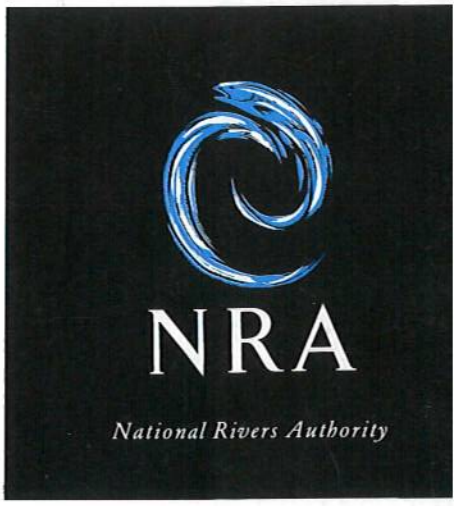
# River Maintenance Evaluation

Silsoe College, Cranfield University

R&D Note 456

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# River Maintenance Evaluation

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This document describes methods, results and conclusions of a study to evaluate the impacts of alternative river maintenance strategies on 12 main river sites in five NRA Regions. It is supported by a set of five Annexes (R&D 317/18-22/ST) and provides background information to the 'Guidelines for the Justification of River Maintenance'.

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# CONTENTS

**ACKNOWLEDGEMENTS**

**ABBREVIATIONS AND ACRONYMS**

**EXECUTIVE SUMMARY**

**1. INTRODUCTION** ..... 1

1.1 BACKGROUND ..... 1

1.2 AIMS AND OBJECTIVES ..... 1

1.3 PHASING OF THE STUDY ..... 3

1.4 REPORT STRUCTURE ..... 3

**2. RIVER MAINTENANCE** ..... 5

2.1 INSTITUTIONAL FRAMEWORK ..... 5

*2.1.1 The NRA* ..... 5

*2.1.2 New developments* ..... 5

*2.1.3 Environmental Agency* ..... 6

2.2 RIVER MANAGEMENT AND MAINTENANCE ..... 6

2.3 AQUATIC VEGETATION ..... 9

*2.3.1 Impact of maintenance on submerged vegetation* ..... 10

*2.3.2 Impact of maintenance on emergent vegetation* ..... 10

*2.3.3 Impact of maintenance on floating vegetation* ..... 10

*2.3.4 Aquatic vegetation and flow resistance* ..... 11

2.4 BANK VEGETATION ..... 11

2.5 TREE AND BUSH MAINTENANCE AND DEBRIS DAMS ..... 12

*2.5.1 Nature of debris dams* ..... 12

*2.5.2 Hydraulic impact of debris dams* ..... 12

2.6 SEDIMENTATION AND EROSION ..... 13

2.7 AGRICULTURAL LAND DRAINAGE ..... 14

*2.7.1 Benefits of land drainage* ..... 14

*2.7.2 Drainage benefit assessment methods* ..... 15

2.8 MAINTENANCE APPRAISAL ..... 17

2.9 ENVIRONMENT ..... 18

2.10 STUDY RATIONALE ..... 19

**3. DATA COLLECTION AND IMPACT ASSESSMENT METHODS** ..... 20

3.1 INTRODUCTION ..... 20

3.2 SITE SELECTION ..... 20
3.3 ENGINEERS' SURVEY ..... 22
3.4 DATA REQUIREMENTS AND COLLECTION METHODS ..... 37
*3.4.1 Baseline survey* ..... 37
*3.4.2 Hydraulic and hydrological data* ..... 37
*3.4.3 Agricultural data* ..... 38
*3.4.4 Lithological data* ..... 39
*3.4.5 Meteorological data* ..... 39
*3.4.6 Environmental data* ..... 39
3.5 IMPACT ASSESSMENT METHODS ..... 40
*3.5.1 Flooding impacts* ..... 40
*3.5.2 Groundwater and drainage impacts* ..... 41
*3.5.3 Morphological impact of maintenance* ..... 45
**Idealised model studies** ..... 45
*3.5.4 Agricultural benefit assessment* ..... 46
**Land drainage** ..... 46
**Flood damage costs** ..... 48
*3.5.5 Maintenance costs* ..... 49
*3.5.6 Scheme justification* ..... 49
*3.5.7 Environmental impact assessment* ..... 50
**Channel and bank category** ..... 51
**Wildlife quality** ..... 51
3.6 SUMMARY ..... 52
**4. RESULTS** ..... 53
4.1 ENGINEERS' SURVEY ..... 53
4.2 LAND USE AND FARMING PRACTICE ..... 56
4.3 DRAINAGE STATUS ..... 59
4.4 FLOOD RISK ..... 59
4.5 STATISTICAL ANALYSIS ..... 61
4.6 AQUATIC VEGETATION ..... 63
4.7 MORPHOLOGICAL IMPACT OF MAINTENANCE ..... 64
*4.7.1 River stability* ..... 64
*4.7.2 Timescale of morphological change* ..... 66
*4.7.3 Idealised model studies* ..... 67
**Widening and deepening** ..... 67
**Vegetation cutting** ..... 68
4.7 RIVER CORRIDOR SURVEYS ..... 69
4.8 ENVIRONMENTAL ASSESSMENT OF MAINTENANCE PRACTICES ..... 69

*4.8.1 Channel quality* ..... 69
*4.8.2 Bank quality* ..... 71
*4.8.3 Maintenance best environmental practice* ..... 72
4.9 BENEFIT ASSESSMENT AND SCHEME EVALUATION ..... 76
*4.9.1 Benefits* ..... 76
*4.9.2 Scheme evaluation* ..... 77
4.10 SUMMARY ..... 80
**5 GUIDELINES** ..... **81**
5.1 INTRODUCTION ..... 81
5.2 GUIDELINES FOR THE JUSTIFICATION OF RIVER MAINTENANCE ..... 81
*5.2.1 Use of guidelines for the justification of river maintenance* ..... 81
*5.2.2 Limitations to use* ..... 82
*5.2.3 Format of the guidelines for maintenance justification* ..... 83
5.3 GUIDELINES FOR DETERMINING BEST PRACTICE ..... 83
*5.3.1 Use of guidelines for determining best practice* ..... 84
*5.3.2 Limitations to use* ..... 84
*5.3.3 Format of the guidelines for determining best practice* ..... 84
5.4 CONCLUSION ..... 85
**6 CONCLUSIONS AND RECOMMENDATIONS** ..... **86**
6.1 SUMMARY ..... 86
6.2 CONCLUSIONS ..... 87
*6.2.1 General conclusions* ..... 87
*6.2.2 Research project management* ..... 87
*6.2.3 Assessment methods* ..... 88
*6.2.4 Maintenance evaluation results* ..... 89
6.3 RECOMMENDATIONS ..... 90
6.4 EPILOGUE ..... 92
**7 REFERENCES** ..... **93**

APPENDIX I RIVER MAINTENANCE ENGINEERS QUESTIONNAIRE
APPENDIX II BASELINE SURVEY QUESTIONNAIRE
APPENDIX III POST MAINTENANCE QUESTIONNAIRE
APPENDIX IV MANNING'S N ROUGHNESS COEFFICIENT
APPENDIX V WATERTABLE MODEL
APPENDIX VI MORPHOLOGICAL CHANGE AND MAINTENANCE IMPACT LONGEVITY
APPENDIX VII LONGEVITY OF MAINTENANCE IMPACTS
APPENDIX VIII RIVER CORRIDOR SURVEY

**LIST OF TABLES8**

Table 2.1 River maintenance methods ..... 8
Table 3.1 Site summary ..... 21
Table 3.2 Cross-section data and channel capacity - River Wensum ..... 41
Table 3.3 Field and channel data required by the watertable model ..... 42
Table 3.4 Drainage status and watertable depth ..... 43
Table 3.5 Drainage status for wet, average and dry seasons, with/without maintenance ..... 44
Table 3.6 Farming practice and performance by drainage status ..... 46
Table 3.7 Estimates of returns for wheat production ..... 47
Table 3.8 Example drainage status benefits attributable to maintenance ..... 47
Table 3.9 Estimated benefits of flood alleviation attributable to maintenance ..... 48
Table 3.10 Average annual maintenance benefits - River Wensum ..... 50
Table 3.11 Maintenance scheme appraisal: River Wensum ..... 50
Table 4.1 Reasons for river maintenance ..... 54
Table 4.2 Criteria for standards of service ..... 55
Table 4.3 Notification procedure ..... 56
Table 4.4 Sampled farms by scheme, farm size and type ..... 58
Table 4.5 Land use and drainage installation ..... 58
Table 4.6 Drainage status according to maintenance situation and climate ..... 60
Table 4.7 Flood risk with and without maintenance ..... 61
Table 4.8 Aquatic vegetation within the study reaches ..... 63
Table 4.9 River classification ..... 65
Table 4.10 Idealised channel parameters ..... 67
Table 4.11 Best practice for channel vegetation management ..... 73
Table 4.12 Best practice for bank vegetation management ..... 74
Table 4.13 Current and best practice channel maintenance ..... 75
Table 4.14 Current and best practice bank maintenance ..... 75
Table 4.15 Representative net returns according to drainage ..... 76
Table 4.16 Typical flood costs ..... 77
Table 4.17 Summary of total maintenance benefits ..... 78
Table 4.18 Summary of maintenance benefits ..... 78

**LIST OF FIGURES**

Figure 2.1 Influence of maintenance on flooding and land drainage ..... 7
Figure 2.2 Variables of maintenance benefit assessment ..... 8
Figure 4.1 River stability ..... 65

**LIST OF PLATES**

Plate 1 to 27 Representative photographs of the study sites ..... 23 - 36

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ADA | Association of Drainage Authorities |
| ASPT | Average Score Per Taxa |
| BA | Benefit Area |
| BMWP | Biological Monitoring Working Party |
| CC | Countryside Commission |
| DoE | Department of the Environment |
| EH | English Heritage |
| EN | English Nature |
| FAO | Food and Agricultural Organisation |
| FD | Flood Defence |
| FDMM | Flood Defence Management Manual |
| FRCN | Fisheries, Recreation, Conservation, Navigation |
| FSR | Flood Studies Report |
| HMIP | Her Majesties Inspectorate of Pollution |
| IDB | Internal Drainage Board |
| LUT | Land Use Type |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| NCC | Nature Conservancy Council |
| NERC | Natural Environment Research Council |
| NRA | National Rivers Authority |
| NVC | National Vegetation Classification |
| NWC | National Water Council |
| PAGN | Project Appraisal Guidance Notes |
| RCS | River Corridor Survey |
| REDS | River Environmental Database |
| RHS | River Habitat Survey |
| RIMS | River Information Maintenance System |
| RPI | Retail Price Index |

| | |
|---|---|
| RSPB | Royal Society for the Protection of Birds |
| SCADE | Silsoe College Agricultural Drainage Evaluation Model |
| SERCON | System for Evaluating Rivers for Conservation |
| SoS | Standards of Service |
| SSEW | Soil Survey of England and Wales (now Soil Survey and Land Research Centre (SSLRC)) |
| STWA | Severn Trent Water Authority |
| WO | Welsh Office |

| | |
|---|---|
| cms | centimetres |
| d/s | downstream |
| ha | hectares |
| kg | kilograms |
| N | nitrogen |
| km | kilometres |
| m | metres |
| m AOD | metres Above Ordnance Datum |
| mm | millimetres |
| 'n' | Manning's 'n' |
| SMD | Standard Man Days |
| t | tonnes |
| u/s | upstream |
| yr | year |

# EXECUTIVE SUMMARY

## Introduction

In January 1989, the National Rivers Authority (NRA) Severn Trent Region commissioned Silsoe College to undertake a three year study to monitor and evaluate the impact of maintenance on six of its main river sites. The study developed methods for the technical and economic appraisal of river maintenance. Subsequent to this, the study was extended to incorporate other NRA Regions, and further develop methods to help design, justify and prioritise maintenance activities. The study reported below involved the monitoring of 12 sites in five NRA Regions during the period March 1992 - October 1995, and the further development of guidelines for the management of the maintenance function.

## Study Aim

The broad aim of the study was to develop and verify methods and databases for the appraisal of river maintenance in rural, predominantly agricultural catchments. Specific objectives included:

- the development of guidelines to enable Flood Defence staff to justify and prioritise maintenance programmes; and,
- the production of guidelines to determine best environmental practice for river maintenance.

## River Maintenance

The main purpose of river maintenance in England and Wales is to provide standards of land drainage service relating to the control, within acceptable limits, of flooding and waterlogging on riparian, mainly agricultural land. The principal maintenance operations are desilting, weedcutting, grass cutting, tree and bush maintenance, debris removal, flood bank protection and repair of structures. The maintenance method selected is influenced by the nature of the watercourse, channel dimensions, flow characteristics, access for machinery, type of vegetation and the size of the operation to be completed.

These maintenance activities affect the Standard of Service (SoS) to riparian land users through the impact on channel hydraulics. Maintenance affects the ability of the river to retain flows of a given magnitude, and thereby the risk of flooding. Similarly, maintenance affects the outfall for field drainage, whether by natural movement of water through soils or assisted by underground pipes. Hence the link between maintenance and SoS.

Maintenance also affects environmental qualities, either directly through its impact on conditions within the channel, or indirectly through its impact on soil water regimes in the adjacent floodplain. There is a strong link between the hydraulic performance of a river and its environmental quality. The requirement to enhance or protect environmental quality has important consequences for the design and implementation of river maintenance activities. Best practice for river maintenance must attempt to reconcile the potential conflict between SoS and environmental quality.

## Data Collection and Impact Assessment Methods

The impacts of maintenance were assessed on 12 main river sites in five NRA Regions in England and Wales. These were the River Arrow, Dreneuydd/Broadway Reen and Dysynni Low Level Drain in Welsh Region, the Hilton Brook and River Sence in Severn Trent, the River Wampool and Pilling Water in North West, the Rivers Yare and Wensum and the Woldgrift Drain in Anglian, and the River Yarty and Sir Arthur's Pill (Braunton Marsh) in the South West.

The sites are representative of main rivers in each Region on which typical maintenance activities are performed. The schemes include seven meandering 'natural' rivers and five trapezoidal 'artificial' channels. Both deep and shallow, fast and slow flowing rivers are represented. Reach length ranged from 3 to 8.5 km and the benefit areas ranged in size from 46 ha to 1362 ha. Land use covers a range of grass and arable enterprises reflecting dominant farming systems in the area (mainly arable in the east and livestock in the west).

The following methods of data collection and analysis were engaged:

- a questionnaire survey of river engineers was carried out to determine the criteria for the design and justification for maintenance practices;

- repeat-visit interviews with farmers were carried out to determine land use, farming circumstances and practices, drainage conditions, flood risk, and perceptions about standards of drainage service;
- detailed assessments were made of site specific physical and hydrological features, namely soils, channel dimensions and drainage installations and networks;
- data on river water levels were collected from the study sites using data loggers, level recorders and gauge boards;
- river corridor surveys were carried out to determine environmental attributes and the impacts of maintenance activities; and,
- secondary data were collected with respect to farm business management and climatic conditions.

The impact of river maintenance on land drainage and flooding was assessed by comparing the hydraulic performance of the watercourse 'with' and 'without' maintenance and the consequences for land use, land users and environmental quality in the area deriving 'benefit' from maintenance.

The influence of river and ditch water levels on field drainage conditions was determined using a model developed at Silsoe College which predicts watertable depth in adjacent areas for given river levels, weather conditions and floodplain characteristics such as soil type and the extent of drainage systems. The model was run using river levels for the 'with' and 'without' maintenance situations in order to isolate the impact of maintenance on watertable levels and field drainage status.

Research literature and farm survey identified three classes of field drainage status (good, bad and very bad) according to the depth of the watertable relative to the soil surface. Drainage modelling was used to determine drainage class for specified site conditions for the 'with' and 'without' maintenance situations, and for different weather conditions namely wet, average and dry. Assessments were made of the productivity and monetary performance of agriculture under each drainage class. Drawing on historical weather data, these benefits were weighted by the relative frequency of the three types of weather conditions to derive an average,

expected annual benefit attributable to the maintenance activity. In this way it was possible to determine the added value attributable to maintenance under specified site and weather conditions.

A similar approach was adopted to estimate the benefits of flood alleviation associated with changes in maintenance standard. The change in average annual flood costs due to a change in flood risk associated with channel maintenance were determined.

HR Wallingford engaged modelling techniques to determine, for specified channel characteristics, the processes of sedimentation and erosion following weedcutting and desilting activities. This helped to determine the impact of river works on hydraulic performance, and the longevity of these impacts.

Benefit : cost analysis was carried out at individual scheme level by comparing the value-added attributable to maintenance with the costs of the maintenance activity over the life of the maintenance interval. The analysis used 1995/6 financial prices as received and paid by farmers in the market place, as well as economic prices which adjusted for government support to the farming sector.

With respect to environmental attributes, checklists of features associated with high wildlife quality of banks and channels were compiled. The sensitivity of these qualities to maintenance was determined and this provided a framework for determining best environmental practice.

## Results

The results of the study take two main forms: an evaluation of maintenance activities on the study sites; and, the formulation of guidelines for best practice.

### Evaluation on Study Sites

With respect to the former, the survey of River Engineers showed that most work was part of a routine maintenance programme based on custom and practice together with inspection of the watercourse. Maintenance was usually justified in terms of land drainage and flood alleviation. Landowners and interested parties were notified as to the extent and nature of work to be undertaken, although follow-up was limited.

The modelling of watertables showed that maintenance delivered improved standards of drainage service, although the extent of the benefit depends on seasonal weather conditions. For the study sites in total, in an average season, 77 % of the benefit area experienced good drainage conditions compared to 39 % without maintenance. In wet seasons, these statistics were 50 % and 31 % respectively. In wet seasons with maintenance, 12 % of the total area experienced very bad drainage conditions, whereas without maintenance, this was 26 %.

Generally, farmers indicated poorer drainage conditions than the model predicts in the absence of maintenance. Farmers considered that maintenance delivered good drainage conditions on 85 % of the area, compared to 30 % without maintenance. Responses may have been biased in order to secure future standards of service.

The analysis of maintenance on flood risk used a combination of farmer information on area flooded and modelled estimates of flood frequency. Overall, maintenance had the effect of reducing the area which floods 'more frequently than once per year' from 68 % to 54 %.

