figure A3.8 Graphical solution to the Manning formula for Retardance E

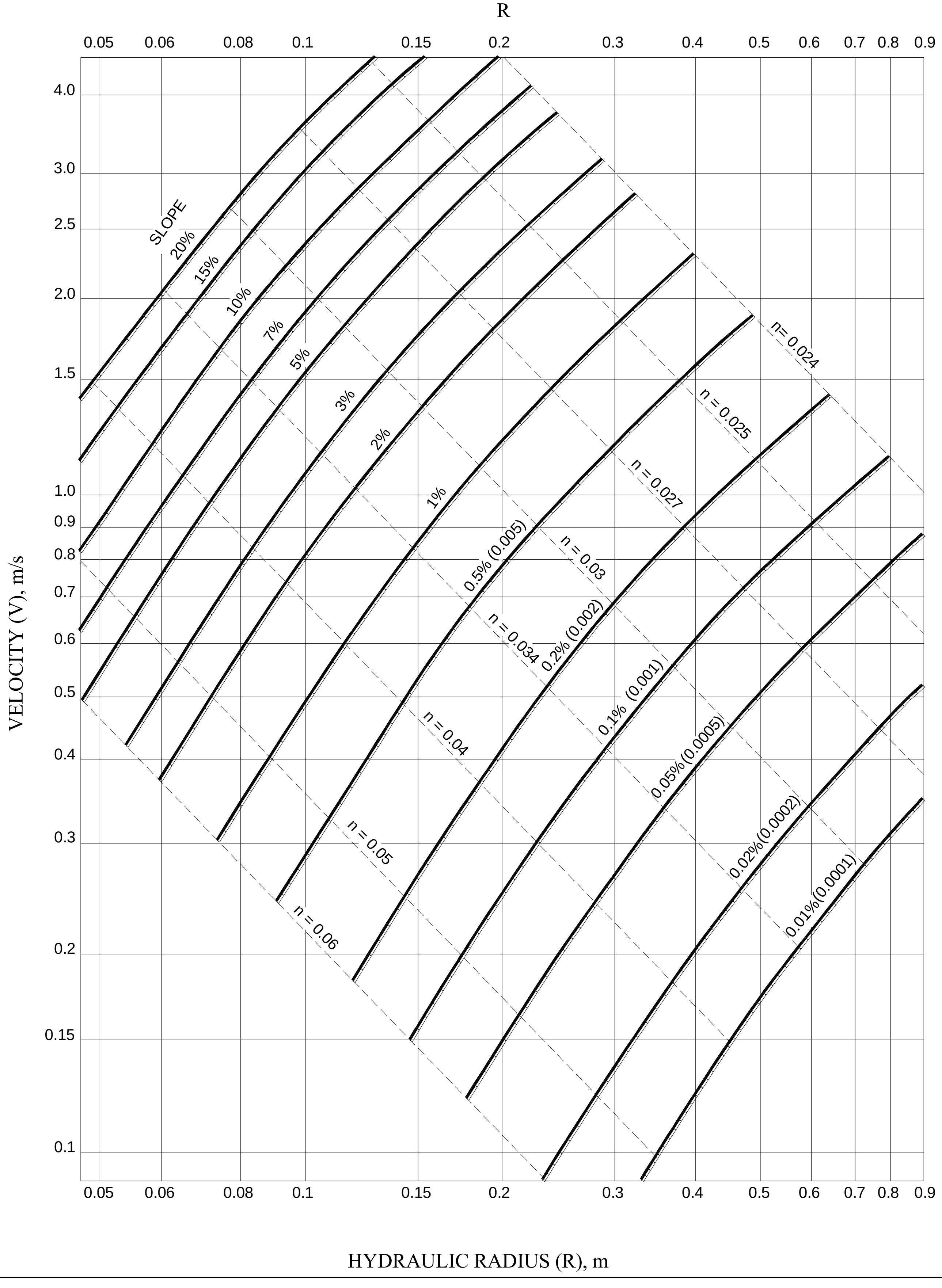


Figure A3.9 Nomograph for solution to the Manning formula

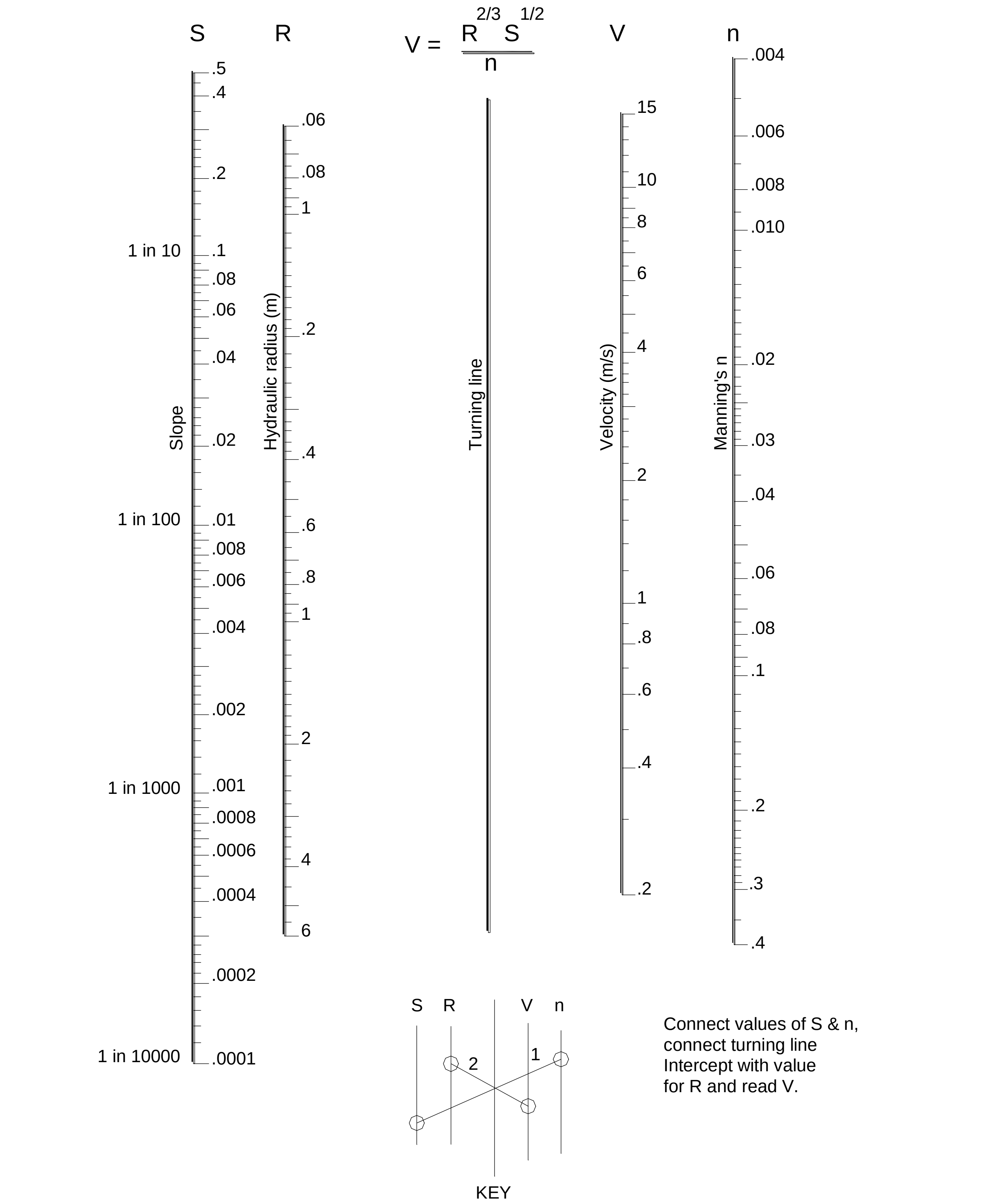
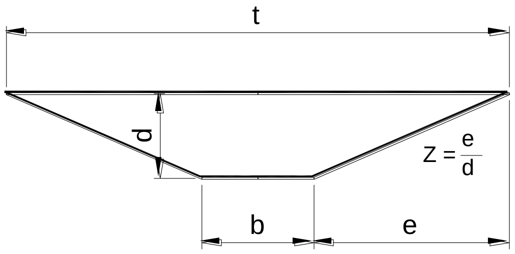
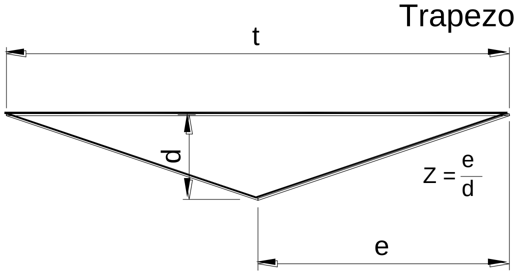


Figure A3.10 Formulae for dimensions for trapezoidal, triangular and parabolic shapes



