71

A guide to the use of grass in hydraulic engineering practice

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FOREWORD

The work reported in this Technical Note was carried out by Mr E. Whitehead at the Hydraulics Research Station, Wallingford, Berkshire and Mr M. Schiele* and Mr W. Bull† of Nickersons of Rothwell, Lincolnshire, a company which specialises in breeding plants, cereals and grasses for specific purposes.

The project was directed by a Steering Group comprising:

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Mr J.K. Picknett (Binnie & Partners)
Mr R.M.J. Butler (Severn-Trent Water Authority)
Mr E. Miller (Wimpey Laboratories Ltd.)

The Group have reviewed and agreed the text of this Technical Note. Members wish to record their indebtedness to Mr Henry B. Rowntree, formerly Deputy Engineer, Lee Conservancy Catchment Board, for the painstaking way in which he collated the comments made by the authors and members of the Group and edited the whole text.

Two recent events made it likely that considerable attention will be paid to examining the capacity of spillways of existing dams. The first event was the publication of the NERC Flood Studies Report which provides comprehensive data on flood flows. The second event was the passage of the Reservoirs Act, 1975 which supersedes the former Reservoir (Safety Provisions) Act 1930.

Some dams will require the capacity of their spillways to be increased, and for many smaller dams a more economic and aesthetically attractive alternative to concrete will be sought. It is possible that a grassed spillway surface could be used for emergency spillways if sufficient reliance could be placed on its engineering properties.

The Steering Group would like to record the fact that the original suggestion for this work came from Mr G.M. Binnie who was considering such an alternative for the improvement of the spillway capacity of existing but inadequate dams.

Because of the scattered nature of much of the information on this subject, many of the statements made in this report are necessarily tentative. It should therefore be regarded as a draft guide, and not as definitive. It is hoped that those with comment and additional information will send these to CIRIA so that the Note can be updated and eventually re-issued. Suggestions for further research will also be welcomed. Members are invited to contact Mr B.B. Desai, Research Manager in Hydraulic and Public Health Engineering.

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CONTENTS

LIST OF TABLES 6
LIST OF ILLUSTRATIONS 6
NOTATION 6
GLOSSARY OF BOTANICAL TERMS 7

1. SUMMARY 9
2. INTRODUCTION 10
   2.1 What is the problem? 10
   2.2 Reasons for preparing a guide 11
   2.3 The object of the guide 11
   2.4 The basis of the guide 12
3. HYDRAULIC ENGINEERING ASPECTS OF THE USE OF GRASS 13
   3.1 Introduction 13
   3.2 Erosion resistance 13
   3.3 Frictional resistance of grass surfaces 17
4. BOTANICAL CHARACTERISTICS OF GRASS FOR USE IN HYDRAULIC ENGINEERING PRACTICE 24
   4.1 General principles 24
   4.2 Survey of information 29
   4.3 Recommendations for grass mixtures: establishment and management 34
5. SEA BANKS 39
   5.1 Reasons for separate treatment 39
   5.2 Survey of information on hydraulic aspects 39
   5.3 Survey of information on botanical aspects 42
6. SITE TRIALS AND RECOMMENDATIONS FOR HYDRAULIC EXPERIMENTS 45
   6.1 Reasons for undertaking preliminary site trials 45
   6.2 Programme for preliminary site trials 45
   6.3 Recommendations for hydraulic experiments 46
7. SUMMARY OF CONCLUSIONS ON CHOICE OF GRASSES 49
   7.1 Hydraulic engineering aspect 49
   7.2 Grass mixtures 49
   7.3 Management 50
8. ACKNOWLEDGEMENTS 51
9. REFERENCES 53

APPENDICES
1. Erosion resistance of vegetation 59
2. Artificial reinforcement and establishment aids for grassed surfaces 62
3. Hydraulic roughness of grass surfaces 69
4. Some examples of recent hydraulic design practice 75
5. Report on site visits to former River Authorities 79
6. The assessment of performance of the grass mixtures in the site trials 85
7. List of recommended varieties of species and plant breeders 87
8. The soil mechanics aspects of the stability of grass-covered banks 92
9. Sources of advice on grass 93
10. Instructions for seeding of grass areas 94

TABLES 97

ILLUSTRATIONS 114

LIST OF TABLES

1. Permissible velocity for channels lined with vegetation (USA)
2. Permissible velocity for channels lined with vegetation (Australia)
3. General guide to vegetal retardance categories
4. Grass mixtures establishment and management for freshwater situations
5. Grass mixtures for sea banks
6. Location of test mixtures in site trials
7. Grasses - common and latin names
8. Grass specification, use and management practice - UK authorities
9. Grass specification, use and management practice - overseas authorities

LIST OF ILLUSTRATIONS

1. Erosion resistance of grasses
2. Frictional resistance of grasses
3. Shape characteristics of channel cross sections
4. Flow parameter versus channel slope - retardance A
5. Flow parameter versus channel slope - retardance B
6. Flow parameter versus channel slope - retardance C
7. Flow parameter versus channel slope - retardance D
8. Flow parameter versus channel slope - retardance E

NOTATION

A	Cross-sectional area
a	Area of grass stem normal to flow
b	Base width of channel
C_1	Coefficient dependent on flow through vegetation
C_2	Coefficient dependent on vegetation stiffness
C_d	Drag coefficient for one grass stem
d	Depth of flow
F	Drag force per unit area
f	Darcy-Weisbach friction factor
g	Acceleration due to gravity
H	Total head above datum
K	Von Karman universal constant
k	Deflected height of vegetation
m	Number of stems per unit area
n	Manning's coefficient of roughness (referred to as the retardance coefficient for grass surfaces)
P	Wetted perimeter
Q	Discharge
q	Discharge per unit width
R	Hydraulic mean depth
s	Slope of channel bed
i	Friction slope - Total energy loss per unit length
u	Velocity at height above bed y
v_*	Shear velocity $(=g.R.i)^{\frac{1}{2}}$
V	Mean velocity
y	Height above bed
ρ	Density
τ	Shear stress

GLOSSARY OF BOTANICAL TERMS

Annual	Plant that lives for one year only
Biennial	Plant that springs one year, and flowers, fructifies and dies the next year
Graminaceous	Like grass
Heading	Period between commencement of growth and appearance of the seed head
Hydroponic	Grown in water
Hydro-seeding	A means of sowing seed on surfaces by blowing or hosing the seed in a water-based medium with a mulch of peat, gypsum or similar material added
Legume	Plant of the (botanical) pulse family (e.g. beans or peas)
Nitrogen (unit of)	These are the numbers of pounds of pure element available per cwt (e.g. 10 unit Nitrogen is 10lbs of pure Nitrogen/cwt). This definition will necessarily alter after metrication. The constituents of the fertiliser are always given in the order $N:P_2O_5:KOH$.
Perennial	Plant living for several, or many, years
Persistency	The ability of the plant to survive under the appropriate management for long periods (records show ryegrasses persisting for over 50 years)
Prostrate/Erect-Growth habits	Lying flat on the ground/vertical
Rhizobia	The symbotic bacteria which enable legumes to fix free nitrogen from the air into a usable form for plants
Rhizome	Prostrate root-like underground stem, or rootstock (see Section 4.1.1(c))
Species	Group (of plants) subordinate to genus, containing individuals agreeing in some common attribute
Stolon	Reclined or prostrate branch of plant that strikes root and develops new plant. Normally lies on surface
Taproot	Chief descending root of plant
Tillering	The production of new shoots from the base of the plant
Variety	Individual group (of plants) usually fertile with any other member of the species to which it belongs, but differing from the type in some qualities capable of perpetuation. Varieties generally out-perform their parent species
Grass names	In the main text of this report, grasses are referred to by the common English name of their species.

Table 7 lists these English names and gives the Latin equivalent. Where applicable, alternative names that are used in the UK or abroad are also listed.

Appendix 7 gives the names of the bred varieties of the main species thought to have application to hydraulic engineering practice.

1. SUMMARY

The Note provides guidance on the use of grass to stabilise surfaces subject to erosion by the intermittent flow of water. For structures like dam emergency spillways, river floodbanks and bywash channels, the frequency of occurrence of flow can be so low that expensive concrete works are not justified.

The main purpose of the guide is to help the water engineer to decide whether a grass lining is appropriate, by providing information on the erosion resistance and frictional resistance of grasses. The Note explains the botanical properties required of grasses that are to be utilised as engineering materials and classifies grass mixtures according to the principal management practice that is anticipated, e.g. agricultural use, amenity use or low maintenance. The Note includes recommendations on grass mixtures, establishment and management procedures.

The main part of the work relates to freshwater situations, but a section is devoted to the important case of sea banks.

A survey of water engineers working for consultants and the Water Authorities was carried out in addition to the normal literature reviews, and the information so obtained is summarised in tables and appendices. However, because of the scattered nature of much of this information, some of the recommendations are necessarily tentative.

2. INTRODUCTION

2.1 What is the problem?

There are a number of hydraulic engineering situations in which conventional treatment for the stabilisation of surfaces subject to erosion by the intermittent flow of flood water are uneconomic or unaesthetic. Examples of such situations include:

(a) dam emergency spillways, typically with a depth of water at crest of up to 1m, a total drop on the downstream side of not more than 20m and with slopes varying between 1:2 and 1:4

(b) river flood banks, typically with a depth of water at crest of up to 0.5m, a total drop of up to 6m, with slopes varying between 1:2 and 1:8

(c) bywash channels with typical maximum longitudinal slopes of 1:100.

For each of these situations the frequency of occurrence of flow can be so low that the cost of protective in-situ concrete, or alternatives such as a blockwork or asphalt, is too high in relation to the benefits to justify its use. Although there can be more risk with a design relying on vegetation, the low probability of occurrence of the high flow renders this acceptable, provided that the engineering designer has a reasonable appreciation of the erosion resistance and hydraulic frictional properties of different types of vegetation.

Although grass is widely used - sometimes deliberately, but often because it has been permitted to grow without serious consideration of alternatives - nearly all the data relate to conditions in the USA and Australia. This lack of information on grasses growing in the UK was pointed out to CIRIA by Mr G.M. Binnie and, after due consideration, the Association's Hydraulic and Public Health Engineering Committee agreed that the Association should look at the problem.

The protection of sea banks on coasts and on the tidal reaches of river estuaries is a somewhat different matter because here the water is salt, the banks are not deliberately designed to be overtopped, and they experience much greater wave action. A separate section in the Note describes briefly the main points that relate to the use of vegetation for these important structures.

It is important to realise that choosing the right grass cover is only one of the problems facing the designer of banks and other slopes subject to erosion from flowing water, and that the choice of grass and maintenance methods may indeed have an effect on other possible modes of failure.

2.2 Reasons for preparing a guide

Prior to placing a contract for this work, CIRIA staff considered whether a full-scale experimental investigation was needed. It was decided that, in view of the cost of such an investigation and the fragmented nature of the available information on vegetation, a critical review of knowledge and data should first be undertaken into the botanical and hydraulic aspects of the design, construction and maintenance of a grass or other vegetative cover, and that a guide should be drawn up based on that review.

2.3 The object of the guide

Grass is by far the most common form of vegetation in practical use as a hydraulic lining, and the bulk of published work and experience relates to it. Of necessity this guide has to respect this constraint, and the great majority of the information it contains is about grass.

The main purpose of the guide is to enable the hydraulic engineer to decide whether a grass lining is appropriate for the particular hydraulic conditions for which he has to design and to help him to select, establish and manage a grass mixture that will appropriately resist erosion.

The criteria he will take into consideration include:

1. hydraulic loading (i.e. velocity duration on duty, frequency of immersion, the interval between immersions)

2. secondary purpose: whether the area to be protected can be used for agricultural purposes (e.g. grazing, hay or silage) or whether it is an amenity area such as parkland)

3. the management that can be provided reliably

4. the climate

5. the local type of soil available.

Information is also provided on the frictional resistance offered by grass surfaces.

It is stressed that this report is not concerned with engineering situations in which continuous flow occurs, because if grass is to perform satisfactorily there must be time for it to recover between periods of immersion.

The report also notes mixed systems in which grasses are combined with mesh or perforated concrete units to present an artificial but vegetative surface to the flow of water.

2.4 The basis of the guide

The guide has been prepared on the basis of the following work:

1. A survey of published UK data from previous investigations, existing works, and the experience of consultants, water authorities and Government agencies.

2. A survey of data obtained from overseas, to clarify points relative to UK.

3. A preliminary examination of types of grasses and other vegetation available at the present time and thought to be appropriate for protection of erodible surfaces, with recommendation of the types thought to be suitable for initial experiment.

4. An estimate of the broad hydraulic requirements that vegetation cover would be required to meet in the situations listed in Section 2.? (i.e. the likely duration of the various ranges of velocity).

5. Consideration of research that should be done that will meet the requirements of the practising engineer, and the best way of organising the work.

We are indebted to the wide range of people and organisations who have given us freely of their experience and knowledge: detailed acknowledgements appear in Section 8.

3. HYDRAULIC ENGINEERING ASPECTS OF THE USE OF GRASS

3.1 Introduction

When considering (for a given situation) whether grass can provide reliable long-term protection to earth slopes against erosion by the intermittent flow of water, the designer will have at least some appreciation of the following hydrological and hydraulic factors:

1. the flood hydrograph
2. velocity-duration data
3. the exceedance probability of floods of various magnitudes.

The designer will then want information on the key hydraulic engineering aspects of grass. These are:

1. the resistance to erosion, preferably expressed in terms of velocity-duration envelope (i.e the length of time for which a grass surface can safely withstand a given flow without dangerous erosion)

2. the hydraulic frictional characteristics of the grass prior to erosion, and any variation there may be in friction with the height and density of grass and the velocity or depth of flow.

This section presents information on these two key aspects. In order to make a final selection of the grass appropriate to his situation, the designer will also need information on the secondary purpose to which the grass-protected area may be put, the ease and speed of establishment of different mixtures, the management that it can be reasonably assumed the grass will receive, and the botanical properties of grasses and mixtures which affect their suitability for engineering purposes. This information is presented in Section 4.1.2.

Grass banks can fail for reasons other than erosion of the grass cover. Water can penetrate into the body of a bank through shrinkage cracks, patches, or tunnels made by burrowing animals and so promote internal collapse of the slope. These soil mechanics aspects are dealt with more fully in Appendix 8.

3.2. Erosion Resistance

3.2.1 General

Grass protects earth surfaces by reducing the velocity of flow at the bed to a value that will not erode the soil.

The root growth, reinforcing the upper soil layers, also retards the erosion of the soil. Ground cover is therefore the most important factor of erosion resistance. The vulnerability of bare patches appears to be dependent on their size relative to the height of the grass, which shades them if it is upright or mats over them if velocity is high enough to lay the grass down.

Failure occurs when scour around the plant roots has weakened the anchorage of the plant to a degree that permits the flow to strip off the cover.

Once a point of attack has been established the scour is progressive and can therefore be considered time dependent.

3.2.2 Factors contributing to erosion failure

A number of factors related to design, construction and management can lead to breaks in the continuity of the grass cover and cause a reduction in the level of protection against hydraulic erosion. These factors include:

1. any feature which causes a concentration of flow at one point must be avoided (e.g. local gullies, low areas, shrubs and tussocky grasses). Steps should be taken to make and keep slopes even.

2. shrubs, tussocky grasses and very long, rank vegetation which can cause bare patches are susceptible to erosion.

3. a slip in the surface of the bank caused by build-up of water pressure within the bank will disrupt the continuity of the slope. Even if the bank itself is not fatally weakened by such a slip,the ability of the grass cover to resist surface erosion will have been gravely weakened.

4. a continuous break in the grass cover along the crest (e.g. of a river bank) caused by the frequent passage of people or animals.

5. gateways in fences used to section flood-banks for grazing purposes. The concentration of traffic through such gates leads to the total destruction of all grass cover in the immediate locality.

6. soil shrinkage which causes gaps at the junction of a rigid structure and a grass surface. Examples of this are grass channels downstream of a concrete crest or apron, and grass channels with concrete side walls.

7. differential settlement between a rigid structure and a neighbouring grass surface, which can quickly lead to preferential erosion of the softer surface.

8. piping under concrete side walls which, in the extreme, can disrupt the grass cover at the foot of the wall.

3.2.3 Reinforcement of grass surfaces

Reinforcement of grass surfaces can be broadly divided into two categories:

1. Surface reinforcements designed to protect newly seeded areas against wash-out by rainfall and to provide support for young grass plants until they are fully established. Examples of such reinforcements are jute mesh, glassfibre rovings and bitumen. Materials such as bitumen break up as the grass is established, and add little to the strength of the cover. A short series of tests carried out in Australia [1] showed that the effect was indistinguishable from the normal variations in the erosion resistance of the grass itself. It was also found that such reinforcements continued to support the grass plant when serious erosion had occurred around the grass roots and this disguised the extent of the damage. Surface reinforcements may assist seed germination by holding moisture or by providing thermal insulation and may be specified primarily for this purpose, but when estimating the erosion resistance of a grass cover they are best disregarded.

2. Reinforcements designed to permanently increase the erosion resistance of the combined surface above that of grass alone. Such reinforcements would normally be completely or partially buried and arranged to bond into the root structure of the grass. Commonly-used materials are plastic mesh, precast concrete grids and in-situ perforated concrete slabs.

At present there is no information available on the performance of these types of reinforcement in hydraulic conditions. The erosion resistance of the concrete reinforcements is very high even in the absence of the grass cover, and under most conditions they are more prone to damage by undermining than by direct surface attack.

More details of available reinforcements are given in Appendix 2.

3.2.4 Interim recommendations

Most information from laboratory or prototype trials on the erosion resistance of grass surfaces comes from the American [2] and Australian [1] work reviewed in Appendix 1.1 and summarised in Tables 1 and 2. This work refers mainly to surfaces protected by a single species of grass and to grasses not commonly used in this country. However, the experimenters point out that the limiting velocity is related to the growth habit of the plant, and a comparison can be made on this basis with commonly used British grasses and grass mixtures.

The velocities given by these workers, and quoted in Tables 1 and 2, are the limits for long-term stability and have no specified time limit.

In some situations, such as emergency spillways, the grass surface may only be required to withstand short-duration flows. As the erosion is progressive it is reasonable to suppose that higher velocities may be tolerated if exposure time is reduced, and evidence from tests supports this view.

Information on performance during natural floods is summarised in Appendix 1.2.

Analysis of the evidence suggests that a well-chosen grass cover can withstand the following velocities:

Up to 2 m/s for prolonged periods (say more than 10h)
Between 3 and 4 m/s for several hours
Up to 5 m/s for brief periods (say less than 2h).

These values are also presented as a velocity - duration diagram in Figure 1.

This Figure is based on information from various laboratory investigations (principally References 1 to 4) and from reports of prototype experience. This basis is further explained by the following notes:

1. Relating the maximum allowable velocity to time is complicated by the experimental practice of running a test at gradually increasing velocities until failure occurs. In these circumstances, the velocity at failure and the total flow time are not directly related. The experimental descriptions were therefore studied to judge the velocity band and time interval which contributed most to failure.

2. The longest continuous run for which data are available was 20 h.

3. Several grasses have been tested for up to 70 hours under intermittent flows spread over several weeks. The ratio of flow time to resting time was approximately 1:3.

4. The upper limit of the velocity envelope is for a dense, tightly-knit turf established for at least a year. The lower limit is for an established cover exclusively made up of tussock grasses, or a grass cover of any type established for only 5 to 6 weeks.

   In practical situations a ground cover between these extremes can normally be achieved and is represented by the solid line on Figure 1. The velocity chosen by the engineer must reflect his judgment upon the probable time of duration of flow.

5. Points within the velocity envelope will be noted, corresponding to intermittent flow.

A good cover is provided by vegetation which forms a dense turf with a relatively deep root system. It is assumed that the cover will be inspected and maintained to a standard commensurate with the hydraulic demands made on it.

3.3 Frictional resistance of grass surfaces

The second key aspect to be considered by the designer is the hydraulic frictional characteristics of the grass cover. Although this does not influence the capacity of a spillway it affectsthe velocity of flow down the slopes and so determines whether grass is appropriate for the unit discharge under consideration. The depth required for bywash channels depends fundamentally on the frictional resistance to be expected.

3.3.1 Basic approach

Flow over a vegetative surface can be divided into three basic régimes:

1. When the flow depth is significantly less than the height of the vegetation, which is not deflected.

2. When the flow depth is close to or greater than the height of the vegetation, which deflects and oscillates.

3. When the velocity is high enough to lay the vegetation down and a relatively smooth, stationary surface is presented to the flow. The effective height of the vegetation is then considerably less than its natural height.

The hydraulic roughness of the plant is thus a function of the physical characteristics of the grass such as the height, stiffness and total density (which includes individual plant density and overall degree of ground cover). These characteristics are variable and depend on the season and the maintenance programme followed. Roughness is also a function of the flow (a unique property among commonly used non-mobile hydraulic surfaces). Any one of the established channel flow equations may be used to calculate the performance of a grass-lined channel provided that the friction factor can be related to readily defined and measurable characteristics of the grass and also to the flow parameters.

These relationships have been the subject of a number of investigations reviewed in Appendix 3.

3.3.2 Interim recommendations for design procedure

The most comprehensively tested procedure for determining the flow in grass-lined channels is that developed by the Stillwater Laboratory in Oklahoma (3 to 9) This method, which is based on Manning's equation, is widely quoted in hydraulic text books and is still the best available for practical use.

Manning's roughness coefficient is related to flow in the form of a flow parameter VR, where V is the mean velocity and R is the hydraulic radius, and to the physical characteristics of the grass which are defined by height and density. The relationships are empirical and are shown graphically in Figure 2. In this context Manning's coefficient includes the effect of all factors tending to retard flow and is referred to as a 'retardance coefficient'. The physical characteristics are divided into five groups and the range of each group is listed in Table 3. To calculate the hydraulic performance of a channel three conditions must then be satisfied:

$$V = \frac{1}{n} R^{\frac{2}{3}} s^{\frac{1}{2}} \quad \text{(Manning's equation in SI units*)}$$

$$n = f\ (VR)$$

$$Q = VA$$

where V is velocity (m/s)
R is hydraulic radius (m)
Q is flow (m^3/s)
A is cross-sectional area (m^2)
n is the 'retardance coefficient' for grass surfaces given in Figure 2 and in Table 3
s is the slope of the channel bed.

* <u>Note</u>: SI units are used throughout. The value of n is numerically equal to that used in the Imperial units version of the formula.

The above equations my be solved by trial and error or graphically to determine channel dimensions by the following procedure:

1. Estimate the minimum height of grass at the time the channel is likely to be in operation and select a retardance value from Table 3. (If the slope is greater than 1:10 the grass tends to be laid down by the flow and Manning's equation give only an approximate answer. Under these circumstances it is sufficient to adopt a constant n value of 0.02).

2. Select a limiting velocity from the velocity duration curve (Figure 1).

3. From the appropriate retardance graph, enter at the known slope and selected velocity and read off the value of VR (This value is approximately equal to unit discharge and an approximate channel width can there be calculated from known total discharge. At this point a judgment can be made whether the width required for a grass-lined channel is practical.)

4. If the value of VR is acceptable R is determined. The base width of a rectangular or trapezoidal channel can be found from Figure 3, noting that the wetted perimeter P = Q/VR.

5. Calculate the cross-sectional area of flow (Q/V) and determine depth of flow. This is minimum depth at maximum discharge.

6. Estimate the maximum height of grass at the time the channel is likely to be in operation. By use of the appropriate retardance graph and the known discharge and channel dimensions, a maximum depth at maximum discharge can be determined by trial and error.

The retardance coefficient of the surface varies with the length of the grass cover, which , in turn, is controlled by the adopted maintenance cycle. For the design discharge there are therefore two extremes of velocity. The maximum velocity is important from the standpoint of erosion resistance and occurs when the grass has been cut. The minimum velocity is important as this gives maximum flow depth and determines the dimensions of the channel.

Australian work suggests that on steep slopes velocities are so high that the friction factor approaches a low constant value independent of grass length. The slope values are outside the normally accepted values for use with the Manning formula and the calculation is therefore approximate. Uniform flow could be expected to develop quite rapidly and maximum velocity to be reached before the end of a typical spillway. Therefore, length is a secondary factor to slope.