Morphological modelling examined the impact of maintenance on bankful discharge and water levels, both immediately after the operation and then with the passage of time. The results show by how much and for how long, deepening, widening and vegetation cutting provide benefits of reduced water depths and increased bankful discharge capacity. These estimates of longevity have been used to determine the return interval of maintenance activities in the Guidelines for the Justification of River Maintenance.

With respect to the Benefit : Cost analysis of the study sites, the modelled results generated average annual economic benefits per scheme of between £ 4 and £ 54/ha (overall average of £ 20/ha), depending on circumstances. In most cases, farmer assessment of average maintenance benefits were higher than modelled estimates, ranging from £ 9 to £ 112/ha in economic prices (average £ 33/ha). The use of financial prices placed average modelled benefits at £ 29/ha, and farmer based assessment at £ 47 /ha.

Maintenance activities involved weedcutting, desilting, grass cutting, tree and bush work and debris removal. Maintenance costs varied from £ 3 to £ 62/ha depending on the intensity of maintenance and the size of the benefit area. Average costs were £ 27/ha.

Using modelled results, for the assumptions made, the evaluation of scheme performance gave the following benefit : cost ratios for 16 cases (comprising 12 schemes and four variants which involved different assumptions about the type of benefits and costs in the assessment).

| Benefit : cost ratio Economic prices | Modelled results No. of cases | Farmer assessment No. of cases |
|---|---|---|
| > 1.00 | 7 | 9 |
| < 1.00 > 0.79 | 3 | 1 |
| < 0.80 > 0.59 | 2 | 1 |
| < 0.60 | 4 | 5 |

Given the inherent uncertainty of the evaluation methods, 10 of the 16 cases could be described as delivering economic benefits greater than or very near to the costs of provision. These results are variable but key factors emerge. The benefit : cost ratio is favourable where either benefits/ha are high due to high value land use which is sensitive to changes in standards of drainage service if maintenance is withdrawn, or average maintenance costs/ha are low because the work is spread over a relatively large benefit area. The best performing schemes have both these attributes.

**Guidelines for the Justification of Maintenance and Environmental Best Practice**

The output from this Study includes 'Guidelines for the Justification of River Maintenance'. Contained within this document (R&D Note 511) are guidelines for the justification of river maintenance schemes and guidelines for determining best practice vegetation management in channel and on banks.

The data bases and methods developed in the course of the study enabled the formulation of 'Guidelines for the Justification of River Maintenance'. These help users to determine and justify the appropriate maintenance regime in order to provide a particular SoS. The user is required to feed into a record sheet average channel parameters of the reach to be maintained. At each stage, if data are unknown, help, information and default values are provided. By progressing through the guidelines, the user is able to determine the impact of widening, deepening and removal of aquatic vegetation on channel capacity, flooding and standard of drainage service in the floodplain for the 'with' and 'without' maintenance situation. Tables

are provided which allow the user to determine the financial and economic benefits and costs of, and justification for, the maintenance regime.

The guidelines for determining maintenance best practice in channel and on bank, enable the best practice vegetation maintenance option in environmental terms to be determined on the basis of the environmental quality. They should be used in conjunction with the 'Guidelines for Justification of River Maintenance'.

Both the channel and bank environmental guidelines are based on a decision tree which works through the main factors which influence best environmental practice. The river is initially classified according to width and gradient. Each class is subsequently divided according to various factors including vegetational structure of the bed and bank and the floodplain community. Based on these classes, the channel and bank quality are determined. The guidelines are supported by check lists and a comprehensive set of photographs which illustrate river category, class and quality. Users are then able to determine the maintenance practices which protect or enhance environmental quality.

## Conclusions and Recommendations

The main conclusions of the study are that it is possible to formulate objective methods to guide decisions on river maintenance in a way which is compatible with the criteria of standards of service, economic rationality and environmental quality.

The evaluation of maintenance on 12 sites confirmed what was, in many respects known already, but not quantified. That is, the more intensive the land use, the better is the standard of field drainage (either due to piped underdrainage or freely draining soils), the greater is the sensitivity to standards of maintenance, and the greater the justification and scope for expenditure on river maintenance. The study used existing knowledge of river environmental management and interpreted this in the context of the river maintenance function.

The formulation of guidelines for the appraisal of river maintenance have been a material output from the research study. These now need to be further tested and demonstrated in practice.

# 1. INTRODUCTION

## 1.1 Background

One of the main purposes of river maintenance is to deliver a particular standard of land drainage service. In rural, mainly agricultural areas, this drainage function relates to the control of flooding and watertable levels on riparian, land within acceptable limits. Such maintenance procedures include aquatic vegetation removal, desilting and tree and bush management.

Organisations responsible for river maintenance are increasingly required to justify and prioritise their maintenance programme. The impact of river maintenance can be assessed by comparing the before and after maintenance conditions in the watercourse, and the effect on land-use, land-users and environmental features in the floodplain. In the case of agriculture, the benefits of river maintenance are the avoidance of losses due to flooding and waterlogging associated with a lower standard of service in the absence of maintenance.

In January 1989, the National Rivers Authority (NRA) Severn Trent Region commissioned Silsoe College to undertake a three year study within the NRA Severn Trent Region to evaluate river maintenance on six sites. The aims, methods, results and recommendations of this study have been presented in a series of reports to the NRA. This study led to an interest in the development and appraisal of river maintenance in other NRA Regions. The NRA subsequently commissioned Silsoe College to continue this study throughout five NRA Regions during the period 1992 - 1995. The study commenced in March 1992.

## 1.2 Aims and Objectives

The aim of this study is to develop and verify methods and databases which assess the benefits associated with alternative maintenance strategies in rural, predominantly agricultural catchments. Subsidiary objectives were:

- to determine the effect of different maintenance procedures on channel characteristics, in particular, freeboard and channel capacity;

- to examine through site monitoring the extent to which benefits vary according to the maintenance strategy, land use and farming practice;
- to design practical procedures for monitoring and evaluating river maintenance works in rural areas;
- to develop and validate guidelines and rural benefit assessment methods for inclusion in NRA systems for prioritising and justifying river and land drainage activities; and,
- to develop guidelines which enable Flood Defence (FD) staff to justify maintenance schemes.

Within the framework of the main study, two sub-contracts were set up to address recommendations arising from the earlier investigation. HR Wallingford Ltd. were commissioned to provide a methodology for predicting the effect of different river maintenance activities on the morphology and hydraulic performance of the river channel. The specific objectives were:

- to develop a broad typology of rivers;
- to predict sediment movement, deposition and erosion due to cross-sectional changes;
- to investigate the relationship between vegetation cutting and sedimentation using changes in channel roughness; and,
- to determine by means of an idealised channel model, changes in water depth and discharge capacity as a result of maintenance.

An environmental impact assessment of maintenance activities was carried out by Andrews Ward Associates and other Consultants under the guidance of Silsoe College. The objectives of this environmental impact assessment were to:

- assess the type and extent of potential short and long term impacts of river maintenance on
  - aquatic and bankside vegetation,
  - adjacent in-field natural vegetation,
  - aquatic invertebrates,
  - fisheries, and,
  - birds and mammals;

- produce guidelines to determine river vegetation maintenance best practice in environmental terms.

## 1.3 Phasing of the Study

The study consisted of three stages as described below :

Stage 1 involved setting up the study, identification of study sites and the baseline survey. This was completed in 1992. Interim Reports (R&D 306/1/ST, 306/4/ST and 317/8/ST present the results of the baseline survey.

Stage 2 consisted of on-going monitoring and evaluation of the study sites through repeated site visits during the period spring 1992 to spring 1995. Watertable modelling and impact assessment techniques were developed during Stage 1 and Stage 2. Preliminary results were presented in the Interim Reports R&D 317/11/ST and 317/13/ST. Stage 2 was completed in May 1995.

Stage 3 involved the analysis of survey results in order to meet the study objectives given in Section 1.2. During this stage, the 'Guidelines for the Justification of River Maintenance' were produced and tested by Flood Defence Managers and staff in various NRA Regions.

During Stage 1 and 2, HR Wallingford were sub-contracted by Silsoe College to produce information on the longevity of river maintenance activities within the study sites. Andrews Ward Associates, Alconbury Environmental Consultants and Silsoe College worked in consortium during Stage 2 and 3 to determine the impact of alternative maintenance activities on environmental quality of the river channel and banks and to identify best environmental practice for river maintenance.

## 1.4 Report Structure

This report summarises the objectives, methods, results and conclusions of the study.

Chapter Two defines the study topic and puts river maintenance evaluation in context. Chapter Three describes the data collection and impact assessment methods. Results are presented in Chapters Four and Five (detailed site reports are presented in the series of five Annexes). Conclusions and recommendations are presented in Chapter Six.

Throughout this R&D Note, reference is made to a series of Appendices which provide further information on data collection methods and to a set of five Annexes which provide detailed information on the individual study sites.

The study has produced guidelines for practitioners which are presented under separate cover as 'Guidelines for the Justification of River Maintenance' (R&D Note 511). Three sets of guidelines are contained within this document, namely:

Guidelines for the Justification of River Maintenance;
Guidelines for Determining Vegetation Management Best Practice in Channel; and,
Guidelines for Determining Vegetation Management Best Practice on Banks.

The guidelines for determining vegetation management best practice are supported by a report (R&D 317/16/ST Background Documentation) containing all the background information and details of methodology.

# 2. RIVER MAINTENANCE

This Chapter defines the purpose and practice of river maintenance in rural, mainly agricultural areas. The institutional framework of the industry is discussed. The impacts of aquatic and bank vegetation, trees and bushes and debris dams on channel hydraulics are outlined. The impact of maintenance on sedimentation and erosion is presented. Benefits of drainage for agriculture and maintenance scheme appraisal are discussed and the impacts of maintenance on the environment presented.

## 2.1 Institutional Framework

### 2.1.1 The NRA

The Water Act of 1989 resulted in the privatisation of the ten Regional Water Authorities and the development of the National Rivers Authority (NRA). The NRA is a single structure public body which is sponsored by the Department of the Environment (DoE) and has policy links with the Ministry of Agriculture, Fisheries and Food (MAFF) and the Welsh Office (WO). The statutory responsibilities and duties of this unitary organisation are to 'protect, improve and manage the water environment throughout England and Wales' (NRA, 1993).

Flood defence, land drainage and conservation are major duties of the NRA. Through the implementation of standards of service (SoS), a consistent approach to flood defence activities is being developed to provide appropriate levels of protection for different land use types (LUT's). Sections 16(1), 16(2) and 2(2) of the Water Resources Act 1991 state that the duty of the NRA is 'to promote the conservation and enhancement of the natural beauty and amenity of inland and coastal waters and of land associated with such waters'. Opportunities are increasingly being identified and taken to enhance the conservation value of the riparian zone whilst still maintaining the desired SoS.

### 2.1.2 New developments

Through commitment to the Citizen's Charter, public awareness is increasingly focused on the 'real world outcome' of the NRA's work. Money provided by the tax payers and industry must be seen to be used in a cost-effective manner whilst effecting a discernible improvement on the quality of the water environment. The NRA has recently undergone a period of structural

change. Through a division of each facet of the NRA into two sections; the Client and the Contractor, the aim is to improve efficiency by pursuing the principle of compulsory competitive tendering and creation of an internal market. At the same time it is recognised that the NRA must guarantee the provision of statutory minimum services.

### 2.1.3 Environmental Agency

In the summer of 1991, The Prime Minister announced plans to merge the NRA and Her Majesty's Inspectorate of Pollution (HMIP) to create a single environmental organisation whose responsibilities will cover land, air and water pollution control. The integration of all NRA functions with those of HMIP and Local Waste Regulatory Authorities will provide a basis for the new Environmental Agency. Dr Kevin Bond, (the then Director of Operations, NRA) has stated that within the duties of the Environmental Agency, flood defence will remain an important function; accounting for approximately 50 % of expenditure (ADA Gazette, Spring 1993). This Environmental Agency will come into affect from 1st April 1996.

## 2.2 River Management and Maintenance

Rivers are managed in order to meet the various demands which are placed upon them. These demands include flood defence and land drainage, control of water pollution and abstractions, conservation of the water environment, provision of recreation, fisheries and navigation facilities.

River maintenance is an essential form of management within many watercourses. The primary function of the river is to drain the land and the purpose of river maintenance is to "provide an acceptable level of flood protection [and land drainage service] through the adequate maintenance of channels and works, and their improvement where necessary" (Bailey, 1991).

The structural reorganisation of the NRA has resulted in the 'in house' workforce being exposed to competition from the private sector with a larger share of works executed by contractors. Thus the costs of each maintenance activity are more easily identified and there is greater pressure to demonstrate that these costs can be justified against the benefits obtained. The situation is complicated, however, by the need for NRA to retain a minimum workforce capability to meet emergency requirements in the event of major flood events but which can be engaged on routine maintenance duties at other times.

Maintenance influences the relationship between flows and levels in the river and drainage system. In rural, mainly agricultural areas, this relates to the control, within acceptable limits, of flooding and watertable levels (Figure 2.1). Maintenance affects the ability of the river to retain flows of a given magnitude, and thereby the risk of flooding. Similarly, maintenance affects the outfall for field drainage, whether by natural movement of water through soils or assisted by underground pipes.

Maintenance also affects environmental qualities, either directly through its impact on conditions within the channel, or indirectly through its impact on soil water regimes in the adjacent floodplain.

Figure 2.2 summarises the variables and relationships considered in the assessment of maintenance benefits. Resultant changes in drainage status due to river maintenance interact with farming systems to determine agricultural productivity benefits. Maintenance appraisal compares maintenance costs and benefits taking into account environmental factors.

The major types of river maintenance procedures are shown in Table 2.1. The maintenance method selected is governed by such factors as the nature of the watercourse, channel dimensions, flow, access for machinery and the size of the operation to be completed.

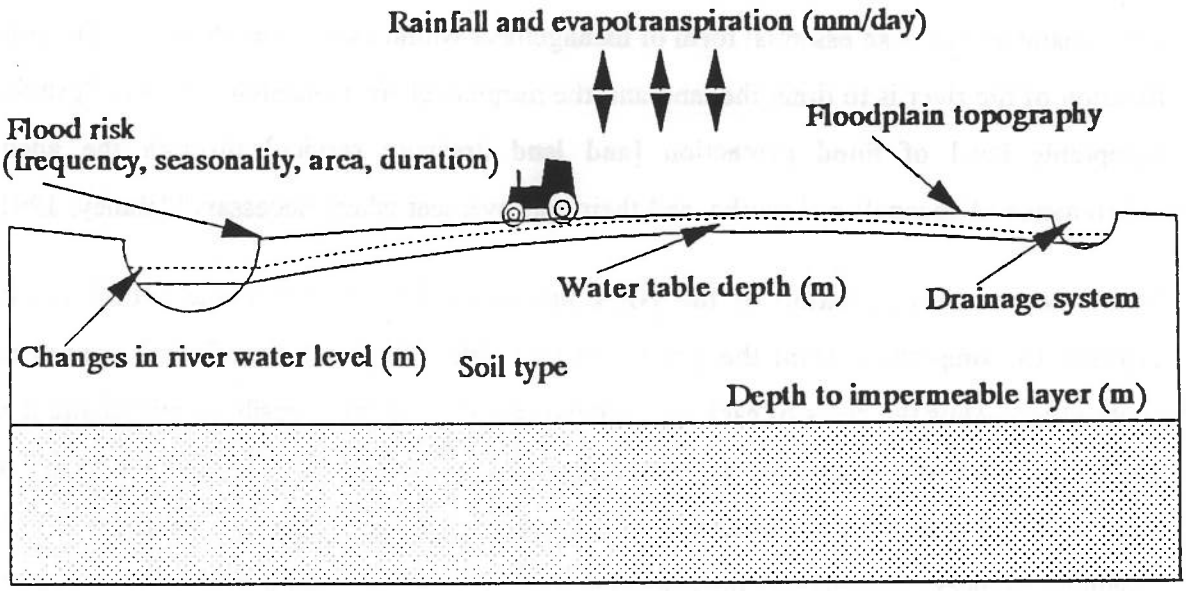



**Figure 2.1 Influence of maintenance on flooding and land drainage**

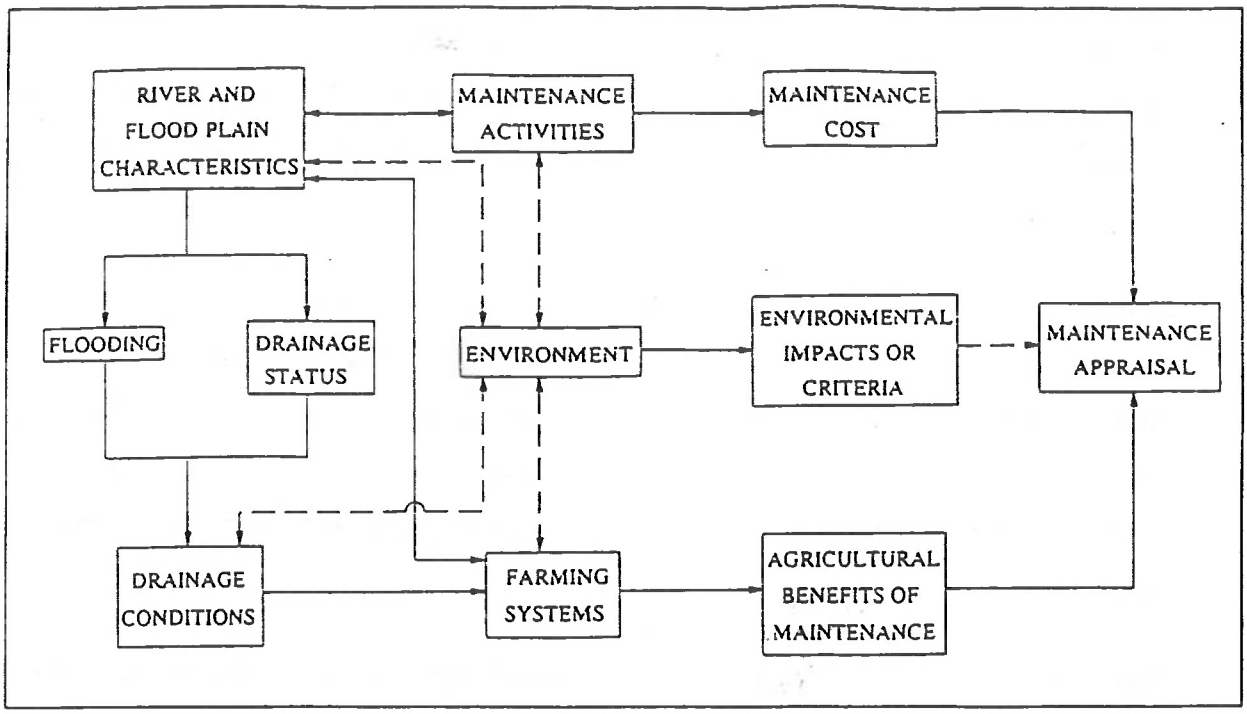



**Figure 2.2 Variables of maintenance benefit assessment**

**Table 2.1 River maintenance methods**

| | | |
|---|---|---|
| Dredging/desilting | - | Hydraulic excavator |
| | - | Dragline excavator |
| | - | Dredger |
| Vegetation clearance | - | Bradshaw Bucket |
| | - | Weed boat |
| | - | Hydraulic excavator |
| | - | Herbicides |
| | - | Hand cutting |
| Flail mowing | - | Bank side vegetation |
| Tree and bush | - | Removal of 'unsafe' and other branches which may impede river flows. |
| Debris and obstruction removal | | |
| River bank and flood bank protection | | |
| Environmental/ biological methods | - | Shading by trees and grazing of vegetation by Grass Carp. |

The main methods of aquatic vegetation regulation are mechanical, chemical and biological processes. Mechanical methods range from simple manual methods to the use of hydraulic excavators, Bradshaw Buckets and weed boats. Cut weed can be removed in a variety of ways. For example, a boom may be set up across the river to trap the floating debris. An excavator with a bucket attachment is then used to scoop out the cut vegetation as practised on the River Wensum.