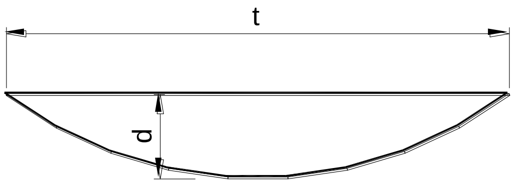
Cross - Sectional Area a	Wetted Perimeter	Hydraulic Radius R
$bd + Zd^2$	$b + 2d\sqrt{Z^2+1}$	$\frac{bd + Zd^2}{b + 2d\sqrt{Z^2 + 1}}$

Trapezoidal cross section



Cross - Sectional Area a	Wetted Perimeter	Hydraulic Radius R
Zd^2	$2d\sqrt{Z^2+1}$	$\frac{Zd}{2\sqrt{Z^2 + 1}}$

Triangular cross section

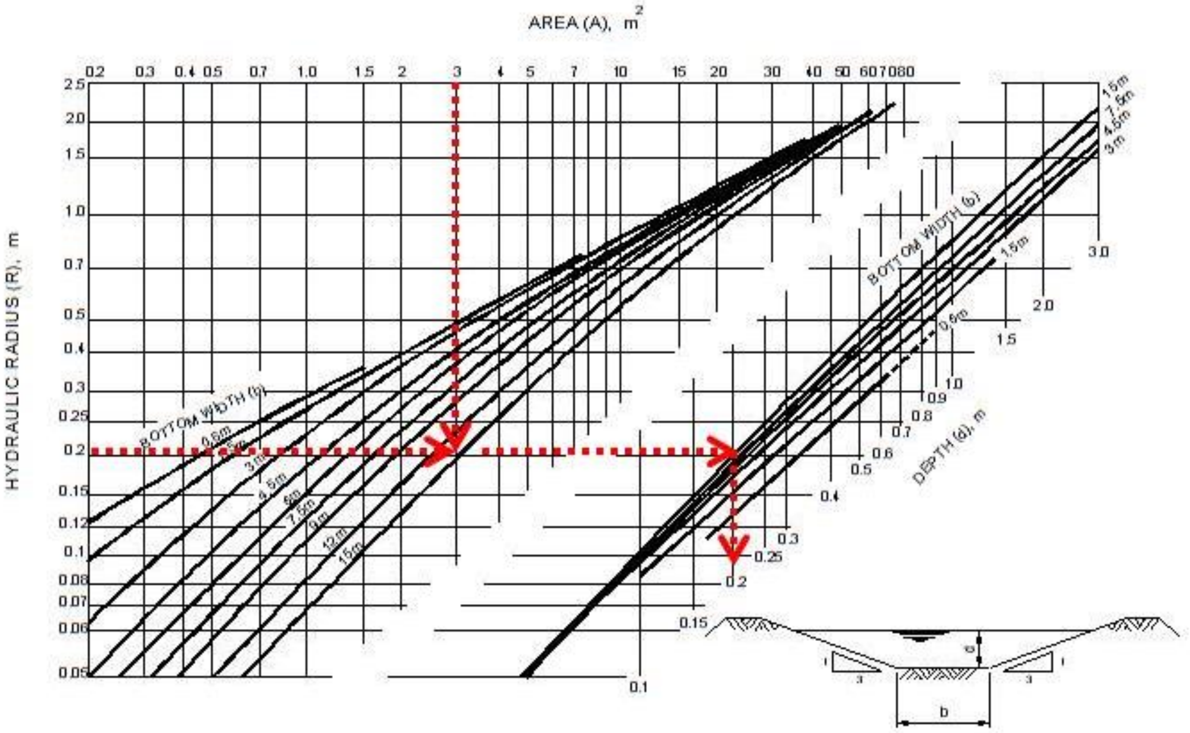


Cross - Sectional Area a	Wetted Perimeter	Hydraulic Radius R
0.66td	$t + \frac{8d^2}{3t}$	$\frac{t^2 d}{1.5t^2 + 4d^2}$

Parabolic cross section

Formulae for channel cross sections

Figure A3.11 Demonstration of the use of a chart to determine waterway dimensions



Use of charts to determine the dimensions of a waterway

If the hydraulic radius and cross-sectional area of a waterway are known, the bottom width of the waterway and the depth of flow can be determined using the above chart (for waterways with 1: 3 batters)