3.3.3 Examples of design procedures

The use of these procedures for bywash channels, emergency spillways, and flood banks is demonstrated in the following examples:

(a) Bywash channels

Assume a slope in the range up to 1:100. The flow in these gently-sloping channels becomes uniform and approaches the normal depth given by the Manning equation for the particular slope, channel dimension and roughness assumed. The velocity is normally low and the retardance coefficient is in the range in which it varies with VR. An iterative calculation may be needed.
Problem: Design atrapezoidal channel with side slopes of 1:5 to carry $3m^3/s$ at 1:25 slope. The grass cover is expected to have a minimum retardance D and a maximum retardance B (Table 3). Allowable velocity is chosen to be 1.5m/s at the lower retardance.

1. Enter retardance graph D (Figure 7) with given slope and velocity and read off the value of VR, the product of flow velocity and hydraulic radius

$$VR = 0.265$$

(At this point, since VR approximately equals unit discharge, an idea of the likely channel width can be gained by dividing VR into the discharge. In this case, approx width = 3/0.265 = 11m)

Calculate R = VR/V =(0.265/1.5 = 0.177m)

Calculate $\frac{\text{Wetted perimeter}}{\text{Hydraulic radius}} = \frac{P}{R} = \frac{Q}{(VR)R}$

= 3/0.265 x 0.177

= 64

From Figure 3 read off $\frac{b}{R}$ = 52.8 for 1:5 side slopes

Since R is known, Channel base width b = 9.3

Cross sectional area of flow A = Discharge/Velocity

= 3/1.5 = 2m^2

For a trapezoidal channel A = (b+md)d

where d = depth of flow
m = side slope

Therefore: Depth of flow for minimum grass height = 0.19m

2. To calculate flow depth for the calculated channel at retardance B, assume an increased value of R, say 0.25

Calculate $\frac{b}{R}$ = 37.2

From Figure 3 read $\frac{P}{R}$ = 49, giving P = 12.25m

Since VR = Q/P, VR = 3/12.25 = 0.245

Enter retardance graph B (Figure 5) with known values of VR and slope, and read off a value for V which gives:

V = 0.95m/s

Therefore: R = 0.245/0.95 = 0.258

If this value of R is sufficiently close to the assumed value, the relationship is solved. If not, choose a new value of R between the assumed and calculated values and repeat the procedure.

When R is determined, determine V and hence the new cross-sectional area.

Determine d as in (1)

In this case A = 3/0.95 = 3.16m^2

Depth of flow for maximum grass height = 0.448m

(b) Emergency spillways

Assumed slopes between 1:2 and 1:4 and a drop of not more than 20m

The calculation proceeds as for a bywash channel, except that n is given a constant value (say 0.03) because of the steepness of the slope, and the calculation is therefore simplified.

Depth at the crest is critical, and can be calculated approximately from:

$$\text{Crest depth, } d_c = \sqrt[3]{(q^2/g)}$$

where q = unit discharge

When a spillway is built on to the flank of an earth dam it is commonly horseshoe-shaped in plan. The effect of the curve is to distort the flow distribution and produce local maximum velocities higher than the mean. This aspect of grassed spillway design has been investigated by Lai, Stone & Hattersley (10).

Estimate maximum flow velocity down a rectangular section spillway 20m wide at a slope of 1:20. Design discharge is 30m^3/s.

At some point on the crest the flow is at critical depth.

$$d_c = \sqrt[3]{(30/20)^2/9.81}$$

$$= 0.614\text{m}$$

Assume a constant friction coefficient of n = 0.03

Estimate a flow depth less than critical depth (say 0.4m).

Calculate the value of hydraulic radius R

$$R = \frac{\text{Area}}{\text{Wetted Perimeter}} = \frac{20 \times 0.4}{20 + 2 \times 0.4}$$

$$= 0.385$$

From Manning's Equation (Section 3.3.2)

$$\text{Velocity } V = \frac{1}{0.03} \times \sqrt[3]{0.385^2} \times \sqrt{0.05}$$

$$= 0.529 \times 0.224/0.03$$

$$= 3.95 \text{m/s}$$

Estimated discharge $Q = 3.95 \times (20 \times 0.4) = 31.6 \text{m}^3/\text{s}$

This may be a close enough approximation to the design discharge. If not, the value for depth d is adjusted and the procedure repeated.

(c) Flood banks

This situation is similar to emergency spillways except that the hydraulic radius equals depth of flow, since the width to depth ratio is extremely large and the calculation becomes that much easier. If the banks are low, uniform flow may not have developed at the foot of the bank and velocities may then be slightly lower than calculated.

The known parameter in this case is not the unit discharge but the river level.

Estimate flow velocity down the face of a bank at a slope of 1:4 assuming a depth of overflow of 0.25m.

Treating the bank as a broad crested weir, discharge per unit length of bank (q) is calculated from the equation:

$$q = \sqrt{gd_c}^3 = \sqrt{g\left(\frac{H}{1.5}\right)}^3 = 1.70\sqrt{H^3}$$

where H = gauged head over crest of bank = $1.5d_c$

$$q = 1.70 \ (0.25)^3$$

$$= \underline{0.212 \text{m}^3/\text{s/m}}$$

With a downstream slope of the order of 1:4 the depth becomes critical over the bank crest. As before

Critical depth $d_c = 2/3 \ H$

$$= 2.0.25/3$$

$$= 0.166 \text{m}$$

Estimate a uniform depth (d) less than critical depth (say 0.07m)

Considering the bank to be of infinite length,

Hydraulic radius $R = d$

Applying Manning's Equation; assuming a constant friction coefficient of 0.03:

$$V = \sqrt[3]{(1/0.03 \times 0.07)^2} \times \sqrt{0.25}$$

$$= 2.83 m/s$$

Discharge/unit width $= 2.82 \times 0.07$

$= 0.198\ m^3/s$

Increase the estimated value of d and repeat the procedure. In this case a depth of 0.075m gives a value for q of 0.217 m3/s and a velocity of

$$V = 2.94 m/s$$

4. BOTANICAL CHARACTERISTICS OF GRASS FOR USE IN HYDRAULIC ENGINEERING PRACTICE

4.1 General principles

4.1.1 The grass plant

(a) The Root

Most grasses have a fibrous root system consisting of fine, numerous root fibres produced from the base of the plant. They do not have a central tap root with lateral roots at right angles as in clovers or alfalfas: alfalfa tap roots over 6m long have been recorded.

Grass roots adapt to their environment. Thus if the water table is high, the roots only grow far enough to reach it and no further. Similarly, if the roots meet a hard compacted area they will not attempt penetration except under unusual conditions or where the area is fissured.

Grass roots penetrate through the soil up to 2m to reach water, especially the particularly drought-resistant fescues, bents and smooth-stalked meadow grasses, but the roots are so small that soil disturbance is minimal. Generally the amount of root produced by grasses is dependent on its management. A well-irrigated area of grass will have short-rooted plants, a dry site deeper rooted plants. If grass is kept well mown and the amount of leaf area low, the water loss by transpiration from the soil is reduced. Similarly, the exclusion of the broader leaved agricultural herbage grasses reduces the transpiration loss still further; the finer reticulate leaves have a greatly reduced surface area available for transpiration compared with Rye Grass and Timothy. The practice of keeping the grass cut to reduce root penetration reduces the amount of water required, and this, in turn, lessens the need for further root penetration.

(b) The leaves

The green parts of the grass consist of the leaves, stems and flower heads. No two species of grass have identical leaves. At one extreme are the Fine Fescue grasses, with leaves which are so solid that they are almost like needles. At the other extreme are species like Smooth and Rough Stalked Meadow Grasses, with broad flat leaves. Some grasses have leaves which taper all the way from base to tip, others expand in the middle before tapering to a fine point. Some have almost parallel sides.

Leaves may have very definite ribs running lengthwise along the upper surface, or they may be more or less flat on the upper surface. Some are very hairy, others are smooth.

(c) The stem

The stem (or culm) of a grass plant is always a slender cylinder, whether it be immature and concealed within the enclosing leaf sheaths, or long, fully developed and bearing the ear or seed head. The stem consists of a series of hollow cylinders divided by small, swollen, solid joints (or nodes).

The sheath of a leaf arises from one node, and then, as a leaf blade, diverges from the stem.

The typical grass stem is erect, and bears the seed head, but in some grasses there is a different sort of stem. This stem is the rhizome, which runs more or less horizontally from the main plant through the soil. Examination of a rhizome reveals the presence of brownish, triangular scale leaves at the nodes of the stem, each one concealing a large bud. It is these buds which produce more new plants with their characteristic roots. Other species of grass develop stolons which are surface stems (or runners) which strike root and develop new plants: an overground equivalent of the rhizome.

(d) Life span of grasses

The life spans of different grasses vary. They may be differentiated as follows:

Annuals - germinate and die in one year

Biennials - germinate in one year, flower and seed the following year, and then die

Perennials - persist over a long period of years.

4.1.2 General considerations governing the choice of grass

Once the designer has determined the likely velocity-duration envelope and the dimensions and shape of the spillway, flood bank or bywash channel appropriate for the selected retardance coefficient, he then has to choose the grass which will provide a stable, erosion-resistant and easily managed surface.

In making this decision the following factors need to be taken into consideration:

1. the secondary purpose to which the grass area may be put (e.g. whether it will be used for agricultural purposes (grazing, hay or silage) or will be part of an amenity area (park or nature reserve)).

2. the type of management practice that can be provided. This is obviously closely related to the secondary purpose of the area and the retardance coefficient. Situations which do not call for agricultural or

amenity uses and where access is different will benefit from the use of grasses requiring little maintenance. This question has to be decided before grass is sown because an agricultural type sward cannot be switched quickly to one suitable for recreational purposes or low maintenance.

The main botanical properties which govern the choice of a grass species or mixture of species for a given set of hydraulic, secondary and maintenance conditions are noted below:

(a) Ground cover and turf matrix

Grass species are typically either prostrate or erect in their growth habits. Because of the type of surface required, the prostrate types are here the most suitable. However, in both prostrate and erect species there are three modes of growth; in some species all new growth appears from the base of the original plant, other species produce stolons which appear above ground, and yet other species produce rhizomes which run underground. For hydraulic engineering purposes, the present evidence indicates that the rhizomatic grasses are the most suitable because their habit of growth contributes to a dense turf which is well able to resist erosion.

(b) Heading dates

'Heading' refers to the period between the start of growth in a new season and the appearance of the seed head. Early heading grasses (which are often also more erect and thus do not provide good ground cover) therefore grow more rapidly, and it is important that the hay or silage cutting operation be timed carefully to achieve the best balance of yield and quality. The yield from the late heading grasses (which are often more prostrate, and so provide good ground cover) is not so sensitive to the timing of the cut. Thus their yield is probably lower than from the early heading, but is less dependent on expert management. The seed head for early heading grasses appears about the third week of May, while later heading grasses seed in the third to fourth week in June.

The differences between heading dates is most noticeable with the ryegrasses.

(c) Root development

A good widespread root system is important. Factors influencing root length include: moisture, soil structure and food. There is a difference of opinion on whether deep rooting can dry out clay banks and accentuate their natural tendency to crack. Research USA has shown conclusively that shorter leaves reduce root depth; and, as there is a smaller surface to transpire, the transpiration losses are considerably less. This obviously would retard the drying out of [illegible]s. (11)

(d) Persistency

All of the grasses recommended should clearly be perennial species. Within a species the degree of persistency varies markedly from variety to variety. Bred varieties are available which are far more persistent than undeveloped commercial varieties. Flowering dates of the varieties have an important bearing on persistency. Generally speaking, late flowering varieties are more persistent than early flowering types.

(e) Animal utilisation

When it is intended that the grass-protected area be used for grazing, the palatability of the crop is clearly of importance, particularly if it is intended that it be let to farmers. The trials conducted, for example, by the National Institute of Agricultural Botany include an assessment of the relative palatability and digestibility of different grasses.

(f) Drought and disease

One of the factors governing the breeding of grasses is that they be resistant to disease and drought. Information upon their performance in this respect is normally obtained during breeding trials.

(g) Immunity to climatic variation

The range of variation of climate and altitude within the UK is not normally great enough significantly to alter the choice of grass. Grasses used should be naturally hardy to British conditions.

(h) Sensitivity to different soils

It is thought that the range of soil types met in the UK will not make a very great difference to the choice of grass. In extreme situations (but very rarely on heavy clay), the mixture may need to be changed.

(i) Ability to establish quickly and give good ground cover

As noted in (b) above, those grasses which grow more quickly are generally of the more erect kind, and provide less effective ground cover. This requirement, therefore, is one that can only be met by the use of mixtures (See Section 4.1.3).

(j) Ability to recover quickly after immersion

This is obviously an important quality in grass used for erosion protection. There are indications that most species currently in use will tolerate long periods of immersion (seven days to three weeks in some instances). (See Section 4.2.2 (a).)

(k) Reaction to grazing and cutting

Some grasses do not thrive under hard grazing, and close cropping will lead to their extinction. For most grasses it is important to cut regularly, but some low maintenance varieties require only one cut per year, whereas others will grow rank and diseased if not cut several times. The soil protection given in such a case is obviously not good.

Although there are 150 to 160 grass species indigenous or naturalised in the UK (out of 10 000 species throughout the world), the choice of grasses combining the properties listed above is not large.

Interim guidance on the selection of grasses which provide a reasonably balanced compromise between these various properties is given in Section 4.3.

4.1.3 Principles of grass mixture

No single grass species has all the characteristics which are desirable for a specific hydraulic engineering purpose.

By utilising a mixture of species the unique properties of each component part can be exploited. For example, a non-graminaceous species (such as clover) might be sown with a grass in order to increase the nutritive value of the vegetation. Other vegetation mixtures might include a rapidly establishing, but poorly persisting, species (Italian Ryegrass and Westerwolds Ryegrass) which would act as a 'nurse crop' to protect the works from an early date and afford cover for the slower developing long-term sward. Regular cutting initially is required to ensure that the 'nurse crop' does not continue by self seeding.

Use of agricultural mixtures thus has marked advantages by providing greater flexibility and scope of application. However, careful management is required to ensure that the established sward retains the planned proportion of each component of the mixture.

A knowledge of species compatability assists in maintaining the balance in the mixture. Hence, it is unwise to mix species of widely differing competitive ability since the less aggressive would be rapidly eliminated.

In general, relatively simple mixtures are more predictable and manageable than complex mixtures in which competition is more likely to change the botanical composition.

When grasses are blended, the proportion of species in the sward may not be related to the proportion by weight, because of the wide variation in seed sizes:

	Appropriate number of seeds, per kg
Bent grasses	9 900 000
Fine fescues	990 000
Smooth Stalked Meadow Grass	4 860 000
Perennial Ryegrass	507 000
Timothy	2 430 000

4.2 Survey of information

4.2.1 General

A survey was made of information from all available sources about the botanical aspects of the use of grass in hydraulic engineering practice. It was hoped that this would indicate whether there was any clear pattern on which recommendations for the choice of grass material could be based. The information is given in Tables 8 and 9.

The survey was carried out in the early part of 1972 and covered the following sources of information.

(a) Existing references

These included published literature and correspondence from home and overseas.

(b) Consulting engineers

Information about recent hydraulic design practice by UK consulting engineers is given in Appendix 4. Associated botanical recommendations are listed in Table 8 against the name of the Public Authority the firm has advised.

(c) UK public authorities

Included under this heading are water authorities, local authorities, and government departments. A number of site visits were made. These are described in Appendix 5. Recommendations are summarised in Table 8.

(d) Advisory services and commercial organisations

A variety of products and services directly applicable to grass protection works in hydraulic situations are offered by commercial organisations. Those which have come to attention are listed in Appendices 2 and 9.

(e) Previous committees

Various reports prepared by the following committees were received and their conclusions have been considered, and those relevant to this study have been incorporated at the appropriate places in the text:

Erosion of Earthen Banks Committee - Report on Great Ouse grass seed trials, 1952 (12).

ICE Research and Development Committee - Note on American and Australian literature on grassed spillways 1971 (13).

Advisory Committee on Sea Defence Research - Set up following the recommendation of the Departmental Committee on Coastal Flooding (the 'Waverley Committee') (14)

A summary of the general conclusions drawn from the survey is given in the following section.

4.2.2 Survey of current experience and practice

The following is a summary of the information collected:

(a) Choice of grass

It is common practice with water authorities to sow a grass mixture of an agricultural type which is almost always based on Perennial Ryegrass. White Clover is frequently included and also small amounts of a number of species including Timothy, Meadow Fescue, Creeping Red Fescue and Smooth Stalked Meadow Grass. The justification for these minority species appears to be to provide variety from the agricultural feeding standpoint. Occasionally it has been noted that species have been included specifically for their prostrate and leafy habit. Quite often a small proportion of Italian Ryegrass is included in a sown mixture to act as a 'nurse crop', although this is only to be used under adverse hydraulic and climatic conditions and where good management is assured. Some authorities have recognised the advantages of bred, rather than local varieties, particularly of the predominant Perennial Ryegrass.

From Table 8, typical examples of mixtures used by water authorities are:

	% (by wt)
Late Perennial Ryegrass S.23	78
Timothy S.50	16
White Clover S.184	3
N.Z. Mother White Clover	3

This mixture was sown at 28kg/ha

	% (by wt)
Late Perennial Ryegrass S.23	53
Red Fescue	18
Smooth Stalked Meadow Grass	9
Crested Dogstail	11
White Clover S.100	9

This mixture was sown at 40kg/ha

Although a combination of hydraulic and agricultural use is most commonly encountered, locations arise where hydraulic protection is combined with public amenity. An example is a balancing reservoir in a built-up area which may, in part, be utilised as parkland during the dry season. In these circumstances the vigorously growing ryegrasses may be reduced to a minor component or omitted altogether in favour of slower growing grasses needing less maintenance such as Browntop, Creeping Bent, Timothy and varieties of Fescue. A practical example (from Table 8) of such a mixture is:

	% (by wt)
Creeping Bent	10
Browntop Bent	5
Chewings Fescue	10
Creeping Red Fescue	45
Hard Fescue	10
Timothy	20

This mixture was sown at 50kg/ha

Much of the published work from overseas comes from tropical or sub-tropical regions where the climate demands either flood disposal or irrigation works. In these regions the botanical aspects of vegetation used for hydraulic purposes have generally been much more intensively studied than in Europe. This appears to be partly because application has been more urgent, and partly because a greater range of possibly suitable species has been available.

Generally, in overseas work, as much attention has been given to the nutritive value of a species as to its primary protective value. This is particularly so in irrigation channel investigations where agricultural interests are, of course, strongly represented. Frequently, there has been more emphasis on providing a companion legume species which will supply fixed nitrogen to keep the sward viable in environments which are typically nutrient deficient. To ensure the successful establishment of the legumes, and that they fix nitrogen successfully, they should be inoculated with the correct rhizobia. The work of the Welsh Plant Breeding Station shows that the use of the correct rhizobia can result in more than 100 'units of Nitrogen' per acre being fixed per year.(15)

American investigations have highlighted Bermuda Grass as particularly suited to hydraulic protection works(2). It is also highly rated in other sub-tropical areas such as India and Australia. Kikuyu and African Star Grass, which have similar characteristics to Bermuda Grass, are also recommended by Australian investigators for their erosion resistance properties although they have a tendency to choke channels because of their vigorous growth(3,10).

Kikuyu, African Star Grass and some varieties of Bermuda Grass have to be established by planting roots because seed is not available. Other species that have been successfully used in hydraulic situations are Centipede Grass, Kentucky Blue Grass, Prairie Grass, Brome Grass, Reed Canary Grass, and Western Wheat Grass in America; mixtures of Perennial Ryegrass, Smooth Stalked Meadow Grass and Clover in the moister, more temperate areas of Australia, and Exotic Prairie Grass in India. The majority of these grasses are likely to be unsuitable for Northern Europe. Bermuda Grass is established in a few maritime localities in SW England and was first recorded here in 1688, but it has not been developed as a commercial grass. Kentucky Blue Grass occurs in Britain as Smooth Stalked Meadow Grass and recently an improved variety has been introduced from America.

The Department of Field Crops and Grassland Husbandry, Wageningen, Holland, recommended the use of grass for the protection against erosion of river banks and river flood banks. In Holland, managing a non-agriculturally used surface is very expensive and so all mixtures are made for agricultural purposes, the particular balance being determined for light or heavy grazing by cattle or sheep, for hay or silage, or for soil fertility.

The Institute for Research on Varieties of Field Crops, at Wageningen, recommends agricultural mixtures based on Perennial Ryegrass and Smooth Stalked Meadow Grass. They point out that it is important to take advantage of the bred varieties, so that, with good management, a good winter hardy mat is produced, able to withstand both drought and floods. Creeping Red Fescues have been found to be a valuable addition as they knit the turf together at the bottom. The Rijkwaterstaat recommend similar grass mixtures.

The resistance of grasses to immersion has not been systematically investigated. However, ryegrass mixtures such as those listed above are known to have tolerated total immersion for up to 10 days with no significant ill effects, and claims of three weeks' immersion without damage have been noted. The Welsh Plant Breeding Station carried out trials in 1962 to determine the persistance of grasses immediately above, at and below top water level, and concluded that the most immersion resistant species were Reed Canary Grass and Plicate Sweet Grass. Immersion resistance varies throughout the life cycle of the plant, and summer flooding is more injurious than winter flooding.

(b) <u>Sowing rate</u>

Sowing rates cannot be reliably compared because of the different constitution of the mixtures. Rates varying from 22 to 56kg/ha have been used under difficult establishment conditions. The Erosion of Earthen Banks Committee (see Section 4.2.1) concluded from the results of the Great Ouse seed trials that a rate of 28kg/ha gave equally as good results as rates twice as high after one or two seasons, and that rates above 28kg/ha were unjustified on economic grounds unless a quick coverage was essential.

(c) Establishment

Several authorities remark upon establishment aids (see Appendix 2). Aids of this kind have been used, particularly on difficult establishment sites such as exposed and steep slopes. All forms appear to be useful and in all known cases the results are considered to have vindicated the decision to use an establishment aid.

Placed turf has been used where an immediate grass cover is required. Success of this technique is variable. The newly-turfed surface is particularly vulnerable at the joints between adjacent turves. Additional labour is required to secure the turf in place before rooting into the substrate is complete, usually by pegging.

Specifically grown turf is now available in sheet form in unit sizes of up to $4m^2$. The advantages claimed are: uniform growth and cover, ease of handling, complete root system, rapid establishment, and lack of shrinkage (see Appendix 2).

(d) Management

Management procedures are varied and sometimes no particular procedure is specified. Generally speaking, where cutting is carried out this may be from one or two, to four or five cuts per year. One cut per year only is common but it is acknowledged that this will not produce a satisfactory sward.

A few authorities have used growth-retardant chemicals in order to reduce their cutting requirement, but there are difficulties of timing, in relation to plant growth and weather conditions, particularly in southern Britain.

Selective herbicides have been used to eliminate competition from weeds and so to maintain the quality of the grass turf.

Sheep grazing has sometimes been used as a means of maintaining a short sward without frequent mechanical cutting. Where the sown mixture consisted of species and varieties which could withstand the close cropping of the sheep, a sward has resulted which seems to adequately fulfil the hydraulic requirements. However, where grasses not adapted to that kind of management have been sown, an open sward has resulted with instances of consequent bank erosion.

Cattle are sometimes grazed on banks, but they tend to pull at the grass (instead of cropping like sheep) and to damage steeply sloping banks with their weight.

However, the experience of the former Trent River Authority was that grazing of flood banks by cattle was acceptable provided that the side slopes of flood banks were not steeper than 1:3, and that grazing was limited to the summer months.

4.3 Recommendations for grass mixtures : establishment and management

On the basis of the information which has been collected and reviewed, a summary of the recommendations for grass mixtures, establishment and management is given below. The mixtures are tabulated for easy reference in Table 4. by principal location and management practice. Names of the bred varieties of each species (given in Table 4) are listed in Appendix 7. Instructions for the seeding of grass in the form of a specimen specification are given in Appendix 10.

As further research is carried out and more expertise gained, these recommendations will require revision.

4.3.1 Grass mixtures

Notes on suitable grasses and mixtures according to principal location are given below.

(a) Dam spillways

Low maintenance species are indicated here because these structures will not be used for agricultural production or recreational purposes, and because machinery access is often difficult, Perennial Ryegrass should be avoided, and less vigorous species such as Creeping Red Fescue, Chewings Fescue, Smooth Stalked Meadow Grass and Browntop should be used. These grasses are not only slow growing, but also have a rhizomatic habit which both provides a dense turf on the surface and binds the topsoil of the spillway.

(b) Bywash channels

The requirements for bywash channels are essentially similar to those for dam spillways. However, maintenance may be less problematical and, where the channel forms a part of meadow land which can be grazed, Perennial Ryegrass can be included with advantage. Because Reygrass has vigorous growth, it is important to manage it carefully so as to maintain the design capacity of the channel. The rhizomatic Fescues and Smooth Stalked Meadow Grass will safely form the major part of a seeds mixture for use in bywash channels.