Herbicides may provide an efficient cost-effective method of aquatic weed control. 'Total' herbicides eradicate all aquatic vegetation whilst 'specific' chemicals are used to target certain types and species of plants. The latter are ideal for localised spot treatment of individual plant communities or the pre-treatment of aquatic vegetation early in the growing season prior to mechanical removal at a later date. This procedure is a feature of river maintenance on the Pilling Water.

Biological methods of control include the grazing of vegetation by the Grass Carp. However, these fish display feeding preferences and feed only sparsely when subjected to cool and cold conditions. They are not native to Britain and do not breed in our watercourses. Other control methods such as the shading of watercourses through the planting of trees on the banks reduce vegetation growth, but this is a long term control method.

With greater importance placed on environmental criteria, river maintenance, in particular vegetation removal, is becoming an increasingly complex issue. Custom and practice are no longer sufficient rationale for river maintenance. Inspections of the watercourse and liaison with conservationists are resulting in less environmentally damaging forms of maintenance.

## 2.3 Aquatic Vegetation

Aquatic vegetation is an integral component of the riverine system. It can be termed a weed when its value becomes that of a nuisance and its distribution is such that it begins to interfere with the management aims of the watercourse. Vegetation has both hydraulic and environmental implications for the channel. Different types of aquatic vegetation respond to maintenance in different ways. Maintenance stimulates weed growth in some species and inhibits it in others. The maintenance regime must be selected according to the type of

vegetation present within the channel. Three types of aquatic vegetation are recognised. These are:

- emergent plants - broad-leaved and narrow-leaved species;
- submerged plants; and,
- floating plants.

The various types of aquatic vegetation respond to maintenance in different ways. The impact of maintenance and its effectiveness in controlling the dominant species of aquatic plants found within the study reaches are outlined below.

### 2.3.1 Impact of maintenance on submerged vegetation

The Pondweed (*Potamogeton*) is a rooted plant. Regular cutting stimulates regrowth of this vegetation. Desilting of the channel every few years is necessary in order to remove the roots from the channel sediments. The Canadian Pondweed reproduces through a system of rhizomes (underground stems). Unless the stems are removed from the hydrosoil, rapid regrowth will occur. A regular programme of desilting or removal using a Bradshaw Bucket, is required to control the Canadian Pondweed effectively.

### 2.3.2 Impact of maintenance on emergent vegetation

The Reed Sweet Grass (*Glyceria*) reproduces through a system of rhizomes. Regular cutting stimulates regrowth of this vegetation. Desilting of the channel or weed removal using a Bradshaw Bucket is necessary in order to remove the rhizomes from the channel bed and to provide effective control.

### 2.3.3 Impact of maintenance on floating vegetation

The Duckweed (*Lemna*) and Water Fern (*Azolla*) reproduce vegetatively and unless every fragment of this vegetation is removed from the channel, reproduction will occur and the weed will rapidly regrow. Chemical methods are most effective in controlling this vegetation. However, these plants do not affect channel capacity as they are free-floating plants and offer no resistance to flow. They can however, reduce water quality.

### 2.3.4 Aquatic vegetation and flow resistance

Vegetation within watercourses, particularly those in lowland areas, can cause major variations in flow resistance. Such increased vegetative resistance depends on the plant species, type and seasonal variation in biomass. The presence of vegetation may effect channel flow in a variety of ways such as these listed below. Vegetation may:

- reduce the flow velocity thus causing the level of water in the channel and watertable of the adjacent land to rise;
- cause a deterioration in land drainage status as the outfalls of artificial land drains become submerged and/or blocked;
- increase flood risk;
- encourage the deposition of suspended sediments;
- cause deflection of currents resulting in localised erosion; and,
- interfere with water users such as fisheries, navigation and recreation.

The effect of vegetation on water flow (flow resistance of aquatic plants) varies with water velocity due to the flexible nature of plant stems and leaves which may bend in the direction of flow. Growth of emergent and submerged aquatic plants can cause a progressive increase in the hydraulic resistance to flow.

Submerged plants with flexible stems offer little resistance to water movement at high flows as the force of water causes the weed to bend in the direction of flow. Effectively, the impact of submerged vegetation is drowned out at higher flows. Under lower flows, the stems act as a barrier to flow, slowing water movement and causing suspended fines to be deposited. Emergent plants offer greater resistance to flow than submerged weeds as they can create a fairly impermeable barrier to flow, depending on the density of vegetation stand. Floating vegetation poses little resistance to flow and does not reduce channel capacity.

## 2.4 Bank Vegetation

In effect, bank vegetation acts in a similar way to emergent vegetation. Un-cut vegetation can restrict the channel width and capacity. It can offer a high resistance to flow, especially at low flows. Under high flows, the impact of some bank vegetation on channel capacity may be

drowned out as the vegetation is flattened against the bank. Woody vegetation however, will not be flattened and will continue to present a barrier to flow.

Bank vegetation maintenance serves a variety of purposes. It keeps bank vegetation under control and prevents it from restricting capacity to an unacceptable level. Regular cutting of grass and herbs encourages root growth which in turn stabilises the channel bank. Cutting of the vegetation also allows the bank to be examined and if necessary, repairs can be made and vermin controlled.

## 2.5 Tree and Bush Maintenance and Debris Dams

Tree and bush maintenance is carried out as a preventative measure to minimise the probability of fallen timber accumulating and causing a blockage which may result in localised flooding, increased water level upstream of the debris dam, waterlogging and structural damage. Tree and bush maintenance in itself has minimal impact on channel friction and capacity. Such maintenance involves the removal of unstable limbs and low, overhanging branches if they pose a restriction to flow. Willows are pollarded and alders coppiced in order to protect and revitalise the tree population as well as to reduce the risks to the watercourse associated with decaying and fallen debris.

### 2.5.1 Nature of debris dams

Debris dams are accumulations of organic matter within the river channel. Such dams form when a piece of woody material such as a tree limb falls into the channel and lodges against boulders or protrusions from the bed or bank(s). Smaller pieces of debris are caught against the original piece of debris. These provide the framework in which leaves and other debris accumulate.

### 2.5.2 Hydraulic impact of debris dams

Unless removed, the accumulation of debris will form a dam and a barrier to flow causing the water upstream of the dam to 'back-up'. Ultimately, debris dams exert a resistance to flow and alter the roughness of the channel. Under low flows, when the water is shallow, irregularities in the dam are exposed and their effects more pronounced. The frictional drag exerted on the water is it crosses the dam reduces the flow and slows the passage of water over the blockage. Water levels are thus raised upstream of the debris dam due to this 'back-

up' effect. This may result in a localised increase in flooding and waterlogging as the watertable locally rises. Under higher flows, the frictional drag of the debris dam is drowned out and the dam exerts less influence over river flow.

In addition to their impact on watertables, debris dams which partially or completely block the channel may exert control over local channel morphology. In meandering streams such as the River Yarty, the formation of debris dams may result in local erosion and scour of the bed and banks around the dam. This may serve to widen the channel thus diverting flow around the blockage. Mid-channel bars may develop immediately downstream of the blockage due to reduced flow levels and flow velocity in the lee of the dam. Stream ecology may be influenced by the dam through the creation of temporary habitats for such wildlife as otters.

## 2.6 Sedimentation and Erosion

River maintenance or improvement works alter the sedimentation and erosion balance of the river and therefore can effect channel stability.

In their natural state rivers are often considered to be in a state of dynamic equilibrium (in regime) where the channel dimensions are determined by sediment supply and type and the frequency of discharge occurrence. When the capacity of a channel to transport sediment is changed due to river maintenance, areas of deposition and erosion may occur.

Most rivers can be placed into one of three categories: stable, dynamically stable and unstable. Stable channels have inert beds and banks with no significant scour or erosion. Their plan form and cross-sectional geometry changes very slowly, if at all with time, and even interference with the flow in the channel causes only local changes in channel geometry.

Dynamically stable channels continually scour and deposit material during times of moderate or high flows. Their cross-sectional shape does not change progressively, but their plan form does change as the channel migrates. Interference to the flow in the river, due to river maintenance, causes changes in channel geometry for some distance upstream and downstream. A meandering river is usually dynamically stable.

Unstable channels are less common in Britain than the other types. They are characterised by very high rates of erosion and bed material transport during floods, and the main channel can

shift to follow a different course during a flood. Rivers which are braided, that is, consisting of more than one channel separated by bars or islands which are mobile during floods, are usually unstable.

The regime characteristics of a river will determine the longevity of the impact of maintenance activities, especially of those which influence channel profile and gradient.

## 2.7 Agricultural Land Drainage

From the agricultural point of view, drainage improvement is necessary when soil wetness becomes a limitation to land use or productivity. Four conditions have been identified under which excessive soil moisture is a constraint to agricultural production (Morris et al. 1984). These are:

- fluvial flooding;
- seasonally or permanently high watertables due to high water levels in local watercourses (arterial drainage problem);
- temporary high watertables in soil due to slow rates of soil-water movement after heavy rain (field drainage problem); and,
- coastal flooding.

Poor drainage can reduce crop yields by retarding plant growth, physically damaging the crop and by delaying field operations such as drilling of the crop. Poor drainage can reduce the number of days on which the soil is fit for the travel of machinery and in the case of grassland, can increase the risk of poaching (surface damage by livestock) and shorten the grazing season.

### 2.7.1 Benefits of land drainage

The aim of agricultural land drainage is to remove the problems caused by waterlogging and flooding. The benefits of improved land drainage are substantial. They are the converse of the detrimental impacts of poor drainage referred to in Section 2.7. Improved drainage provides a better growing environment, reduces the risk of crop damage and improves the trafficability and workability of the soils. The benefits of improved drainage show themselves in a number of ways. In some cases, drainage has facilitated the reclamation of land otherwise unsuitable for commercial agriculture, enabled increased production from existing land uses, or supported

a change to new land uses. In many cases, improved drainage has reduced the costs associated with flood damage, poor field working conditions in the field and unreliable grazing seasons. The maintenance of river and drainage systems is concerned with securing continued delivery of these potential drainage benefits.

### 2.7.2 Drainage benefit assessment methods

The overall approach to assessing the effects of changes in land drainage on agricultural performance involves a comparison of the value-added by agriculture under different drainage conditions. The benefit area (BA) of a maintenance scheme is defined as the area of the floodplain benefiting from the maintenance works in terms of its effect on land drainage and flooding. The benefit area is sub-divided into separate blocks according to field management, land use, drainage condition and flooding variables. For each block of land within the benefit area, the extra net benefit (value-added) attributable to maintenance is the difference between 'with' and 'without' maintenance net returns. Net returns are defined in terms of enterprise gross margins (the value of output less direct inputs), farm fixed costs, 'extras' such as the value of grazing days and flood damage costs.

The Silsoe College Drainage Evaluation Model (SCADE) incorporates this approach and assesses the agricultural benefits associated with a given standard of, or change in, land drainage condition (Hess and Morris, 1985). Data describing farming practice and drainage conditions are combined in the model with a database containing relevant agricultural economic and management data. The model is adapted to simulate changes in drainage status as a result of maintenance.

A distinction is made between the benefits of reduced waterlogging and reduced flooding within the SCADE model. Estimates of the benefits of reduced waterlogging on arable land are based on research findings which show the depressant effect of waterlogging on crop yields. These estimates are adjusted according to farm survey and regional statistics. The impact of waterlogging on grassland is assessed through energy from grass and stocking rates. Stocking rates are converted into gross margins and fixed costs per hectare, with adjustment for the value of extra grazing days and forage production costs. Extra energy from grass due to a change in drainage status may be used to increase stocking rates, as a substitute for purchased feeds or allow the release of grassland for other purposes and for other rotations.

Flood damage costs are comprised of the loss of agricultural output due to inundation and the cost of remedial works. Loss of agricultural output depends on the flooding frequency, length of inundation, seasonality of flooding and land use. Large catchments exhibit predominantly winter flooding whereas smaller catchments (< 25 sq. km) are characterised by 60 % winter flooding and 40 % summer flooding. SCADE incorporates a seasonal probability distribution for flooding based on catchment characteristics which combine with flood return period estimates to determine monthly flood probabilities. These are combined with estimated costs of a flood occurring on a given crop during a given month to give an average annual expected flood damage cost (£/ha) (Morris and Hess, 1988). The effect of flooding on arable crops is based on reduction in yield, reseeding costs if necessary and the savings in harvesting, drying and storing costs if the crop is lost. In the case of grassland, flood costs are based on the cost of replacing energy losses due to lost grazing days with alternative stock feedstuffs, emergency housing for stock and net savings in harvesting costs if forage crops are destroyed. The impact of multiple flood events is also taken into account within the model.

Estimates of net agricultural benefits are sensitive to assumptions regarding the need for additional farm expenditure on regular labour, power and machinery, buildings, storage and drying. These fixed costs are often equivalent to 70 - 80 % of total farm gross margins. The SCADE model distinguishes between the need for extra recurrent expenditure on these items (e.g. machinery running costs) and extra capital expenditure (e.g. depreciation of machinery). Any net increase in fixed costs 'before' and 'after' a change in drainage condition is identified.

The model may be run with financial and economic prices for agricultural commodities. These take into account 1995/96 farm gate prices, current levels of subsidy, agricultural legislation and requirements of set-aside. Financial values show the return to the farmers. Economic values show the return to the nation after removing government price support.

The Ministry of Agriculture, Fisheries and Food (MAFF, 1993) issued Project Appraisal Guidance Notes (PAGN) on procedures to be used for the economic assessment of flood defence (and land drainage) works. They identified three commonly encountered scenarios for the 'without' project situation. Scenario III, which assumes that the future without project situation will result in recurrent output loss, applies to the appraisal of river maintenance. PAGN advise reductions to the value of gross output (the value of output plus crop area and

livestock headage payments) in that the subsidies and protected prices received by farmers over-value the real contribution of farm output to the national economy. For example, at present under the set aside scheme, about 28 % and 48 % of the gross outputs of wheat and oil seed rape are obtained through area payments of £ 247 and £ 436 respectively. Approximately 28 % of the gross value of a suckler beef cow is made up of a subsidy payment.

Scenario III requires that the gross output (value of output plus area payments) of cereals, oil seeds and grain legumes such as peas and beans are reduced by 10 % to derive economic values. Beef and sheep gross outputs are reduced by 35 % and 25 % respectively. Enterprises subject to quota such as milk, potatoes and sugar beet are treated as wheat equivalent on the grounds that output losses in one area would be made up by increased production elsewhere, displacing wheat in the process. The 15 % set-aside area is treated as wheat equivalent because the set-aside scheme is seen as a transitional programme with land returning to productive use at some future time.

MAFF's PAGN reflect a wish to protect the integrity of existing flood defence systems and land use into the future, which otherwise may be prejudiced by short term policy or circumstances. In the case of livestock systems, the large reduction factors may no longer be compatible with recent introduction of quotas on headage subsidies paid to farmers in accordance with the concept of a national herd. This could justify the treatment of beef and sheep in the same way as milk production. The PAGN guidelines are likely to be reviewed in the near future. They have been used in the present analysis for reasons of consistency with current practice.

## 2.8 Maintenance Appraisal

For the purpose of appraising expenditure on maintenance, the benefits of maintenance are compared with the costs of maintenance. Maintenance costs have been adjusted to a constant price base of 1995/96 using inflation adjusted factors based on the Retail Price Index (RPI).

Generally, following maintenance, there may be a deterioration in SoS and benefits decline with time until the 'without' maintenance condition is reinstated. For frequent maintenance activities such as annual weed cutting, there maybe little or no post-maintenance deterioration, hence the benefits remain constant.

For long interval operations, such as desilting, there may be an advantage in scheduling repeat operations before the full deterioration of maintenance standards is reached. Additional annual maintenance such as weedcutting to reduce rates of deterioration and prolong the life of desilting, may be justifiable, depending on local circumstances.

The best maintenance strategy will depend on the rate of deterioration in SoS, the relative sizes of maintenance benefits and costs, and the discount rate used to convert future values to present values.

## 2.9 Environment

The history of maintenance on many rivers may have resulted in the loss of many habitats for wildlife and a lowering of the environmental quality of the river corridor. Prior to 1993, the NRA have used a river corridor survey (RCS) produced by the Nature Conservancy Council (NCC, now English Nature (EN)) to record river channel and bank features. These surveys provided a base from which the environmental impacts of maintenance were determined. The RCS also provides a tool which aids the specification of environmentally acceptable maintenance. However, the RCS does not provide the information required for the evaluation of sites in an objective and comparative way. In 1993, the NRA initiated the development of the River Habitat Survey (RHS) which is described as a standard methodology for evaluating and classifying riverine habitats.