Figure A3.12 Dimensions of trapezoidal channels with 1:1.5 batter slopes

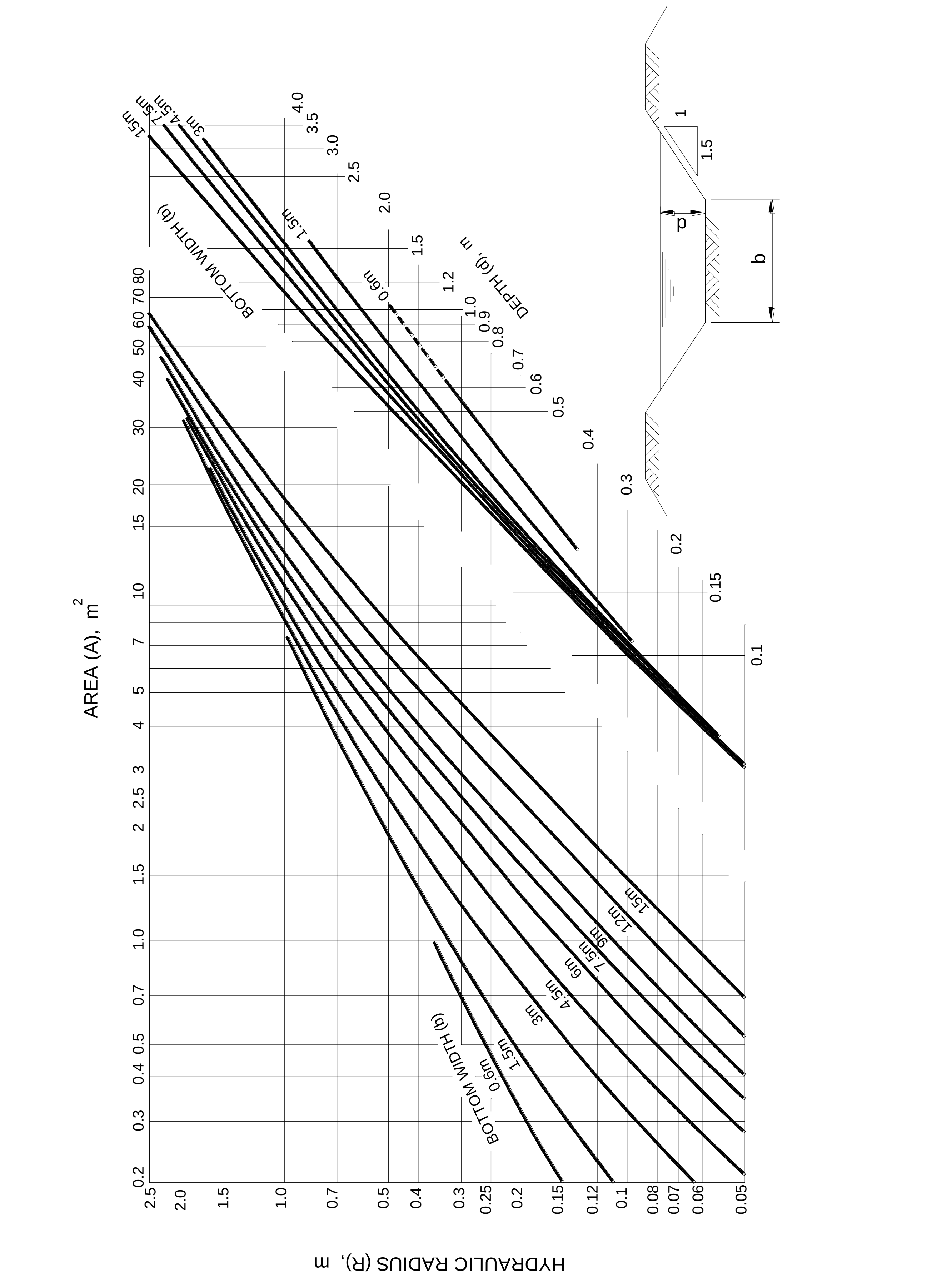


Figure A3.13 Dimensions of trapezoidal channels with 1:2 batter slopes

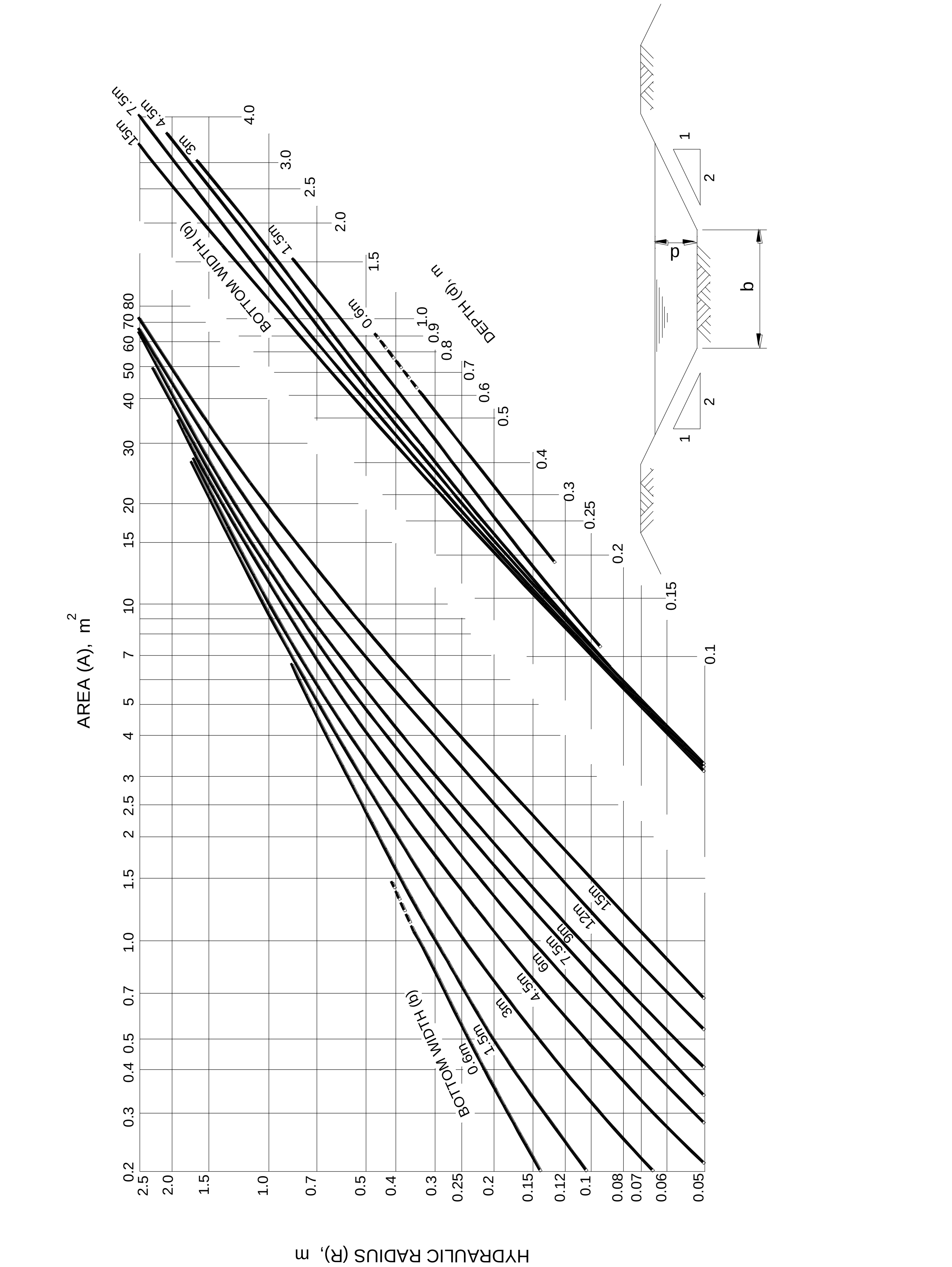


Figure A3.14 Dimensions of trapezoidal channels with 1:2.5 batter slopes