(c) River floodbanks

This situation differs from dam spillways and bywash channels in that the floodbanks are often adjacent to (and often part of) meadowland. They can sometimes be constructed to slopes which allow profitable agricultural utilisation by the grazing animal, for hay or for silage. Pasture mixtures based on Perennial Ryegrass, with the inclusion of other agricultural species such as Timothy and possibly Cocksfoot and herbage legumes such as White Clover, which improve the nutritive value of the forage, can be sown here. Even in this situation there is probably a place for fine-leaved bottom grasses to provide a dense foundation for the sward.

Where there is any doubt about the standard of management a river bank will receive, it is probably prudent to use a low maintenance mixture similar to those recommended for spillways and bywash channels. Such a mixture will not suffer from animal grazing, and the chief disincentive to its use by water authorities is likely to be its higher cost. Low maintenance mixtures are essential in situations where agricultural access is restricted or where the river runs through an urban area.

4.3.2 Establishment

The grass species described above are generally adapted to rather fertile soil situations. However, where high forage production is not important, as in these applications, it is unlikely that a low fertility soil would restrict the choice of species. Rather, the species should be chosen with the primary purpose in mind. Where engineering considerations permit, it is advisable that all areas to be seeded are top-soiled after contouring. On steeply sloping sites it may be desirable to protect the area immediately after sowing to secure the seed and topsoil against rainfall erosion (see Appendix 2). Alternatively, the seed may be sown into the subsoil (16), but a temporary protection such as bitumen or resin must be used to fix the seeds and encourage germination, or establishment will be slower and less complete and the turf may be weak in spite of high rates of application of fertilizer.

An advantage of sowing into subsoil is that it eliminates the danger of importing undesirable vegetation in the top-soil. A further argument against imported topsoil is that grass roots tend to grow selectively in it and therefore fail to form a strong key between the topsoil and subsoil. However, the first requirement must be a high-quality sward, and a site must be very carefully assessed before the reliability of establishment conferred by sowing into top-soil is discarded.

For dry sites, if the proportions of the drought-resistant species are increased relative to the mixture for medium loam, and those of Ryegrass and Timothy are then also reduced, a greatly improved sward should result. For wet sites, the reverse proportions apply. For waterlogged sites, Rough Stalked Meadow Grass can be substituted for Smooth Stalked Meadow Grass. Varietal performance within the individual species now allows greater flexibility of use of a selected mixture.

A basic dressing of compound fertilizer prior to seeding is desirable, particularly to correct deficiencies of phosphate and potash. A compound of 2:3:4 units of nitrogen, phosphorus and potassium, respectively, is recommended. The small supplement of nitrogen assists with establishment, while phosphate and potash initiate strong root development which is also assisted by spiking.

Sowing may be carried out by whatever method is convenient. Where large areas are involved mechanical drilling may be used. On steep and inaccessible sites, broadcasting either by hand or by fiddle is effective and has the advantage of producing a denser sward since the seeds are not restricted to drills. Hydroseeding may also be used advantageously on such sites (see Appendix 2).

A most important aspect of establishment is through consolidation of the seed bed by rolling. This process anchors the seed and helps preserve soil moisture. A draft specification for seeding of grass areas is attached as Appendix 10.

4.3.3 Management procedures

Once the correct grass mixture is chosen, the next biggest single factor affecting the success of swards is standard of management. Where cutting is neglected, or adequate grazing pressure is not maintained, the grass becomes rank, its bottom structure is destroyed, and there is a tendency to clumping, particularly amongst the vigorous agricultural grasses. Clumping is dangerous because it results in local scour.

(a) Use of animals (see also Section 4.2.2 (d))

Use of grazing animals has the disadvantage of any form of agricultural maintenance in that control rests with the farmer rather than with the responsible authority.

An advantage of animals for the maintenance of vegetation is that the plant nutrients are cycled in-situ and so maintain the fertility of the structure. When forage grasses are cut this does not occur.

Two classes of farm animal are commonly grazed in Britain: sheep and cattle. Of these, sheep tend to maintain the banks in better condition than cattle; they are lighter animals and therefore cause less damage to the turf surface, and they are also less selective eaters and graze the sward down closer. These two points result in a higher quality sward because broad-leaved plants, which may invade and lead to weaknesses in the surface, cannot withstand such intense treatment.

Where banks are managed under cattle grazing it is not uncommon to see a progression in growth through broad-leaved weeds to small shrubs.

Grazing both by sheep and cattle usually leads to the formation of tracks, particularly along bank crests. As was pointed out in Section 3.2.2., this reduction in grass cover increases the vulnerability of the bank to erosion.

(b) Use of machinery

This kind of maintenance falls into two classes: silage, or hay cropping, where the land is under agricultural usage; and specialised cutting at varying frequencies, purely for maintenance purposes. There are four main types of grass-cutting equipment:

1. hand-propelled machines
2. self-propelled machines
3. tractor-drawn and self-driven machines
4. tractor-drawn and tractor-driven machines.

The most adaptable type of equipment falls into the latter category, particularly when mounted on hydraulically operated extensible arms which can be adjusted to match the size and slope of the bank.

The only respect in which a grassed hydraulic structure is likely to differ from other grassed areas is in the steepness of the slope. However, a number of tractors are available for difficult terrain, capable of operating on slopes of the order of 1:3. Short slopes steeper than this may be reached by an extensible arm from a tractor running on an adjacent level area, but maintenance by cutting of extensive steep slopes may not be possible with machinery now available.

Three types of mower action have been developed:

Cylinder mowers

This type of machine is intended for close cutting of grass, and is not suitable for maintaining swards which have been allowed to become very long. Machines of this type are not in widespread use by local authorities for highway-type work, and it is unlikely that they would be particularly appropriate for waterway maintenance applications.

Rotary machines

This type of action is intended to deal with herbage of intermediate length, where between three and five cuts per year are given. This would be very good for many spillway and channel situations.

Flail mowers

These are heavy-duty machines intended for long and rank vegetation. This type of mower is commonly mounted on a tractor on extensible and adjustable telescopic arms, and because of the flexibility and manoeuvreability which this arrangement affords is likely to be good for maintenance of hydraulic works where tractor access is possible.

Useful guides to grass cutters and groundsmanship appear in the "Surveyor" from time to time (e.g. References 17 and 18).

(c) Chemical maintenance procedures

Chemicals are used in grass management practice to control weeds and retard the growth of grass. Advice on appropriate chemicals can be obtained from either the Ministry of Agriculture, Fisheries and Food or the Weed Research Organisation (WRO). It has not been possible to find information on the effect of these chemicals on the erosion resisting qualities of grass.

5. SEA BANKS

The word 'bank' is generally understood to include the terms 'wall', 'river wall', 'seawall' and 'dyke'. It has seldom been defined in any Act of Parliament, but is commonly understood to mean an artificial barrier of earthen materials.

5.1 Reason for separate treatment

This aspect of the use of grass for the protection of earth structures subject to the erosive action of waves is treated separately because:

1. the prevailing environment is radically different from inland situations, being exposed to harsher climate and a salt-laden air flow

2. the material in sea bnks is often of lower fertility than inland freshwater banks and may contain some salt

3. sea banks are not deliberately designed to be overtopped

4. the form of hydraulic attack is fundamentally different because the banks are subjected to wave action rather than reasonably steady flow.

   Wave attack takes several forms:

   a) direct impact on the seaward face

   b) erosion due to run-up on the seaward face

   c) erosion by run-up that overtops the bank

   d) impact on the landward face, either by breaking waves or by run-up deflected into the air (e.g. by parapet walls).

   Additionally, sea banks are subject to the same forms of attack as are inland banks:

   e) continuous overtopping by high water levels

   f) hydrostatic pressures

   g) weakening of the soil base by water penetration.

5.2 Survey of information on hydraulic aspects

The disastrous East Coast floods of 1953 provided an opportunity, albeit unfortunate, to observe the behaviour of grassed sea banks tested to failure. Of the investigations made after the flooding, notable reports are those of the Waverley Committee set up by the

Government (19) and the Institution of Civil Engineers Conference on the North Sea Floods (20). Dutch practice has been summarised in Reference 21 (Reference 22 is a translated summary of this work).

In the ICE report is a section by Cooling and Marsland (23) of the Building Research Station, who inspected the damage immediately after the flood. Although evidence of the initial causes of failure had been obliterated in the repaired breaches, evidence could be collected from partial or incipient failures adjacent to the breaches.

Referring to the possible causes of failure listed in Section 5.1 above, the following conclusions were drawn.

Direct frontal attack by waves occurred only in a few exposed positions and was not a major cause of failure. However, it is unlikely that grass would be used for the whole of the seaward face of a sea bank unless that were fronted by saltings which would reduce the wave force at the bank.

The major cause of the failure was collapse of the landward side of the banks. The most common initial cause appeared to be shallow slips, caused by seepage drag through fissures in the upper surface of the bank, which were in evidence even where banks had not been overtopped. When overtopping did occur, the damaged rear face was rapidly eroded to failure. Banks with good vegetation cover seemed able to stand a fair degree of overtopping, and direct erosion of back slopes unaffected by slips appeared to be restricted to localities of severe overtopping. In the circumstances it is not possible accurately to define 'severe'.

In a few cases it was clear that the primary cause of failure was uplift pressure in pervious layers under the banks causing collapse of the landward toe, again creating an opportunity for erosion by overtopping flow.

With particular reference to grass covers: on the one hand grass provided an effective defence against scour, but on the other hand, the presence of vegetation may have intensified shrinkage and fissuring of the surface, thereby contributing to the seepage that led to failure of the cover. These soil mechanics aspects are discussed in more detail in Appendix 8.

This paradox was also noted by Wiersma (22) who, referring to Dutch analysis of soil samples, pointed out that the quality of the turf improves with the clay content of the soil (i.e. particles <0.002mm (<0.00008in)) if that is between 15 and 25 per cent, but that a soil with this clay content would contract on drying out. Conversely, a light loam soil (clay content 5 to 12 per cent) rarely cracks but is not ideal for good turf. Wiersma also attributed most bank failures to slips due to weakening of the soil, but maintained that the presence of grass delayed the slips or limited the consequences.

Marsland also visited Holland after the floods of 1953 and reported his findings in an unpublished note (24). Much of the damage followed the same pattern as on the east coast of England, but a further aspect was raised relating to the use of small parapet walls on top of sea banks. Overtopping waves were thrown into the air by parapet walls and, carried along by their momentum, impacted on the landward face of the bank. If the parapet were not high enough to significantly reduce the quantity of overflow, it would seem that this type of attack would be more serious than a clean overtopping and should be avoided, if possible, by not providing a parapet.

The behaviour of grass cover under impact forces is not know with any certainty, but the forces can be extremely high. The Waverley Committee quoted estimates of 22 to 33 tonnes/m^2 for the sea face of a bank. However, Dutch authorities (21) quote much smaller figures of the order of 1 t/m^2. Various investigations on the subject of wave forces on structures are reviewed by Minikin (25). Dutch practice (21) does not rely on grass to withstand attack from breaking waves, although examples are quoted in which grass has stood up well to attack of several hours' duration.

The run-up of waves on a sea bank can be calculated with a fair degree of accuracy, and a bank crest level can be determined such that it will be exceeded by only a certain percentage of the run-up for a given significant wave height (26). The equivalent overtopping discharge was investigated by the Hydraulics Research Station for the proposed development at Maplin (27). Although the wave conditions used in this work were specific to Maplin, the data in the report will provide guidance on the order of discharge to be expected at other sites.

Dutch authorities have observed the closure of bank breaches and found that water velocities of up to 2m/s caused little damage (22).

Some quantitive evaluation of the force of wave attack on a sea bank can therefore be made, but the related limitations of the resistance of a grass cover are not known.

In practice, grass covers have acquitted themselves well under arduous conditions, but an area of uncertainty remains as to the extent to which grass covers reduce their own effectiveness by controlling the moisture content of the soil through evapotranspiration and shielding against precipitation and evaporation.

5.3 Survey of information on botanical aspects

5.3.1 Grass species

Where sea walls have been built, a herbage mixture has been sown almost always based on Perennial Ryegrass. Very often the strains used have been cheaper commercial types which lack persistency. Small proportions of other species including legumes have been included in these mixtures. Because of the relatively inferior nature of the Perennial Ryegrasses used, and particularly where maintenance has been poor, sown species have declined markedly, and natural coastal species such as Couch Grass (Agropyron Repens) and Sea Couch (Agropyron Pungens) have dominated the banks.

It has been found that when more persistent strains of Perennial Ryegrass have been sown, invasion is less likely to occur, particularly where a high standard of maintenance is practised. It is clear that under the exposed saline conditions of a sea bank, Perennial Ryegrass, which is normally aggressive, does not compete successfully with more suitably adapted species but these may not give a sward which is fully protective. Thus, whilst the Agropyron species have rhizomes which bind the bank surface, they do not give that dense turf which is best able to withstand wave and splash effects.

Details of the practice of public authorities responsible for sea banks are included in Table 8.

5.3.2 Establishment

In some respects, establishment on sea banks is more critical than establishment on inland sites. Particularly because of the necessity of avoiding unfavourable weather conditions and periods of spring tides, the periods available for successful sowing are more restricted.

Autumn sowing is preferable since this avoids spring and early summer droughts, but it is accompanied by risk from severe weather in the late autumn and early winter months, before cover is complete. In situations of this kind a 'nurse crop' or temporary stabilisation (e.g. using bitumen) is particularly beneficial. The annual species Westerwold Ryegrass has been used as a 'nurse crop'. If this is used it must be managed by cutting, or else it will persist. It is tufted and is not rhizomatic. Generally, sowing should not be attempted after the middle of October.

Continental workers, particularly, have drawn attention to the advantages of using turf to establish vegetation on sea walls. This method is likely to be more costly than conventional seeding but has the dual advantages of providing immediate cover and also of transferring a quantity of high-grade topsoil to the usually impoverished banks. (But see Section 4.2.2 (c), paragraph 2 above).

5.3.3 Management

Management requirements do not differ significantly from those of inland sites. One aspect of care which is perhaps more important is that adequate fertilization should be given. This will tend to encourage sown species such as Perennial Ryegrass at the expense of wild invaders and so improve the nutritive value of the turf where the bank is maintained under animal grazing. It is improbable that herbage length would be adequately controlled by grazing where the predominant species is Couch Grass because of the unpalatability of this grass.

The satisfactory way in which sea banks grazed by sheep withstood the east coast flooding in 1953 has been remarked by several authorities. The Dutch have also found sheep to be beneficial (24).

5.3.4 Field observations

Trials of management procedures were carried out under the auspices of the Advisory Committee on Sea Defence Research between 1961 and 1964 on sites at Tollesbury in Essex and Southwold in Suffolk, but the reports were not published.

One section of the Essex site was covered with indigenous Couch Grass, and a second section was planted with a mixture based on a non-persistent variety of Perennial Ryegrass. The first section was found to respond best to a single yearly cut. Frequent cutting and hard grazing weakened the Couch Grass and allowed infestation by weeds and by the native annual Sea Barley, to the detriment of the cover. At the second section it was found that the Ryegrass was replaced by indigenous Couch Grass. Hard grazing and frequent cutting was again found to weaken both the Ryegrass and the emerging Couch Grass, leading to infestation as on the first section. Management by a single yearly cut allowed the Couch Grass to grow strongly and largely to replace the Ryegrass without invasion by weeds.

The Suffolk site was sown with Perennial Ryegrass. The major difference to note, compared with the Essex site, is that this grass was a persistent variety (S.23). In this case, frequent cutting maintained the sward in good condition and the Ryegrass remained dominant. Grazing, which was admitted to be spasmodic in this instance, also encouraged the Ryegrass to persist well and to resist competition by weeds and Couch Grass. A single yearly cut resulted in serious deterioration of the sward, leaving 60 per cent of the area either bare or infested with weeds. A section that was left completely untreated was reported to be a 'jungle of vegetation' containing much dead vegetation at the base of the sward.

The report on the site trials in Essex and Suffolk concluded that 'sowing of a persistent Ryegrass under these circumstances (i.e. under threat from indigenous grasses) entails proper follow-on maintenance practices of a high order' and that if the required maintenance facilities were not available it was preferable to sow a non-persistent grass and encourage a controlled colonisation by indigenous grasses by lenient management practices.

5.3.5 Recommendations for grass mixtures

Interim guidance for the use of grass mixtures on sea banks is given in Table 5. As further research is carried out and more experience is gained, these recommendations will require revision.

6. SITE TRIALS AND RECOMMENDATIONS FOR HYDRAULIC EXPERIMENTS

6.1 Reasons for undertaking preliminary site trials

Because of the ad hoc nature of knowledge on species of grass suitable for hydraulic applications in the UK it was decided at an early stage in this study to initiate informal site trials of species and varieties which might be appropriate. The overall purpose of these trials was to make a comparative appreciation of the main types of the many available grass mixtures under a range of typical field conditions. It was hoped that recommendations could then be made of a few mixtures worthy of exhaustive hydraulic tests at full scale.

The tests were not planned as botanical assessments because all the species and mixtures used had received the approval of the National Institute of Agricultural Botany, Cambridge. Instead, observations were made of a kind that could be undertaken by the engineer after short training.

6.2 Programme of preliminary site trials

Outline information on the trials is given below. Details of the procedures used and the conclusions drawn will be given in a subsequent CIRIA Report.

6.2.1 Sites chosen

In all, seven sites are under study. Two of these sites, on the River Severn and on the River Trent, are inland riverside locations, a third site in the Anglian Water Authority area on the Humber Bank is an estuarine location, and at Milton Keynes there is a spillway site. Three further sites at Rothwell and at Holton-le-Clay, Lincolnshire, and at Strathclyde Park, have been established as observation and reference areas.

6.2.2 Grass Mixtures Sown

Seventeen different grass seed mixtures have been sown on the sites mentioned. Some details are given in Appendix 6. The overall consideration was that they had to fulfil the hydraulic requirements, but emphasis was also placed on their secondary purpose; in other words, those mixtures which were meant for agricultural use, amenity use or for low maintenance treatment. Table [illegible] shows the location of each mixture under test.

6.2.3 Observations

Eleven characteristics have been systematically observed at regular intervals at each site. Details are given in Appendix 6.

6.2.4 Arrangements for future supervision

Arrangements have been made for the twice-yearly observation of the plots, and progress reports will be received by CIRIA.

6.3 Recommendations for hydraulic experiments

Full-scale hydraulic tests carried out over a range of grass depths and slopes are inevitably expensive and it is hoped that the preliminary site trials will enable firm recommendations to be made of a few grass mixtures suitable for test.

Outlines of possible types of mixture to be tested (subject to the results of the preliminary site trials) and of the hydraulic aspects of the tests are given below.

6.3.1 Grass mixtures to be tested

There are two classes of vegetation on which tests might be run:

(a) Species already commercially available as seed

Seed of a wide range of grass and legume species adapted to British and North West European conditions is available for agricultural and general amenity purposes. Tests could be set up to examine all these species. However, on the basis of what is known from experience to date, a few species can be usefully selected for intensive examination. The most rewarding approach will be to compare varieties which have been developed within species. Recent breeding work has resulted in a diverse range of varieties which are superior to the unimproved species.

In this category, varieties of the following appear to deserve further examination:

Italian Ryegrass, Perennial Ryegrass, Smooth Stalked Meadow Grass, Rough Stalked Meadow Grass, Creeping Red Fescue, Chewings Fescue, Browntop Bent, Creeping Bent, Timothy (Cocksfoot) and White Clover.

(b) Species not at present commercially available but which may be of use

One species alone might be considered on its morphological merits, and this is Couch Grass (Agropyron Repens), which is an extremely rhizomatous grass which should have a strong soil-binding ability. However, disadvantages of this grass are:

1. it grows erect and does not form a dense turf.

2. it is regarded as a serious weed in agricultural situations.

Nothing is known about the seed production characteristics of this species. However, it may well be that because of its unique growth habit, it could be established by transplanting rhizomes.

6.3.2 Hydraulic aspects of tests

(a) Frictional resistance

Manning's equation would normally be adequate for grass-lined channels with slopes up to 1:100. American work has provided considerable data defining the relationship between Manning's coefficient, the flow variables and the physical characteristics of the grass. The results of this work imply that physical features such as grass height and overall density of cover overshadow differences between individual species. This work would therefore appear to be applicable to grasses used in this country. It would be desirable to collect extensive prototype data to prove or disprove this opinion before putting aside the conclusions of such comprehensive research.

However, erosion damage is greatest and potentially most dangerous on steep slopes such as flood banks and spillways, but this is the situation where present methods of calculating velocities are most unreliable. The widely-known flow formulae are not immediately applicable and the deflection of grass under dynamic forces is much more significant.

There is, therefore, a need to devise a reliable method of calculating flow velocities on steep grass-covered slopes.

(b) Erosion resistance

Grass has been used successfully for many years in conditions of low velocity (of the order of 1m/s). There is evidence that grass will withstand very high velocities (over 5m/s) for short periods but the evidence is scanty and inconsistent. It is clear that grass could be a viable and low-cost alternative protection in a number of situations for which it would not at present be considered. However, for its use to be confidently adopted, more positive information is needed on its performance under high velocities, with particular reference to the influence of running time and installation design. This is also linked to the need mentioned above to be able to accurately predict high velocities.

(c) Test methods

The major problem facing investigators is the number of variables involved. The quality of the cover depends on soil quality, climate, management, length of establishment and time of year. A comprehensive investigation of frictional characteristics involves testing at a range of slopes. The list may be simplified or rationalised in a number of ways. For example, it may be considered that a closely-specified preparation and management procedure will minimise the effect of soil variations, that it may be justifiable to assume that flooding is likely to occur only at narrowly-defined periods in the growing cycle, and that testing may be limited to slopes that most commonly occur.

Two further points of contention also arise. First, should the grass be grown outdoors and thus be subjected to strictly local weather conditions or indoors under controlled conditions? Second, should erosion testing in particular be done on natural slopes or can the transference of seed boxes or turves to a conventional flume provide realistic results?

These are all points which need to be fully discussed in relation to effectiveness and cost before a test programme can be initiated.

In general, it is clear that a useful investigation would take a considerable time, since the natural growth pattern of grass is relatively slow and cannot be accelerated. In order to test reasonably large areas of grass at the slopes and discharges that are required, the testing facilities would have to be extensive (and therefore costly).

(d) Cost

In view of the preceding remarks, a sum of between £50 000 and £100 000 would be needed for a reasonably comprehensive set of tests.

7. SUMMARY OF CONCLUSIONS ON CHOICE OF GRASSES

At this stage, with varied evidence and little hard data, it is impossible to draw firm conclusions.

However, from a review of information reported here, the following general comments may be made:

7.1 Hydraulic engineering aspect

1. There is considerable scope for the use of appropriate grass mixtures in hydraulic engineering practice, and their use can provide an economical solution to a difficult problem (Section 4.1.3).

2. Hydraulic information of practical use is based on ad hoc tests on specific grasses, and development of a general theory is still at an early stage (Section 5.2).

3. There is some circumstantial evidence that grass can resist velocities of up to 5m/s, although there is little hard information on duration of overtopping. Australian practice with Kikuyu, Rhodes and Couch Grasses at least 15 weeks old showed that they would resist flow velocities of up to 3m/s for up to 3h (Sections 3.2.4 and 4.2.2 (a)).

4. Selection of roughness values for vegetation is difficult, because it lays flat under the flow in a progressive manner. Work in USA showed that $n = f(VR)$, but it is possible to select n for grasses whose height and density is known with only fair assurance (Section 3.3.2).

5. An even surface is better than one which is irregular or gulleyed and which concentrates the flow (Section 3.2.2).

6. Tussock-forming grasses, trees and shrubs should not be used because they cause undesirable concentration of the flow (Section 3.2.2).

7. Long grasses with deep roots on fat clay banks may dry out the bank interior more than shorter grasses and so lead to cracking (Sections 4.1.2(c) and 5.2).

7.2 Grass mixtures

1. A mixture of grasses providing a balance between agricultural and amenity properties (good bottom cover and fuller leaves) could be the answer in a situation where maintenance is reasonably good (Sections 4.1.3 and 5.3.1).

2. Many different mixtures are in current use, some overcomplicated (Section 4.3.1).

3. Modern plant breeding techniques provide persistent drought-resistant mixtures which are not utilised to the full in hydraulic engineering practice. Correct combination means that one species does not swamp others (Section 4.3.1).