At the present time, no standard methodology exists for determining riverine wildlife quality. Checklists of features which indicate channel and bank quality may be used as a quick method of determining the environmental value of the river. Checklists for determining channel and bank quality have been developed within the framework of this study.

There is a strong link between the hydraulic performance of a river and its environmental quality. Enhancement and restoration of rivers within the UK has provided varied habitats for flora, fauna and fish and is continuing to reinstate the water quality, amenity value and ecological diversity within the river and its associated floodplain. The inclusion of environmental enhancement features such as low stone weirs, pool and riffle sequences, berms and multi-stage channels mean that the hydraulics of the river are more complex than the straight trapezoidal channel. For example, the creation of shoals and islands reduces the cross-

sectional area of the channel and therefore reduces the conveyance. The channel will have variations in roughness and these must be combined to give a overall global roughness of the river channel. The creation of multi-stage channels with berms above the normal water level and low flow berms below the normal water level, allow a low flow channel to be maintained. The creation of low-lying wetter river margins encourage the growth of marginal vegetation which in turn stabilises the banks. Multi-stage channels can increase the flow capacity of the channel.

The requirement to enhance or protect environmental quality has important consequences for the design and implementation of river maintenance activities. Best practice for river maintenance must attempt to reconcile the potential conflict between SoS and environmental quality.

## 2.10 Study Rationale

This Chapter has identified the main issues surrounding river maintenance. Particular attention has been given to technical, hydrological, engineering, economic and environmental factors. Changing circumstances have placed greater emphasis on the need for objective methods for assessing the value and design of appropriate river maintenance programmes. The next chapter summarises the methods developed in pursuit of this requirement.

# 3. DATA COLLECTION AND IMPACT ASSESSMENT METHODS

## 3.1 Introduction

The aim of this study is to develop and verify methods and databases which assess the benefits associated with alternative maintenance strategies in rural areas. This Chapter describes the methods used in pursuit of this aim.

## 3.2 Site Selection

Collaboration between the NRA and Silsoe College enabled criteria to be drawn up which were used in site selection. Twelve sites in five NRA Regions were selected for study. These include two sites from the previous River Maintenance Evaluation Project (Hilton Brook and the River Sence) to allow for an extended period of monitoring and to allow a representative cross-section of maintenance schemes to be studied. The selection criteria included the following factors:

- NRA Region;
- river characteristics;
- river maintenance activities / methods; and,
- river corridor / flood plain characteristics and land use.

It was required that each scheme could be studied as an individual project to which costs and benefits could be identified and attributed. The sites are representative of main rivers in each Region on which typical maintenance activities are performed. The scheme reports are presented in a series of five Annexes to this R&D Note (R&D 317/18 - 22/ST) and are grouped according to NRA Region.

The selected schemes include seven meandering 'natural' rivers and five trapezoidal 'artificial' channels. Both deep and shallow, fast and slow flowing rivers are represented. The study is mainly concerned with agricultural land use which covers a range of crops and livestock activities. Land use covers a range of grass and arable enterprises. Some of the sites include

non-agricultural enterprises such as golf courses, turf production and gravel workings. A summary of the 12 sites is presented in Table 3.1.

**Table 3.1 Site summary**

| Region & Watercourse | Reach | Reach Length (km) | Size (width / capacity) | Main Features | Maintenance Operations | Land Use |
|---|---|---|---|---|---|---|
| *Welsh* | | | | | | |
| River Arrow | Pembridge (392 585) to Arrow Green (438 587) | 8.5 | 8-9 m | Meandering flat floodplain | Tree & bush Selective desilting | Pasture, arable, caravan park, orchard |
| Dysynni Low Level Drain | 636 067 to A493 road bridge (602 038) | 6 | 1-4 m | Straight arterial drain, slow flowing | Weedcutting | Pasture |
| Dreneuydd / Broadway Reen | Cidwely Arch (276 832) to B4239 road bridge (273 810) | 3 | 3 m | Serves Wentlooge IDB straight, trapezoidal channel | Weedcutting & desilting | Pasture, arable, golf course, turf production |
| *Anglia* | | | | | | |
| Woldgrift Drain | 780 446 to Washdyke Bridge (794 476) | 7 | 1.5-4 m | Trapezoidal channel, straight, slow flowing | Banks flail mown & weedcutting | Mainly arable, some pasture |
| R. Wensum | Billingford (202 004) to Swanton Morley (019 185) | 3 | 2-12 m | Meandering, weirs, moderately deep | Weedcutting | Pasture, arable, gravel works |
| R. Yare | Bawburgh (157 088) to Colney (183 083) | 3 | 2-15 m | Meandering, slow flowing | Weedcutting | Pasture, arable, gravel works, horticulture |
| *Severn Trent* | | | | | | |
| R. Sence | 616 963 to Crow Mill Bridge (588 977) | 4 | 20 cumecs | Moderately deep, fast flowing & meandering | Weedcutting & occasional shoal removal, desilting | Mainly pasture, some arable |
| Hilton Brook | Bartonfields Farm (221 352) to (229 339) | 2.75 | 10 cumecs | Shallow, fast flowing & meandering, cobbled brook | Tree & bush Selective desilting Weedcutting | Mainly pasture, some arable |
| *South West* | | | | | | |
| R. Yarty | Long Bridge (255 055) to Beckford Bridge (266 015) | 5 | 1-4 m | Narrow floodplain, meandering, heavy tree growth | Tree & bush clearance | Pasture |
| Sir Arthur's Pill | 464 376 to sluice gate (478 342) | 5 | 1.5 m | Straight drain, serves IDB, trapezoidal | Weed cutting & silt removal | Pasture, arable, horticulture, holiday homes |
| *North West* | | | | | | |
| R. Wampool | Wampool Bridge (240 543) to Howwath Bridge (238 574) | 6 | 10-12 cumecs | Tidal in lower sections, slow flowing & silty bed (quick sand) | Weedcutting & banks flail mown | Arable, pasture, turf production |
| Pilling Water | 453 456 to Pilling Marsh outfall (406 495) | 5.75 | 10-12 cumecs | Agricultural arterial drain with flapped outfall & slow flowing | Weedcutting & banks flail mown | Arable, pasture |

A variety of maintenance activities are performed on the selected reaches. The majority of the sites are subject to annual weedcutting using mechanical methods. Desilting is performed at three of the sites. A programme of desilting was scheduled to take place on the River Yare in 1992, however, this has still not taken place. Tree and bush clearance is practised on the Hilton Brook, River Yarty and River Arrow. All these sites have areas of dense tree growth and have fast flowing, meandering channels. Plates 1 to 27 show representative sections of each watercourse included in the Study.

## 3.3 Engineers' Survey

Information concerning the history of river maintenance on the watercourses within the study sites was collected via a questionnaire (Appendix I) which was completed by an engineer with experience of the study site.

The questionnaire covered all aspects of river management including capital works and river maintenance, maintenance impacts, criteria for selecting a particular SoS and notification procedures. Data concerning the costs of various maintenance procedures on each watercourse were collected throughout the study period.