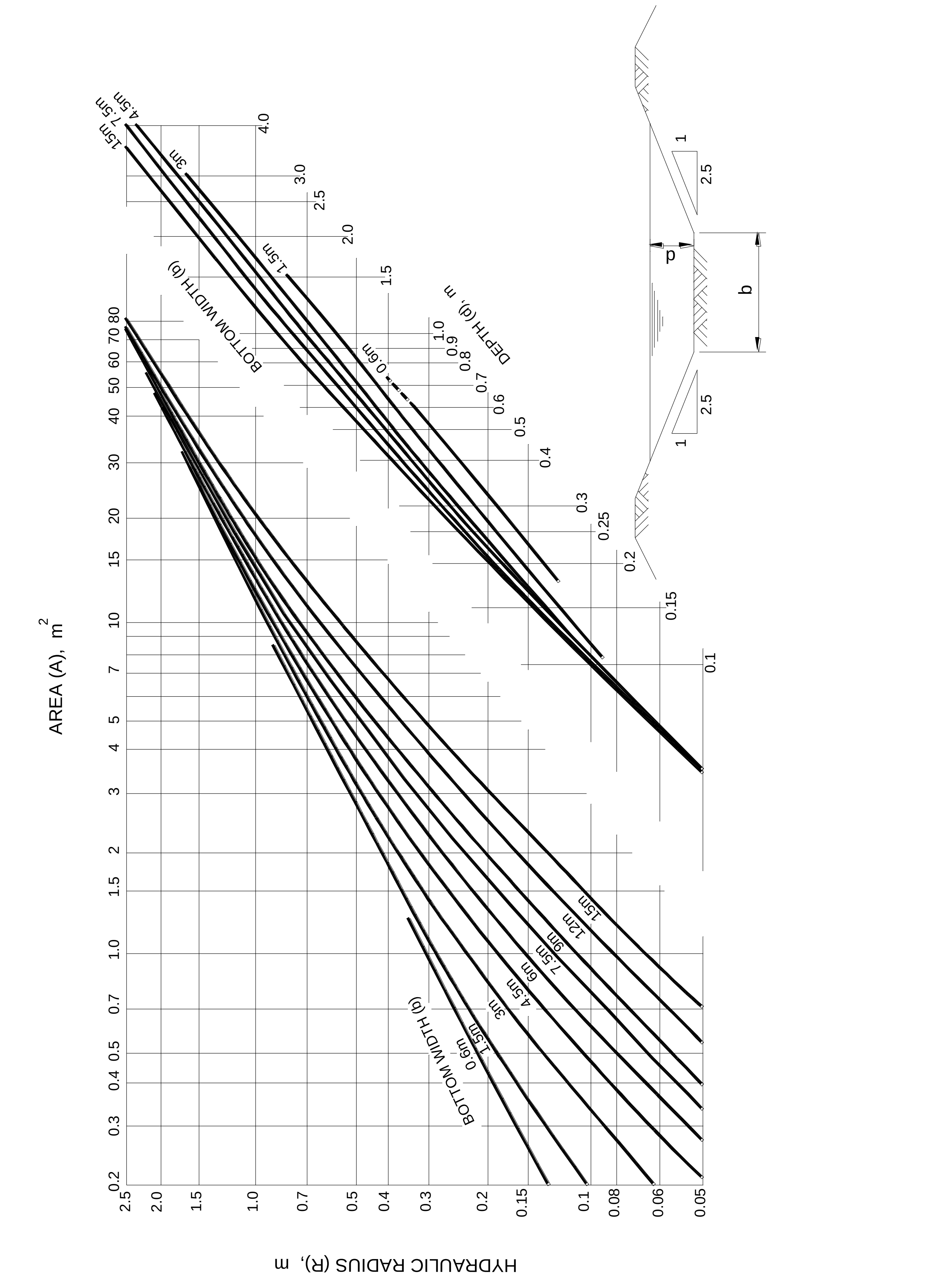


Figure A3.15 Dimensions of trapezoidal channels with 1:3 batter slopes

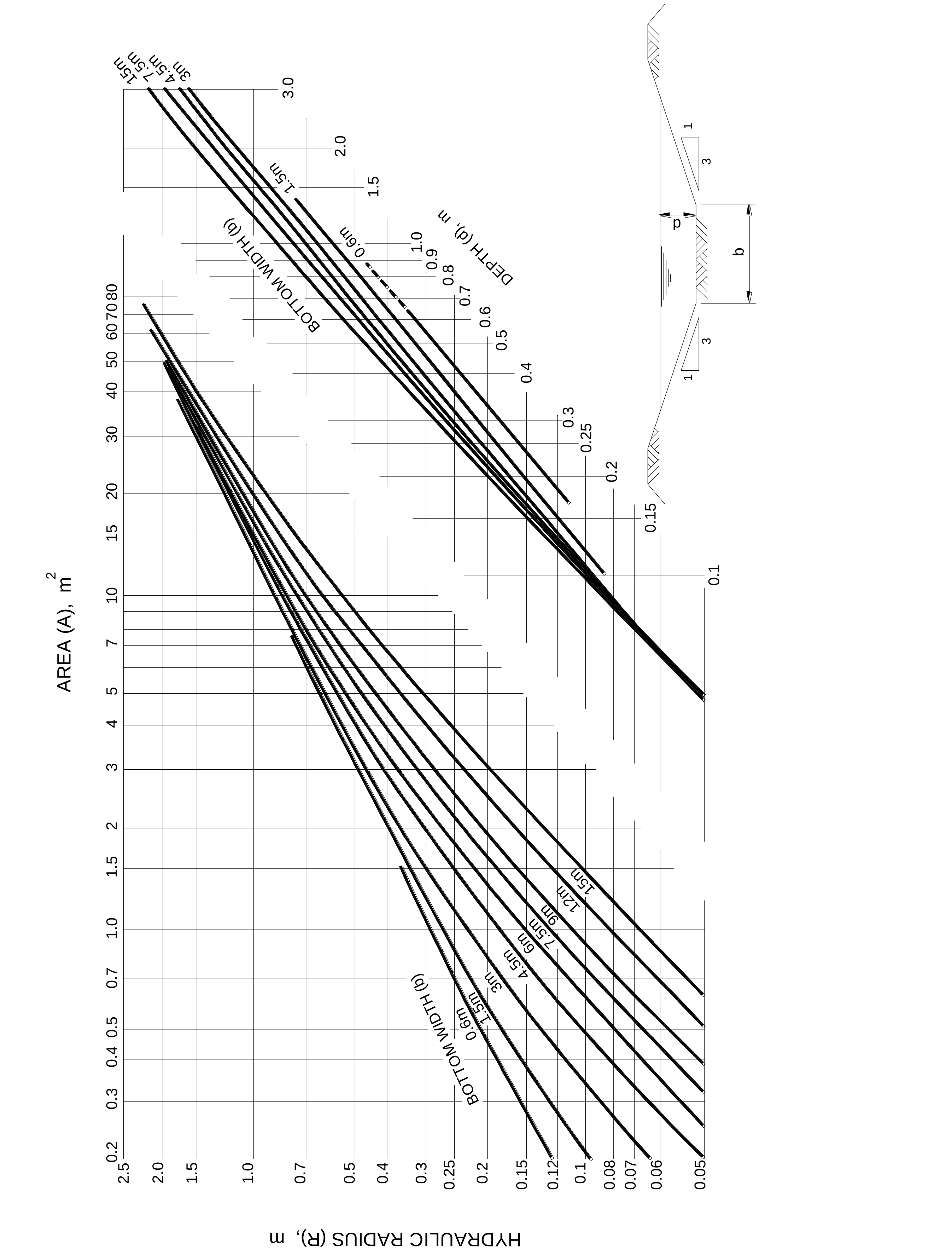


Figure A3.16 Dimensions of trapezoidal channels with 1:4 batter slopes

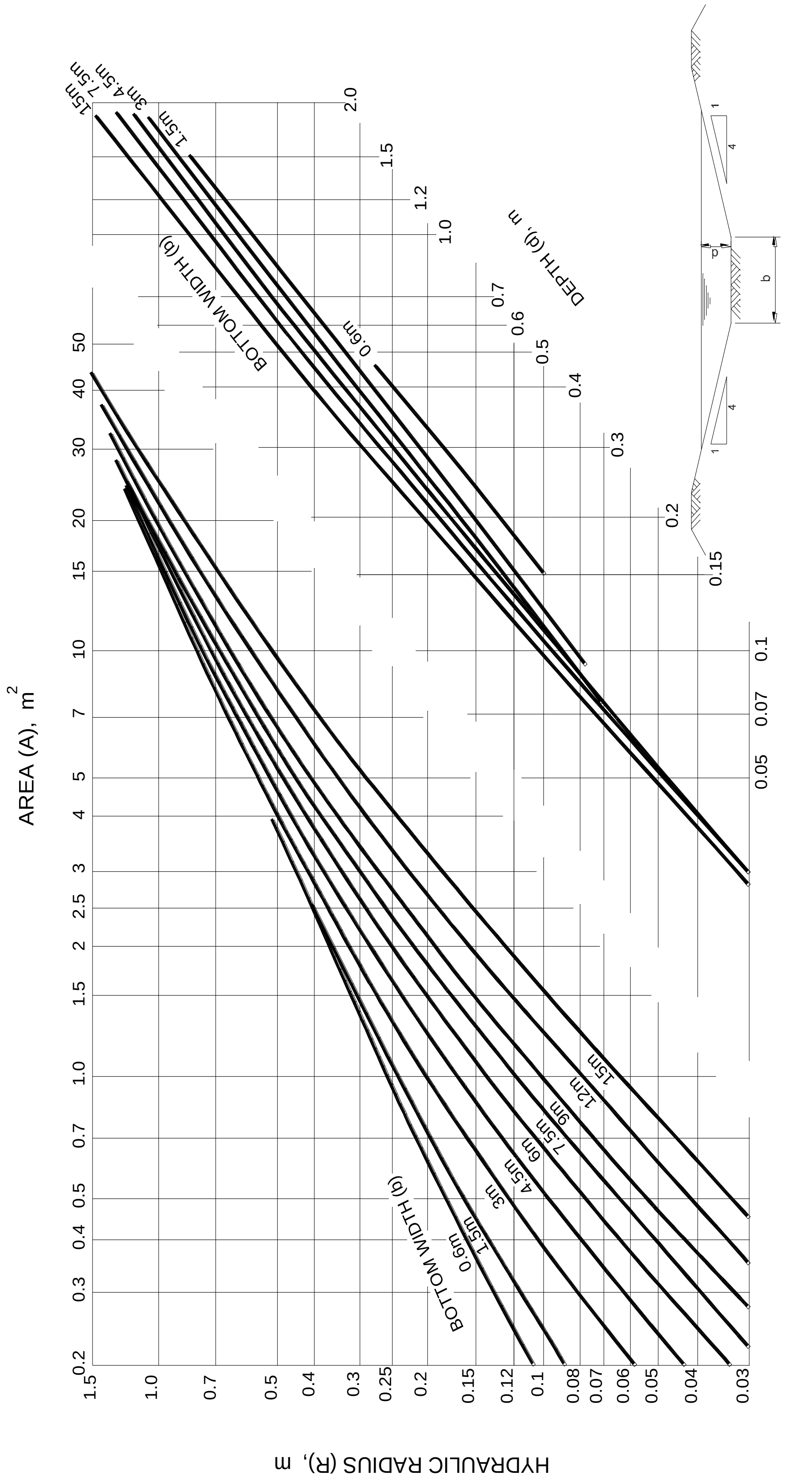


Figure A3.17 Dimensions of trapezoidal channels with 1:5 batter slopes