4. Rhyzomatic grasses are better than stoloniferous ones, because the roots of the former create a turf matrix <u>within</u> the soil (Section 4.3.1).

7.3 Management

1. The management procedure adopted is vital to the success in practice of a modern grass mixture (Section 4.2.2 (d)).

2. Keeping grass cover short, and frequently cut, reduces the risk of harbouring animal vermin that can damage flood banks.

3. Maintenance by sheep is beneficial. Cattle should only be used with caution (Sections 4.2.2, 4.3.1 and 4.3.3).

4. If space permits, flood banks in agricultural areas should have slopes of no more than 1:4, so that farmers can, if they wish, use them as part of their grazing (Section 4.3.3).

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UK Public Authorities (the designations prior to 1974 are given with the name of the Water Authority now responsible in brackets)

Avon & Dorset River Authority (Wessex Water Authority)
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APPENDIX 1 EROSION RESISTANCE OF VEGETATION

1.1 Laboratory tests and prototype trials

1. Laboratory tests have been carried out in the United States and Australia to determine safe velocity limits for grass channel linings. Values recommended by Stillwater Outdoor Laboratory (2) are given in Table 1. The grass species quoted are native to America for the most part, but the velocities quoted give guidelines to the limitations of (all) grasses of similar growth habit.

   The American work was mainly concerned with the lining of irrigation channels of low slope, and Bermuda Grass was the only grass recommended for slopes greater than 1:10. Bermuda Grass was described as a uniform, sod-forming grass having a dense, relatively deep root system.

2. In Australia, where grass is widely used for lining bywash spillways, slopes range up to 1:3, and a series of tests were made at New South Wales University to test grasses on slopes of this order.

   Cornish, Yong and Stone [1] tested four grasses (Kikuyu, Rhodes, Couch (Cynodon Dactylon) and a pasture mix on a slope of 1:4.5. Kikuyu grass and Rhodes grass withstood velocities of 5.5m/s before failure. Couch grass failed at velocities between 3 and 4m/s, and the pasture mix at 2.7m/s.

   In no test was the entire bed washed away. Minor erosion began at low velocities and failure was considered to have occurred when scour had not stabilised after 1h at a particular velocity or when the scour was considered to be unacceptably large.

   Yong and Stone tested Kikuyu, Rhodes and Australian Couch grass on purpose-built spillways with a curved profile varying in slope from 1:10 to 1:3. Although potentially high velocities were available, the tests were dogged by premature failure of the grass cover, the cause of which is instructive. The turves in question were seeded in the spring, transferred to the test channels in late summer, and tested the following spring (i.e. they were one year old at the time of testing). Following the failure, the turf was rolled back into position, without the sand layer, and re-tested 11 weeks later. No mention was made of root depths.

   Initially the grass was sown directly in the natural soil of the channel. Because of the relatively poor soil and washout under rainfall, propagation was unsatisfactory. The grasses were therefore prepared outside the channels and put in place as turves, laid on a 50mm layer of sand to assist drainage. When scour had penetrated to the sand layer, piping occurred under the turf causing the surface to slump and pull away from the sidewalls, with consequent local scour at the edge, and, in one case, a total failure of the cover, which rolled up into the bottom of the spillway.

Despite these setbacks, the grass covers were shown capable of withstanding velocities of the order of 3m/s. A notable duration test was carried out on a channel lined with Kikuyu grass after the lower section has been re-turfed without an underlying sand layer. Velocities up to 2.7m/s at the downstream end were maintained for 20h with no significant scour damage.

During the tests the velocities were stepped up from 0.6m/s to failure velocity, each velocity being held for 1h. This indicates that the surfaces were tested for between 7 and 16h without repair.

Eastgate[3] tested the same grasses with the addition of Queensland Blue Grass (Dicanthium sericeum) on a slope of 7:100 for periods of 4h at velocities between 1.5 and 2m/s without any scour. The age of the turves used by Eastgate was unspecified.

The Queensland Soil Conservation Service produced a table of maximum allowable velocities for commonly used Australian grasses (Table 2). The various experiments recorded above largely confirm these recommendations.

1.2 Erosion resistance of vegetation - performance during natural floods

1. Francis[13] reported that dams protected by grass and mesh in Queensland successfully withstood floods generated by cyclones in 1971. Unconfirmed estimates put the velocity at 3m/s. Although no information is available for the duration of the immersion it is likely to have lasted several hours.

2. Messrs. G.H. Hill & Sons and the then County Borough of Huddersfield provided information about an incident in 1944 at the rebuilt earthfill Bilberry Dam in the Digley Valley near Holmfirth. It is estimated that between 90 and 100mm of rain fell, 50mm of this occurring in an hour. Reservoir water level rose to crest level and large volumes of water went down the downstream shoulder. Witnesses believed the bulk of this overflow was due to wave action but it is not unlikely that some actual overtopping occurred. Visually the flow depth at the crest appeared to be of the order of 300mm and velocities would have been of the order of 3m/s. The dam slope was protected by a thick carpet of long wiry grasses consisting probably of indigenous grasses, fescues and moor grasses. This had been laid flat during the passage of the flood and looked as though it has been brushed in a downstream direction. Sheep grazing was noted to have been beneficial.

3. Chew Magna dam, an earthen bank built in 1848 with inadequate spillway capacity, was overtopped in July 1968 by a flood produced by 173mm of rain falling in 6.5h on a catchment of 1740 hectares. The dam forms a small reservoir from which water is pumped into the larger Chew Stoke reservoir as part of the operation of the Bristol Waterways Company. The

downstream shoulder slopes at 1:3, and the crest height is about 6m above the floor of the dam.

The dam was overtopped along the central half of the crest, which had settled to some extent. The depth of overtopping has been variously estimated at between 127 and 380mm. At the greater depth, the velocity might have reached 3.7m/s on the slope, about the maximum generally expected for grass protection. Stone had been pounded into the crest in 1956. Although severe damage was caused in the vicinity of the spillway, the crest and the main part of the downstream shoulder were largely unharmed, apart from one or two holes caused by local erosion at stones resting on the slope.

Grasses present in 1972 included Timothy, Tall fescue, Creeping Bent, Smooth Stalked Meadow Grass and Clover.

4. Clatworthy dam, a mass concrete structure built in 1962 to a design by Rofe and Raffety for the (then) West Somerset Water Board, discharges flood water down the spillway into a concrete lined tailbay. The water then passes over a measuring weir into the river channel, the first part of which is formed into a stone-pitched rectangular channel 16m wide. The pitching which is 150 to 230mm thick, is hand placed but ungrouted. and has a cross fall to a central channel. The pitching was subsequently covered by topsoil and turf, which knit into a spongy but tough sward. The grasses included Smooth Stalked Meadow Grass, Common Bent, Creeping Red Fescue and Meadow Brome. The first three species are rhizomatic. A conservative estimate for the maximum spillway flow to date is $200m^3/s$, which, from a simple energy calculation from the measuring weir downstream, could mean that the grass experienced velocities of up to 5.5m/s for an hour or so. The grass appears to have recovered satisfactorily after exposure to this flow.

   The grass is cut about twice a year with a normal farm reciprocating mower. Occasionally it is grazed (and trampled) by stray cattle.

5. Sir M. MacDonald & Partners provided information about the use of the washlands between the Old Bedford River and the Hundred Foot River in the Fens. In times of flood, the low bank of the Old Bedford River (crest maximum overtopping depth 50mm slope 1:2) is overtopped over a considerable length and so the discharge intensity is not high and conditions are not critical. A ryegrass mixture is used (see Table 8). Although grazing was common, the grass is now cut once or twice a year by flail mowers.

6. During closure of a breach on Schouwen Island, Holland, velocities of up to 2m/s occurred and caused no erosion damage.

APPENDIX 2 - ARTIFICIAL REINFORCEMENT AND ESTABLISHMENT AIDS FOR GRASSED SURFACES

The information given below is of typical aids and covers the main types on the market. It is not exhaustive.

2.1 Temporary reinforcements

This category of reinforcement includes those that are designed to protect newly-seeded areas against erosion by rainfall; to provide thermal protection; to retain moisture; and to support newly-emergent plants. The materials described offer various combinations of these features, and are particularly useful in exposed locations or on problem sites (e.g. steep slopes). They are not intended permanently to strengthen a grass covered surface.

2.1.1 Bitumen emulsion

The emulsion is sprayed on to the newly-seeded surface at a typical rate of 1.1 l/m^2. The skin so formed binds the surface and retains the warmth. As the grass establishes, the skin disintegrates. The extra warmth can speed germination. A large number of authorities mentioned that they found that sprays successfully aided growth and gave early protection.

2.1.2 Curasol AE

A high polymer plastic dispersion sprayed on to the surface after seeding at a rate from 330 to 560kg/ha, depending on site conditions. The film penetrates the soil to a depth of between 0.2 and 10mm and binds the surface into a porous matrix long enough to allow the grass to establish. The film will not stand much traffic unless the application rate is raised to 1100kg/ha.

2.1.3 Epok V 7100

A latex sprayed on to the surface after seeding at a rate between 330 to 560kg/ha, which dries to give a plastic film binding the topsoil particles together. The film will not withstand traffic over the surface but minor damage 'self-heals' under the action of rainfall which causes slight reactivation of the latex.
Originally made by BP Plastics, similar material now available from Vinyl Products Ltd., Mill Lane, Carshalton, Surrey.

2.1.4 Huls 801

A liquid plastic which penetrates the top layer of the soil up to 10mm in depth. On hardening, the soil particles are bound together but no surface skin is formed. The surface therefore absorbs rainwater. The stabiliser is sprayed on after seeding at rates between 100 and 1500kg/ha according to the quality of the soil and the degree of stabilisation required. At the higher rates of application the surface can be walked on without damage.

2.1.5 Essbinder X and Z

A liquid water-based product that forms a micro-thin layer a few mm down in the soil which binds the soil particles and reduces surface evaporation. Coverage varies from 220 to 780kg/ha, depending on the site.

2.1.6 Unisol 91

An oil-based synthetic rubber latex which is diluted with water in the ratio 1:40 and sprayed over the surface, after seeding, at a rate of 1.8 l/m^2. The latex binds the top layer of soil particles to an approximate depth of 10mm. The surface formed will not withstand traffic.

2.1.7 'Stabil' netting

An open-weave Hessian netting pegged over the newly-seeded surface. The netting is claimed to have a life of 6 to 9 months and to act as a mild fertiliser as it decays, since the material is made of vegetable matter. The Department of Agriculture and Fisheries for Scotland has used this netting with success for the stabilisation of banks of friable sandy material during the period when the grass cover was getting established. A spray of oil-based synthetic rubber latex solution covered the seeds and netting.

2.1.8 Grunling grass mat

A preformed mat consisting of a layer of peat containing seed, fertiliser and trace elements topped by a layer of straw which rots after laying. The surface covering is rot-proof and remains in place after establishment of the grass. Horizontal threads are incorporated in the surface to trap surface moisture and increase frictional resistance under heavier surface flows. The mat is laid in place and dug-in along its edges.

2.1.9 Pegged turves

The use of turves, pegged at centres of between 0.5 and 1.0m and fastened in the mesh along vulnerable edges, has been mentioned by a number of organisations (e.g. Babtie, Shaw & Morton, Department of Agriculture and Fisheries for Scotland, C.H. Dobbie & Partners and Thames Water Authority). Such procedure gives a measure of immediate protection to an area.

2.1.10 The practice of the former Thames Conservancy for the stabilisation of newly-formed sloping-side channels included the use of wattle hurdles pegged down and grassed over. The hurdles lasted long enough for the grass roots to become well established.

NOTE: The use of bitumen mulch and glass-fibre rovings in the context of hydraulic seeding to provide temporary protection is described in Section 2.3 of this Appendix.

2.2 Permanent reinforcements

2.2.1 'Land Mesh'

A 25mm mesh polypropylene net designed to add permanent strength to a grass surface. After a period of consolidation the mesh becomes firmly embedded in the grass roots to form a reinforcing matrix.
Manufacturers: Bridon Fibres and Plastics Ltd., Teams Factory 8, Dunston, Gateshead, Tyne and Wear, NE8 2QY

2.2.2 Mono BG slabs

Precast concrete grids 600mm by 400mm weighing 36kg. Each grid consists of four crenellated ribs linked by two cross members. If the surface is not required to carry heavy traffic the slabs are laid directly on to the contoured soil surface. The slots between the ribs are filled with soil and seeded. On sloping surfaces the lowest course may be supported by large stone pitching, or the slabs may be anchored by staking the courses at intervals of two or three slab widths. When grass has established in the interstices of the grid, the root growth anchors the combined surface still more securely.

The resulting surface is flexible and local subsidence may be repaired by lifting the slabs and backfilling.
Manufacturer: Mono Concrete Ltd., Wettern House,
Dingwall Road, Croydon CR9 2NY

2.2.3 'Grasscrete'

A perforated concrete surface laid in-situ. A light-weight plastic former is laid on a prepared sub-base and a single layer of reinforcing mesh is laid around the formers. Concrete is poured into the formers, tamped and screeded off. Sections of the formers which are visible on the surface are burned out with a flame gun to leave perforations through the concrete layer. The perforations are then filled with soil and seeded.

The concrete layer may be varied in thickness from 50 to 150mm, according to the loads the surface is required to bear. In some circumstances the sub-base may be omitted and the concrete cast straight on to the contoured sub-soil.
Manufacturers: Grass Concrete Ltd., 22 Bond Street, Wakefield, Yorks

2.2.4 Dymex Blocks

Interlocking cellular revetment blocks with full depth cavities which are earth filled and grass seeded. The size of the standard block is 900mm by 450mm by 100mm deep and the weight is 45kg. In the completed work the ratio of grass area to concrete at the surface is 3:1. The ground contact area of the block is 70 per cent of the total area.

The blocks are laid dry on a granular base layer and in some applications a filter membrane may be specified. A toe beam or alternative form of protection is needed to prevent scour under the lowest course on sloping surfaces, and on steep slopes additional stability may be provided by staking alternate blocks.

The interlocking design transmits shear forces between adjacent rows of blocks in the plane of the revetment and nylon dowels may be specified to transmit shear forces at right angles to the plane to create a flexible mattress.

2.3 Establishment Aids

2.3.1 Hydraulic seeding

Hydraulic seeding is a technique of seeding particularly useful for the river banks which are too steep for, or inaccessible to, conventional machinery.

Basically the grass seed is applied as a suspension in a high pressure water spray. It is a simple step to add fertiliser, trace elements, chopped straw mulch, surface binding resins, etc. to the spray. Alternatively, these (or other) materials my be applied separately to give a temporary protection. Two commonly-used materials are:

(a) Bitumen mulch

The mulch of chopped straw, hay or wood cellulose is sprayed-on in an emulsion of bitumen and water. The bitumen serves to bind the mulch together and prevent erosion of the protection by wind or rain.

(b) Glass-fibre rovings

The glass fibre, in the form of a string, is applied by hand, using an air gun. The glass fibre forms small coils, and as the rovings are distributed over the area the coils interlock to form a mattress. The mattress may subsequently be pegged in place for additional security.

Combinations of these methods may also be used. For example, a mulch may be mixed with the seed before the application of glass-fibre rovings, or bitumen emulsion may be sprayed over the finished glass-fibre mattress.

Authorities which have reported the successful use of hydraulic seeding include the Department of Agriculture and Fisheries for Scotland, the (former) South West Wales River Authority and Wye River Authority.

2.3.2 Sheet turves

In recent years, methods of growing turf in large sheets under controlled conditions to provide uniform growth, ease of handling, complete root system and lack of shrinkage have been developed.

These methods include:

(a) Netlon Bravura Turf

The selected grass seed is mixed with a sterile moisture-retaining compound and allowed to germinate. This mixture is then laid onto a backing sheet composed of an impermeable plastic film with a fine 'Netlon' mesh laminated to its upper surface. Seminal root development takes place very quickly, and because downward growth is prohibited by the backing sheet, the roots interweave laterally with the mesh binding the whole sward together and encouraging the production of the secondary root system. When Bravura turf is lifted some six weeks later with the backing sheet still in place, this root structure is totally intact and kept safe from damage during handling. The developers have licensed growers who undertake to produce turf of the selected type free from disease, weeds and weed grasses. Netlon Bravura turf is guaranteed.
Roll size: 2.74m^2 (or 3.65 linear m, 0.75m wide)
Manufacturer: Netlon Bravura Sales Ltd., N.E.Wing, Bush House, Aldwych, London WC2 B4PX

(b) Tana Turf

A slurry of Hygromull, a synthetic peat from BASF and wood ash, is poured into lagoons 1m wide and 50mm deep where it floats on water. The slurry is then covered with a 2mm thick layer of polyurethane foam (the foam is bio-degradable under normal conditions). The selected seed is then sown on the top of the foam layer, it germinates within 10 to 15 days under polythene cloches. After the seeds have germinated, the roots penetrate the foam layer and form a fibrous system in the hygromull, binding it together into a firm carpet and allowing it to be picked up without damage. Being produced by flotation on the lagoon, the grass carpets are flat and of a constant

thickness, also weed and weed grasses free. As with other methods the growers are licensed.
Roll size: 3 to 4m^2 (or 3 to 4 linear metres, 1m wide)
Manufacturer: Plantagenet Seeds Ltd, 5A Market Place,
Pickering, Yorkshire

(c) Rolawn (Originally S.A.I. Turf Mat)

A peat or peat/sand mixture is laid on an impermeable surface after the seed has been sown. Gold N slow-release nitrogen fertiliser is incorporated in the peat mix (as can be reinforcement). Within 8 weeks, this produces a densely woven grass mat suited specifically to the end purpose. This is because of the lateral growth of the roots, resulting in a firm interwoven matting effect. Rolawn turf is weed and weed grasses free produced under controlled conditions by licensed growers.
Roll size: 2 to 3m^2
Manufacturer: Scottish Agricultural Industries Ltd
Ingliston, Newbridge, Midlothian

(d) Grasscarpet

A perforated polythene/nylon mesh is laid on a well-watered, smooth, impervious, non-toxic surface (tarmacadam, concrete, or polythene). The selected seed is spread on the mesh and the whole covered with peat/soil/sand mix incorporating fertiliser to a depth of 12.5mm. The whole is kept moist throughout, and within 8 weeks the roots have woven through the mesh to form a strong light turf. The turf produced is free from weed and weed grasses, produced under controlled conditions by licensed growers.
Roll size: 2 to 5m^2 (or 2 to 5 long by 1m wide)
Manufacturer: Grasscarpet (UK) Ltd., Crown Chambers,
22 South St Mary's Gate, Grimsby, S.Humberside

The Sports Turf Research Institute tested in the field: Tana, Bravura and Rolawn. They rated Rolawn the highest. Not enough work has been done on any of these to recommend any one over the other.

Main Advantages

1. Speed of production: a material to the client's specification can be ready within a few weeks of his order.

2. Freedom from weeds and diseases that may affect turf during production on natural soil.

3. Convenience in handling and laying.

4. Time gained: the period between sowing and establishment is likely to be prolonged when conditions are unfavourable for germination and growth, particularly between one year and the next.

5. Uninterrupted vigorous uniform germination and establishment from all the seed.

6. Immediate cover for a prepared site to avoid weed establishment, erosion, desiccation, etc.

Main Disadvantages

1. Handling: All turves, whether specifically grown or conventional, are by their very nature bulky and heavy when compared with seeding.

2. The trouble involved in ensuring that the vigorous impetus of young growth is not lost by drought or inadequate nutrition after the turf leaves the nursery where it is raised.

APPENDIX 3 HYDRAULIC ROUGHNESS OF GRASS SURFACES

3.1 Research based on Manning's equation of flow

The US Soil Conservation Service began studies of the flow of water through and over vegetation at Spartanburg Hydraulics Laboratory in 1936 (28). From 1940 to 1943 similar testing was carried out at Stillwater, Oklahoma in co-operation with the Oklahoma Agricultural Experimental Station (5,6). From 1943 onwards the Soil Conservation Service continued testing at Stillwater (7,8 9). In 1954, a handbook of channel design was published, based on almost 20 years of experimentation (2).

Manning's flow equation was adopted as the basis of the analysis. This equation is familiar to most engineers, and although it has limitations these are reasonably well understood. Values of Manning's coefficient were derived for a wide range of grasses, both cut and uncut. The coefficient 'n' was referred to as the 'retardance coefficient' since, in this case, it included the effect of all factors tending to retard the flow and the effects of the channel area blocked by vegetation.

Analysis of the tests led to the conclusion that the product of velocity V and depth D was a satisfactory criterion for judging the variation of 'n' with flow. For general application to all shapes of channel, D was replaced by the hydraulic mean depth R, and their product has been termed a 'flow parameter' in this publication. The majority of the tests were carried out in channels with slopes between 1:33.3 and 1:16.6. Only one or two tests were carried out at slopes of 1:10, 1:5 and 1:4.16. It was concluded that slope was not an independent variable, but in the one test made on a 1:4.16 slope, the value of Manning's 'n' was noted to be unusually low. This was ascribed to defects in the testing technique, particularly the measurement of the effective depth, but is of no interest in the light of the Australian tests mentioned later.

The tests covered all lengths of grass likely to be met in practice, from 50mm to 900mm. Within these boundaries any number of curves of 'n' against VR could be derived. Five curves were selected as sufficient to cover the range, and the final plot is shown in Figure 2. The retardance ranges were labelled A-E and the curves are used in conjunction with Table 3.

The grasses tested were native to the Southern States of the USA, but the range of data was such that it was possible to compile Table 3 for use with other grasses. It can be seen that the height of the grass is considered to be a more important characteristic than the density in determining frictional resistance.

The curves of Figure 2 demonstrate three phases of flow: at low flows (when depth is less than the height of the grass), the retardance is high; at intermediate flows the grass is becoming inundated and retardance drops rapidly with increase of flow; and at high flows the retardance approaches a constant low value. At this stage the grass is laid over and presents a relatively smooth surface to the flow.

Palmer (29) tested grass covers at extremely low discharges when values of the flow parameter VR were well below those shown in Figure 2. These tests showed that at such low flows the grass remains essentially rigid, and Manning's 'n' was virtually constant and in the range 0.2 to 0.3 for all grass lengths until water depth approached grass height.

Eastgate (3) investigated the applicability of the American work to conditions in Queensland, Australia. The grasses tested were Kikuyu, African Star Grass, Rhodes Grass and Queensland Blue Grass. The general shape of the retardance curves developed by the Stillwater Outdoors Hydraulics Laboratory was verified by the test results.

The results of all these tests related to the use of grass as a lining for intermittently-operative drainage channels and similar applications where slopes are small (i.e. less than 1:1000) and flow is usually subcritical. Eastgate's work showed some slope dependence for short grasses.

To apply these data to grass-covered bywash spillways with slopes up to 1:3 would require an unacceptable extrapolation of tested conclusions. Therefore Yong and Stone (4) at the University of New South Wales tested linings of Kikuyu, Rhodes Grass and Couch Grass of various lengths on vertically curved spillways with slopes varying approximately from 1:10 at the upstream end to 1:3 at the downstream end.

According to the Stillwater classifications, the Kikuyu Grass tested was in retardance range B, C and D, and the Rhodes Grass in the range B to C (i.e. Manning's 'n' was in the range 0.03 to 0.3). Eastgate's tests on these grasses had shown that on low slopes these classifications would be reasonably accurate.

However, the tests on steep slopes placed the retardance in the range E to D in all cases, Manning's 'n' varying only from 0.03 to 0.05. The explanation given for this was that under high velocity flow, the long grasses lay over and present an almost smooth surface to the flow. The resistance to flow is then no greater than that of a short grass of a height similar to that of the deflected height of the long grass. The Couch Grass was in the category D to E for low slopes and exhibited a retardance coefficient in the same range on the steep slopes.

The fact that grass lays over under high velocity flow, and presents a smooth surface of near constant roughness to the flow, had been noted in the American tests. Apparent discrepancy between the American and the Australian tests could be a result of the short-comings of the simple 'n-VR' presentations when applied to steep slopes.

A point to note is that the value of slope is properly that of the total energy line whose gradient equals the bed slope only when the flow is uniform. On these vertically curved spillways the flow is accelerating throughout the length, but bed slope is used in the calculation.

The end product of the work of the US Soil Conservation Service is a graphical relationship between the retardance 'n' and the product of flow velocity and hydraulic radius, VR (Figure 2). The other variables (length of grass and density of growth) yield a family of curves, and the validity of this relationship has been confirmed by extensive experiment. Some criticism has been made of the use of VR as the basis of the graph. However, VR is a form of Reynolds number and the relationship is therefore very similar to the resistance coefficient relationship of Nikuradse and Colebrook-White. This gives support for the adoption of VR as a parameter. The Australian investigations of flow on steep slopes point to a requirement for a further parameter, in the case of vegetation, which takes account of the distortion of the roughness elements under the influence of velocity.