**Plate 1** **River Arrow, April 1993, post-maintenance**

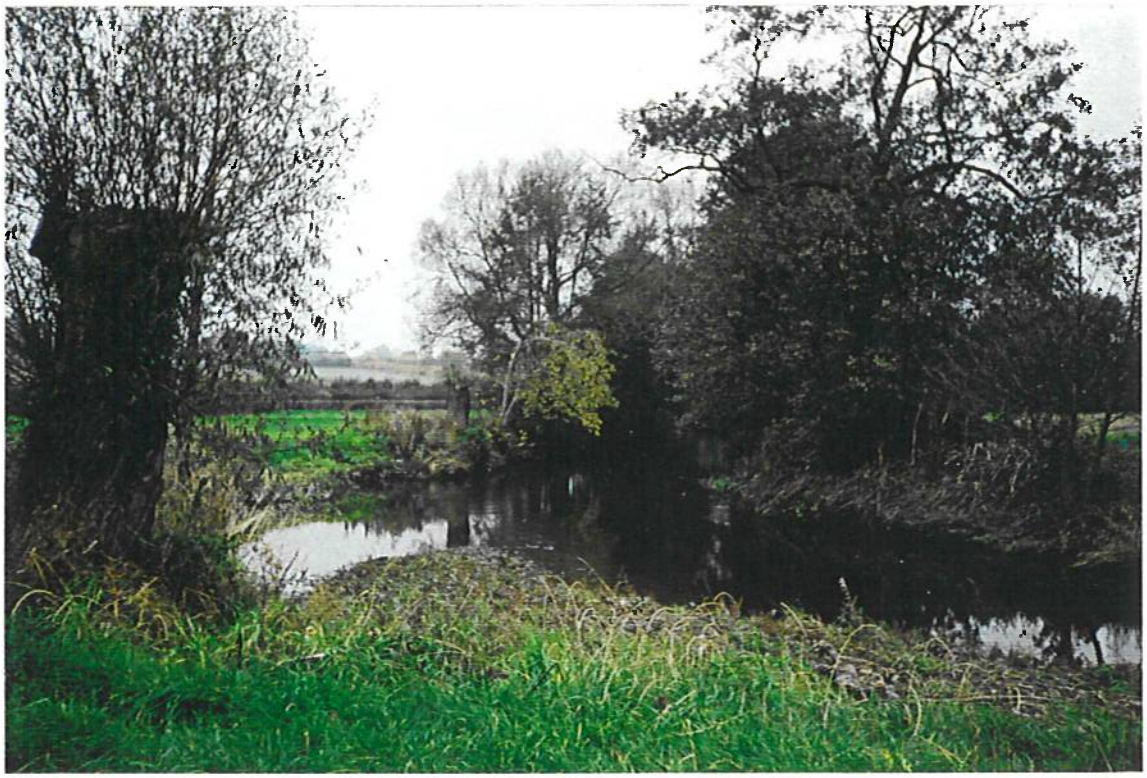


**Plate 2** **River Arrow, November 1993, post-maintenance**



**Plate 3** **River Arrow, April 1993, post-maintenance**



**Plate 4** **Dysynni Low Level Drain, April 1993**



**Plate 5** **Dysynni Low Level Drain, April 1993**



**Plate 6** **Dreneuydd / Broadway Reen, August 1992, pre-maintenance**



**Plate 7** **Dreneuydd / Broadway Reen, April 1993, post-maintenance**

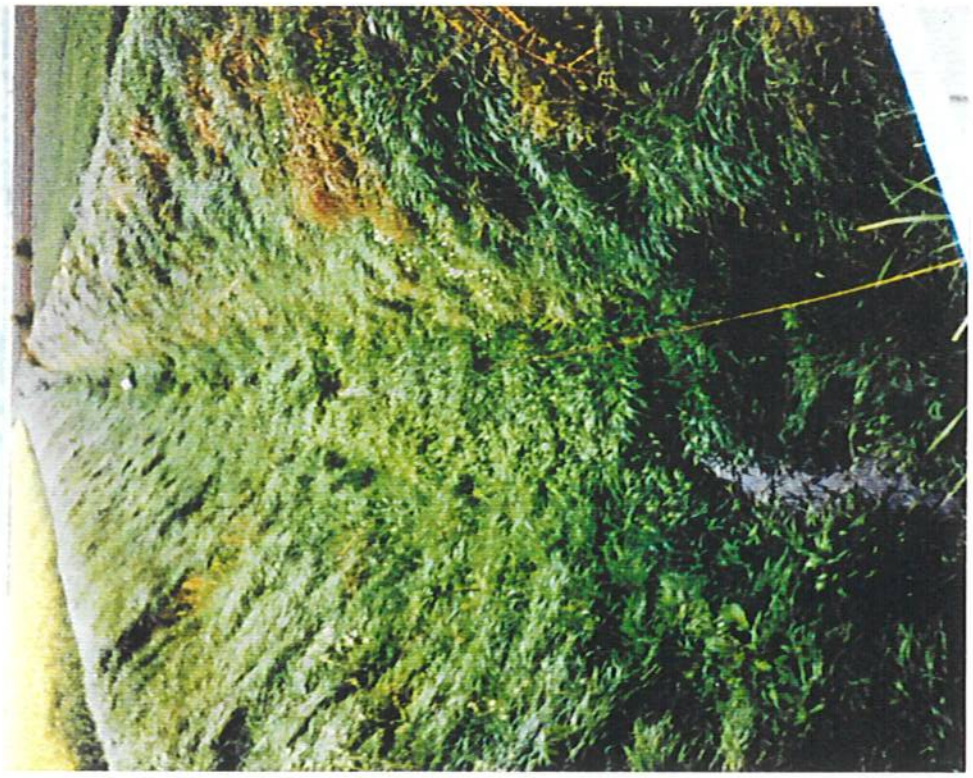


**Plate 8** **Woldgrift Drain, May 1992, pre-maintenance**



**Plate 9** **Woldgrift Drain, April 1993, post maintenance**



**Plate 10** **River Wensum, August 1993, maintenance**



**Plate 11** **River Wensum, April 1994, post-maintenance**



**Plate 12** **River Yare, May 1992, pre-maintenance**



**Plate 13** **River Yare, April, 1994, pre-maintenance**

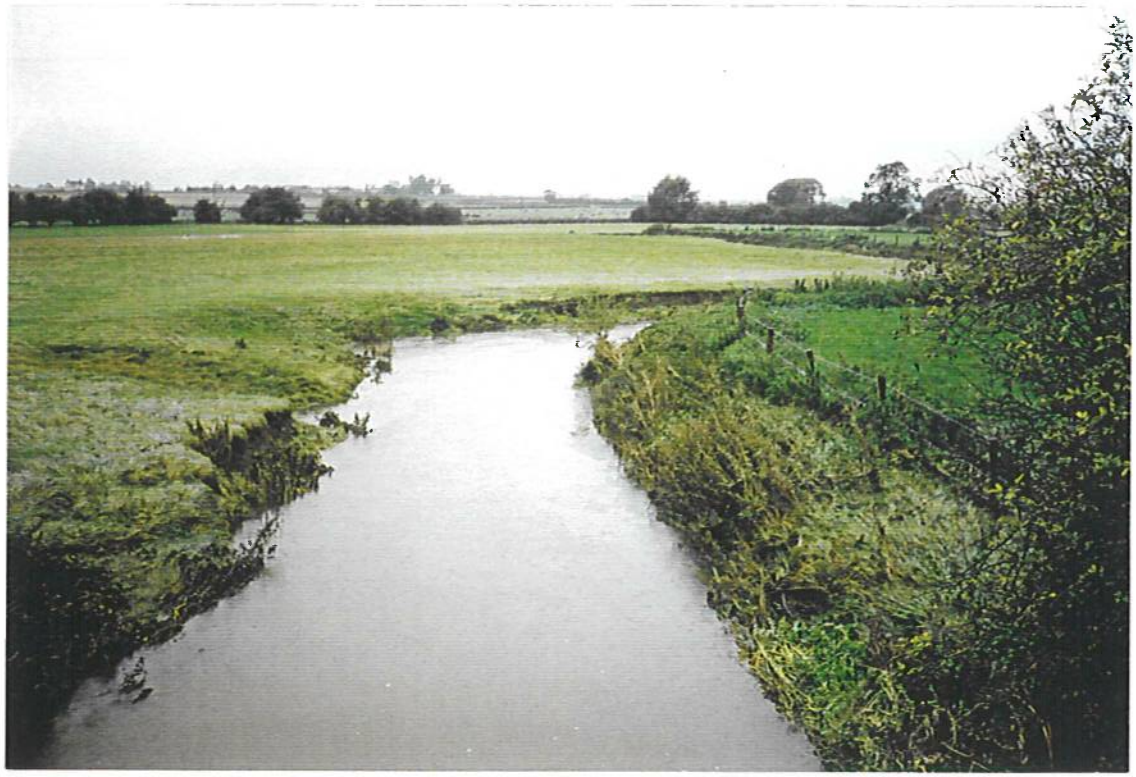


**Plate 14** **River Sence, September 1992**



**Plate 15** **River Sence, October 1994**



**Plate 16** **Hilton Brook, March 1994**



**Plate 17** **Hilton Brook, October 1994**



**Plate 18** **River Yarty, October 1994**



**Plate 19** **River Yarty, debris dam**

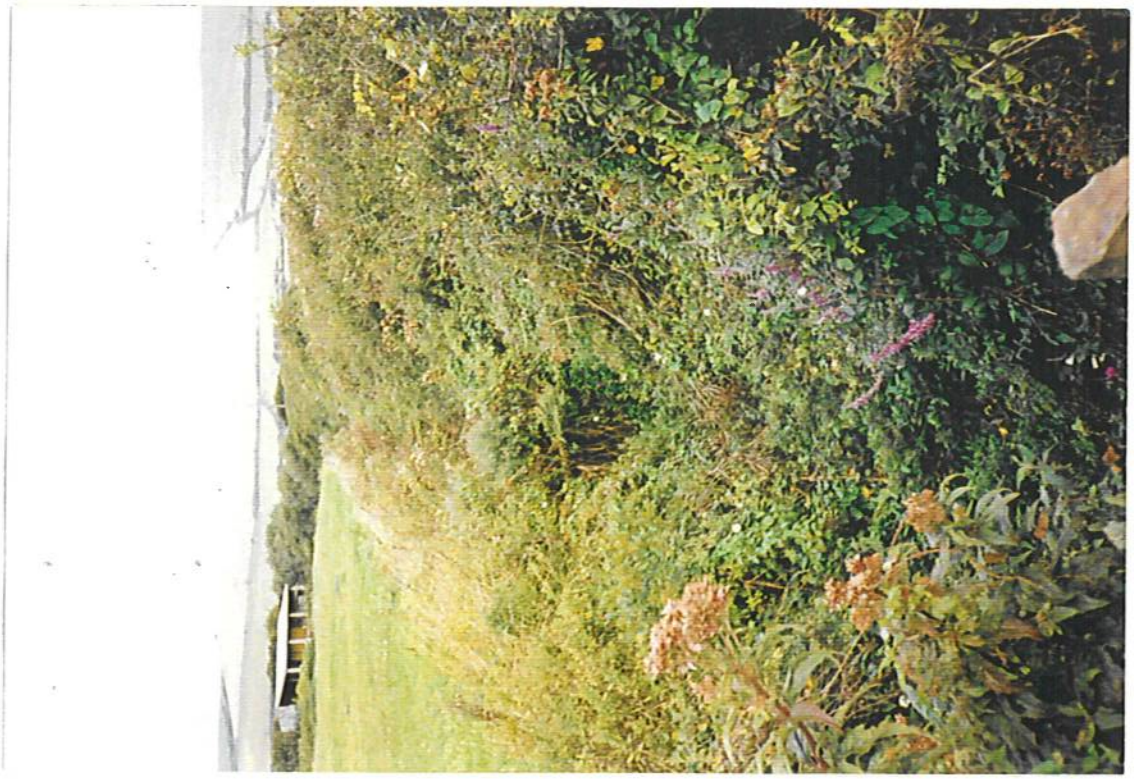


**Plate 20** **Sir Arthurs' Pill, August 1992, pre-maintenance**

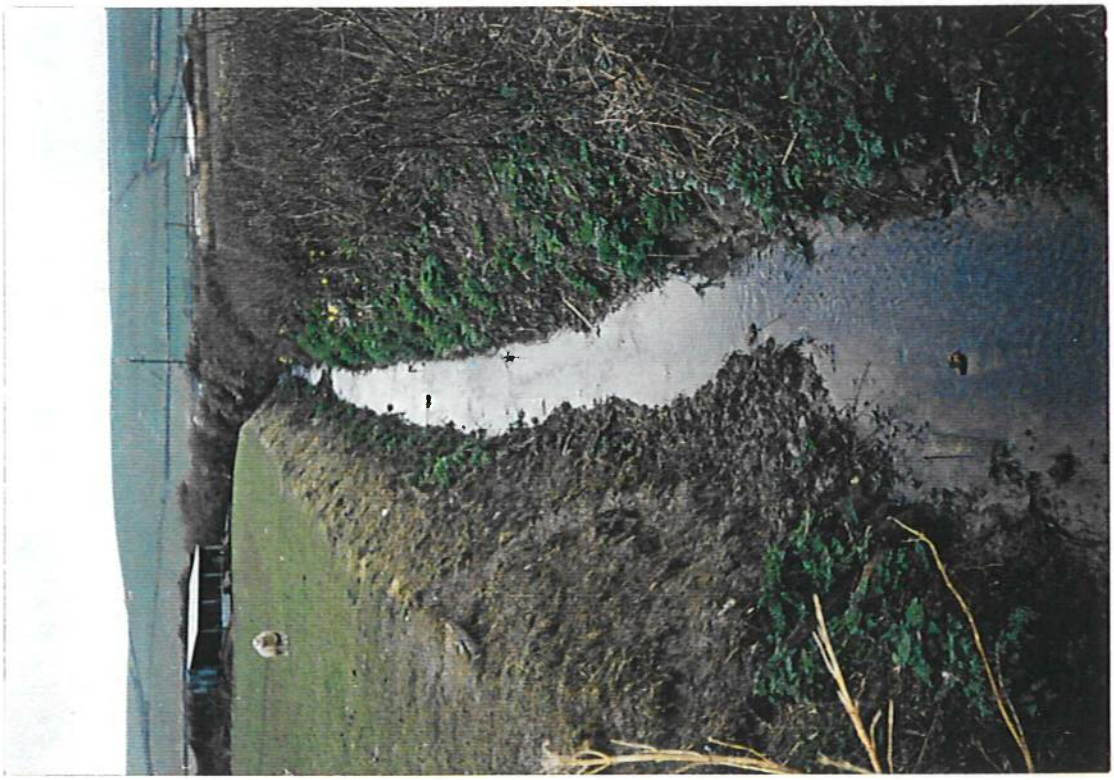


**Plate 21** **Sir Arthurs' Pill, March 1993, post-maintenance**



**Plate 22** **River Wampool, April 1994**



**Plate 23** **River Wampool, May 1994**



**Plate 24** **Sally Sough, November 1993, pre-maintenance**



**Plate 25** **Sally Sough, April 1994, post-maintenance**



**Plate 26** **Pilling Water, May 1993, pre-maintenance**



**Plate 27** **Pilling Water, May 1994, post-maintenance**

## 3.4 Data Requirements and Collection Methods

Data have been collected on land management, land use, channel hydraulics, climate and the environment. A variety of collection methods have been used ranging from interviews and site survey to a literature review and on site monitoring.

The information required can be divided into five areas:- hydrological, agricultural, lithological, meteorological and environmental data.

### 3.4.1 Baseline survey

A baseline survey was carried out during the period March to June of the first year of study (1992). This provided a record of the pre-maintenance status of the selected reaches which enabled subsequent assessment of the impact of maintenance activities. Hydrological, agricultural and environmental variables which contribute to the status of the channel and adjacent environment were identified. Further details are presented in the individual scheme reports (R&D 317/18 - 22/ST) presented as a set of five Annexes to this R&D Note.

### 3.4.2 Hydraulic and hydrological data

The hydraulic and hydrological information was collected on flow data, channel capacity, channel gradient and the drainage network. Channel dimensions and gradient were provided by the NRA in the form of cross-sectional and longitudinal surveys.

On the River Sence and Hilton Brook where desilting has taken place, the channel was surveyed again following the maintenance work in order for the pre- and post-maintenance channel dimensions to be compared. The pre- and post-maintenance cross-sections were surveyed at the same location. Details of the cross-sectional surveys are presented within the Annexes (R&D 317/18 - 22/ST). Cross-sectional information for the River Sence and Hilton Brook is presented in the two Scheme Reports submitted to the NRA in May 1993.

Flow data in the form of gauging station or level recorder records have been obtained from the various Hydrology Departments within the NRA Regions. Such data were not available, or very limited for the Rivers Yarty and Wampool, Hilton Brook, Pilling Water, Dysynni Low Level Drain, Dreneuydd / Broadway Reen and Sir Arthur's Pill. Gauge boards were installed at various points within these reaches. Water levels were read from the gauge boards on a

regular basis by NRA staff. However, repeated vandalism to equipment installed within some reaches led to broken and incomplete records of water levels and flow, particularly within the Dreneuydd / Broadway Reen.

Information regarding flood frequency and duration was collected from farmers through a series of questionnaires and informal discussions. Data concerning ditch networks, drainage pipe outfalls and structures such as weirs were obtained through site surveys and discussions with drainage engineers and farmers.

As the majority of sites are subject to vegetation maintenance, the types of aquatic vegetation present in the channel were identified.

### 3.4.3 Agricultural data

Both primary (farm survey) and secondary sources (Regional Farm Management Surveys) were used to collect agricultural data. The majority of the data were obtained during the baseline survey through structured discussions with farmers and major land-users in the benefit area. Six main topics were covered in the baseline survey:

- farm details and land use;
- waterlogging and field drainage;
- impact of changes in drainage status;
- flooding;
- knowledge, perception and views on river maintenance; and,
- environmental features and quality.

The information collected related to both the farm and field level scale. Data relating to post-maintenance conditions and farming practice were collected through a series of farm surveys during the autumn of 1992, spring and autumn of 1993 and 1994; the beginning and end of the farming year. The questionnaire used in the baseline survey is presented in Appendix II. An example of a post-maintenance questionnaire is presented in Appendix III. These post-maintenance questionnaires were altered prior to each visit according to the specific information required. General information on farming practice within the area was also collected through informal discussions with farmers.

### 3.4.4 Lithological data

An on-site survey of soil provided information on soil type, characteristics and composition. The records of the Soil Survey of England and Wales (SSEW) provided details of individual soil Association and Series. Details of soil hydraulic conductivities were obtained through the site survey, SSEW and laboratory analysis. Results of the soil survey information for each watercourse are presented in the individual Scheme Reports (Annexes).

### 3.4.5 Meteorological data

Rainfall data in the form of daily totals since 1992 and monthly records over a period of 11 to 33 years were provided by the NRA. The monthly records were used to determine the probability of dry, average and wet seasons and years occurring. Further information is presented in Appendix IV, Section 2.1. Daily rainfall totals were collated into weekly totals for use in watertable modelling. Potential evapotranspiration data were provided by the NRA and the Meteorological Office. These data were converted from monthly figures into weekly values for the purpose of watertable modelling.

### 3.4.6 Environmental data

Environmental information was gathered from a variety of sources. A river corridor survey was completed for each watercourse following the methodology of the Nature Conservancy Council (NCC, now English Nature (EN)). Each site was analysed in 500 m sections for which a map and record card were completed. The survey concentrated on the river and the immediate corridor of adjacent land (50 m either side of the banks). Any areas of land which would be affected by the proposed maintenance work were also surveyed.

In addition to the river corridor survey, environmental information was collected from the farmers and local interested parties and conservation bodies. Discussions were held with representatives from the Fisheries, Conservation, Recreation and Navigation Departments (FCRN) within each NRA Region. Information was obtained from these departments relating to such variables as:

- the incorporation of environmental criteria into maintenance planning and implementation;
- the involvement of conservationists in the determination of river maintenance practices;
- environmental impacts of maintenance;

- environmental enhancement works;
- timing of maintenance operations and the rate of environmental recovery; and,
- details of liaison procedures between the NRA and specialist organisations.

## 3.5 Impact Assessment Methods

The impact assessment methods used in the study are described in the following sections.

### 3.5.1 Flooding impacts

The impact of flooding was assessed from flood frequency information and area inundated. On sites where the channel dimensions were altered during maintenance such as by desilting, cross-section surveys were taken pre- and post-maintenance in order for comparisons of channel dimensions and capacity to be made.

The survey data were stored in spreadsheet format to enable graphical representation of the channel dimensions. Channel capacity was calculated using the Manning's n equation. Table 3.2 shows an example of information and calculations for a cross-section on the River Wensum.

Manning's roughness coefficient (Cowen, 1956) was used to estimate channel friction both before and after river maintenance. This coefficient is composed of six parameters which describe channel character and conditions. The parameters are listed below:

- predominant bed material ($n_0$);
- degree of irregularity of channel sediment ($n_1$);
- variations of channel cross-sections ($n_2$);
- relative effect of obstructions ($n_3$);
- vegetation ($n_4$); and,
- degree of meandering ($m_1$).

Further information on these parameters is presented in Appendix IV.

**Table 3.2 Cross-section data and channel capacity - River Wensum**

| Point | Cross-section 1 (Datum 17 m AOD, Chainage 250 m) m AOD (m) | Relative Height (m) | Chainage (m) | Area ($m^2$) | Perimeter (m |
|---|---|---|---|---|---|
| 1 | 21.71 | 0.00 | 7.10 | 0.20 | 1.62 |
| 2 | 21.46 | 0.25 | 8.70 | 0.74 | 1.45 |
| 3 | 20.82 | 0.89 | 10.00 | 1.13 | 1.31 |
| 4 | 19.78 | 1.93 | 10.80 | 2.96 | 1.45 |
| 5 | 19.41 | 2.30 | 12.20 | 11.08 | 5.21 |
| 6 | 19.75 | 1.96 | 17.40 | 8.63 | 5.23 |
| 7 | 20.35 | 1.36 | 22.60 | 0.78 | 0.85 |
| 8 | 20.84 | 0.87 | 23.30 | 1.91 | 3.04 |
| 9 | 21.31 | 0.40 | 26.30 | 0.80 | 4.02 |
| 10 | 21.71 | 0.00 | 30.30 | | |
| Total | | | | 28.22 | 24.19 |

| | |
|---|---|
| Hydraulic radius | 1.17 |
| Water level at 250 m | 20.50 |
| Water level at 3500 m | 18.86 |
| Slope (%) | 0.000656 |
| Manning's 'n; | 0.035 |

Channel capacity according to Manning's 'n' is 22.87 cumecs

Information on channel roughness and dimensions were combined to determine flow capacity of the channel pre- and post-maintenance. These flows were read off flood return period graphs which were used to estimate the change in flood risk associated with river maintenance. The flood return period graphs were constructed from historical flow records where available, otherwise the methodology contained within the Flood Studies Report (FSR) (NERC, 1975) was used. Full details of this FSR methodology are presented in Appendix II of the Interim Report submitted to the NRA (317/11/ST) in June 1994.

### 3.5.2 Groundwater and drainage impacts

A non-steady state model, developed at Silsoe College (Hess et al, 1989) was used to assess the influence of changes in river and ditch water levels on watertable levels in the floodplain. The model takes into account daily rainfall, evapotranspiration figures, river levels and site specific information such as soil type and drainage intensity and identifies the likely equilibrium field watertable height for specified climatic conditions.

Data required by the model take two separate forms:

- continuous data for the survey period at weekly intervals (rainfall (mm), evapotranspiration (mm) and river water level (m AOD)); and,
- in-situ field data relating to field variables and channel features. These data include ditch/pipe spacing (m), hydraulic conductivity of topsoil and subsoil (m/day), soil boundary depth (m), ditch base and land surface elevation (m AOD).

The field data relates to the specific block of land under consideration whilst the river channel information refers to the nearest cross-section to the block. A complete list of the in-situ data required and example values taken from the River Wensum are presented in Table 3.3. Ditch spacing refers to the spacing of the ditch network if the field is naturally drained or to the spacing between field drainage pipes if the field is artificially drained.

**Table 3.3 Field and channel data required by the watertable model**

| | |
|---|---|
| Ditch spacing (m) | 35 |
| Depth to impermeable layer (m) | 2.5 |
| Geometrical factor for ditch system | 0.9 |
| Initial water table depth (m) | 0.2 |
| Hydraulic conductivity of topsoil (m/day) | 1.67 |
| subsoil (m/day) | 0.67 |
| Soil boundary depth (m) | 0.3 |
| Specific yield of topsoil (m/m) | 0.17 |
| subsoil (m/m) | 0.12 |
| Unsaturated hydraulic conductivity exponent | 6 |
| Surface elevation (m AOD) | 21.7 |
| Ditch base elevation (m AOD) | 19.41 |
| Weekly water level data (m AOD) | |
| Weekly rainfall data (mm) | |
| Weekly evapotranspiration data (mm) | |

Example data taken from the River Wensum, undrained land, light soils
The river channel information required by the model is drawn from the nearest cross-section to the block

The output produced by the model contains results for a particular block of land. It takes the form of two columns of data (Appendix V) which indicate the river water level and the modelled watertable height.

Through an extensive review of literature and survey of farmers, the drainage status of land was classified into three categories according to watertable depth during each of the seasons of the year (Winter, Spring, Summer, Autumn). Agriculture in the UK is particularly sensitive to land drainage conditions in the spring during which timeliness of field operations and turnout of livestock are of paramount importance. The three watertable depth bands are identified: deeper than 0.5 m from the surface, between 0.3 and 0.5 m from the surface and within 0.3 m of the surface. Depending on the percentage of time the watertable lies within these bands, the drainage status for that time period is classed as Good (G), Bad (B)or Very Bad (VB) respectively. More information on this banding is provided in Table 3.4.

In terms of agricultural productivity, under conditions of good drainage, no restrictions are placed on farming practice and agricultural productivity may be described as Normal. A bad drainage status poses some limitations to farming and the productivity scenario is described as Low. Crop and grass yields may be reduced and field operations and turning out of livestock may be delayed. Breakdown conditions of agricultural productivity are associated with very bad drainage. Severe restrictions are placed on land use and farming practice in some cases. Farming may no longer be commercially viable.

**Table 3.4 Drainage status and watertable depth**

| Watertable Depth (m from surface) | % Time Watertable at Given Depth | Drainage Status | Productivity Level |
|---|---|---|---|
| > 0.5 | > 80 % | Good | Normal |
| > 0.5 | < 80 % | Bad | Low |
| > 0.3 | > 50 % | | |
| < 0.3 | > 50 % | Very Bad | Breakdown |

The amount of rainfall falling within a given period influences the impact of river maintenance on flood risk and watertable height. River maintenance is likely to have a greater impact during wet periods rather than in dry ones. Recognising this, monthly rainfall records spanning a period of 11 to 33 years from the nearest meteorological station to the study site were analysed. The four seasons of the year were classified as dry, average and wet in accordance with the FAO (Food and Agricultural Organisation) guidelines. Dry and wet seasons are classified as those with less than 75 % of the mean and more than 125 % of the mean

respectively. The sensitivity of the watertable model to rainfall totals and distribution within the seasons has been analysed and the results presented in Appendix V.

The watertable model was run for each site for 'with' and 'without' maintenance river water levels for wet, mean and dry weather conditions in order to identify the impact of maintenance on watertable levels and drainage status. The drainage conditions were linked with estimates of agricultural productivity to determine the benefits attributable to river maintenance under different weather conditions. Table 3.5 shows an example of the output of this procedure taken from the River Wensum. The example shows that maintenance can prevent a deterioration in drainage conditions, especially in average and wet seasons. In some cases, however, maintenance may not have a significant impact.

**Table 3.5 Drainage status for wet, average and dry seasons, without/with maintenance**

| Block No | | Wet Season * | | Average Season * | | Dry Season * | | Farmer Assessment With Maintenance | | | Without |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Without | With | Without | With | Without | With | Wet | Average | Dry | |
| 101 | N | G | G | G | G | G | G | G | G | G | G |
| 201 | N | B | B | G | G | G | G | *G* | G | G | B |
| 202 | N | **VB** | **B** | **B** | **G** | G | G | B | G | G | B |
| 203 | N | **VB** | **B** | G | G | G | G | B | G | G | B |
| 301 | N | G | G | G | G | G | G | G | G | G | G |
| 501 | Y | B | B | **B** | **G** | **B** | **G** | B | G | G | B |
| 601 | Y | **VB** | **B** | **B** | **G** | **B** | **G** | B | G | G | B |

NB : * Modelled results

Y or N refers to the presence or absence of field drainage, bold type indicates a change in drainage status due to maintenance, italics indicate differences between farmer and modelled assessment of drainage with maintenance

G = Good drainage, B = Bad drainage, VB = Very Bad drainage

As an alternative to the watertable model, farmers were asked to assess the drainage status of blocks of land for 'with' and 'without' maintenance situations (also shown in Table 3.5). Their assessment of the change in drainage status due to maintenance under average weather conditions was used to provide a measure of maintenance benefit.