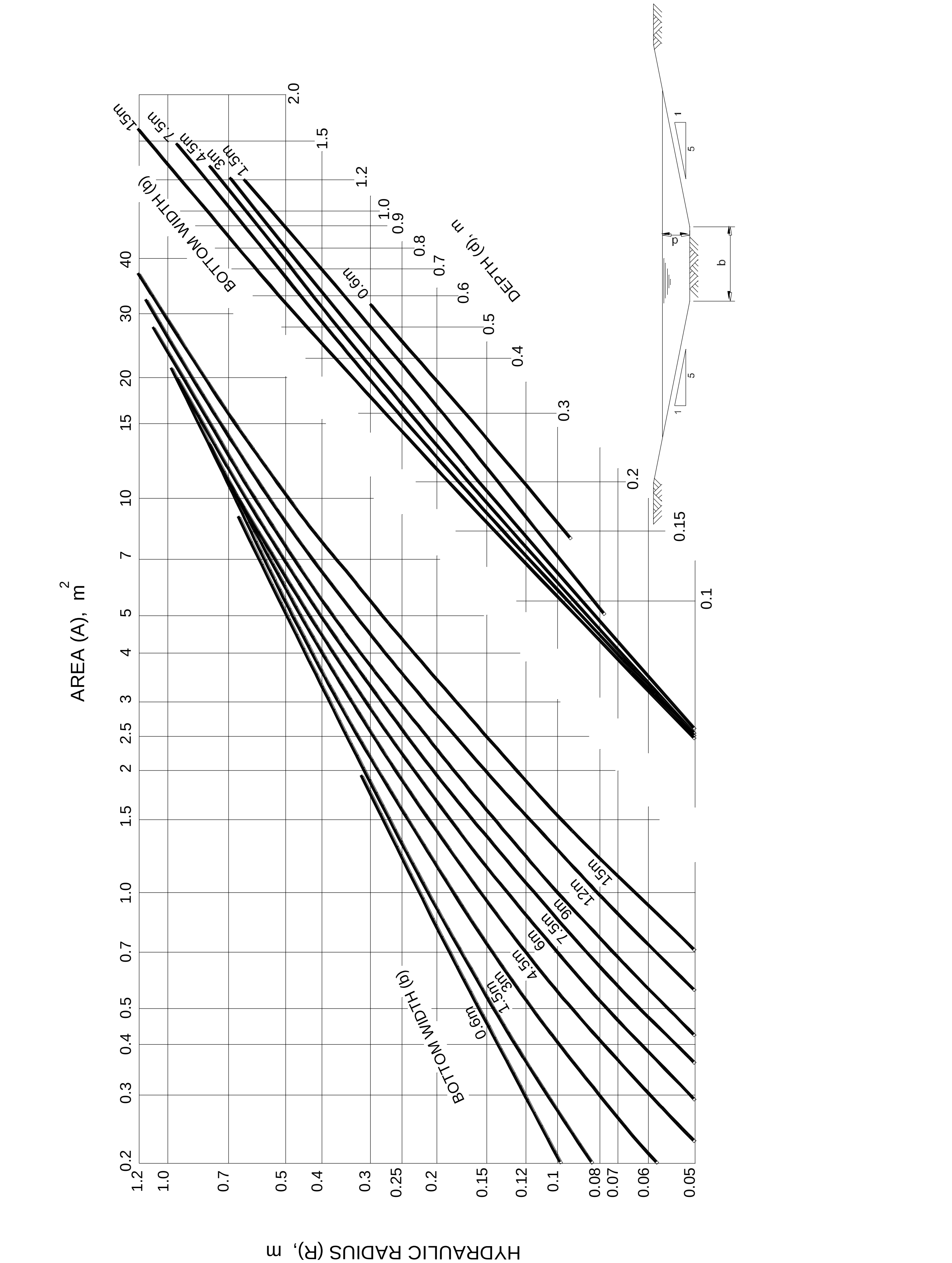


Figure A3.18 Dimensions of trapezoidal channels with 1:6 batter slopes

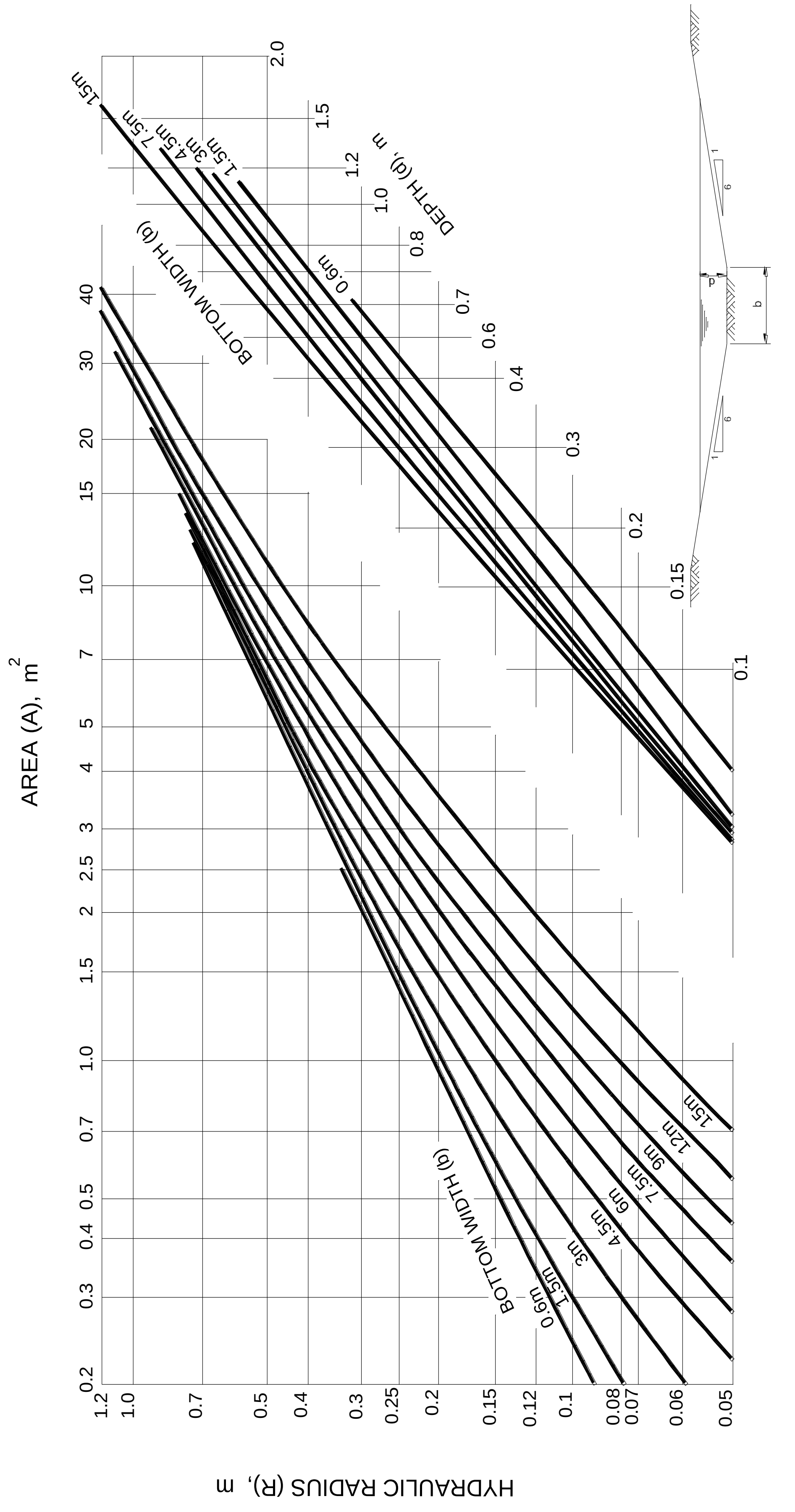


Figure A3.19 Dimensions of parabolic channels (1 of 2)

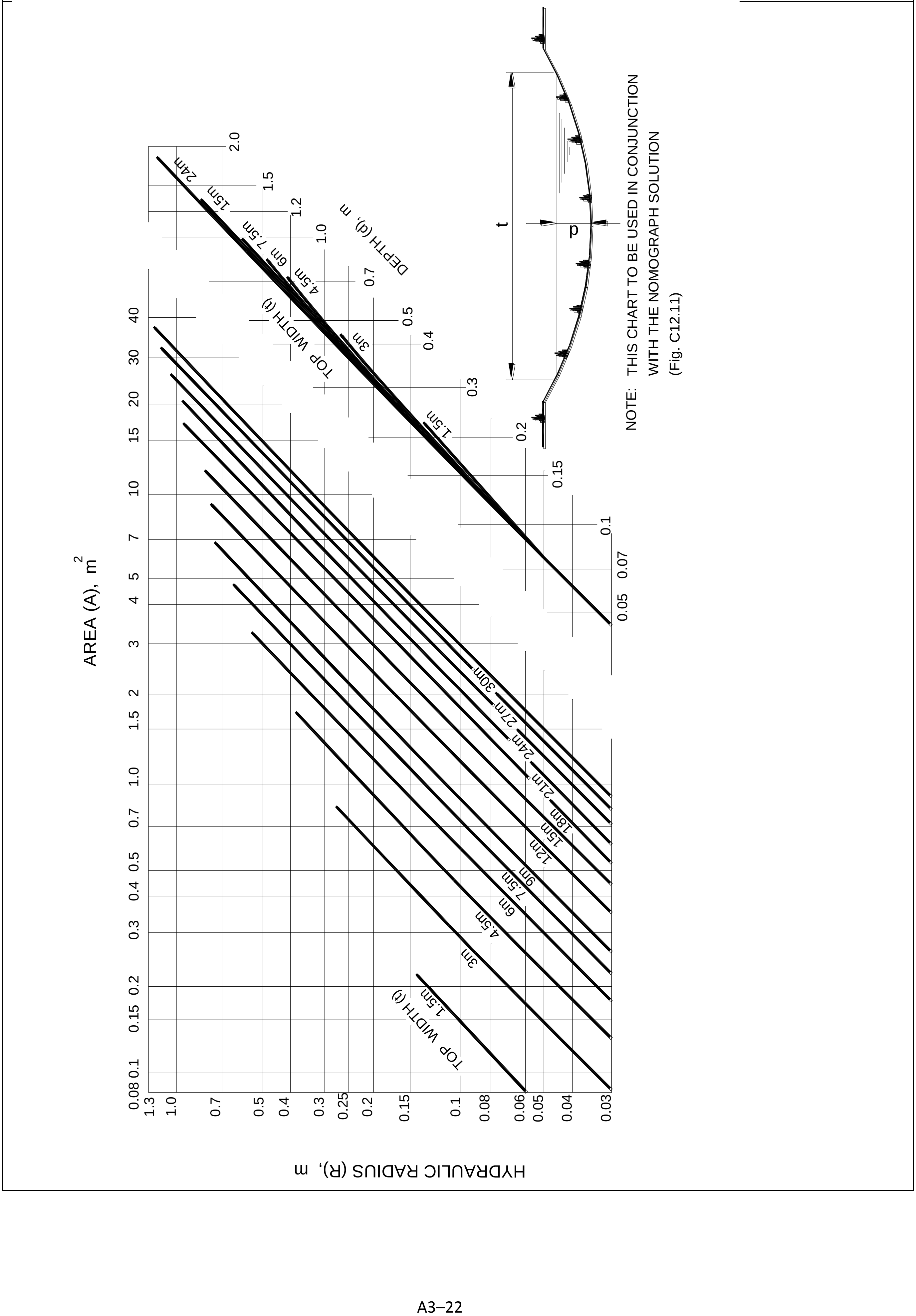


Figure A3.20 Dimensions of parabolic channels (2 of 2)