A more general presentation should perhaps be of the form:

$$n = f(VR,\ i)$$

where i = friction slope or slope of the total energy line.

The retardance is related to the flow velocity by Manning's equation. For slopes greater than (say) 1:1000, inaccuracies begin to appear but the evidence is that they are not extreme. At the present time, this work is the best basis for practical use.

3.2 Research based on alternative equations of flow

Kouwen, Unny and Hill (30) investigated the flow retardance in vegetated channels using 100mm long strips of flexible styrene glued to the floor of a flume to represent the vegetation. They concluded that the representations of Manning's 'n' as a function of the flow parameter VR was not satisfactory.

Their alternative approach was based on the Prandtl-Von Karman velocity distribution equation written in the form

$$\frac{u}{v_*} = \frac{1}{k} \log_e \frac{y}{y'} \qquad \ldots\ldots (1)$$

where u = velocity at height above bed y

v* = shear velocity = $\sqrt{gRi}$

K = Von Karman universal constant

y' = a constant of integration evaluated by reference to some datum velocity

Taking the datum velocity as u_k (referred to as 'slip velocity') at a height k above the bed, where k = the deflected height of the vegetation, Equation (1) becomes

$$\frac{u}{v^*} = \frac{u_k}{v^*} + \frac{1}{K} \log_e \frac{(y)}{(k)} \qquad \ldots\ldots (2)$$

On the assumption that u_k is proportional to u_*

$$\frac{u_k}{u_*} = \text{constant} = \beta$$

Applying the above formula to calculate unit discharge, and integrating yielded the general equation:

$$\frac{v}{u_*} = \alpha + \frac{1}{k} \log_e \frac{d}{\gamma} \qquad \ldots\ldots (3)$$

where v = mean velocity

$$\alpha = \frac{1}{u_* \, y_n} \int^k u.dy$$

$$\gamma = k.\exp.(1-K\,\beta)(1-\frac{k}{d})$$

It can be seen that α is a function of the flow through the vegetation, and therefore of the density of the vegetation, and γ is a roughness parameter dependent on deflected height k and the relative roughness k/d.

The results of the tests, with artificial roughness, showed the form of Equation (3) to be correct for bed slopes between 1:2000 and 1:1000.

For practical purposes, the authors rearranged Equation (3) to:

$$\frac{V}{v_*} = C_1 + C_2 \log_e (\frac{d}{k}) \qquad \ldots\ldots (4)$$

and then to:

$$\frac{V}{v_*} = C_1 + C_2 \log_e({}^{A}/_{A_v}) \qquad \text{..... (5)}$$

where A = total cross-sectional area

A_v = area of cross-section blocked by vegetation

Coefficient C_1 depends mainly on flow through the vegetation and C_2 was considered by the authors to be a function of vegetation stiffness. It should be noted that k and also A_v refer to the deflected height of the vegetation, which itself is dependent on flow conditions and the physical characteristics of the particular grass. The coefficients C_1 and C_2 and the variation of k with u would need to be obtained experimentally for Equations (4) and (5) to be of practical use.

In a discussion of this paper, however, Gourlay (31) analysed Eastgate's results (3) in terms of Equation (4), indicating that there was a slope effect not allowed for by the formula, and showing evidence that in some circumstances $\frac{V}{v_*}$ was largely independent of d/k

If the flow is entirely within the grass (i.e. d = k) then Equation (4) reduces to $V/v_* = C_1$.

Since $u_* = \sqrt{\tau/\rho}$ a rearrangement of terms gives:

$$\tau = C_d \ \rho V^2/2 \qquad \text{where } C_d = 2/C_1^{\ 2}$$

where τ is the shear stress on bed

This is the familiar drag equation and implies that, under this flow, the resistance is predominantly due to the form resistance of the grass stems.

An investigation of low flows through vegetation by Lal and Pandya (32) was based on the same assumption, that of water depths less than the height of the vegetation the principal resistance is the form resistance of the grass stems.

The drag force, F, per unit area is then given by :

$$F = \frac{1}{2} C_d \, m \, a \, V^2 \qquad \text{..... (6)}$$

where C_d = drag coefficient for each stem

m = numbers of stems per unit area

a = area of each stem normal to the flow

V = mean velocity of flow

Force acting on unit area is given by:

$$F = \rho g i d \qquad \ldots\ldots (7)$$

where i = slope of energy line

d = flow depth

ρ = mass density of fluid

From the Darcy-Weisbach flow equation:

$$i = \frac{V^2 f}{\rho gR} \qquad \ldots\ldots (8)$$

where f = coefficient

R = hydraulic mean radius

Substituting for i in Equation (7) and assuming $R = d$ for broad shallow flow gives:

$$F = \rho\frac{V^2 f}{8} \qquad \ldots\ldots (7A)$$

Equating Equations (6) and (7A) gives a value for the resistance coefficient:

$$f = 4\ C_d\ m\ a \qquad \ldots\ldots (9)$$

To verify the theoretical relationship, Lal and Pandya (32) conducted a flume experiment in which the grass was represented by a series of combs built-up from mild steel rods approximately 6mm diameter and 250mm long. A group of the rods was attached to a strain gauge in order to measure the drag directly. Values of C_d could therefore be calculated from Equation (6) and substituted in Equation (9) to yield values of f. Equivalent values of f were then calculated from Equation (8) and each pair compared. Allowing for the fact that a value of f calculated from the bulk flow formula took bed resistance into account, whereas the directly measured drag did not, good agreement was found.

In the case of real grasses, selection of the values of the parameters in Equation (9) obviously presents problems, and no information is at present available on the best way in which it could be done.

APPENDIX 4 SOME EXAMPLES OF RECENT HYDRAULIC DESIGN PRACTICE

In this Appendix a résumé is given of a selected number of examples of the use of grass in recent practice. The examples were quoted in response to the survey carried out for the Project. The original material is held in CIRIA Project Record 170 (33).

4.1 Bywash channels

The flood-relief provisions for the River Exe, designed by the former Devon River Authority, incorporated a number of grass-lined bypass channels. For the most part, these channels operate only in times of severe flood. Water depth is controlled by weirs, and velocities are extremely low. On Alphin Brook, however, a roofed culvert through the village of Alphington discharges through a stilling basin into a grass-lined channel 21m wide. The water depth is controlled by a broad crested weir at the downstream end which is designed to give a nromal depth in the channel of 2.4m at a flow of 113m3/s. Design velocities are therefore of the order of 1.5 to 1.8m/s. A 920mm deep x 6.1m wide cunette, or central gutter, down the centre of the channel carries flows up to 5.1m^3/s. Immediately downstream of the stilling basin, where the flow tends to be turbulent, flows over the banks of the cunette are reportedly common, and inspection of this area only a day after a 3-day immersion showed the grass cover to be in excellent condition. It is definitely known that the grassed surfaces in this scheme have been immersed for as long as 10 days, and in one small area total immersion has continued for 3 weeks. No re-surfacing has had to be carried out, and the quality of the grass cover indicates that these periods of immersion have had no lasting detrimental effect on the plants. The grass mixture used is given in Table 8.

4.2 Emergency spillways

Examples are described below of emergency spillways that have recently been built in the UK. The spillways have not yet been tested and it may be many years before their operation can be observed, but they are interesting examples of the practical use of grass linings in a hydraulically-demanding situation.

4.2.1 Brick-kiln Dam, Milton Keynes

The dam was designed by J.D. & D.M. Watson to create a balancing reservoir to control downstream discharge in times of flood, while normal flow is carried under the dam in a small culvert. The reservoir capacity is designed to control a high level of flooding and the emergency spillway only operates during a flood with a return period of the order of 200 to 300 years.

The spillway crest is parallel to the dam, and the spillway then curves to follow the intersection of the downstream face of the dam and the valley side.

The spillway crest is of concrete and is followed by a 10m long concrete apron. A section extending approximately 70m from the crest is lined with Mono BG concrete grids planted with grass. The lower section of the spillway is completely grass covered. From the crest to the end of the concrete grids the width of the channel is 30m, and at this point the slope is approximately 1:20. The grass-lined section of the spillway tapers to 15m at the downstream end and has a slope of the order of 1:17.

Throughout the length the section is rectangular and the side walls are of concrete.

The expected maximum flow is 29m^3/s and related velocities vary from 1m/s at the crest to 3m/s maximum. The spillway was planted with five trial seed mixtures. (See Table 6).

4.2.2 Hemlington Reservoir

Hemlington Reservoir was designed by Scott Wilson, Kirkpatrick & Partners to be a balancing lake for a storm-water sewerage system for the Borough of Teesside. It was completed in August 1972, but is also to be developed as a recreational centre. Normal discharge is through a pipe outlet spillway but floods (approximate return period 25 years) are discharged by a grass-lined emergency spillway. The dimensions are:

Width at crest:	16.8m
Total length:	128m
Fall:	2.13m in 27.4m + 35m in 100m
Width on lower slope:	6.1m
Side slopes:	1:3

The grass cover is carried over the crest and continues upstream for 28.3m at a slope of 1:31. The spillway is reinforced with Grasscrete, a method of laying a perforated concrete lining in-situ (See Appendix 2). In this case, the small amount of concrete visible through the vegetation was considered to be obtrusive and the Grasscrete has therefore been covered by a 150mm layer of topsoil and it acts as a back-up protection.

The spillway has been designed for a peak flow of 51m^3/s with a head over the crest of 1.2m. Estimated velocity on the spillway is 5.0 to 5.5m/s, but it is not anticipated that the spillway will have to carry such flows for more than 30 min. Details of the grass mixture are given in Table 8.

4.3 River flood banks and channel sides

4.3.1 Lee Valley flood alleviation scheme

In 1969-71 the (former) Lee Conservancy Catchment Board constructed a trapezoidal flood alleviation channel (28.5m bed width, 2.5m deep) through some worked out gravel pits near Ware, Hertfordshire, which had been used as lagoons for the dumping of ash and grit. The channel bank was formed using gabions filled with hardcore covered with gravel and topped with a thin layer of topsoil. After seeding (see Table 8 for mixture), a cold bitumen emulsion was sprayed on, and cover was established within 6 months.

The channel carries flood flows only and the grass has successfully withstood the intermittent flows.

The Board have also used grass to line emergency side-spill weirs, 122m long, off the River Lee near Hoddesdon. To-date it has not been necessary to divert flow over it.

4.3.2 River Spey

The Department of Agriculture and Fisheries for Scotland gives advice and prepares specifications for the agricultural promoters of drainage works, including the restoration of new flood banks and channels. It is normal practice to seed down with agricultural grass mixtures all exposed floodbank and river bank faces, and where conditions are critical, turf is used, held down by agricultural netting stapled to wooden pegs. One interesting and recent example of the use of these techniques on Departmental advice occurred in 1969 when considerable lengths of the floodbanks of the River Spey required restoration.

In the area of the Dell of Killiehuntly, the River Spey runs at a flat gradient, about 1 in 40 000, between 1m high riverbanks and 2.5m high flood banks. The riverbanks and flood banks consist of light friable sandy material which compacts well when wet, but has the texture of fine flour when dry. The flood channel is generally about 92m wide but erosion was occurring in a reach that was 77m wide. To provide uniform channel conditions and remove the basic cause of the erosion, it was decided to realign the flood banks on one side by moving them back from the river by 15m. Stabilisation of the new bank was essential until a good grass cover could be established.

Heavy rock revetments and turfing were both expensive and the method finally adopted consisted of soaking the raw material of the newly formed bank, hydroseeding with a wood cellulose mulch and fertiliser, stabilisation of the surface by spraying with oil-based synthetic rubber latex (Unisol) and covering the bank with open-weave hessian netting (Stabil net) pegged down over the surface. The operation was successful and 8 weeks after hydroseeding the grass was well established. Some damage occurred to the latex surface as the netting was placed and it was felt that it would have been better to lay the netting before spraying.

4.3.3 Yorkshire Rivers

The former Yorkshire River Authority had a policy of constructing banked washlands for the storage of flood-water. In most cases these are filled by flow over grass-lined spillways situated at their upstream ends. The downstream shoulders of these spillways slopes at 1:5.

4.3.4 Russian practice

In the USSR, it is not uncommon for embankments to be designed with overlapping layers of polythene sheet and grassed. The idea appears to be that if the vegetation fails on overtopping a second line of defence is provided by the polythene. It is felt, however, that firstly the introduction of a plane surface of polythene means that all rainfall will be diverted into a thin outer layer of soil, leading possibly to washout at time of high rainfall; secondly a plane of structural weakness is introduced, so that the overlying layer of earth and grass would all too readily slide down the slope under mechanical influences (e.g. while grass cutting was in progress); and thirdly the soil below the sheet would dry out and fissure. Perforated sheet, however, would allow for internal drainage and for the roots of the grass to pass through the sheet and to bind the soil either side of the sheet. The difficulty could be that when the upper layer is stripped, the grass roots would damage the sheet. Perforated sheet is merely one type of net, other types of which are more effective.

APPENDIX 5 REPORT ON SITE VISITS TO FORMER RIVER AUTHORITIES

This appendix describes visits made to various of the then River Authorities. General conclusions are given in Section 4.2.2. The grass mixtures used are summarised in Table 8.

5.1 Essex River Authority (now part of Anglian Water Authority)

The Authority maintain some 480km of sea banks. Many of the banks are built of clay naturally infested with Couch Grass which it is virtually impossible to eradicate. It was found in consequence that sown grasses were displaced by the Couch Grass in a short time. Earlier practice of sowing bred varieties of Perennial Ryegrass on new banks was therefore discontinued in favour of the use of a cheaper Italian Ryegrass mixture which merely acts as a nurse crop until the Couch Grass is established.

The grass is generally cut twice a year with flail mowers in early and middle season. It is considered that the timing of the cuts is important but, with such large areas to manage and with other maintenance work to be fitted in, cutting may be spread over a period so that not all banks can be cut at the ideal time.

Sheep grazing is considered beneficial, but this is limited to relatively small areas. It was reported that, during the floods of 1953, a section of the sea bank that had been grazed by sheep remained intact when adjacent sections about 450mm higher had failed. The composition of the grass at that time is not known.

Inspection of the damage after the East Coast floods have made the Authority very aware of the opposing effects of grass on clay banks. A grass cover reduces surface evaporation and prevents drying out of the surface which would lead to rapid erosion by overtopping flows. On the other hand, long vegetation with deep roots dries out the banks by evapo-transpiration, leading to fissuring of the clay which allows ingress of water and failure by internal slips.

The Authority considered that, on balance, a short grass regime would be better because it would prevent surface evaporation but not have such deep roots that the bank would be dried out at depth. Experience confirmed this conclusion.

On inland freshwater banks the Authority use a pasture mix based on Perennial Ryegrass, Meadow Fescue and Timothy (see Table 8).

5.2 Lincolnshire River Authority (now part of Anglian Water Authority)

The inspection covered river banks in the Lincoln area, grassed within the last 10 years, and tidal estuary banks on the River Humber. On the river banks the hydraulic duty is not onerous, river velocities are low and overtopping is not permitted because of the value of the farmland. River levels come to within a metre or so of the crest of the bank in flood time and immersion normally lasts for less than a day. However, in at least one case, (the flood relief channel around Lincoln) the flows are controlled and immersion can last for up to three weeks.

The river banks are sown with a grass mixture of Perennial Ryegrasses and Clover (See Table 8), and the swards for the most part are still of similar composition as was originally sown. In some places the simplicity of the mixture has led to a lack of body at ground level.

The preferred method of maintenance is to let the banks for grazing to farmers. There are few sheep in the area, and cattle grazing is therefore allowed with satisfactory results although some hoof damage was apparent on steep banks. However, this maintenance policy can have very variable results and, as the number of farmers wishing to use the banks for grazing is falling, the River Authority foresee that mowing will be needed.

On the tidal estuary banks spartina was used with some success to help stabilise the mud flats between low and high water marks. Above normal high water the grass mixture used had not been very successful, but distinct flourishing colonies of Chewing Fescue were found. This grass was not meant to be in the original mixture and its presence could not be explained.

Cattle are not allowed on tidal banks. Sheep grazing would be approved, but there are not many sheep in the area. Maintenance is therefore mainly by cutting once a year.

5.3 <u>Severn River Authority</u> (now part of Severn-Trent Water Authority)

The Authority actively encourages farmers to maintain their embankments by normal pasture management of the meadow land of which they form a part. The banks are set at a level which gives limited flood protection up to a return period of 5 years and are not often more than 1m high. This makes it possible to flatten the side slopes to 1:5 and promote the policy of normal pasture management. The crest width is a minimum of 2.5m. The banks are formed from materials produced by reshaping the original river bank and, where this fertile material dredged from the river forms the surface of the bank, the vigour of the sward is noticeably greater.

Some of the lands protected were formerly inundated for 7 to 10 days once or twice a year. The present banks are overtopped on average one year in five. The overtopping averages 150mm with a maximum of about 300mm, the bank acting as a very long weir until the flood plain area inside it is full. Flow in the main channel at these times averages 1.5 to 2m/s but the marginal velocities are usually much less.

The standard seeding mixture was recommended by the Grassland Officer of the Ministry of Agriculture, Fisheries and Food, and is based on Perennial Ryegrass, Timothy and White Clover (see Table 8). Well-managed banks under frequent cattle grazing have swards in good, dense condition and the grass cover was noticeably good on banks grazed by sheep.

Absence of damage by the hooves of cattle demonstrated the advantage of gentle side slopes on banks intended for maintenance by the grazing of these animals. Sheep paths were in evidence on some banks especially where limited access to a bank made it regularly necessary to drive a flock along a bank top to reach a distant grazing area. Two examples were seen of the damage that can be caused to a grass cover by features which cause a concentration of cattle into one spot: one, a gate in a cross fence located on the top of a bank and the other, a clump of trees, the shade of which attracted cattle in warm weather. It is standard practice where access ramps, cattle crossings and fence lines occur to raise the height of the banks locally by about 0.30m to counteract any possible damage by farm machinery or animals.

On ungrazed banks it was the Authority's practice to cut mechanically with an Allen Scythe. Cutting has been done twice a year or as dictated by the season, but this is not enough to prevent some deterioration in the sward.

One pasture had been repeatedly haycropped, and the sown grasses had been replaced as a result by natural 'Severn Pasture' species including Cocksfoot, Yorkshire Fog and Sweet Vernal. The sward had a dense appearance but the agricultural worth of the grasses present will be lower than that of sown Perennial Ryegrass.

In one area, siltation associated with osiers growing on the river bank produced bare patches of mud which had killed the grass on the lower slopes. On the other hand, in another area Ryegrass was successfully regrowing through several inches of silt deposited by natural levée formation near the river.

5.4 Trent River Authority (now part of Severn-Trent Water Authority)

Banks were examined at several locations between Gainsborough and Scunthorpe. All these banks are tidal estuary banks and are high enough to avoid overtopping. Consequently, although they are constructed with silt which tends to fissure when drying-out occurs during hot summers, the danger of breaching from overtopping is said to be negligible.

In general, the banks have seaward slopes of 1:2, landward slopes of 1:2.5 and crest widths of 1.8m. All the banks with one exception, were sown with a grass mixture made up of Perennial Ryegrass, Timothy, Rough Stalked Meadow Grass, Crested Dogstail and Clover. Since 1972, the Clover has been omitted and the Ryegrass component increased (See Table 8).

The bank differently treated had been sown with Fescues in 1957 and 1958 as a result of unrecorded trials made by the Authority in the early 1950s, when it is assumed that these grasses did well. The Fescue-sown areas appeared to have done well. The cover was tough and dense, although somewhat patchy.

Allen Scythes are used for cutting rough vegetation. Rotary mowers are also used, but in most cases the banks are mown with flail mowers at intervals of 3 to 4 weeks. Limiting slope for running the machines along the bank has been found to be 1:2.5.

Apart from the Fescues, none of the grasses sown is rhyzomatic and the Rye Grass was probably a variety with limited persistance. Tillering has probably been discouraged, and self-seeding prevented, by the short and frequent cutting. The Crested Dogstail in the mixture, which is not drought-resistant, has largely died off. Observation suggests that segregation of the different seeds had occurred during transport, causing uneven sowing. This was particularly noticeable with the clover.

The section sown with Fescues has a much better grass cover. These grasses tolerate close cutting and propagate from rhyzomes to fill-in bare patches. Some invasion by other grasses had taken place, but where the Fescues had established well the cover was so close that invasion by weeds and other grasses was impossible. The only difficulty experienced had been with jamming of the mowers if the thin, dense wiry grass was allowed to grow to any height.

South of Gainsborough the main flood banks are set back from the river by up to 4.8km to create peak flood storage areas. Adjacent to the river are smaller flood banks up to 1.25m high to contain minor floods. These are overtopped by 380 to 460mm every 3 years or so, but damage from the overflow is relatively rare. Many lengths of bank in this area are maintained by cattle grazing. However, cattle are not encouraged on the banks in wet or frosty weather. Chemical growth regulators were used in 1967, 1968 and 1969 but their use was discontinued for the following reasons:

1. ill effects on the operators applying the chemical

2. the grey and lifeless appearance of the treated grass aroused public protest

3. treated grass became brittle and very difficult to cut.

5.5 Usk River Authority (now part of Welsh National Water Development Authority)

Sea banks facing the Severn Estuary are typically about 3m high with a face slope of 1:2. Large sections of the banks are protected by natural saltings extending some 100m and acting as a berm about 6m above mean sea level. The banks have not been overtopped, but receive heavy spray and immersion over the toe for about 3 days during high spring and autumn tides. Where the saltings are eroded, the toe of the bank is protected by rip-rap. The banks are constructed largely of clay with some topsoil if necessary.

The saltings have an excellent natural grass cover consisting almost exclusively of Red Fescue, while the banks were sown with a mixture of Perennial Ryegrass, Timothy and White Clover at a rate of 31.4kg/ha.

A section of the seaward side, reseeded in 1968, had been treated with bitumen emulsion to assist germination directly into the clay. The seeding was reasonably successful, albeit with a high degree of infestation by thistle. Considerable lengths of the seaward slope elsewhere were also infested with thistle which had apparently colonised uncovered ground early in the life of the bank.

The banks are for the most part maintained by grazing with sheep and, less commonly, with cattle. In general, grazing by sheep resulted in higher quality sward than by cattle grazing. Cattle had not grazed as closely nor on such steep slopes as would sheep and, in those areas, invading Meadow Grasses, weeds and small shrubs were more common. In places, pedestrian traffic had produced worn areas on the top of the banks, and localised patches of bare ground were observed on the seaward slopes, particularly at the junction of the toe of the bank and the 'berm'. This was thought to be due to immersion, light wave action and siltation, as sediment from the eroding seaward face of the saltings is carried to the bank by breaking waves and deposited on the bank toe as the wave energy dies.

Occasional clumps of rushes were noticed on the seaward side of some banks, causing poor cover near their bases. Normally these clumps are removed by hand.

River banks at Usk were also inspected. The East bank, seeded between 1967 and 1970, is a public amenity area and had an excellent cover of low maintenance grasses. The composition of the mixture was not known. The West bank was seeded in 1970 and the pattern of the seed drill was still apparent, with relatively sparse areas between clumps. The cover was predominantly Perennial Ryegrass.

5.6 Wye River Authority (now part of Welsh National Water Development Authority)

A bank near Hereford was inspected, known as Hampton Bishop

Stank. The original bank was breached and overtopped in 1960 and was raised and grassed during 1963. The main slopes are 1:2.5 to 1:2 with a berm at old meadow level where the side of the bank is shortened by land scarcity.

The grass is general pasture mixture, West Midlands S33 (see Table 8). The grass on the berm was in good condition, consisting mainly of Perennial Ryegrass, Smooth Meadow Grass, Red Fescue and Browntop. Constant grazing by cattle had left the slopes in poor condition, and tearing of the surface as the cattle climbed these considerable inclines had reduced the grass cover to between 30 to 50 per cent. On the damper areas, the bare soil supported a moss which competed with the grass. The river bank was trodden into irregular steps by the cattle and supported thick clumps of Tussock Grass.

Photographs were seen of a small stream at Penybont where the banks immediately downstream of a gabion weir were so steep that conventional methods of grass seeding were not possible. The problem was solved by using the technique of hydraulic seeding with wood mulch and pegged fibreglass, (see Appendix 2). An excellent grass cover had been established.