### 3.5.3 Morphological impact of maintenance

The impacts of maintenance on sediment movement, erosion and deposition were investigated using a numerical morphological model developed by HR Wallingford. Drawing on historical data, and estimates of stream power and sediment transport rates pre- and post-maintenance, the stability of each study reach has been determined and the likely rates of sedimentation and erosion occurring following maintenance predicted.

**Idealised model studies**

The model was used to estimate changes in bankful discharge and water level following maintenance and the longevity of these changes in terms of the number of years for the 'without' maintenance situation to be reinstated.

Channel dimensions of the 12 sites were studied and used to determine channel parameters for idealised sand, silt and gravel bed channels on which river maintenance is performed. These parameters were used as the basis for creating idealised channels which are 'in regime' (state of dynamic equilibrium). The morphological model was then run for a sand, silt and gravel bed channel using the idealised channel parameters.

Maintenance in the form of widening, deepening and vegetation cutting was simulated in the modelling of idealised sand, silt and gravel bed channels to determine the impact of maintenance on bankful discharge and water depth over a 30 year period. The impacts on bankful discharge and water depth of deepening by 5 % to 40 % and widening by 5 % to 50 % were estimated. Similarly, the impact of removing 40 % to 100 % of the vegetation cover on an annual basis was determined. The original vegetation cover was set at levels which represented typical conditions according to those which would occur in the absence of maintenance. During the modelling it was assumed that the vegetation was of the submerged, streamlined type and was removed in a strip down the centre of the channel. Removal of emergent vegetation was treated as channel widening.

For each combination of 'without' maintenance vegetation cover and amount of vegetation removed, the Manning's 'n' roughness coefficient was calculated by relating 'n' to the percentage cover of vegetation. Estimates of changes in water depth and discharge capacity following maintenance were obtained using the numerical morphological model, flow velocity and channel dimensions.

### 3.5.4 Agricultural benefit assessment

**Land drainage**

Productivity scenarios for each block of land within the benefit area were determined through the farm survey information and a literature search. Input - output relationships and resultant financial and economic performance of agricultural practice under conditions of good, bad and very bad drainage were determined. SCADE (Silsoe College Agricultural Drainage Evaluation Model) was used to determine the input - output relationships associated with these different drainage conditions. Constant 1995/96 prices were used throughout the analysis.

Estimates of financial and economic returns obtained from SCADE formed the basis for attributing benefits associated with river maintenance. Differences in net returns associated with conditions of good, bad and very bad drainage illustrate the extra benefits of maintaining a particular level of land drainage service and the benefits of avoiding losses associated with deteriorating drainage conditions.

Table 3.6 contains general information on representative farming practice and performance under conditions of good, bad and very bad drainage.

**Table 3.6 Farming practice and performance by drainage status**

| Land Use | Drainage Status | | |
|---|---|---|---|
| | Good | Bad | Very Bad |
| *Grassland* | | | |
| - nitrogen application, % of application on 'good' category | 100 % | 70 % | 50 % |
| - grass conservation | 2 cut | 1 cut | 1 cut hay |
| - grazing season, penalty days c.f. 'good' category: | | | |
| spring | 0 | - 14 | - 28 |
| autumn | 0 | - 14 | - 28 |
| *Arable* | | | |
| - yield as % of 'good' category | | | |
| winter wheat & barley | 100 | 80 | 50 |
| spring wheat & barley | 100 | 90 | 80 |
| oilseed rape | 100 | 90 | 80 |
| potatoes, peas, sugar beet | 100 | 60 | 40 * |

* not grown if persistently very bad

Table 3.7 shows an example of the financial and economic returns associated with the three drainage categories for a winter wheat crop. The distinction between financial and economic returns are based on MAFF guidelines as described in Section 2.7.2.

**Table 3.7 Estimates of returns for wheat production**

| Winter Wheat | Drainage Status | | |
|---|---|---|---|
| | Good | Bad | Very Bad |
| Yield (t/ha) | 7.25 | 5.80 | 3.63 |
| Crop value at £ 90/t | 653 | 522 | 327 |
| Area payment (£/ha) | 247 | 247 | 247 |
| Gross output (£/t) | 900 | 769 | 574 |
| Variable costs (£/ha) | 260 | 226 | 195 |
| Gross margin (£/ha) | 640 | 543 | 379 |
| Semi fixed costs (£/ha) | 143 | 135 | 124 |
| Financial net return (£/ha) | 497 | 408 | 255 |
| Economic net return (after deducting 10 % of gross output) (£/ha) | 810 | 692 | 517 |

Using the watertable model, the drainage status of each block of land was assessed for average, wet and dry weather conditions 'with' and 'without' river maintenance. Benefits of maintenance were thus determined under different weather conditions. These benefits were weighted by the relative probability of the wet, dry and average years occurring (Appendix VI) in order to derive the expected annual benefit. This procedure is shown in Table 3.8 for a sample block of 6 ha. Table 3.8 shows that the annual benefit of maintenance in terms of preventing a deterioration in drainage status is £ 94/ha, or £ 564 over a 6 ha field.

**Table 3.8 Example drainage status benefits attributable to maintenance**

| Example: per ha | Net Return (£/ha) under Different Weather Conditions | | |
|---|---|---|---|
| (Drainage status in parentheses) | Wet | Average | Dry |
| *Land under wheat production* | | | |
| Economic net return with maintenance (£/ha) | 692 (B) | 810 (G) | 810 (G) |
| Economic net return without maintenance (£/ha) | 517 (VB) | 692 (B) | 810 (G) |
| Difference due to maintenance (£/ha) | 175 | 118 | 0 |
| Probability of weather conditions | 0.2 | 0.5 | 0.3 |
| Expected annual benefits (£/ha) | | 94 | |
| Average expected annual benefit for a 6 ha field | | 564 | |

**Flood damage costs**

The frequency of flooding is influenced by river maintenance and hence channel capacity. Flood damage costs were assessed for each land block for 'with' and 'without' maintenance under different productivity scenarios using SCADE. This model identifies flood costs associated with each land use and drainage class. Multiple floods occurring in a year are assumed to have an additive effect. Flood costs are weighted by the relative probability of wet, average and dry seasons. Catchment size affects the seasonal distribution of flooding. Large catchments experience predominantly winter flooding, whereas small catchments contain a relatively higher incidence of summer floods. Flood costs per hectare are grossed up according to the area liable to flooding.

Changes in flood costs attributable to maintenance were identified. An example is provided in Table 3.9 relating to the aforementioned block of 6 ha assuming all of it is liable to flooding.

**Table 3.9 Estimated benefits of flood alleviation attributable to maintenance**

| Example: per ha (Drainage status in parentheses) | Flood Return Period (years) | Flood Cost (£/ha) under Different Weather Conditions | | |
|---|---|---|---|---|
| | | Wet | Average | Dry |
| *Land under wheat production* | | | | |
| Flood costs with maintenance (£/ha) | 2 | 8 (B) | 9 (G) | 9 (G) |
| Flood costs without maintenance (£/ha) | 1 | 16 (VB) | 17 (B) | 19 (G) |
| Difference due to maintenance (£/ha) | | 8 | 8 | 10 |
| Probability of weather conditions | | 0.2 | 0.5 | 0.3 |
| Expected annual flood alleviation benefits (£/ha) | | | 9 | |
| Average expected annual flood alleviation benefit for a 6 ha field | | | 54 | |

As shown in Table 3.9, the annual benefit of maintenance in terms of reducing the incidence of flooding is £ 9/ha, or £ 54 over a 6 ha field.

Benefits of drainage and flood alleviation are combined to provide an estimate of total benefits of maintenance. Using the examples presented in Table 3.8 and 3.9, total benefits attributable to maintenance are £ 103/ha or £ 618 over a 6 ha field.

### 3.5.5 Maintenance costs

Maintenance costs were identified from NRA records for the study reaches. The cost of maintenance has been expressed as an annual equivalent cost in 1995 prices. Annual weed maintenance has been treated as an annual recurrent cost. In the case of infrequent operations such as desilting and tree and bush work, the cost of works were amortised over their expected life at 6 % rate of interest to derive an equivalent annual cost. The onset of compulsory competitive tendering has increased the degree of information available on maintenance costs.

### 3.5.6 Scheme justification

The estimated benefits attributable to maintenance have been compared with costs to determine the justification for work. All maintenance costs and benefits are expressed in 1995 prices. Because maintenance is a recurrent, predominantly annual activity, it is appropriate to express benefits and costs on an annual basis in order to determine profitability. A simple benefit : cost ratio is used for this purpose.

The method of scheme justification is best explained through the use of an example from the River Wensum. Table 3.10 shows the average annual economic and financial benefits of drainage and flood alleviation, per block of land within the benefit area attributable to maintenance, using modelled results.

The total average annual benefits attributable to maintenance using economic prices based on the current PAGN are approximately £ 927 for the benefit area, equivalent to £ 27/ha. By comparison, financial prices would generate a total benefit of £ 1589 per year (£ 46/ha).

Maintenance activities on the River Wensum involve annual weed clearance. The average annual cost in 1995 prices was £ 870, equivalent to approximately £ 25/ha of benefit.

The estimated benefits attributable to maintenance are compared with estimated costs to determine the justification for expenditure. Table 3.11 shows that using modelled results, the existing maintenance scheme is viable in financial terms (benefit : cost ratio 1.8). Using economic values, the benefit : cost ratio is 1.1, indicating that the benefits of maintenance are marginal and the maintenance scheme is just viable.

**Table 3.10 Average annual maintenance benefits - River Wensum (Modelled results)**

| Block | Area (ha) | Change in Economic Net Benefit due to Maintenance (£) Wet Season | Average Season | Dry Season | Total Change (£/yr) | Change in Financial Net Benefit due to Maintenance (£) Wet Season | Average Season | Dry Season | Total Change (£/yr) |
|---|---|---|---|---|---|---|---|---|---|
| 101 | 9.96 | 9 | 9 | 9 | 89 | 9 | 9 | 9 | 90 |
| 201 | 2.10 | 8 | 8 | 8 | 17 | 8 | 8 | 8 | 17 |
| 202 | 1.20 | 534 | 244 | 1 | 268 | 540 | 248 | 1 | 272 |
| 203 | 0.40 | 18 | 1 | 1 | 1 | 27 | 1 | 1 | 1 |
| 301 | 8.26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 401 | 24.84 | Gravel workings | | | | | | | |
| 501 | 6.68 | 6 | 46 | 45 | 285 | 6 | 64 | 6 | 327 |
| 601 | 5.88 | 14 | 48 | 48 | 267 | 58 | 158 | 158 | 882 |
| Total | 35 * | | | Total (£) | 927 | | | Total (£) | 1589 |
| | | | | (£/ha) | 27 | | | (£/ha) | 46 |
| Probability of : | | | | | | | | | |
| Wet conditions | | | 0.08 | | | | | | |
| Average conditions | | | 0.74 | | | | | | |
| Dry conditions | | | 0.18 | | | | | | |

NB: * Excluding area under gravel workings

**Table 3.11 Maintenance scheme appraisal: River Wensum**

| Average Annual Benefit (£) | Average Annual Benefits (£) | Average Annual Costs (£) | Benefit: Cost Ratio |
|---|---|---|---|
| *Modelled Estimates* | | | |
| Financial Prices | 1589 | 870 | 1.8 |
| Economic Prices | 927 | 870 | 1.1 |
| *Farmer Estimates* | | | |
| Financial Prices | 2287 | 870 | 2.6 |
| Economic Prices | 1507 | 870 | 1.7 |

Farmer assessment gave an average annual financial benefit of £ 2287 and an economic benefit of £ 1507 due to maintenance in average weather conditions. The scheme generates an annual benefit : cost ratio of 2.6 and 1.7 in financial and economic terms respectively. According to farmer assessment therefore, the current maintenance scheme is viable.

### 3.5.7 Environmental impact assessment

An environmental impact assessment of maintenance activities was carried out by Consultants within the framework of the River Maintenance Evaluation Study and under the guidance of Silsoe College. The objectives of this study are presented in Section 1.2.

Short and long term impacts of various maintenance activities on channel, bank and adjacent in-field natural vegetation, aquatic invertebrates, fisheries, birds and mammals were determined. Full details of the methodology followed are presented in the report (R&D 317/16/ST) 'Environmental Impact Assessment Background Documentation'.

**Channel and bank category**

Characteristics of the 12 study reaches were examined and used as the basis for determining channel and bank category. Bank categories were determined from bed width (which influences the degree of potential shading from bank vegetation) and vegetation structure (which influences the fauna that can be supported). In order to minimise differences between assessment systems, the classification adopted for vegetation structure was that used by the River Habitat Survey (RHS) - uniform, simple and complex.

The habitat types within the floodplain which might be affected by vegetation maintenance or changes in maintenance regime were identified. The range of flora and fauna associated with the different river, bank and adjacent land categories were determined and the range of plants and animals likely to occur in each category were identified. This provided a basis for the overall assessment of the potential impacts of vegetation maintenance on each environmental component and allowed checklists of features associated with high wildlife quality to be developed.

**Wildlife quality**

The wildlife quality of the river was used as a basis for determining maintenance best practice. Quality criteria were derived in a two stage process. Firstly, the thresholds of quality for each group of flora and fauna were identified on ecological grounds. Secondly, the structural vegetation features that were present at each level of quality were documented.

The range of river vegetation management practices were identified from NRA sources. A literature review was used to determine the potential impacts of channel and bank maintenance on each environmental component. For the ranges of practices identified, impacts on the quality of flora and fauna in different categories of river and bank as a result of different maintenance regimes were identified. Maintenance practices were classed as best, acceptable, poor and unacceptable.

## 3.6 Summary

This Chapter has reviewed the study methods. Chapter Four applies these methods to obtain the study results.

# 4. RESULTS

This Chapter presents the results of the study. It describes the results of the river engineers' and farmers' survey and the impact assessment of flooding and drainage. The impact of maintenance on different types of aquatic vegetation are discussed and the morphological impacts of maintenance described. Results of the benefit assessment and scheme appraisal are presented. The environmental assessment of maintenance practices is discussed.

## 4.1 Engineers' Survey

Replies to a questionnaire were received from engineers responsible for maintenance on 11 of the 12 sites. No information was obtained concerning the maintenance history of the River Yare. Results from the questionnaires are presented in Tables 4.1 to 4.3.

On eight of the 11 watercourses the main reason for performing maintenance was because it was scheduled as part of an ongoing regular programme (Table 4.1). The result of a recent inspection highlighting the need for maintenance was the determining factor in the case of tree and bush clearance on the River Yarty. Customer demand was the primary reason which led to the desilting of the Hilton Brook. Recent inspection was cited as the second main criteria for determining the need for maintenance. The two exceptions to this were the Woldgrift Drain and River Yarty in which customer demand and a change in management policy were important.

The main criteria for standards of maintenance (Table 4.2) were recommendations following an engineer's survey or supervisor's inspection, and custom and practice. This applies for all the sites. Various criteria were taken into account when selecting the maintenance method. Proven suitability, cost effectiveness and conditions in the watercourse were quoted most frequently. Environmental factors were a consideration on the Dreneuydd/Broadway Reen, River Wensum and River Sence. The availability of skills and machinery were the most important factors in the determination of method in the case of dredging and repairs to bank structures on the River Wampool.

**Table 4.1 Reasons for river maintenance**

| NRA Region | Watercourse | Operation | Reason (In order of importance) |
|---|---|---|---|
| Welsh | River Arrow & Dreneuydd/ Broadway Reen | River bank maintenance<br>Tree & bush clearance<br>Weedcutting | 1. Regular work programme<br>2. Result of recent inspection<br>3. Response to customer demand<br>4. Equipment & labour available |
| | Dysynni Low Level Drain | Weedcutting | 1. Regular work programme<br>2. Result of recent inspection |
| Anglia | Woldgrift Drain | Weedcutting | 1. Regular work programme<br>2. Response to customer demand<br>3. Result of recent inspection |
| | River Wensum | Weedcutting | 1. Response to customer demand<br>1. Change in river condition<br>2. Result of recent inspection<br>3. Regular programme & labour available |
| Severn Trent | River Sence | Desilting<br>Weedcutting | 1. Regular work programme<br>2. Result of recent inspection<br>3. Response to customer demand<br>4. Equipment & labour available |
| | Hilton Brook | Desilting | 1. Response to customer demand<br>2. Result of recent inspection |
| South West | River Yarty | Tree & bush clearance | 1. Result of recent inspection<br>2. Change in management policy<br>3. Labour & equipment available<br>4. Regular work programme |
| | Sir Arthur's Pill | Weedcutting | 1. Regular work programme<br>2. Result of recent inspection<br>3. Labour & equipment available<br>4. Response to customer demand |
| North West | River Wampool & Pilling Water | Weedcutting | 1. Regular work programme<br>2. Result of recent inspection<br>3. Response to customer demand |

In most cases (10 out of the 11), post-maintenance evaluation took the form of a visual inspection by a supervisor, engineer or operations controller. The River Yare was excluded from this analysis through lack of information. The Pilling Water was not generally subject to post-maintenance evaluation and the Dysynni Low Level Drain is subject to occasional evaluation. The river bailiff and an engineer inspected work on the River Yarty whilst the FRCN Officer inspected work completed on the River Sence. The actual maintenance work

completed on the River Sence was compared to recommendations made in a river corridor survey produced by the NRA Conservation Department.