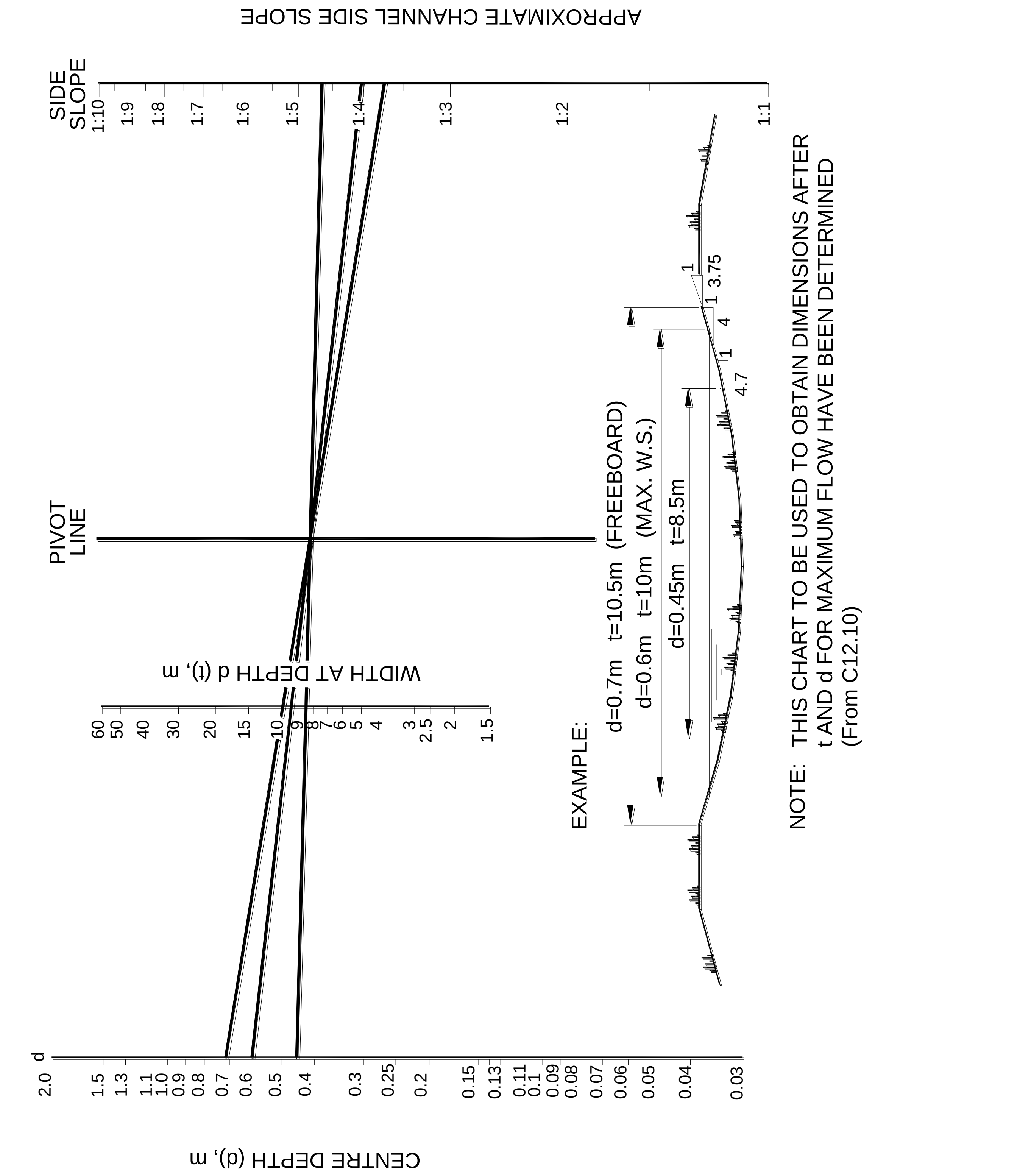
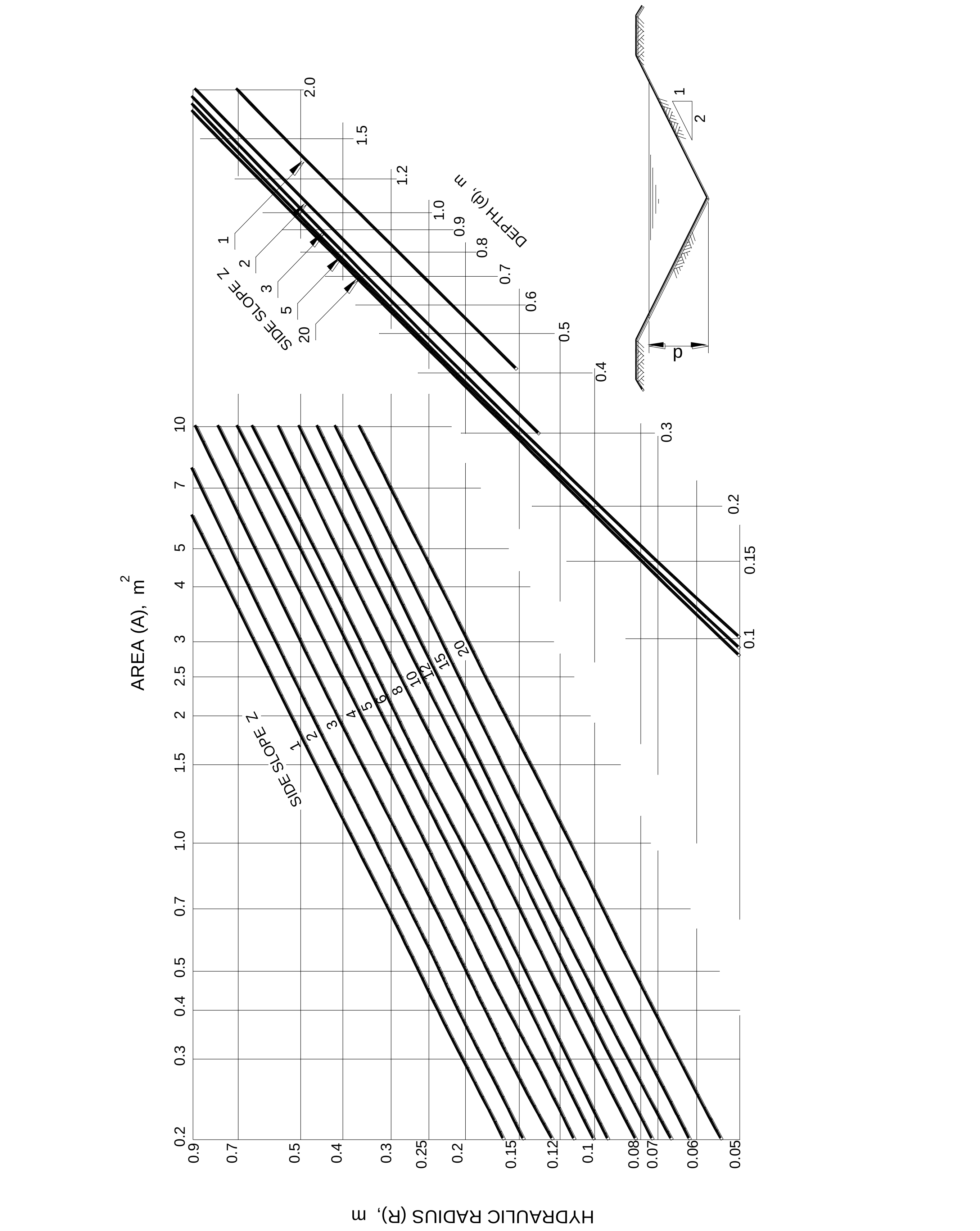