APPENDIX 6 THE ASSESSMENT OF PERFORMANCE OF THE GRASS MIXTURES IN THE SITE TRIALS

As noted in Table 6, 17 grass mixtures of various types are being tested at six sites. The following characteristics are being observed at regular intervals:

1. Percentage germination

   Expressed in the range 0% to 100%, the latter representing total emergence.

2. Germination vigour

   Expressed on an arbitrary scale from 0 to 100% as judged visually. Performance on this score is not related to the eventual quality of the turf. Rather, species which have a high germination vigour are among the least persistent.

3. Establishment

   Establishment scored on a visual basis on a scale from 1 to 9. This characteristic indicates the extent to which the germinated seedlings are forming into a close-knit sward. A high score indicates a superior sward-forming ability.

4. Establishment true to mixture

   This checks to what extent the seedlings establish in the young sward, and projects the proportions of each species in the mixture sown. A single record was made at approximately 10 weeks from sowing. A high score shows that the mixture is establishing in the intended proportions.

5. Smothering-out effects

   These are an indication of the compatability of the species included in the mixture. A high score suggests that one, or possibly two, particular species are a lot more aggressive than the rest and are beginning to dominate their companion species. The same effect can result from sowing at too high a rate.

6. Ground cover percentage

   100% represents total vegetation cover with no bare ground visible looking from directly above. A single score was made at approximately 10 weeks after sowing. It is important not to confuse this character with sward density.

7. <u>Density of sward</u>

A high score represents dense sward formation independent of percentage ground cover. High score represents high density, and a single score was made at approximately 10 weeks after sowing.

8. <u>Invasion by weeds</u>

1 denotes little invasion, and 9 denotes high invasion, by weeds. The score reflects to some extent a percentage ground cover and density of sward.

9. <u>Invasion by other grasses</u>

Scored as (8) above.

10. <u>Height of growth</u>

(Self explanatory)

11. <u>Diseases</u>

Scored on a scale from 0 to 9: 0 shows that the turf was clear of infection; 9 would represent total infection with mildew or other diseases. The single score was made when the turf was established.

It is too soon, of course, to draw firm conclusions, but the following indications may be of interest.

As expected, the mixtures which contained Ryegrass established quickest. However, soon after establishment it became apparent that the fine-leaved grass seed mixtures produce a denser turf. Where mixtures have been sown at very high sowing rates the grasses were confronted with competition from the other species sown and started to smother each other. The low maintenance mixtures had established fairly well but had become infested with weeds, owing to their slow establishment.

The removal of these weeds had left bare patches. The agricultural, and (former) river authority mixtures had established well and at an early stage there was little noticeable difference. Differences should become apparent after 2 to 3 years when the less persistent grasses have died. The amenity mixtures had established fairly well but some slight invasion of weeds was noticeable. After 2 years, however, it is hoped that, because of the prostrate dwarf growth habit and their rhizomes which will then have developed, the amenity mixtures will give such close swards that the weeds will be suppressed. Some plots were monocultures (i.e. single varieties). Here differences were already noticeable at a very early stage.

APPENDIX 7 LIST OF RECOMMENDED VARIETIES OF SPECIES AND PLANT BREEDERS

Breeding new varieties of grasses is a long and complicated process, during which the Breeder's aim is to improve certain characteristics of a grass species.

Grass breeding is a continuous programme, and some of the varieties listed before might well be replaced in the next years by even better performing ones.

The list below has been compiled on the basis of:

1. test at the National Institute of Agriculture and Botany (CMAB) Cambridge
2. tests at the Sportsturf Research Institute, Bingley, Yorkshire
3. tests at Rothwell Plant Breeders, Lincs.
4. practical experience
5. tests at Instituut voor Rassenonderzoek van Lanbouwgewassen (IVRL) Holland

7.1 INTERMEDIATE (MEDIUM LATE) PERENNIAL RYEGRASSES

Variety	UK Agent	Breeder
Terhoy (Tetraploid)	Nickerson Seed Co	Cebeco (NL)
Agresso (Tetraploid)	Pope & Chapman	Van Englen (NL)
Taptoe (Tetraploid)	W.W. Johnson	Van der Have (NL)
Barlatra (Tetraploid)	Goldsmith Bros.	Barenbrugs (NL)
Barlenna	Goldsmith Bros.	Barenbrugs (NL)
Combi	Pope & Chapman	Joordens & Van der Have (NL)
Talbot	W.W. Johnson	Van der Have (NL)
Aberystwyth S101	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Scotia	N.S.D.O.	S.S.R.P.B. Edinburgh (UK)
Moretti	Mommersteeg Seed Co	Mommersteeg (NL)
Stadion	Mommersteeg Seed Co	Mommersteeg (NL)
Animo	Mommersteeg Seed Co	Mommersteeg (NL)

7.2 LATE PERENNIAL RYEGRASSES

Variety	UK Agent	Breeder
Aberystwyth S23	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Barenza Pasture	Goldsmith Bros.	Barenbrugs (NL)
Caprice	British Seed Houses	C.I.V. (NL)
Compas	Pope & Chapman	Van Englen (NL)
Lamora	Mommersteeg Seed Co.	Mommersteeg (NL)
Pelo	W.W. Johnson	Van der Have (NL)
Perma	Nickerson Seed Co.	Cebeco (NL)
Semperweide	J. Picard & Son	Zwaan en de Wiljes (NL)
Melle	Nickerson Seed Co.	R.V.P. Belgium
Spirit	J. Picard & Son	Zwaan en de Wiljes (NL)
Wendy	W.W. Johnson	Van der Have (NL)
Springfield	W.W. Johnson	Van der Have (NL)
Barpastra (Tetraploid)	Goldsmith Bros.	Barenbrugs (NL)
Fortis (Tetraploid)	J. Picard & Son	Zwaan en de Wiljes (NL)
Petra (Tetraploid)	W.W. Johnson	Van der Have (NL)
Endura	Pope & Chapman	Van Englen (NL)
Angela	W.W. Johnson	Van der Have (NL)

7.3 AMENITY TYPE PERENNIAL RYEGRASS

Manhattan	Twyfords	Rutgers A.E.S. (USA)
Sprinter	J. Picard & Son	Zwaan en de Wiljes (NL)
Grandstand	Mommersteeg Seed Co.	Mommersteeg (NL)
Athletic	Mommersteeg Seed Co.	Mommersteeg (NL)
Majestic	Mommersteeg Seed Co.	Mommersteeg (NL)
Sportiva	Pope & Chapman	Van Englen (NL)
Ensporta	Pope & Chapman	Van Englen (NL)
Pennfine	Pope & Chapman	Pennsylvania A.E.S. (USA)
Romney	Kent N.F.U.	Kent N.F.U.

7.4 TIMOTHY

Aberystwyth S352	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Scots	S.A.I.	
Kampe II	Nickerson Seed Co.	Weibulls (Sweden)
Erecta R.V.P.	Nickerson Seed Co.	R.V.P. (Belgium)
Aberystwyth S51	N.S.D.O.	W.P.B.S. Aberystwyth (UK)

7.4 TIMOTHY (CONT'D)

Variety	UK Agent	Breeder
Pecora	Nickerson Seed Co.	Vilmurin-Andrieux (FR)
Comet	Pope & Chapman	Van Englen & Joordens (NL)
Notim	Mommersteeg Seed Co.	Mommersteeg (NL)
Aberystwyth S48	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Intenso	J. Picard & Son	Zwaan en de Wiljes (NL)
Oakmere	Gartons	Gartons (UK)
Olympia	Pope & Chapman	Van Englen (NL)
Pastremo	Mommersteeg Seed Co.	Mommersteeg (NL)
Aberystwyth S50	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Evergreen	Hursts	Weibull (Sweden)
King	W.W. Johnson	Van der Have

7.5 WHITE CLOVERS

Grasslands Huia	Most wholesalers	D.S.I.R. (NZ)
Cultura	Nickerson Seed Co.	Cebeco (NL)
Milkanova	Nickerson Seed Co.	Pajberg (Denmark)
Blanca	Nickerson Seed Co.	R.V.P. (Belgium)
Aberystwyth S184	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Kent Wild White	Kent N.F.U.	Local Selection
Aberystwyth S100	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Sabeda	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Kersey	Most wholesalers	Local variety
N.F.G. Gigant	Nickerson Seed Co.	D.S.V. (West Germany)

7.6 CREEPING RED FESCUE

Reptans	Hursts	Weibulls (Sweden)
Dawson	W.W. Johnson	Van der Have (NL)
S 59	N.S.D.O.	W.P.B.S. Aberystwyth (UK)
Oasis	Pope & Chapman	Van Englen
Polar	Hursts	Weibulls (Sweden)
Bargena	Goldsmith Bros.	Barenbrugs (NL)
Novarubra	Mommersteeg Seed Co.	Mommersteeg (NL)
Linora	Nickerson Seed Co.	D.S.V. (West Germany)
Theodor Roemar	Nickerson Seed Co.	D.S.V. (West Germany)

7.7 SMOOTH STALKED MEADOW GRASS

Variety	UK Agent	Breeder
Bensun	Hursts	Warren (USA)
Sydsport	Hursts	Weibulls (Sweden)
Fylking	Mommersteeg Seed Co.	Mommersteeg (NL)
Prato	W.W. Johnson	Van der Have (NL)
Arista	Pope & Chapman	Van Englen (NL)
Primo	Hursts	Weibulls (Sweden)
Baron	Goldsmith Bros.	Barenbrugs (NL)
Birka	Hursts	Weibulls (Sweden)
Monopoly	Mommersteeg Seed Co.	Mommersteeg (NL)
Nugget	Pope & Chapman	Otto Pick (Canada)
Geronimo	Mommersteeg Seed Co.	Otto Pick (Canada)
Merion	Pope & Chapman	Van Englen (NL)
Enmundi	No agent yet	Van Englen (NL)

7.8 CHEWING FESCUE

Erika	Hursts	Weibulls (Sweden)
Highlight	Pope & Chapman	Van Englen (NL)
Koket	Mommersteeg Seed Co.	Mommersteeg (NL)
Barfalla	Goldsmith Bros.	Barenbrugs (NL)
Waldort	W.W. Johnson	Van der Have (NL)
Lirouge	Nickerson Seed Co.	D.S.V. (West Germany)
Lifalla	Nickerson Seed Co.	D.S.V. (West Germany)
Encota	Pope & Chapman	Van Englen (NL)
Checker	Nickerson Seed Co.	Oregon A.E.S. (USA)

7.9 BENT

Boral	Hursts	Weibulls (Sweden)
Highland	Most wholesalers	Oregan A.E.S. (USA)
Tracenta	Mommersteeg Seed Co.	Mommersteeg (NL)
Bardot	Goldsmith Bros.	Barenbrugs (NL)
Emerald (Creeping)	Hursts	Weibulls (Sweden)
Penncross (Creeping)	Most wholesalers	Pennsylvania A.E.S. (USA)
Enate	Pope & Chapman	Van Englen (NL)
Ligrette	Nickerson Seed Co.	D.S.V. (West Germany)

7.10 HARD FESCUE (Festuca Longifolia)

Variety	UK Agent	Breeder
Biljart	Mommersteeg Seed Co.	Mommersteeg (NL)

7.11 FINE LEAVED SHEEP'S FESCUE (Festuca Ovina Tenuifolia)

Novina	Mommersteeg Seed Co.	Mommersteeg (NL)
Livana	Nickerson Seed Co.	D.S.V. (West Germany)
Barok	Goldsmith Bros.	Barenbrugs (NL)

APPENDIX 8 THE SOIL MECHANICS ASPECTS OF THE STABILITY OF GRASS COVERED BANKS

by J.K. Picknett, Binnie & Partners

In order to assess the safety of floodbanks, various modes of failure must be considered. Erosion of the landward face by overtopping is only one of these.

Immediately after construction of a new floodbank, failures may occur, either to seawards or to landwards due to its own weight and the high pore pressures which have not been dissipated. Large settlements of the bank or the foundation material may render the bank inadequate even if failure does not occur.

Under flood conditions, failure may occur due to the hydrostatic water load on the front face, or by erosion of the front face of the bank by waves. Failure may also occur immediately after the flood subsides due to the pore pressures which have built up within the bank during the flood. Marsland (23) has drawn attention to a further danger to banks caused by the build-up of water pressures, due to high flood levels, in pervious layers underlying the bank.

When the flood level rises still further and overtopping of the bank commences, additional modes of failure become possible. Erosion of the landward face and the resistance of grass thereto (the subject of this publication) is one of the subjects to be considered. Slipping or slumping of the landward face, caused by seepage through the bank or by the filling of surface cracks in clay banks with water due to overtopping, is another mode of failure to which attention has been drawn, again by Marsland.

An excellent introduction to the modes of failure mentioned above is given in Reference 36.

The failure of clay floodbanks, under overtopping, due to surface cracking, is particularly relevant to the present study both because many floodbanks are built of clay and because the grass used to resist surface erosion may affect the surface cracking. All clays shrink and crack. Guidance on the potential shrinkage and danger of cracking, its effect on stability and measures to minimise the danger are outlined in the work by Marsland mentioned above. In the opinion of some, the use of deep-rooted grass to resist erosion may exacerbate the drying and shrinkage problem. On balance it would appear that well-maintained grass, kept short-cut and giving a good turf, provides the best covering on clay banks, although longer grasses could be used on silt banks with advantage, if properly maintained.

To conclude, it is important to realise that choosing the right grass cover is only one of the problems facing the designer of banks and other slopes subject to erosion from flowing water, and that the choice of grass and maintenance methods may indeed have an effect on other possible modes of failure.

APPENDIX 9 - SOURCES OF ADVICE ON GRASS

The British Association of Grain Feed Seed and Agricultural Merchants
4 Whitehall Court
LONDON SW1

British Association of Landscape Industries (UK)
18 Church Road
Great Bookham
SURREY

Horticultural Trades Association
Belmont House
18 Westcote Road
READING RG3 2DE
Berkshire

Institute of Park and Recreation Administration
The Grotto
Lower Basildon
READING RG8 9NE
Berkshire

Ministry of Agriculture, Fisheries and Food
Agricultural Development and Advisory Service
Great Westminster House
Horseferry Road,
LONDON SW1P 2AE ; and Regional Offices

National Institute of Agricultural Botany
CAMBRIDGE

National Playing Fields Association
57b Catherine Place
LONDON SW1E 6EY

Royal Horticultural Society
Horticultural Hall
Vincent Square
LONDON SW1 2PE

Sports Turf Research Institute
St. Ives Research Station
BINGLEY
Yorkshire

NOTE: There are many other institutes and organisations concerned with grassland, but the majority are interested only in agricultural crops for grazing, cereal, or animal feeds.

APPENDIX 10 INSTRUCTIONS FOR SEEDING OF GRASS AREAS

10.1 Introduction

The British Standard recommendations for seed and the seeding of grass areas are contained in British Standard 4428; 1969 (35). In certain circumstances the BSI recommendations may not be sufficiently detailed and a specification could usefully include some of the following items.

10.2 Seed selection

The seed mixture shall be selected according to the intended management and use of the area, taking into account the soil type, site conditions and climate.

The germination and purity of each constituent of the mixture shall conform to the EEC regulations now in force. These figures shall be related to the annual test commencing on 1 August each year and shall be considered valid for up to 14 months, covering supplies of seed in the following August and September.

Seeds shall be obtained at least 21 days before sowing and if required by the purchaser, samples shall be taken from the sealed bags after delivery with a Cambridge type seed sampler and tested for composition, purity and germination at an official seed testing station before sowing. Samples shall be taken from each bag of the consignment and mixed together to form a representative sample of at least 110g in weight.

A certificate shall be obtained from the seed merchant and submitted to the engineer showing:

origin of seed
purity of seed
percentage germination
date of harvest

for each of the varieties specified in the seed mix.

The seed shall be protected from damp and vermin until required. Any unused seed shall be either correctly stored or returned to the seed merchant until required on site.

10.3 Preparation of ground

Fallow period: During any fallow period the soil shall be kept free from weeds.

Final raking and harrowing: The surface shall be lightly and uniformly firmed and reduced to a fine tilth up to 25mm depth by raking and harrowing with spike and chain harrows.

All large stones (for general areas stones more than 50mm in any dimension) shall be removed. (Note: See alternative method under Sowing, below)

An appropriate pre-seed fertiliser to stimulate new growth shall be applied as instructed.

No seed shall be sown until the preparatory work and cultivations have been approved by the engineer or his representatives.

10.4 Sowing

Although in some areas and on some soils, sowing may be undertaken at all seasons providing a satisfactory tilth can be obtained, sowing from the end of July to mid October is recommended.

Note: Preparation and sowing can be carried out in one operation by machines such as the Lely Cultiseeder, Lely Buryvator and Brillion seeders.

Sowing shall be carried out in suitable calm weather conditions at a rate of $45g/m^2$ for small areas and lawns, and from 37.5kg to 125kg/ha for large areas where an efficient seed drill or distributor shall be used. The operation shall be carried out in equal sowings in transverse directions wherever possible.

After sowing, the ground shall be slightly raked or chain harrowed (except in the case of the Lely or Brillion seeders).

For seeding on steep banks and other inaccessible areas where normal seeding operations are not practicable, consideration shall be given to the use of hydroseeding process or the control of erosion by bitumen emulsions, latex or similar products.

Where fallowing has not been possible, a pre-emergent weed killer may be applied after sowing in accordance with the manufacturer's instructions.

Germination: Should the seed fail for any reason whatsoever, the contractor shall make good at his own expense the soiling and repeat the seeding until a satisfactory sward is obtained.

Grass areas are only accepted as reaching practical completion when the germination has proved satisfactory and all weeds and stones have been removed to the approval of the engineer.

10.5 Initial cut

About 48 h prior to topping, large stones (more than 50mm in any dimension) shall be removed and all areas rolled with a light roller to firm the grass and press in any remaining stones.

When the grass is established between 40 and 75mm high, according to the mixture, it shall be topped with a rotary mower to leave between 25 and 50mm growth, and thus cutting and controlling weeds, coarser grasses and encouraging tillering. Where mowing without a box produces a swathe, this shall be spread evenly to prevent damage to the growing grass beneath. This applies particularly to grass cut during periods of dull or wet weather.

10.6 Maintenance and defects liability

Damage, failure or dying back of grass due to neglect of watering, especially for seeding other than normal seeding, shall be the responsibility of the contractor.

Any shrinkage below the specified levels during the contract or defects liability period shall be rectified at the contractor's expense.

The contractor is to exercise care in the use of rotovating, cultivating and mowing machines to reduce to a minimum the hazards of flying stones, bricks and other objects in the soil. All rotary mowing machines are to be fitted with safety guards to the approval of the engineer.

Standard forms of contract for the work described in the instructions given above are issued on request by the following organisations:

Institute of Landscape Architects

British Association of Landscape Industries

Spons' Landscape Handbook

Housing Development Note LF 1: 7.5: 9.5 issued by the Department of the Environment

TABLE 1 PERMISSIBLE VELOCITIES FOR CHANNELS LINED WITH VEGETATION (USA)

(from US Soil Conservation Service-Reference 2)

Cover	Slope range %	Permissible velocity ft/s: Erosion resistant soils	Permissible velocity ft/s: Easily broded soils
Centipede Grass Bermuda Grass, good turf kept mown	0 to 5 5 to 10 Over 10	9 8 7	7 6 5
Bermuda Grass	0 to 5 5 to 10 Over 10	8 7 6	6 5 4
Buffalo Grass Kentucky Bluegrass Smooth Brome Blue Grama	0 to 5 5 to 10 Over 10	7 6 5	5 4 3
Orchard Grass Redtop	0 to 5 5 to 10	5 4	4 3
Italian Ryegrass Common Lespedeza	(Do not use on slopes steeper than 1:10)		
Lespedeza Sericea Weeping Lovegrass Ischaeidum (Yellow Bluestem) Kudzu Alfalfa Crabgrass	0 to 5 (Do not use on slopes steeper 1:20, except for side-slopes in a combination channel)	3.5	2.5
Annuals, used on mild slopes Or as temporary protection until permanent covers are established	0 to 5 (Use on slopes steeper than 1:20 is not recommended)	3.5	2.5
Common Lespedeza Sudan Grass		5 5	

TABLE 2 PERMISSIBLE VELOCITIES FOR CHANNELS WITH VEGETATION (AUSTRALIA)
(after Queensland Soil Conservation Service-quoted in Reference 4)

Cover	Slope range %	Maximum permissible velocity (ft/s)	
		Erosion resistant soils	Easily eroded soils
Kikuyu	0 to 5	8	7
	5 to 10	8	7
	Over 10	8	7
African Star Grass	0 to 5	8	6
Couch Grass	5 to 10	7	5
Carpet Grass	Over 10	6	4
Rhodes Grass	0 to 5	7	5
	5 to 10	6	4
	Over 10	5	3
Native Grasses			
Rhodes Grass on 'Black' soil	0 to 5	5	4
Other Tussock Grasses			
Lucerne, Sudan Grass	0 to 5	3.5	2.5

TABLE 3 GENERAL GUIDE TO VEGETAL RETARDANCE CATEGORIES (after US Soil Conservation Service-Reference 1)

Stand	Average length	Retardance
Good	Longer than 30 in	A
	11 in to 24 in	B
	6 in to 10 in	C
	2 in to 6 in	D
	Less than 2 in	E
Fair	Longer than 30 in	B
	11 in to 24 in	C
	6 in to 10 in	D
	2 in to 6 in	D
	Less than 2 in	E

Note: Since the lengths of grass quoted in this Table are from an American source, figures have been kept in inches.

(See Appendix 3 for detailed information)

TABLE 4 - GRASS MIXTURES, ESTABLISHMENT AND MANAGEMENT FOR FRESHWATER SITUATIONS

Table 4.1 gives interim guidance on the grass mixtures and establishment procedures considered suitable for the principal freshwater locations described in the body of the report. The names of the bred varieties of the species listed, the breeders and suppliers are given in Appendix 7.

Table 4.2 indicates the management schedule appropriate for each location. As further research and experience is gained, these recommendations will be revised.

TABLE 4.1 GRASS MIXTURES AND ESTABLISHMENT

PRINCIPAL LOCATION	MANAGEMENT PRACTICE : AGRICULTURAL USE	
Floodbanks	a) Grazing, cattle and sheep	b) Hay/silage for cattle and sheep
	65% Perennial Ryegrass 15% Timothy 10% Creeping Red Fescue 10% Wild White Clover	60% Perennial Ryegrass 10% Timothy 10% Creeping Red Fescue 10% Smooth stalked meadow grass 10% Wild White Clover
	Sowing rate for both a) and b) 25kg/ha (10kg/acre) Fertiliser rate for both: 100/150 units NPK/ha (40/60 units/acre)	
Bywash Channels	65% Perennial Ryegrass 10% Smooth stalked meadow grass 15% Timothy 10% Wild White Clover Sowing rate: 25kg/ha (10kg/acre) Fertilise: 100/150 units NPK/ha (40/60 units/acre)	
Dam Spillways	60% Perennial Ryegrass 15% Smooth stalked meadow grass 15% Timothy 10% Wild White Clover Sow and Fertilise as Bywash Channels	

	MANAGEMENT PRACTICE : AMENITY USE		
Floodbanks	Hard Wear	Medium Wear	Light Wear
	40% Perennial Ryegrass 40% Smooth stalked meadow grass 20% Timothy	20% Perennial Ryegrass 50% Smooth stalked meadow grass 20% Creeping Red Fescue 10% Timothy	40% Smooth stalked meadow grass 20% Creeping Red Fescue 20% Chewing Fescue 10% Browntop Bent
	Sowing rate for all: 37/125kg/ha (15/50 kg/acre) (Std 33kg/acre) Fertilise for all : 100/150 units NPK/ha (40/60 units/acre)		
Bywash Channels	As Light Wear above		
Dam Spillways	As Light Wear above		

TABLE 4.1 (CONTINUED)

PRINCIPAL LOCATION	MANAGEMENT PRACTICE : LOW MAINTENANCE
Floodbanks	40% Perennial Rye Grass 25% Smooth Stalked Meadow Grass 35% Creeping Red Fescue
Bywash Channels	20% Smooth Stalked Rye Grass 70% Creeping Red Fescue 10% Browntop Bent
Dam Spillways	20% Smooth Stalked Meadow Grass 50% Creeping Red Fescue 20% Chewings Fescue 10% Browntop Bent
	Sowing rate : 37 to 125kg per ha (15 to 50kg per acre) Fertiliser rate : 100 to 150 units NPK per ha (40 to 60 units per acre)

NOTES :

1. All seed and fertiliser rates will need to be reviewed for each location dependent on the speed into use required and site conditions (i.e. poor conditions and immediate use requires high rates and vice versa).