**Table 4.2 Criteria for standards of service**

| NRA Region | Watercourse | Operation | Criteria for SoS | Criteria for method choice |
|---|---|---|---|---|
| Welsh | River Arrow | River bank maintenance | Custom & practice<br>Engineer's survey | Proven suitability |
| | Dysynni Low Level Drain | Weedcutting | Engineer's survey | Proven suitability<br>Cost effectiveness |
| | Dreneuydd/ Broadway Reen | Dredging<br>Weedcutting | Custom & practice<br>Engineer's survey | Proven suitability<br>Watercourse condition<br>Cost effectiveness<br>Environmental factors |
| Anglia | Woldgrift Drain | Weedcutting | Custom & practice | Watercourse condition |
| | River Wensum | Weedcutting | Custom & practice<br>Supervisors inspection | Environmental factors<br>Proven suitability |
| | | Obstruction removal | Supervisors inspection | Proven suitability |
| Severn Trent | River Sence | Desilting | Custom & practice &<br>Engineer's survey<br>Supervisors inspection | Environmental factors & cost effectiveness<br>Proven suitability |
| | Hilton Brook | Desilting | Engineer's survey | Watercourse condition<br>Proven suitability<br>Cost effectiveness |
| South West | River Yarty | Tree & bush clearance | Engineer's survey | Watercourse condition<br>Availability of skills & machinery |
| | Sir Arthur's Pill | Dredge/desilt | Custom & practice | Proven suitability<br>Cost effectiveness<br>Watercourse condition<br>Availability of skills/machinery |
| | | Repair of structures | Custom & practice | Proven suitability<br>Cost effectiveness |
| North West | River Wampool | Dredging | Supervisors inspection | Availability of skills/machinery<br>Proven suitability |
| | | Weedcutting & flail<br>Bank maintenance | Custom & practice<br>Supervisors inspection | Proven suitability<br>Proven suitability<br>Availability of skills/machinery |
| | Pilling Water | Weedcutting & flail | Supervisors inspection | Watercourse condition<br>Proven suitability |

Before maintenance work was carried out on the watercourses, notification was given to various bodies and interested parties as to the extent and nature of work to be undertaken. Such notification took the form of a written or telephone communication, personal visit or at an annual meeting to which interested parties were invited to attend to discuss the planned maintenance activities. More detailed information on the notification procedures is presented in Table 4.3.

**Table 4.3 Notification procedure**

| NRA Region | Watercourse | Operation | Who Notified | Method of Notification |
|---|---|---|---|---|
| Welsh | River Arrow | Bank maintenance, Tree & bush | Landowners/tenant | Phone / visit |
| | | | Fisheries owners | Letter |
| | | | Conservation bodies | Meeting / site visit |
| | Dysynni Low Level Drain | Weedcutting | Landowner/tenant | Phone / visit |
| | Dreneuydd/Broadway Reen | Dredging | Landowner/tenant | Letter / phone |
| | | Weedcutting | Conservation bodies | Meeting / phone |
| Anglia | Woldgrift Drain | Weedcutting | Frontages | Visit |
| | River Wensum | Weedcutting | Conservation bodies | Letter / meeting |
| | | | Frontages | Visit |
| Severn Trent | River Sence | Desilting | Landowners | Visit |
| | Hilton Brook | Desilting | Landowners | Visit / letter |
| | | | Conservation bodies | Site visit |
| | | | Public utilities | Letter / plans |
| | | Weedcutting | Landowners | Visit |
| | | | Conservation/fisheries | Visit / meeting |
| South West | River Yarty | Tree & bush | Conservation/fisheries Pollution control | Meeting / map / survey |
| | | | Landowner/tenant Fisheries owners | Phone / meeting |
| | | | Public utilities | Phone / letter / map |
| | Sir Arthur's Pill | Dredge/desilt | Landowners | Visit |
| | | | Pollution control | Phone |
| North West | River Wampool | All operations | Landowner/tenant | Phone / visit (if machinery involved) |
| | | | Conservation/fisheries bodies | Meeting |
| | Pilling Water | Weedcutting & flail | Landowner/tenant | Visit |
| | | Dredge | Landowner/tenant | Letter & visit |
| | | | Conservation bodies | Meeting |

## 4.2 Land Use and Farming Practice

Table 4.4 shows the benefit area and the number, size and type of farms within the benefit areas. A total of 118 farmers were interviewed on repeat visits. They covered a total of 2618 ha. Overall, average farm size in the sample was 104 ha compared to the national average in

England and Wales of 110 ha. Overall, the main farm types were livestock (37 % of farms), dairy (20 % of farms), specialist cereal (20 % of farms) and general cropping (14 % of farms).

Farm type (and underlying land use) reflect regional patterns: predominantly dairy and livestock farms in the west and arable farms in the east. Arable farms tended to be larger in size than dairy and livestock farms.

Table 4.5 shows the correlation between land use and the installation of field drains which outfall into the river or tributary ditch system. The incidence of field drains is higher on arable land than grassland.

The majority of arable farmers participated in the current set-aside scheme whereby in the study period, approximately 15 % of the area of combine harvested crops remained empty each year. The new subsidy arrangements for livestock limit headage payments to a maximum herd size. Farmers in the study areas for the most part did not exceed these limits and therefore qualified for these subsidies.

**Table 4.4 Sampled farms by scheme, farm size and type**

| Scheme | Benefit Area (ha) | No. of Farms Surveyed | Average Farm Size (ha) | Average SMD Requirement | Type of Farm : % of Farms | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Dairy | Livestock (rearing & fattening) | General Cropping | Specialist Cereal | Pig & Poultry | Horticulture |
| River Arrow | 297 | 12 | 43 | 287 | 17 | 42 | 17 | - | - | 17 |
| Dreneuydd/Broadway Reen | 312 | 17 | 43 | 190 | - | 23 | - | 12 | 6 | - |
| Dysynni Low Level Drain | 452 | 8 | 104 * | 1412 | - | 100 | - | - | - | - |
| River Wensum | 59 | 5 | 131 | 221 | - | - | - | 80 | 20 | - |
| Woldgrift Drain | 264 | 10 | 472 | 477 | - | - | 70 | 20 | 10 | - |
| River Yare | 100 | 7 | 100 | 182 | 14 | - | - | 57 | - | - |
| River Sence | 184 | 8 | 97 | 800 | 38 | 38 | 24 | - | - | - |
| Hilton Brook | 94 | 5 | 69 | 510 | 40 | 20 | - | 40 | - | - |
| Sir Arthur's Pill | 242 | 9 | 86 | 1630 | - | 78 | - | 11 | - | 11 |
| River Yarty | 85 | 13 | 65 | 290 | 38 | 23 | 8 | - | - | - |
| River Wampool | 233 ** | 12 | 71 | 753 | 42 | 33 | 25 | - | - | - |
| Pilling Water | 296 | 12 | 43 | 522 | 50 | 16 | 18 | 8 | - | - |

NB: * Excluding upland grazing areas
** Area of River Wampool and Sally Sough benefit area surveyed in detail

**Table 4.5 Land use and drainage installation**

| Scheme | Benefit Area (ha) | Grassland Area (% of total) | % With field drains (%) | Grass/Arable Rotation | | All Arable Rotation | | Horticulture | | Other *** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Area (% of total) | Field drains (%) | Area (% of total) | Field drains (%) | Area (% of total) | Field drains (%) | Area (% of total) |
| River Arrow | 297 | 65 | 13 | 1 | 0 | 31 | 28 | 2 | 100 | 1 |
| Dreneuydd/Broadway Reen | 312 | 31 | 28 | 15 | 100 | 20 | 0 | - | - | 34 |
| Dysynni Low Level Drain | 452 | 100 | 32 | - | - | - | - | - | - | - |
| River Wensum | 59 | 74 | 13 | 13 | 100 | - | - | - | - | 13 |
| Woldgrift Drain | 264 | 9 | 76 | 6 | 100 | 85 | 99 | - | - | - |
| River Yare | 100 | 46 | 24 | 5 | 0 | - | - | 2 | 100 | 47 |
| River Sence | 184 | 67 | 49 | 29 | 72 | 4 | 100 | - | - | - |
| Hilton Brook | 94 | 43 | 5 | 19 | 11 | 35 | 26 | - | - | - |
| Sir Arthur's Pill | 242 | 74 | 12 | - | - | 16 | 11 | 8 | 58 | 2 |
| River Yarty | 85 | 99 | 52 | - | - | 1 | 0 | - | - | - |
| River Wampool | 233 ** | 71 | 4 | 16 | 100 | 7 | 19 | - | - | 6 |
| Pilling Water | 296 | 46 | 65 | 25 | 83 | 29 | 84 | - | - | - |

NB: ** Area of River Wampool and Sally Sough benefit area surveyed in detail
*** 'Other' includes small holdings and grazing for horses

## 4.3 Drainage Status

Table 4.6 shows the estimates of drainage status with and without river maintenance on the study sites. The table shows the results derived from watertable modelling for wet, average and dry weather conditions occurring in a given season. The table also shows farmer perception of drainage conditions in an average, typical year. Generally, farmers' indicated poorer drainage conditions than the model predicts in the absence of maintenance.

The modelled results confirm that drainage conditions are worse in wet seasons, with or without maintenance. Table 4.6 confirms that maintenance makes its greatest contribution in wet and average seasons. There are exceptions. In the Hilton Brook, maintenance has its biggest impact in dry seasons because at other times, drainage conditions are inherently poor such that maintenance has little impact. It must be recognised however, that impeded drainage could be beneficial if it prevents pastures from drying out in droughty periods.

In an average season, 77 % of the total benefit area experienced good drainage conditions compared to 39 % without maintenance. In wet seasons, these statistics were 50 % and 31 % respectively. In wet seasons with maintenance, 12 % of the total area experienced very bad drainage conditions, whereas without maintenance, this was 26 %.

Farmers assessed that maintenance delivered good drainage conditions on 85 % of the area, compared to 30 % without maintenance.

## 4.4 Flood Risk

The analysis of maintenance on flood risk used a combination of farmer information on area flooded and modelled estimates of flood frequency.

Table 4.7 shows the percentage areas reported by farmers to be affected by flooding and modelled flood return periods for the 'with' and 'without' maintenance situation. Overall, maintenance has the effect of reducing the area which floods more frequently than once per year from 68 % to 54 %. The largest changes in flood risk attributable to maintenance are on the River Wensum and River Yare. These schemes are predominantly for flood defence. They are characterised by relatively heavy undrained soils where the impact of maintenance on watertable levels is small.

**Table 4.6 Drainage status according to maintenance situation and climate**

| Scheme | Maintenance Situation | % Area Wet Weather Conditions | | | % Area Average Weather Conditions | | | % Area Dry Weather Conditions | | | % Area Farmer Assessment Average Conditions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VB | B | G | VB | B | G | VB | B | G | VB | B | G |
| River Arrow | With | - | 54 | 46 | - | 17 | 83 | - | 5 | 95 | - | 11 | 89 |
| | Without | 2 | 80 | 18 | - | 64 | 36 | - | 36 | 64 | 5 | 38 | 57 |
| Dreneuydd/Broadway Reen | With | 20 | 68 | 12 | 10 | 40 | 50 | - | - | 100 | - | 14 | 86 |
| | Without | 56 | 43 | 1 | 17 | 82 | 1 | - | - | 100 | - | 93 | 7 |
| Dysynni Low Level Drain | With | 7 | 18 | 75 | 7 | 8 | 85 | - | 11 | 89 | 7 | 8 | 85 |
| | Without | 15 | 48 | 37 | 7 | 82 | 11 | - | 16 | 84 | 7 | 73 | 20 |
| River Wensum | With | - | 47 | 53 | - | - | 100 | - | - | 100 | - | - | 100 |
| | Without | 21 | 26 | 53 | - | 40 | 60 | - | 17 | 83 | - | 47 | 53 |
| Woldgrift Drain | With | - | 32 | 68 | - | - | 100 | - | - | 100 | - | - | 100 |
| | Without | - | 34 | 66 | - | 20 | 80 | - | - | 100 | - | 18 | 82 |
| River Yare | With | 78 | 13 | 9 | - | - | 100 | - | - | 100 | - | 22 | 78 |
| | Without | 90 | 8 | 2 | - | 26 | 74 | - | 26 | 74 | - | 77 | 23 |
| River Sence | With | 20 | 61 | 19 | - | 60 | 40 | - | 29 | 71 | 9 | 37 | 54 |
| | Without | 65 | 25 | 10 | - | 86 | 14 | - | 69 | 31 | 16 | 74 | 10 |
| Hilton Brook | With | 100 | - | - | 41 | 45 | 14 | - | 41 | 59 | 54 | 37 | 9 |
| | Without | 100 | - | - | 57 | 43 | - | 7 | 63 | 30 | 69 | 31 | - |
| Sir Arthur's Pill | With | 16 | 41 | 43 | - | 49 | 51 | - | 18 | 82 | - | 34 | 66 |
| | Without | 31 | 41 | 28 | 22 | 49 | 29 | - | 18 | 82 | 8 | 85 | 7 |
| River Yarty | With | 29 | 59 | 12 | - | 15 | 85 | - | - | 100 | - | 12 | 88 |
| | Without | 40 | 48 | 12 | - | 15 | 85 | - | 3 | 97 | 11 | 24 | 65 |
| River Wampool | With | - | 16 | 84 | - | - | 100 | - | - | 100 | - | - | 100 |
| | Without | 15 | 14 | 71 | - | 23 | 77 | - | 7 | 93 | 7 | 76 | 17 |
| Pilling Water | With | 6 | 29 | 65 | - | 10 | 90 | - | - | 100 | - | - | 100 |
| | Without | 12 | 55 | 33 | 1 | 31 | 68 | - | 5 | 95 | 0.3 | 66.7 | 33 |
| Total | With | 12 | 38 | 50 | 3 | 20 | 77 | 0 | 7 | 93 | 3 | 12 | 85 |
| Total | Without | 26 | 43 | 31 | 7 | 54 | 39 | 0 | 17 | 83 | 6 | 64 | 30 |

Table 4.7 **Flood risk with and without maintenance**

| Scheme | Area Flooded Reported by Farmers | | Average Flood Return Period * (years) | |
|---|---|---|---|---|
| | Ha | % of BA | With Maintenance | Without |
| River Arrow | 27.16 | 9 | 2.20 | 0.70 |
| Dreneuydd/Broadway Reen | 5.20 | 2 | 0.50 | 0.1 ** |
| Dysynni Low Level Drain | 47.60 | 11 | 1.60 | 0.90 |
| River Wensum | 10.28 | 17 | 3.50 | 0.60 |
| Woldgrift Drain | 25.40 | 10 | 2.00 | 0.50 |
| River Yare | 14.01 | 14 | 3.50 | 0.90 |
| River Sence | 128.65 | 70 | 2.10 | 1.00 |
| Hilton Brook | 47.00 | 50 | 0.84 | 0.30 |
| Sir Arthur's Pill | 0.00 | 0 | | |
| River Yarty | 14.51 | 17 | 3.00 | 0.60 |
| River Wampool | 57.79 | 25 | 2.10 | 0.90 |
| Pilling Water | 21.06 | 7 | 2.00 | 0.60 |
| Total | 398.66 | 15 | | |

NB: * Modelled estimates ** Prolonged winter flooding

## 4.5 Statistical Analysis

Data relating to farming systems within each region were analysed statistically in order to determine relationships and the strength of association and correlation between different land use, soil type, farming system and drainage variables. Full details of this analysis in which the 12 sites were grouped according to NRA Region, are contained in the Interim Report R&D 317/13/ST, December 1994.

Various conclusions can be drawn from the statistical analysis of fields in the benefit area of the maintenance programmes examined. The Annexes to this R&D Note contain statistical results for each individual scheme. The conclusions of the regional analysis are presented here:

- the dominant farming system influences land use within the benefit area;

- land use is strongly associated with soil type;
- soil type and the installation of field drains do not appear to be related. However, land use is strongly associated with soil type and with field drainage installation. A link exists therefore, between soil type and field drainage installation, albeit an indirect association;
- a strong positive relationship exists between grass conservation systems and levels of nitrogen application within the Welsh and Severn Trent Regions. In other areas, levels of nitrogen application and the conservation system are more likely to be determined by farm policy;
- a strong positive relationship exists between nitrogen application rates and installation of field drainage in the Welsh Region;
- field wetness conditions in the spring are dependent upon the installation of field drainage in the Anglian, Welsh and Severn Trent Regions;
- grazing seasons are not generally determined by soil type. They are a function of spring and autumn field wetness conditions which are a function of the presence of field drainage;
- in areas where flooding occurs, land use is associated with flood frequency; and,
- a strong relationship exists between farmer assessment of drainage status and that calculated by the watertable model for the 'with' and 'without' maintenance situation.

It is evident that river maintenance does provide an improved standard of service to land within the benefit area. This is supported by farmer perception of field wetness conditions and those calculated by the watertable model for the 'with' and 'without' maintenance situation. Although land use is determined by the dominant farming system and soil type, land use intensity within the benefit areas is dependent upon flood frequency, spring wetness condition and provision of an adequate outfall for piped drainage. These factors are all influenced by river maintenance.

## 4.6 Aquatic Vegetation

The aquatic vegetation present within the study reaches was identified and classified as submerged, emergent or floating vegetation. Filamentous algae was also present within the study reaches. Algae however, does not impede flow and has no impact on channel capacity. Therefore, algae is not considered here.

Table 4.8 provides information on the types of aquatic vegetation found within each study reach. The River Yarty, Arrow and Hilton Brook are not considered here as they are gravel bed rivers and vegetation growth is limited. These sites were also subject to tree and bush maintenance and not weedcutting.

**Table 4.8 Aquatic vegetation within the study reaches**

| Site | Aquatic Plants Identified within the Study Reaches | | |
|---|---|---|---|
| | Submerged | Emergent | Floating |
| Dreneuydd/Broadway Reen | Canadian Pondweed | Reed Sweet-Grass, Fools Water-Cress, Common Reed | Duckweed, Water Fern, Pondweed |
| Dysynni Low Level Drain | Rush | Reed Sweet-Grass, | Pondweed, Duckweed, |
| Woldgrift Drain | Canadian Pondweed, | Reed Sweet-Grass, Brooklime, Speedwells | Pondweed, |
| River Yare | | Reed Sweet-Grass, Arrowhead | Pondweed, Yellow Water Lilly |
| River Wensum | Canadian Pondweed, Rush | Reed Sweet-Grass, Sedge, Rush | Water-Crowfoot |
| River Sence | Pondweed * Rush | Reed Sweet-Grass, Rush, Fool's Water Cress, Arrowhead | |
| Sir Arthur's Pill | Canadian Pondweed, Rush | Common Reed, Reedmace/Bulrush, Reed Canary Grass | Duckweed, Water Fern |
| River Wampool | Canadian Pondweed, Rush | Reed Sweet-Grass, Reed Canary Grass | Pondweed |
| Pilling Water | Canadian Pondweed, Rush | Reed Canary Grass | Pondweed |

NB: The Pondweed may be classified as a submerged or floating plant according to its dominant form

Canadian pondweed is the most common type of submerged vegetation found within the study reaches. The emergent weed Reed Sweet-Grass was found in seven of the nine sites. Pondweed and Duckweed were the most common forms of floating vegetation identified.