Figure A3.21 Dimensions of triangular channels



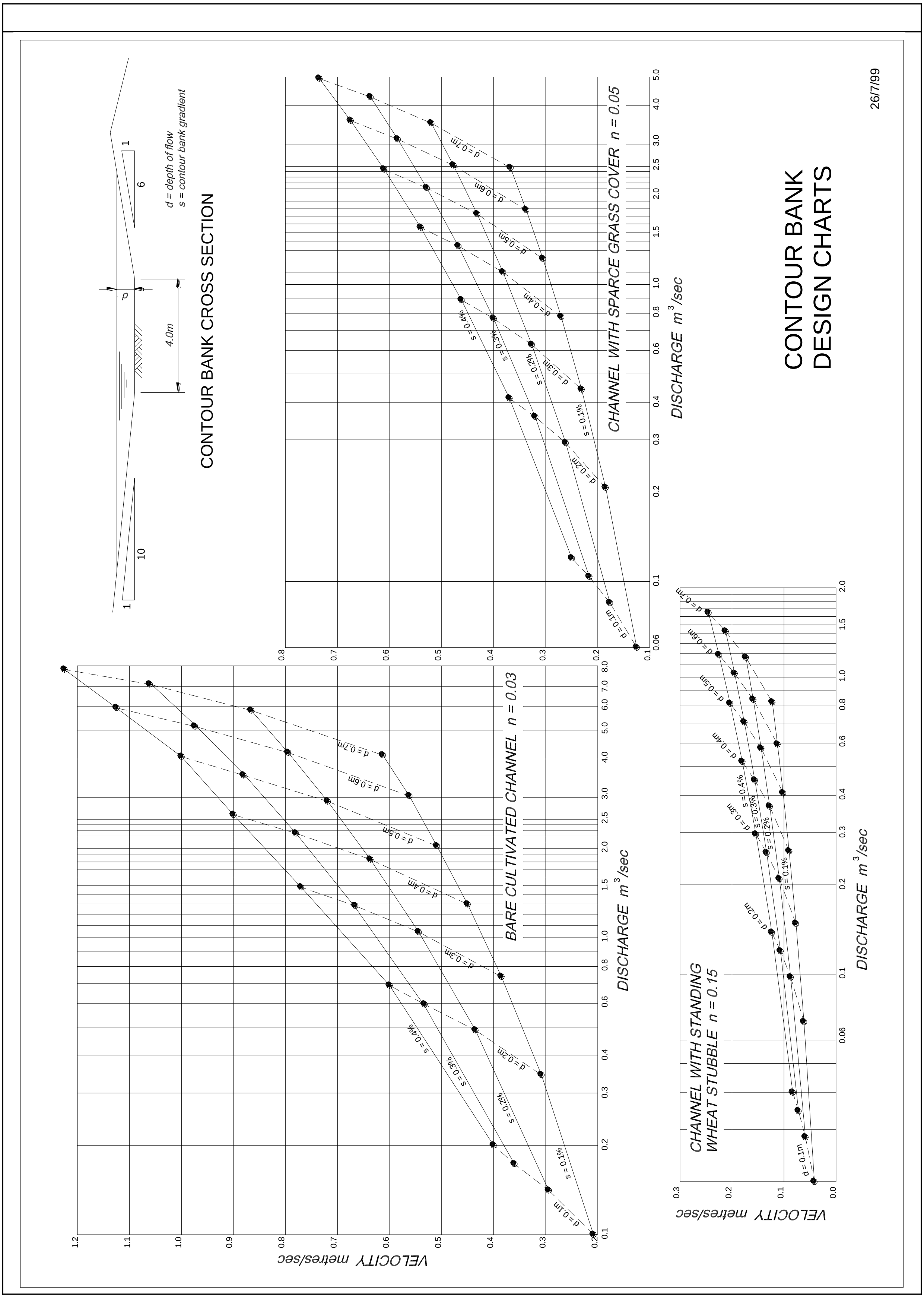

CONTOUR BANK
DESIGN CHARTS
26/7/99
CONTOUR BANK CROSS SECTION
4.0m
d = depth of flow
s = contour bank gradient
CHANNEL WITH SPARCE GRASS COVER n = 0.05
BARE CULTIVATED CHANNEL n = 0.03
CHANNEL WITH STANDING WHEAT STUBBLE n = 0.15
DISCHARGE m³/sec
VELOCITY metres/sec

Figure A3.23 Contour bank design chart for a trapezoidal shape and a range of values for Mannings *n* and flow depth