2. Because of continuing farm practice, the sowing and fertiliser rates are also given in kg/acre.

3. Units of fertiliser refer to the number of pounds of active ingredients applied per acre, N = nitrogen, P = phosphate, K = potash, viz. 100/150 units NPK per hectare means 100 to 150 of each constituent per hectare. A soil analysis will show the exact requirement (e.g. 150N, 100P, 120K).

4. Mixtures are given in percentages by weight.

TABLE 4.2 MANAGEMENT SCHEDULE

	Dam Spillways	Bywash Channels	Flood Banks
Access	Generally poor, usually pedestrian machinery only	Average/poor pedestrian or tractor mounted	Generally good as adjacent to or part of meadow land
Use	Normally none, Possible amenity or agricultural	Normally none except when adjacent to meadow land then agricultural or amenity	Agricultural or amenity
Management	Normally low maintenance, flail mower with or without chemicals	As for dam spillways or sheep/cattle grazing, dependent on slopes or light amenity	Generally sheep grazing or amenity or conservation. Light, medium and hard wear
Turf Requirement	Dense compact sward, capable of withstanding over topping	As for dam spillways, with grazing add Perennial Ryegrass for food value	As for bywash channels, with greater emphasis on herbage value
MAINTENANCE MACHINERY			
Hand-propelled rotary	recommended	possible	unlikely
Self propelled rotary or reciprocating knife	recommended	recommended	possible
Tractor drawn/ self-driven rotary flail	unlikely/possible	probable	recommended
Tractor drawn/ driven rotary/ flail/reciprocating knife	unlikely	possible	recommended

CHEMICALS (see item 2 of Bibliography)

Selective herbicides : used to eliminate weeds and improve the quality of the sward, usable in all situations

Growth retardants : especially effective in Northern UK, not for grazed areas

TABLE 5 GRASS MIXTURES FOR SEA BANKS

MANAGEMENT PRACTICE: AGRICULTURAL

Sheep Grazing

50% Perennial Rye Grass
20% Creeping Red Fescue
5% Creeping Bent
10% Smooth Stalked Meadow Grass
15% Chewings Fescue

Sowing rate: 25 kg per ha (10 kg per acre)
Fertiliser rate: 100/150 units NPK per ha (40/60 units NPK per acre)

MANAGEMENT PRACTICE: AMENITY

High Wear	Medium Wear	Light Wear
40% Perennial Rye Grass	15% Perennial Rye Grass	20% Chewings Fescue
20% Smooth Stalked Meadow Grass	30% Smooth Stalked Meadow Grass	50% Creeping Red Fescue
20% Creeping Bent	40% Creeping Red Fescue	20% Creeping Bent
20% Creeping Red Fescue	15% Creeping Bent	10% Browntop Bent

Sowing rate: 37/125 kg per ha (15/50 kg per acre)
Fertiliser rate: 100/150 units NPK per ha (40/60 units per acre)
These rates apply to Hard, Medium and Light Wear areas.

MANAGEMENT PRACTICE: LOW MAINTENANCE

60% Creeping Red Fescue
20% Hard Fescue
20% Creeping Bent

Sowing rate: 37/125 kg per ha (15/50 kg per acre)
Fertiliser rate: 100/150 units NPK per ha (40/60 units per acre)

NOTES:

1. All seed and fertiliser rates need to be reviewed for each site as they depend on the speed into use and site conditions. (i.e. for immediate use and poor site conditions high rates apply and vice versa).

2. Because of continuing farming practice, the sowing and fertiliser rates are also given in kg per acre.

3. Units of fertiliser refer to the number of pounds of active ingredients applied per acre, N = nitrogen, P = phosphate, K = potash, viz. 100/150 units NPK per hectare means 100 to 150 of each constituent per hectare. A soil analysis will show the exact requirement (i.e. 150N, 100P, 120K).

4. Mixtures are given in percentages by weight.

TABLE 6 LOCATION OF TEST MIXTURES IN SITE TRIALS

Site (2)	Mixture Type: Agricultural Mixture (AG)				Amenity Mixture (AM)				Low Maintenance (LM)		River Authority Mixture (RA)					Special Mixture (1)
	1	2	3	4	1	2	3	4	1	2	1	2	3	4	5	E
Rothwell	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Holton-Le-Clay	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Strathclyde		+	+	+	+		+	+	+	+	+	+	+	+	+	
Milton Keynes					+	+	+		+	+						+
Lincs. R.A.	+	+	+		+	+	+	+	+	+						
Trent R.A.	+	+	+	+	+	+	+	+	+	+						
Severn R.A.	+	+	+	+												

NOTES: (1) Special Mixtures specified by Milton Keynes Development Corporation and by J D & D M Watson, Consulting Engineers

(2) Designations were those correct in 1972/3.

TABLE 7 GRASSES : Common & Latin names

The table lists the main grasses, herbs and legumes in use for hydraulic purposes in various parts of the workld with their latin names and where applicable the names in common usage in other areas.

Common English name Latin name Foreign name

Common English name Latin name Foreign name

Common English name	Latin name	Foreign name
Marrum grass	Ammophilia Arenaria	
Couch (Twitch)	Agropyron Repens	
Sea Couch (Twitch)	Agropyron Pungens	
Creeping Bent	Agrostis Stolonifera	
Common Bent (Browntop Bent)	Agrostis Tenuis	
Crested Dogstail	Cynosurus Cristatus	
Cocksfoot	Dactylis Glomerata	Orchard Grass (USA)
Hard Fescue	Festuca Longifolia	
Chewings Fescue	Festuca Rubra Commutata	
Creeping Red Fescue	Festuca Rubra Rubra	
Plicate Sweet Grass	Glycaria Plicata	
Italian Rye Grass	Lolium Multiflorum	
Westerwolds Ryegrass	Lolium Westerwoldium	
Perennial Ryegrass	Lolium Perenne	
Timothy	Phleum Pratense	
Smooth Stalked Meadow Grass	Poa Pratense	Kentucky Blue Grass (USA)
Rough Stalked Meadow Grass	Poa Trivialis	
Reed Canary Grass	Phlaris Arundinacea	Reed Canary Grass (USA)
Common Saltmarsh Grass	Puccinellia Maritima	
Tussock Grass	Deschampsia Cespitosa	
Cord Grass	Spartina Anglica	
Wild White Clover	Trifolium Repens	
Suckling Clover	Trifolium Dubium	
Birds Foot Trefoil	Lotus Corniculatus	
Yarrow	Achillea Millefolium	
	Agropyron Smithii	Western Wheatgrass
	Andropogen Ischaemum	Yellow Bluestem (USA)
Red Top	Agrostis Alba	Red Top (USA)
Smooth Brome	Bromus Racemosus	Smooth Brome (USA)
Hairy Finger Grass	Digitaria Sanguinalis	Crabgrass (USA)
	Eragrostis Curvula	Weeping Lovegrass (USA)

TABLE 7 (CONT'D)

Common English name		
	Eremochloa Ophiuroides	Centipede grass (USA)
	Lespedeza Cuneata	Lespedeza grass (USA)
	Lespedeza Striata	Common Lespedeza
	Paspalum Dilatatum	Dallis grass (USA)
	Sorghum Vulgura Sudanense	Sudan grass (Africa)
	Buchloe Dactyloides	Buffalo grass (USA)
	Calamovilfa Longifolia	Prairie Sand Reed (USA)
	Chloris Gayana	Rhodes grass (Australia)
Bermuda Grass	Cynodon Dactylon	African Star grass (Africa)
	Dycanthium Sericeum	Queensland Blue grass (AUST)
Rye grasses	Lolium Species	Wimera Ryegrass (Aust)
	Pennisetium Clandestinum	Kikuyu grass (Africa)
	Phlaris Tuberosa	Hardinggrass (Aust & Africa)
	Cenchrus Ciliaris	Buffelgrass (S.Africa)
	Digitaria Species	Slenderstem Digitgrass (S. (S. Africa)
	Eleusine Species	Crabgrasses (S.Africa)
	Hyparrhenia Hirta	
	Paspalum Notatum	Bahia grass (Aust & Africa)

TABLE 8 - GRASS SPECIFICATIONS, USE AND MANAGEMENT PRACTICE - UK AUTHORITIES

Authority * (Consultant) 1	Area of Use 2	Grass Mixture 3	Sowing Rate 4	Management Specification 5	Establishment Practice 6	Hydraulic Features 7	Comments 8
AVON & DORSET RA	River floodbanks	48% Perennial Ryegrass S23 48% Italian Ryegrass 4% Wild White Clover					This mixture is not used on peat
BRISTOL AVON RA	Floodbanks bywash channels			Cut once per year, twice if possible	No topsoil used. Seed preferred to turf. Standard fertilizers		
BRITISH WATERWAYS BOARD	Canal banks Emergency spillways	No specific policy					Sheet piling driven to support seeping banks
CORNWALL RA	Floodbanks	50% N.Z. Perennial Ryegrass (Ruanui) 25% Italian Ryegrass (Danish 486) 25% Red Fescue (Brit.Cert. 559)		Cut twice per year	Tar sprayed if so:' is very non-cohesive		Area climate promotes a good growth at any time of year
	Seabanks	50% N.Z. Perennial Ryegrass (Ruanui) 25% Canadian Meadow Fescue 25% Canadian Timothy		Cut twice per year			
DEVON RA	Bywash Channels	53% Perennial Ryegrass S23 18% Red Fescue 9% Smooth Stalked Meadow Grass 11% Crested Dogstail 9% White Clover S100	3100kg/ha (1oz/yd^2)	Cut six times per year (Haytor Bankrider rotary cutter slopes 1:3) Cuttings left on banks		Flow velocities up to 1.5m/s (5ft/s) in places. Immersion up to 10 days with no harmful effect	
DEPT. OF AGRICULTURE AND FISHERIES FOR SCOTLAND	Floodbanks	43% Perennial Ryegrass 29% Cocksfoot 14% Italian Ryegrass 11% Chewings Fescue 5% Yarrow	38.5kg/ha (35lb/acre) raised to 55kg/ha (55lb/acre) if the soil is poor	Grazing by sheep	Turf on riverside held down with pegged netting. (Expensive) When seeding: Topsoil as required. Initial protections used; Hessian netting, Unisol, singly or together. Hydroseeding also employed.	Slopes 1:1.5 to 1:3	Unisol distinctly speeds up germination of establishment (for a fuller account refer to CIRIA library)

* Designations were those correct in 1972/3

TABLE 8 (Cont'd)

1	2	3	4	5	6	7	8
ESSEX RA	Seabanks	Irish Perennial Ryegrass Grade A Red Fescue or Perennial Ryegrass S.23 or Irish Perennial Ryegrass Grade A as an initial cover before establishment of indigenous Couch		Grazing by sheep (recommended). Cut for hay once or twice per year. Chemical methods tried but not very successful	Fertiliser not normally used	Old banks: Crest 1.2m Slope 1:1.5 New banks: Crest 1.8m Slope 1:2 or 1:2.5	(See Appendix 3) No maintenance resulted in rank grass and bare patches. Grass kept short to minimise fissuring of clay banks
	Floodbanks	20% Perennial Ryegrass (Dan. cert.) 20% Perennial Ryegrass S23 13.5% Meadow Fescue S53 13.5% Meadow Fescue S215 10% Canadian Timothy 10% Timothy S48 8% Red Clover - late flowering 5% White Clover, Kersey	33kg/ha (30lb/acre)				
LEE CONSERVANCY CATCHMENT BOARD	Bywash channels	50% Perennial Ryegrass 20% Italian Ryegrass 10% Broad leaved red clover 20% Giant trefoil clover	22kg/ha (20lb/acre)		Hydraulic seeding employed with bitumen emulsion spray		Initial protection gave high percentage of germination in 2 months. Well established in 6 months
LINCOLNSHIRE RA	Tidal banks	67% Evergreen Perennial Ryegrass 13% Red Fescue S.59 20% Agrostis from White Clover	44kg/ha (40lb/acre)	Grazing by sheep only or cut once per year	Raked to a fine tilth and fertilised (Fisons No. 33) at 375kg/ha (3cwt/acre) 1 wk before sowing		
	Floodbanks	43.5% Perennial Ryegrass (N.Z. cert.) 43.5% Perennial Ryegrass (S.23 or Melle pasture strain) 13% White Clover (N.Z.cert.)	33kg/ha (30lb/acre)	Grazing by sheep and cattle	As above: Fertiliser, Fisons 'High N62' (20:10:10), or similar, at 250kg/ha (2cwts/acre)		
MILTON KEYNES DEVELOPMENT CORPORATION (Consultants: J D & D M Watson)	Reservoir margins and other areas liable to flooding	<u>Mixture E</u> 80% Creeping Bent 10% Rough stalked meadow grass 10% S.48 Timothy <u>Mixture D</u> 50% S.23 Perennial Ryegrass 20% Creeping Red Fescue 10% Smooth stalked meadow grass 10% Oregon Browntop 5% Crested Dogstail 5% Kent or English Wild White Clover		Amenity	Topsoil 150mm free of stones. Fertiliser: 150:50:50 NPK Lightly rolled. Sloping areas covered with 25mm of sand after sowing & spraying with bitumen emulsion. Further sand applied after bitumen was broken.		
	Emergency spillways	Trial mixtures					Trials carried out on Brick kiln dam spillway

TABLE 8 (Cont'd)

1	2	3	4	5	6	7	8
NORTHUMBRIAN RA	Floodbanks	89% Perennial Ryegrass (Dan.Cert. Presto Pajbjerg) or Irish Leafy Perennial Ryegrass 4.5% Timothy (Can.Cert. Drummond or Swedish Omnia) 4.5% Timothy S.48 2% English Wild White Clover		Northern area: Grazed or cut once a year manually. Southern area: Cut twice a year with Lupat trimmer		Northern area: Crest 2m Slope 1:1.5 Southern area: Crest 3m	
SEVERN RA	Floodbanks	78% Perennial Ryegrass S.23 16% Timothy S.50 or S.48 3% Wild White Clover S.184 3% N.Z. Mother White Clover	35kg/ha (32lb/acre)	Cattle grazing or cut twice per year		Crest 2.5m, slope 1:5 wherever possible	Mixture specified by Grasslands office, Min. of Ag. Fish & Food
SOMERSET RA	Floodbanks spillways	15% Dutch Westernwolth 23% Meadow Fescue S.215 23% Canadian Hay Meadow Fescue 11.5% Timothy S.48 11.5% Timothy Swedish Omnia 8% Canadian Alsike 4% Mother White Clover 2% Clover S.184 2% Australian/Palestine Strawberry Clover	28.5kg/ha (26lb/acre) river banks 55kg/ha (50lb/acre) spillways		Cold emulsion sprays with peat and grass sand mixtures have proved very successful	Good protection up to flow velocities of 2.4m/s (8ft/s). Wherever possible slopes no steeper than 1:4	Various unspecified grass mixtures are used on seabanks. Saltings are naturally colonised by Creeping Red Fescue
SUSSEX RA	Floodbanks	53% Perennial Ryegrass S.23 9% Meadow Fescue 6% Meadow Grass (smooth or rough stalked) 6% Creeping Red Fescue 6% N.Z. White Clover 20% Kentish Rye		Agricultural crop			Naturally occurring with Water Foxtail and Agrostis found on parts of river banks
COUNTY BOROUGH OF TEESSIDE-HEMLINGTON RESERVOIR (Consultants:Scott Wilson, Kirkpatrick & Partners)	Emergency spillway to balancing reservoir	10% Creeping Bent 5% Browntop 10% Chewings Fescue 45% Creeping Red Fescue 10% Hard Fescue 20% Timothy		An amenity area: Mowing to 100mm (4in) length two or three times a year		Spillway designed to take up to 5.5m/s(18ft/s) for 30min on a 25 yr flood. Backup protection by 'Grasscrete' perforated concrete, 150mm(6in) below surface	
TRENT RA	Floodbanks	55% Perennial Ryegrass 20% Timothy, American 10% Cocksfoot S.143 5% Cocksfoot, Danish 5% Rough stalked meadow grass 5% Crested Dogstail	3400kg/ha (1oz/yd²)	Grazing by cattle and sheep or cut every 2 wks. (Cattle not allowed in wet or frosty weather)	Autumn sowing preferred. Fertiliser not required on tidal banks constructed of dredged silt. Otherwise Fisons PS5 fertiliser is used	Slopes 1:3	See Appendix 5
	Tidal banks	50% Perennial Ryegrass 25% Timothy S.50 10% Rough stalked meadow grass 10% Crested Dogstail 5% Wild White Clover	3400kg/ha (1oz/yd²)	Chemical growth retardants used but discontinued		Slopes: Riverside 1:2 Landward 1:2.5	

TABLE 8 (Cont'd)

1	2	3	4	5	6	7	8
USK RA	Tidal banks	50% Perennial Ryegrass (N.Z.Cert. Ruanui) 14% Timothy 11% Perennial Ryegrass S.23 11% Perennial Ryegrass S.24 11% Perennial Ryegrass S.321 3% Wild White Clover - Danish	31kg/ha (28lb/acre) up to 154kg/ha (140lb/acre) on exposed sites	Grazing by sheep or, less commonly, by cattle	Topsoiled if proportion of clay in bank is very high. Bitumen emulsion cover used successfully in exposed locations. Spring sowing preferred		(See Appendix 5)
WYE RA	Tidal banks	73% Perennial Ryegrass S.23 18% Timothy S.48 9% White Clover S.100	24kg/ha (22lb/acre)				Mixture suggested by M.A.F.F. (Newport)
	Floodbanks	6.5% Irish Ryegrass S.22 27% Perennial Ryegrass S.24 10% Perennial Ryegrass S.23 20% Perennial Ryegrass S.321 6.5% Timothy S.48 6.5% Timothy S.51 10% Perennial Ryegrass (Kent approved grade) 1% Wild White Clover (Kent approved grade) 6.5% Timothy (Swedish Svalof Omnia) 5% N.Z. Suia Mother White Clover 1% Danish Pajbjerg IV White Clover	33kg/ha (30lb/acre)	Grazing by cattle			Grass mixture known as West Midlands Farmer's Mix No.S33
YORKSHIRE RA	Overflow banks	21% Florin 28% Perennial Ryegrass (Scotch) 3% Crested Dogstail 7% Cocksfoot 7% Timothy 8% Meadow Fescue 4% Red Fescue 12% Rough stalked meadow grass 3% Kentucky Bluegrass 4% Wild White Clover 3% Sheeps Parsley	44kg/ha (40lb/acre)	Grazing or cutting		Grass lined spillways (downstream slope 1:5) used to fill flood storage areas	Mixture recommended from trials in 1942. (For a fuller account refer to CIRIA library)

TABLE 9 - GRASS SPECIFICATION, USE AND MANAGEMENT PRACTICE - OVERSEAS AUTHORITIES

Source 1	Area of Use 2	Grasses and Grass Mixtures 3	Sowing Rate 4	Management 5	Establishment 6	Hydraulic Features 7	Comments 8
RIJKSWATERSTAAT (Holland)	Floodbanks seabanks	36% Perennial Ryegrass 24% Smooth stalked meadow grass 16% Browntop 12% Creeping Red Fescue 12% White Clover					No distinction made between river banks and seabanks
INSTITUTE FOR RESEARCH ON VARIETIES OF FIELD CROPS (Holland)	Floodbanks	10% Browntop 20% Chewings Fescue 30% Creeping Red Fescue 40% Sheeps Fescue or Hard Fescue	60 to 100 kg/ha		For light soils		
		5% Browntop 35% Creeping Red Fescue 60% Smooth stalked meadow grass	60 to 100 kg/ha		For heavier soils		
		34% Perennial Ryegrass 34% Smooth stalked meadow grass 16% Creeping Red Fescue (little & short rhizomes) 8% Creeping Red Fescue (long rhizomes) 8% White Clover	60 kg/ha	For pastures and haymaking			
		7% Perennial Ryegrass 44% Smooth stalked meadow grass 28% Creeping Red Fescue (little & short rhizomes) 21% Creeping Red Fescue (long rhizomes)	70 kg/ha	For shorter mowing			All purpose
US DEPARTMENT OF AGRICULTURE (Soil Conservation Service)	Tidal banks	a) Smooth cordgrass (Spartina atterniflora) b) Sattmeadow cordgrass (Spartina patens Ait.Muhl.) c) Bermuda Grass d) Tall Fescue		Heavy fertilisation needed to maintain bank cover on c) and d)		a) and b) planted on 3:100 slope a) below mean high tide, b) between m.h.t. and bank of slope 1:3. c) planted on lower third of bank, d) on upper two thirds	10-year tests in Virginia. No mixtures - single species planted in strips to suit local conditions. For fuller details see Reference 40
	Bywash channels	<u>Generally recommended varieties, usually planted singly or with legumes</u>					
		Bermudagrass) Centipede grass)				)Sod forming.)Considered excel-)lent hydraulically	
		Kentucky Bluegrass		For organic matter			

TABLE 9 - (Cont'd)

1	2	3	4	5	6	7	8
US DEPARTEMENT OF AGRICULTURE (Soil Conservation Service) (Cont'd)	Bywash channels	Timothy) Redtop) Bromegrass)			For deep fertile soil		
		Chewings Fescue) Switch grass)		Switch grass provides good forage	Sandy soil or loamy fine sand		
		Prairie cord grass) Read Canary grass) Tall Fescue)			Wet soil		
		Wheat Grass			Wet saline areas	Not rhizomatic but suitable for gentle grades	
		Bluestem		Needs little maintenance	Low fertility soils	Sod forming	
WATER RESEARCH FOUNDATION OF AUSTRALIA AND WATER RESEARCH LABORATORY (University New South Wales)	Bywash channels Emergency spillways	Kikuyu African Star Grass Rhodes Grass				)Velocities as)high as 6m/s)tested	
SOUTHERN RHODESIA	Farm dams or emergency spillways	African Star Grass Tall Fescue			Generally poor soil	Slopes <1:100	Trickle flows cause damage to grass covers by creating runnels. Common practice to fit a trickle flow channel (say 150mm (6in) wide)
SOIL CONSERVATION RESEARCH DEMONSTRATION AND TRAINING (India)	Bywash channels	Recommended grasses in order of importance					
		Panicum repens			(Established by) (planting root) (stock. Grows in) (moist soil)		Stands flooding
		Brachiaria mutica			(Propagated by) (stem cuttings.) (Grows well in) (moist soil)		Stands prolonged flooding and water-logging
		Cynodon plectostachysus		Two weedings first year. Cut twice a year. Fertilised with 22kg/ha (20lb/acre) in alternate years. Grazing avoided during wet conditions	(Established by) (cuttings)	) Planted) February after) winter rain.) Mulched to) protect from) summer heat	
		Cynodon Dactylon			(Propagated by) (cuttings and) (rhizomes)		
		Paspalum notatum			(Established by) (seed and root) (stock. Medium) (textured soils)		Slow growing in first year

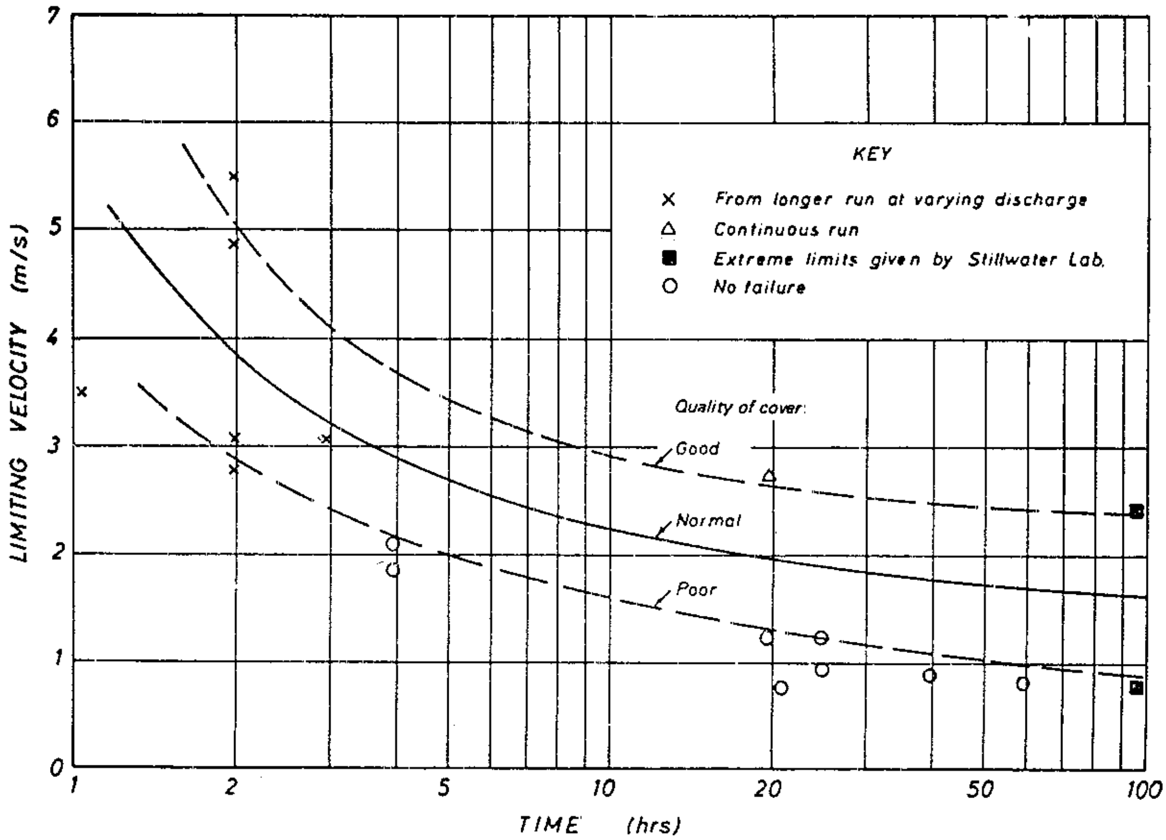

Figure 1 *Erosion resistance of grasses*

Note: *The letters by the curves refer to the retardance ranges*

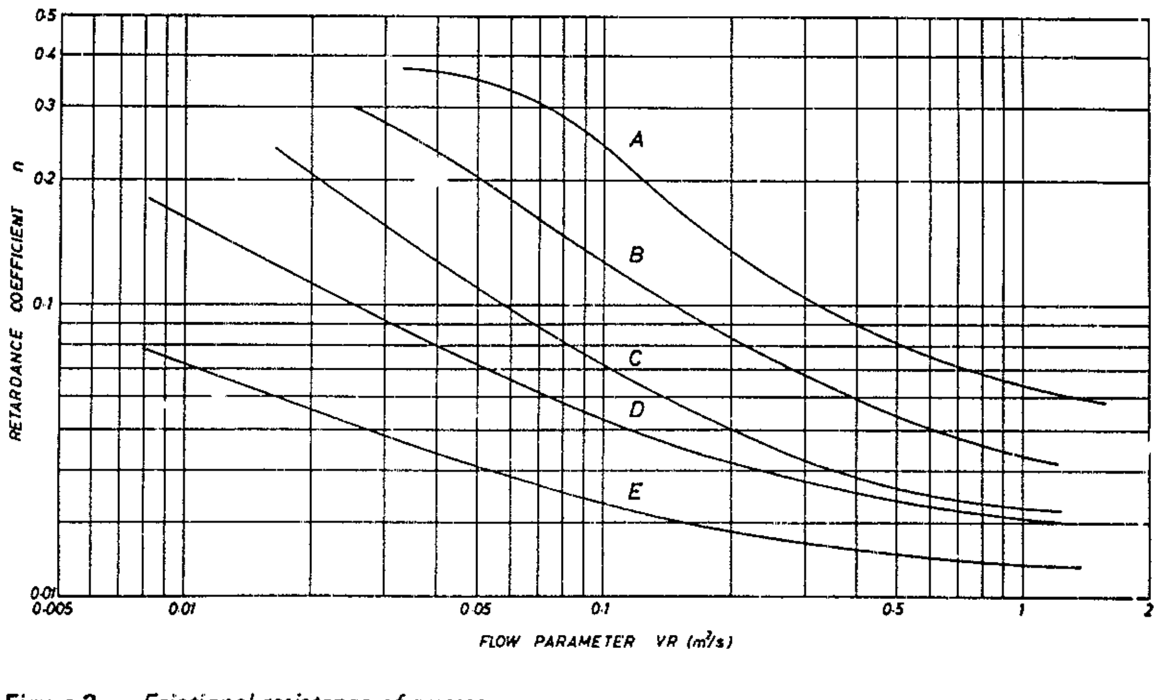

Figure 2 *Frictional resistance of grasses*

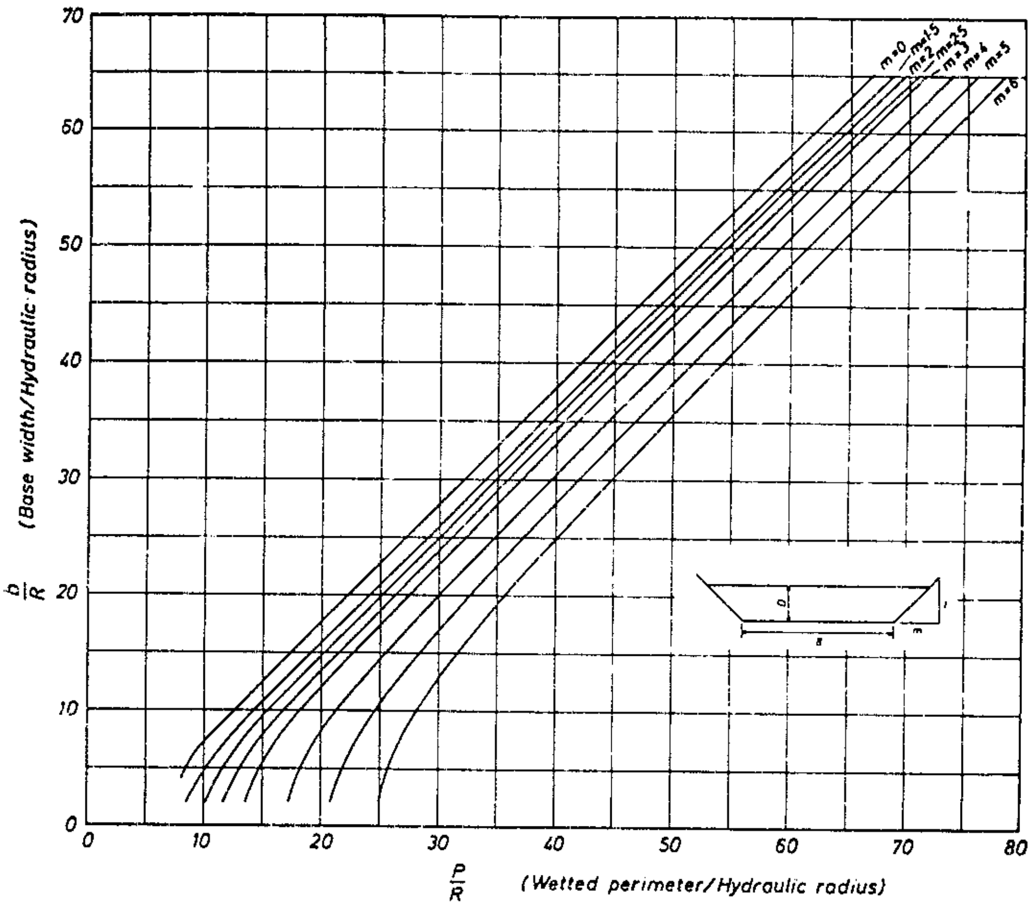

Figure 3 *Shape characteristics of channel cross-sections*

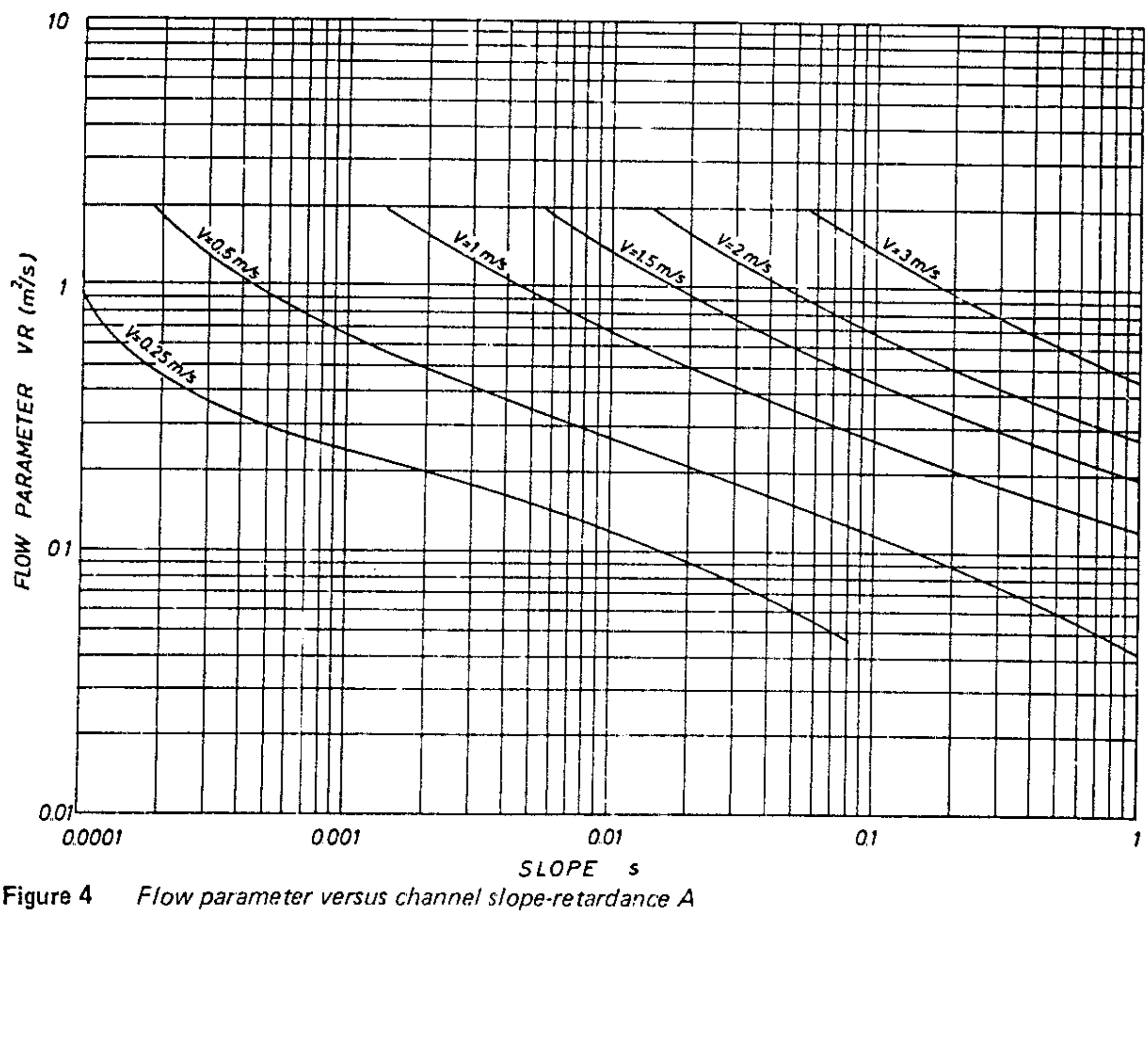

Figure 4 *Flow parameter versus channel slope-retardance A*

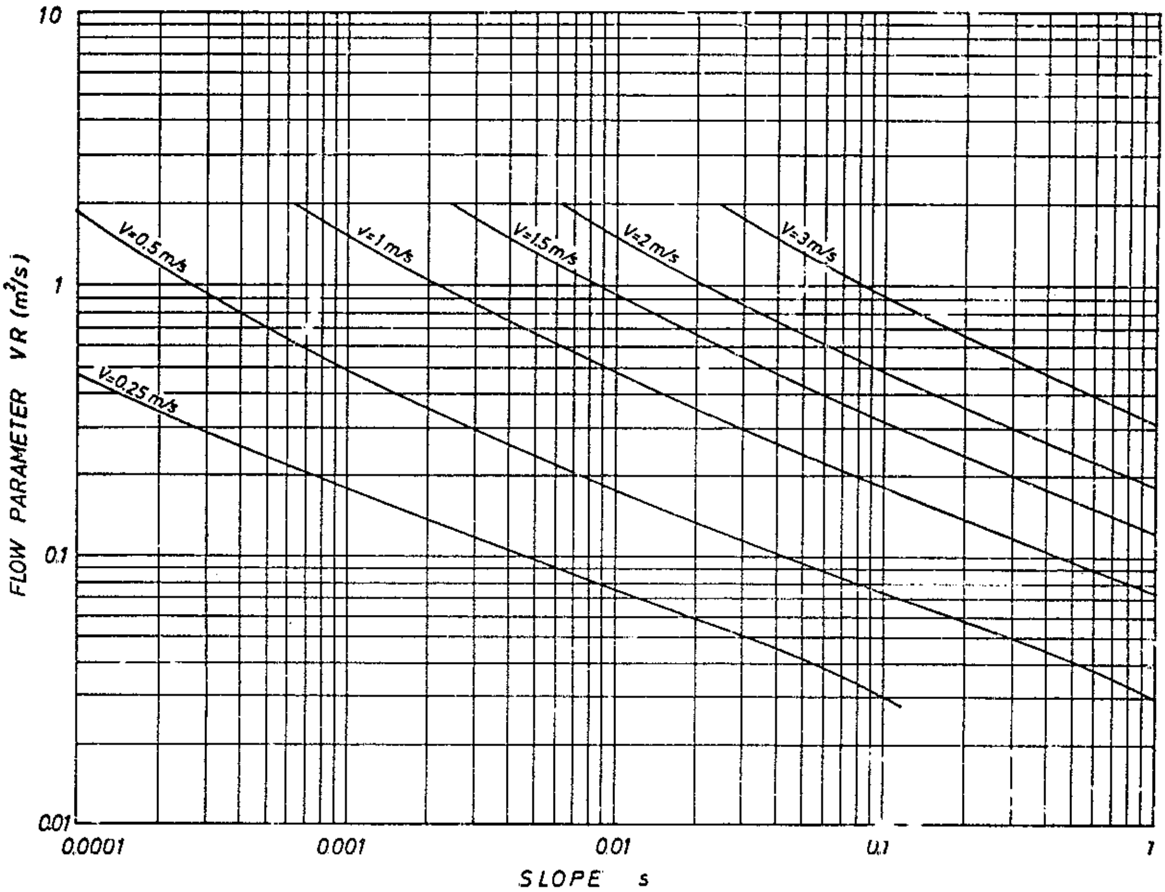

Figure 5 *Flow parameter versus channel slope-retardance B*

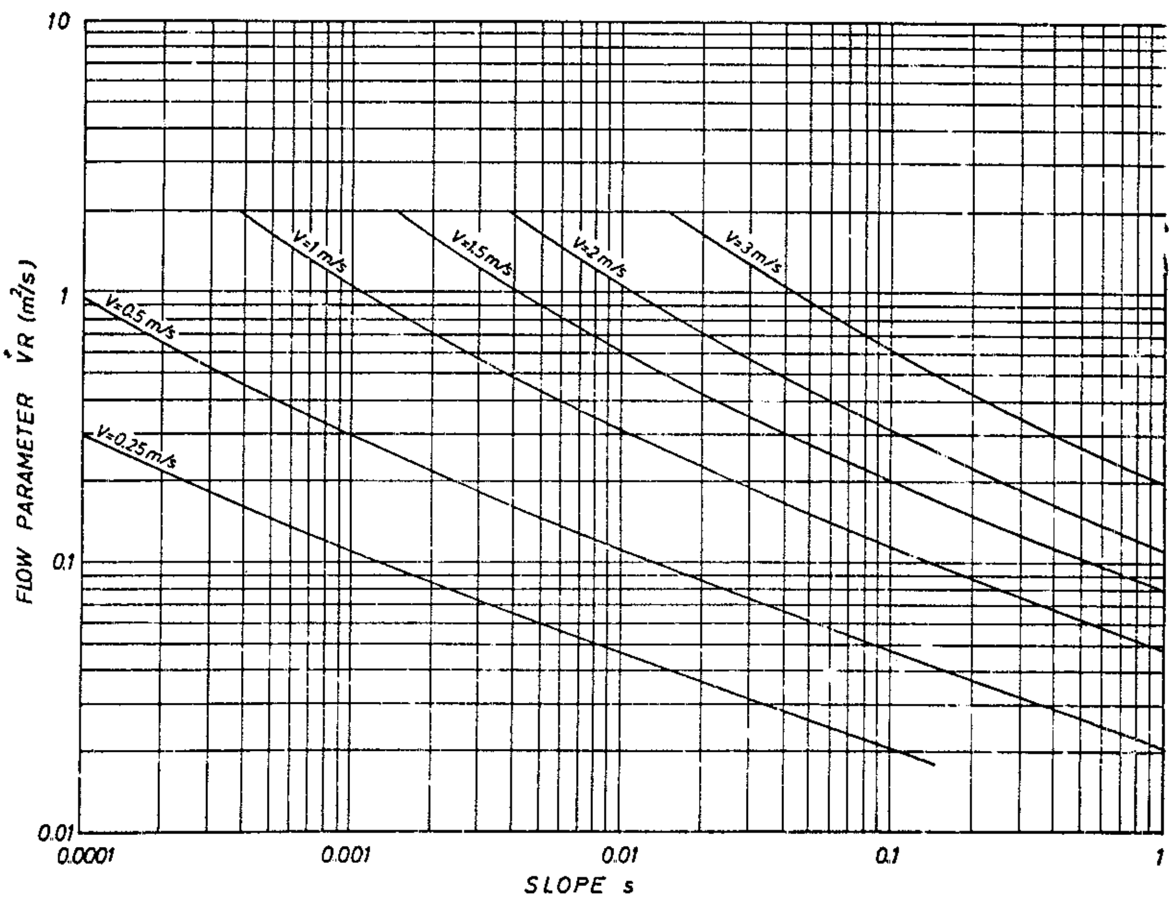

Figure 6 *Flow parameter versus channel slope-retardance C*

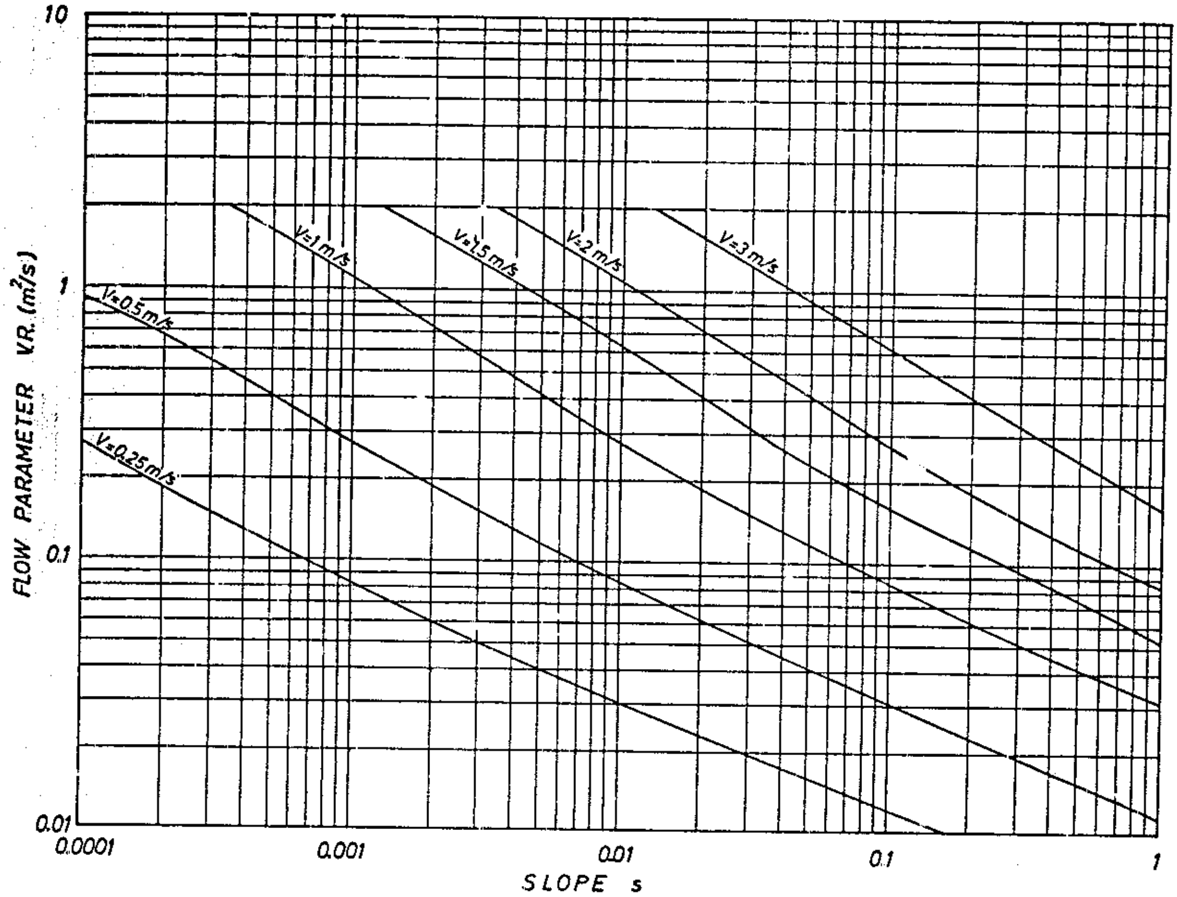

Figure 7 *Flow parameter versus channel slope-retardance D*

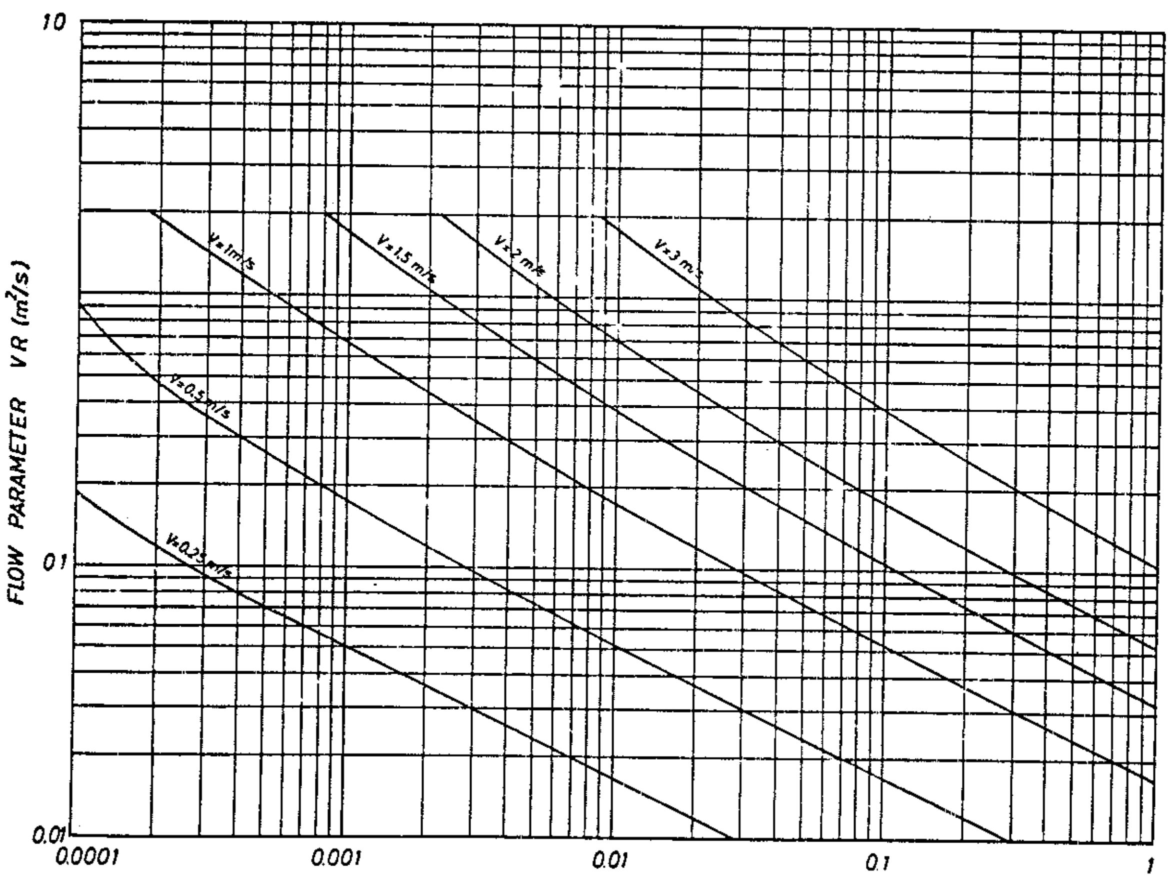

Figure 8 *Flow parameter versus channel slope-retardance E*