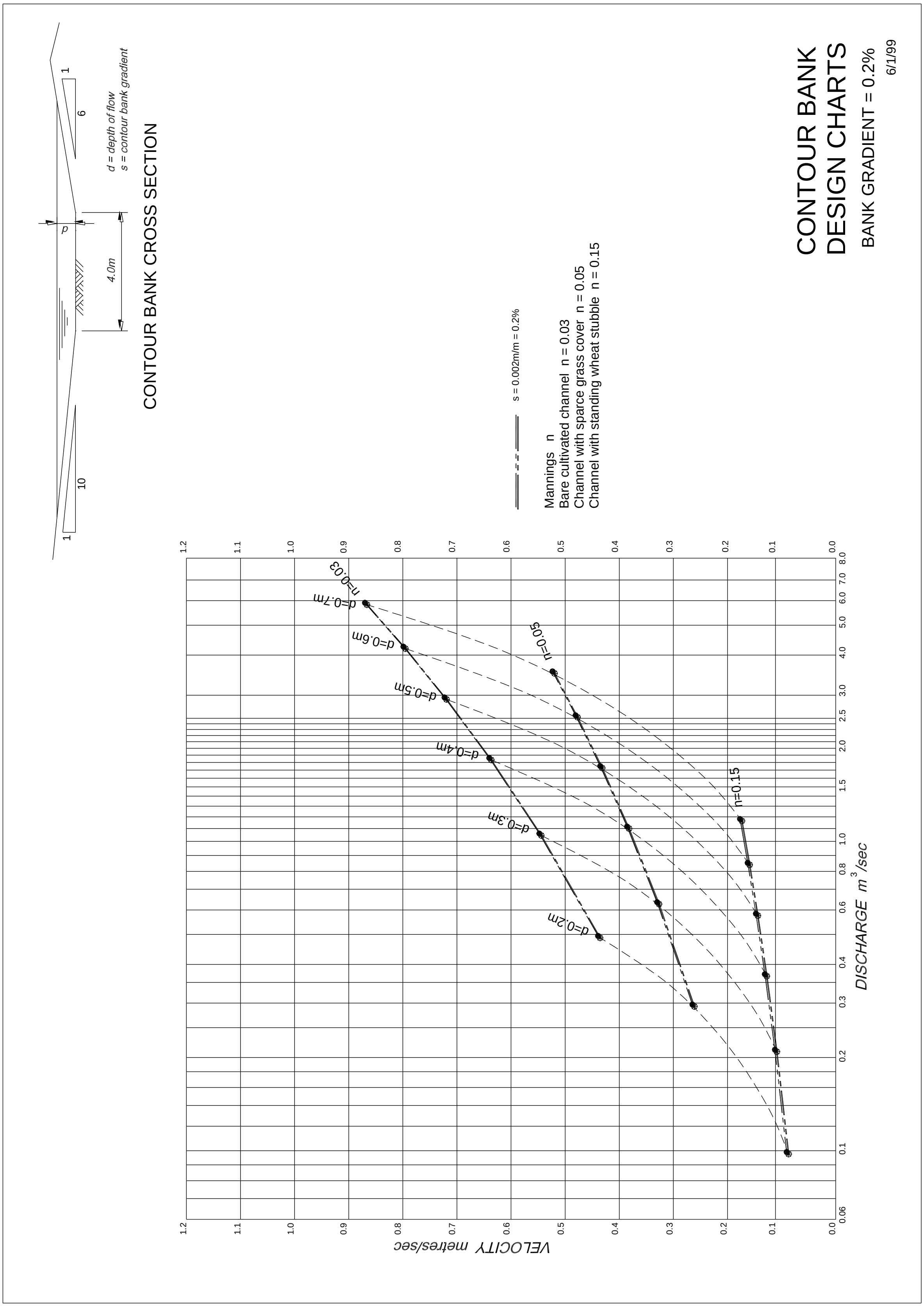


Figure A3.24 Wide waterway design ,Retardance C, velocity 1 m/s

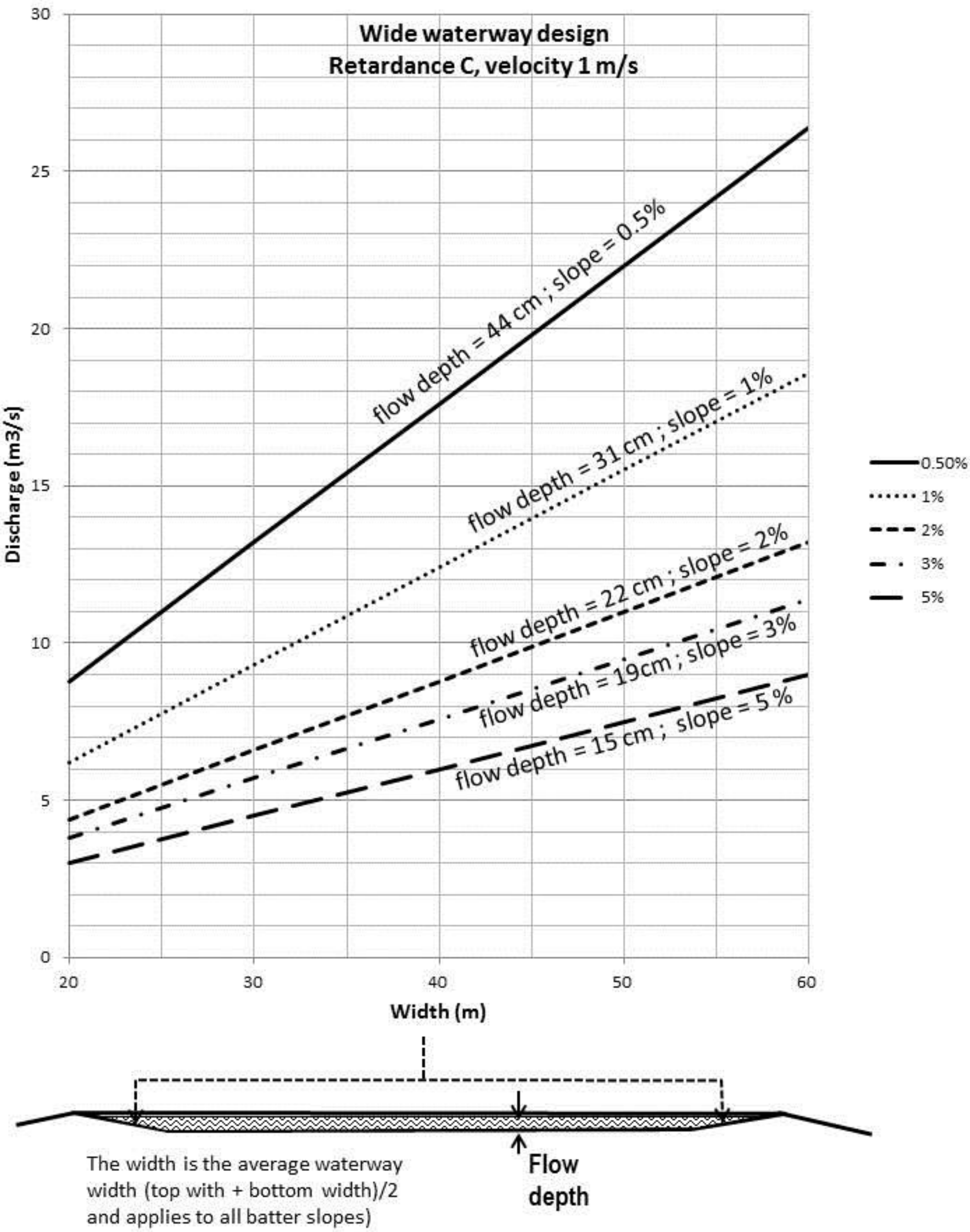


Figure A3.25 Wide waterway design, Retardance C, velocity 1.2 m/s

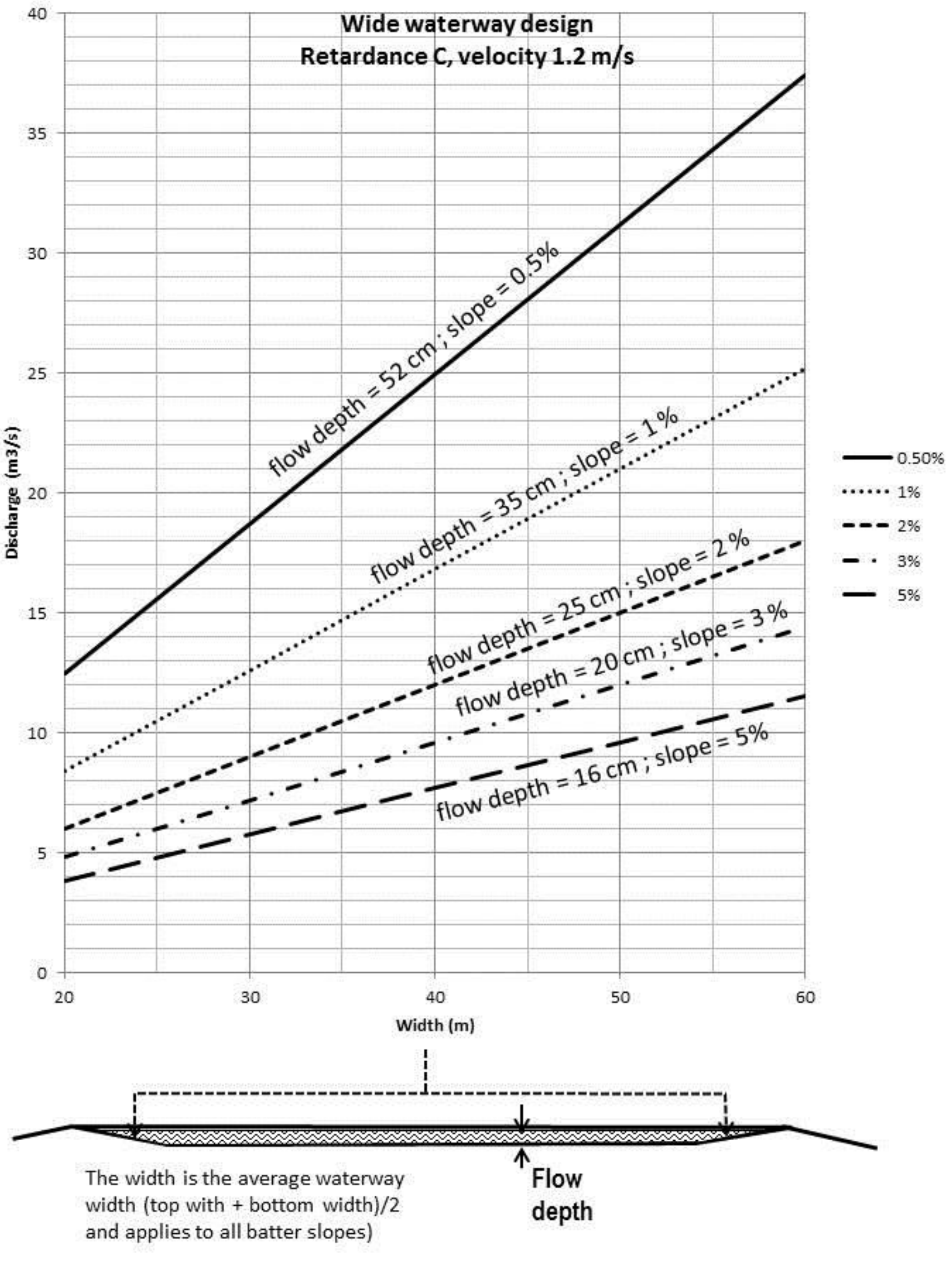


Figure A3.26 Wide waterway design, Retardance D, velocity 1 m/s

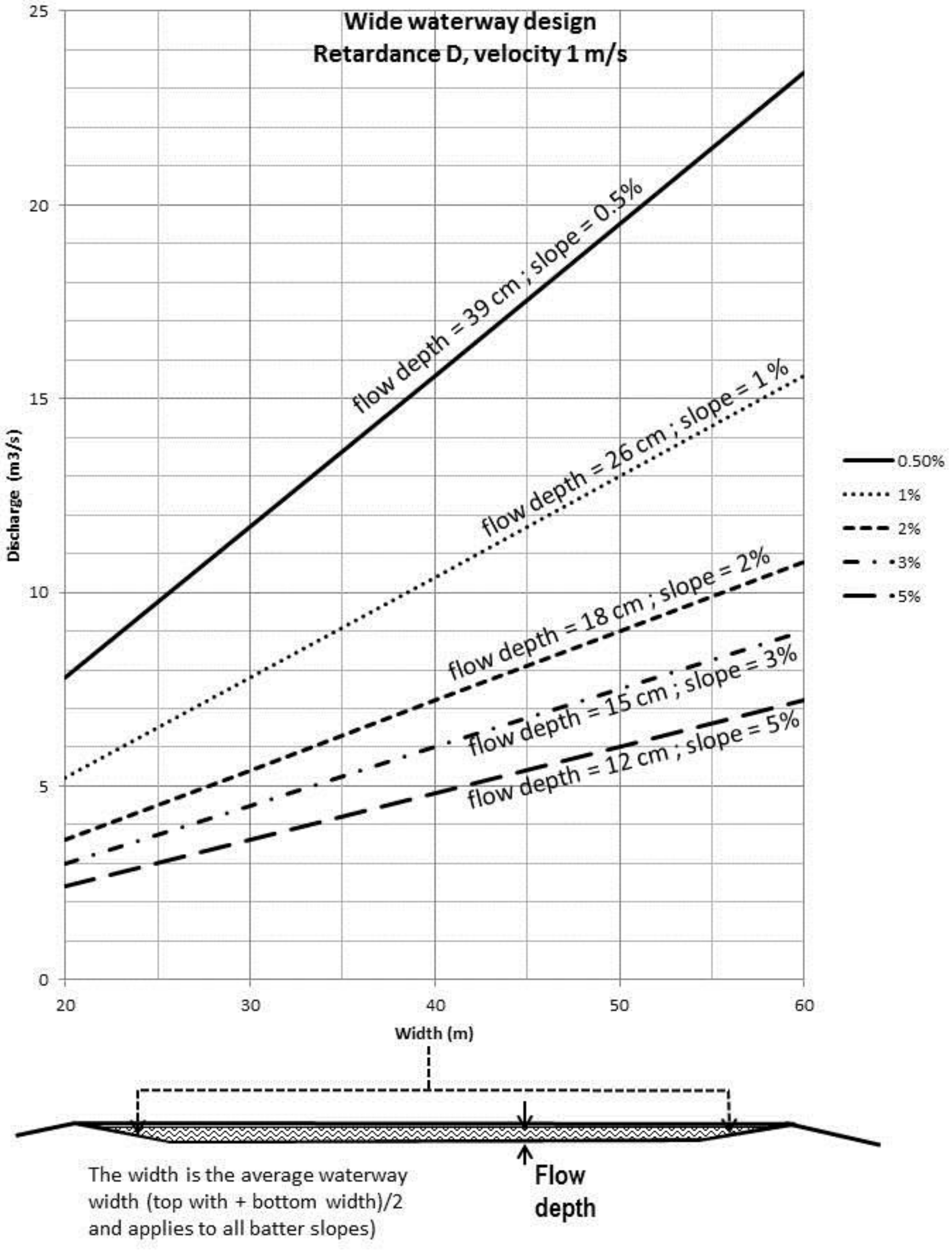


Figure A3.27 Wide waterway design , Retardance D, velocity 1.2 m/s