## 4.7 Morphological Impact of Maintenance

Widening or deepening of a river in order to increase the channel capacity reduces the flow velocity and deposition may occur. Vegetation cutting on the bed and banks reduces the overall roughness of the channel and increases the discharge capacity whilst also increasing the flow velocities. This however, may cause erosion. Leaving vegetation to grow without a cutting programme, increases channel roughness, decreases discharge capacity and decreases flow velocities thus causing sediment deposition.

Changing the plan form of a river may cause morphological problems. During the course of this Study, HR Wallingford have developed a classification system which allows the likely morphological impacts of maintenance to be determined. This is presented in Appendix VI. If an actively meandering river is straightened (such as the River Arrow), causing an increase in slope and stream power, the result could be accelerated bank erosion as the river attempts to regain its previous slope and meander pattern. A similar effect may be seen if lateral shifting of part of a channel takes place. A river may be shortened by means of a "cut-off" which realigns or straightens the channel. The effect of this is to increase the channel slope which in turn increase flow velocity. The increase of channel slope enables the transport of more sediment than would be supplied at the upstream end of the channelized reach. The extra sediment is obtained from the bed and bank erosion. Further downstream, where the channel gradient becomes less steep, and velocities are slower, the sediment is deposited.

### 4.7.1 River stability

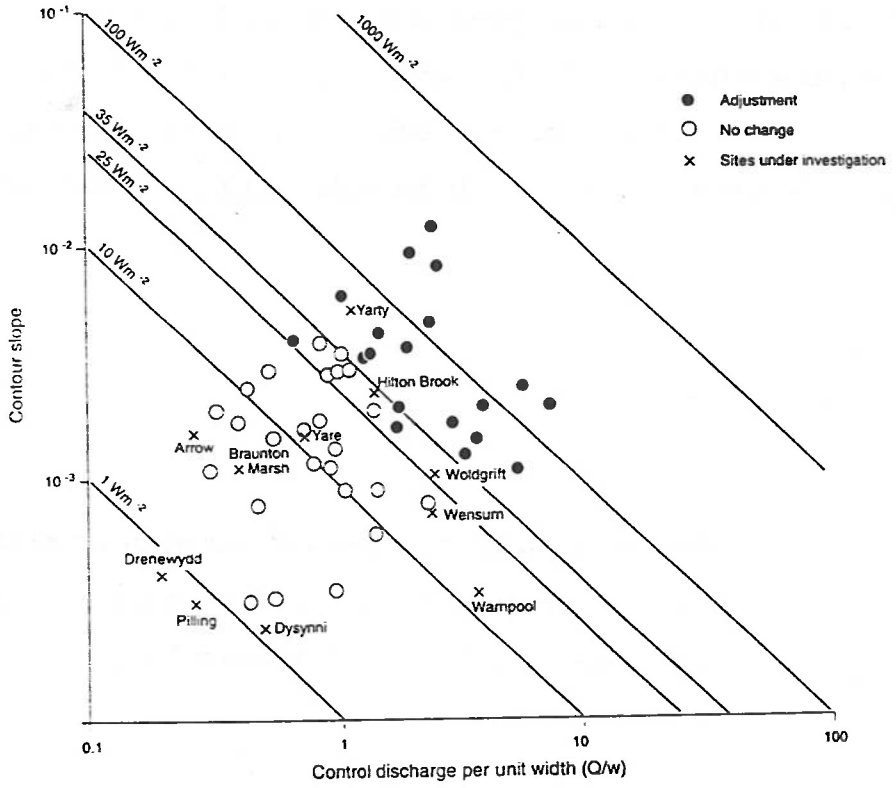
When the capacity of the channel to transport sediment is altered as a result of maintenance, areas of deposition and erosion usually arise. A classification system for rivers (Table 4.9) has been developed by HR Wallingford, to allow the determination of potential impacts of maintenance on channels of different types.

The 12 study sites fall into two distinct categories - those which are likely to experience morphological problems following maintenance and those which are not. Stream power (the rate of energy expended per unit length of the channel) was used as the basis for predicting channel change. Steam power is highly dependent upon gradient. Figure 4.1 provides further information on the stability of each study reach. The Hilton Brook and River Yarty are deemed to be unstable and liable to morphological change following maintenance. The effect

of major maintenance works is therefore short-lived. The Dreneuydd / Broadway Reen, Pilling Water and Dysynni Low Level Drain are the most stable of the study reaches.

**Table 4.9 River classification**

| River Size | Topography / Stream Slope | Plan Form | Bed Material | Stability |
|---|---|---|---|---|
| Canal | Flat | Straight or gently meandering | Sand/silts | Stable |
| Rock cut channel or entrenched in valley | Any slope | - | Bed rock | Stable |
| Controlled river | Stream slope | Straight or meandering | Gravel/sands or silts | Stable |
| River | Flat | Straight or meandering | Sand/silts | Dynamically stable |
| | Hilly slope | Straight or meandering | Gravels/sands | Dynamically stable |
| | Steep | Straight or meandering | Gravels/sands or silts | Dynamically stable |
| River | Steep | Straight or braided | Gravels/sands or cobbles | Unstable |
| Tidal | - | Any plan form | Silts/muds | Unstable |




Source: HR Wallingford (after Brookes, 1988)

**Figure 4.1 River stability (Relationship between bankful discharge, width and slope)**

### 4.7.2 Timescale of morphological change

The rate at which rivers react to maintenance works and the time that elapses before full readjustment is achieved depends on many factors, including :

- magnitude of changes in discharge;
- magnitude of changes in sediment supply;
- nature and size of bed and bank sediments;
- size of the river; and,
- degree to which man-made constraints are applied.

Following vegetation cutting, the timescale of morphological change may be difficult to determine. This is because maintenance procedures and seasonal changes in vegetation structure influence rates of sedimentation and erosion. For example, if the river banks and bed were cut at the beginning of the summer, the roughness would be reduced and discharge capacity and flow velocity would increase. This may initially lead to erosion of the banks and bed whilst the vegetation remains short. As the vegetation grows during the summer, the channel roughness increases, thus reducing discharge capacity and flow velocity. This vegetation serves to reduce and slow down any previous erosion and has the potential to increase deposition as sediment is trapped by the vegetation. Tables 1 to 4 in Appendix VI provide an indication of the time over which changes would be achieved and the nature of changes expected for particular maintenance works. The timescale of change is categorised as follows:

- Long term change, > 20 years
- Medium term change, 10 - 20 years
- Short term change, < 10 years

These timescales may have implications for maintenance in terms of maintenance frequency and the method selected. For example, the morphological impacts of deepening a meandering sand bed river (gentle slope) are generally long lasting (> 20 years, Appendix VI, Table 4).

### 4.7.3 Idealised model studies

The channel parameters for idealised sand, silt and gravel bed channels on which river maintenance is performed were based on the 12 study sites. These idealised channel parameters are shown in Table 4.10.

**Table 4.10 Idealised channel parameters**

| Channel | Gravel | Sand | Silt |
|---|---|---|---|
| Depth (m) | 1.5 | 1.25 | 1.0 |
| Bed width (m) | 12.0 | 9.0 | 6.0 |
| Top width (m) | 16.0 | 15.0 | 14.0 |
| Bed slope (m) | $4 * 10^{-3}$ | $2.5 * 10^{-4}$ | $1 * 10^{-4}$ |
| Discharge range (m3/s) | 0.3 to 500 | 0.3 to 500 | 0.04 to 10 |
| Bankful discharge (m3/s) | 30.0 | 9.0 | 3.0 |

Using these parameters for idealised channels in a morphological model, the impact of maintenance on bankful discharge and water depth over a 30 year period was determined for gravel, sand and silt bed rivers. The impacts of channel deepening (by 5 %, 10 %, 20 %, 25 %, and 40 %) and channel widening (by 5 %, 10 % and 50 %) on bankful discharge capacity and water depth are shown Tables 1 to 6 in Appendix VII. The tables show the impact at the midpoint of the maintenance.

The percentage changes in bankful discharge and water depth are cumulative. For example, if deepening a sand bed channel by 20 % leads to an initial decrease in water depth of 13 % (Appendix VII, Table 5) and the channel is also weed cut resulting in a drop in water depth of 9 %, (Appendix VII, Table 14) the resultant decrease in water depth is 22 %.

#### Widening and deepening

The relative changes in discharge capacity attributable to a single maintenance activity which produces a relative change in channel depth or width are shown in Tables 1 to 3 in Appendix VII. The change in discharge capacity is estimated over the post-maintenance period. The initial impact of deepening the channel is greatest on gravel rivers compared to sand and silt. However, silt rivers are relatively more stable than gravel bed rivers and the impacts of maintenance are longer lasting. In all cases deepening the channel has a greater initial impact on bankful discharge capacity than widening by an equivalent amount. Widening a gravel bed river eventually has a negative impact on discharge as channel capacity is reduced through deposition.

A similar pattern emerges with respect to the impact on water depth of widening and deepening (Appendix VII, Tables 4 to 6). The initial impact is greatest in gravel rivers but the degree of reduction in water depth is longer lived in silt compared to sand and gravel rivers.

To gain an initial large reduction in water depth it is more effective to deepen rather than widen the channel. For a gravel bed channel, the initial decrease in water depth is lost more rapidly when the river is deepened rather than widened, but for a sand bed channel, there seems to be little difference between the rates of change for deepening and widening by similar amounts. In a silt bed channel the initial benefits of both widening and deepening are retained over a 30 year period.

These results appear to be consistent with common practice. Major deepening operations are rarely carried out on gravel rivers and desilting operations on sand and silt rivers are usually carried out at 10 and 20 year intervals respectively.

**Vegetation cutting**

The effect of annual vegetation cutting on discharge capacity in gravel, sand and silt bed rivers varies according to the levels of vegetation 'without' maintenance and the selected cutting intensity (Appendix VII (Tables 10-11, 15-17, 21-23).

In a gravel bed channel where the proportion of vegetation cut and incidence of cutting is usually low, the impact of cutting vegetation has a minor effect on discharge capacity. In sand bed rivers, the increase in discharge capacity due to annual vegetation control, declines over time due to sedimentation. In sand bed channels therefore, weedcutting alone may not be sufficient to maintain standards of service - desilting may be required. In silt bed rivers however, the additional discharge capacity provided by vegetation control is greater than for other river types and discharge capacities remain relatively constant over time with annual vegetation control.

The impact of weedcutting on water depth is shown in Appendix VII (Tables 7-9, 12-14 and 18-20). For typical vegetation cover and cutting regimes, the impact of annual cutting on water depth is greatest in silt rivers and least in gravel bed rivers. The longevity of the impact is also greatest in silt bed rivers.

The tables in Appendix VII can be used to determine for how long and by how much deepening and widening retain the benefits of reduced water depths and increased bankful discharge capacity. For example for a gravel bed channel, the impact on water depth of deepening by 20 % once in 20 years and deepening by 10 % twice in 20 years can be compared. In the first 10 years the benefits are greater in terms of reduced water depth by deepening by 20 % but between 10 and 20 years it would be more beneficial to choose the option of deepening by 10 % twice in 20 years.

The results of the analysis of maintenance longevity have been used to determine the return interval of maintenance activities in the 'Guidelines for the Justification of River Maintenance'.

## 4.7 River Corridor Surveys

The completed river corridor surveys pre- and post-maintenance are presented within the scheme reports. If river maintenance did not alter the channel characteristics, a complete post-maintenance corridor survey was not necessary and the post-maintenance survey took the form of a vegetational survey. This concentrated on the location and percentage cover of channel vegetation. An example of 500 m of a completed river corridor survey and record card is shown in Appendix VIII.

River corridor surveys pre- and post-maintenance for the Hilton Brook and River Sence are contained within the individual scheme reports RIMS Project Evaluation - River Sence and RIMS Project Evaluation - Hilton Brook which were presented to the NRA in 1992.

## 4.8 Environmental Assessment of Maintenance Practices

The 'best practice' vegetation management methods for the 12 study reaches were determined using the channel and bank category and wildlife quality determinants outlined in Section 3.5.4. The channel and bank categories and associated quality are classed as high, medium or low.

### 4.8.1 Channel quality

A checklist of riverine features which indicate high quality was developed during the course of this study by Andrews Ward Associates and others. It enables channel quality to be determined.

The riverine features (each given a numerical code) indicating high channel quality are:

1. well-developed riffle/pool structure with changes in flow speed (except in the slowest drains);
2. varied (but segregated) sediments;
3. extensive beds or well-developed fringes of dense submerged and/or emergent vegetation;
4. well-developed transitional zone between river and edge of channel at times of low flow, with extensive exposed sediments or well-developed band of wetland vegetation, or both;
5. many minor habitat features; submerged tree roots, logs, small backwaters with accumulations of fallen leaves, large rocks, overhanging and trailing branches, marginal flood litter, etc.;
6. four or more forms of aquatic 'macrophyte' plant growth within a 500m stretch; and,
7. overall structure of channel, marginal and bank vegetation showing no more than slight change from historical conditions.

Rivers of the best wildlife quality are likely to hold large amounts of all or most of the features listed. However, a river may still be of high quality if it has several of them in moderate amounts or extensive areas of just one or two. Moderate quality rivers have some of these features along about half of a 500 m reach. Low quality rivers may have a few of them in small amounts or in extreme case all may be absent. The majority of rivers which are managed for vegetation control are inherently less physically diverse than many upland or un-managed lowland rivers so the structure as well as the vegetation is a very important element in determining wildlife interest.

Of the 12 sites, the channel of the River Wensum is classed as high quality. The marginal vegetation is well developed and consists of emergent and submerged plants and many forms of aquatic macrophyte can be found within a 500 m reach. At times of low flow, the transitional zone between the river and channel edge is well developed. Sediments are exposed and a band of wetland vegetation borders the river.

Four channels are of medium quality and the remaining four (Sir Arthur's Pill, River Wampool, Pilling Water and River Sence) are classed as low quality. The Sir Arthur's Pill, Wampool and Pilling Water are all trapezoidal channels with lower channel quality due to lack of variation in channel structure, depth and width. The River Sence is a deep, fast flowing, predominantly sand bed channel. The deep water and fast flows combine to reduce channel quality. If sediments were exposed or pools and riffles were present, channel quality would be enhanced.

### 4.8.2 Bank quality

A checklist of features most often associated with high wildlife value of banks was developed within the course of this study and used to determine the existing wildlife quality of each site.

The riverine features (each given a numerical code) indicating high bank quality are:

1. well-developed transitional zone between river and edge of channel at times of low flow, with extensive exposed sediments or well-developed band of wetland vegetation, or both;
2. roots stabilising banks and providing bank and underwater habitats;
3. herbage of varied heights with a mix of tall stands and shorter areas. If grazed then at low intensity with some areas untouched;
4. stands of bushes or scrub with gaps or glades holding grass and herbs;
5. trees, bushes or (especially on narrow channels) tall herbage overhanging the channel, but not casting continuous dense shade;
6. stands of trees or well-spaced specimens;
7. banks with a wide variety of flowering herbs in spring and early summer (good botanical quality); and,
8. earth cliffs.

Banks of the best wildlife quality are likely to hold large amounts of all or most of these features. However, a bank may still be of high quality if it has several of them in moderate amounts or extensive areas of just one or two. Moderate quality banks will have some of these

features along about half of a 500 m reach. Low quality banks may have a few of them in small amounts or in extreme cases, all may be absent.

The banks of the River Yarty are classed as being of high quality. At times of low flow there is a well developed transitional zone between the river and channel edge and sediments are exposed. The structure of the bank vegetation is varied consisting of trees, bushes, scrub areas and grassland; some of which is grazed by sheep and/or cattle. Tree roots stabilise some banks and provide bank and underwater habitats. Earth cliffs provide ideal habitats for sand martins and kingfishers.

The banks of the River Wensum are of medium to high quality. The trapezoidal channels of the River Wampool, Pilling Water and Sir Arthur's Pill are classed as low quality. The remaining study sites have banks of medium wildlife quality.

### 4.8.3 Maintenance best environmental practice

The 'best practice' vegetation maintenance options in accordance with the channel and bank wildlife qualities identified in Sections 4.8.1 and 4.8.2 are shown in Table 4.11 and Table 4.12. Channel and bank quality are also indicated in the tables along with the numerically coded features from the checklists which are present within the study reach. Although in some cases, a wider range of best practice options are available, those management practices listed represent the very best options on environmental grounds. They should however, be assessed against the option of 'do nothing'. The final choice of maintenance option is likely to depend on other considerations such as the SoS required, maintenance costs and machinery availability.

**Table 4.11 Best practice for channel vegetation management**

| Study Reach | Quality and Features Present | Best Practice Maintenance Options | |
|---|---|---|---|
| | | Emergent Vegetation | Submerged and Floating Vegetation |
| River Sence | Low | Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective | Biennial cutting - selective<br>Cutting 3-5 yr rotation - 10 - 30%<br>Cutting 3-5 yr rotation - selective |
| Dreneuydd/ Broadway Reen | Med. 3/4/6 | Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective | Annual cutting autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective |
| Pilling Water | Low | Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective | Annual cutting autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective |
| River Yare<br>Hilton Brook<br>River Arrow<br>River Yarty | Med. 2/3/5<br>Med. 1/2/4/5<br>Med. 1/2/4<br>Med. 1/5/7 | Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective | Annual cutting autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective |
| River Wampool | Low | Annual cutting autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective | Multiple annual cutting in summer/autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective |
| Woldgrift Drain (upper) | Med. 3/4/6 | Annual cutting autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective | Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective |
| Sir Arthur's Pill | Low | Annual cutting autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective | Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective |
| Dysynni Low Level Drain | Med. 2/3/6 | Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective | Biennial cutting - 10 - 30%<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - 10 - 30%<br>Cutting 3-5 yr rotation - selective |
| Woldgrift Drain (lower) | Low | Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective<br>Desilting/raking on a 2 - 7 year cycle - selective | Biennial cutting - 10 - 30%<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - 10 - 30%<br>Cutting 3-5 yr rotation - selective |
| River Wensum | High 2/3/4/6 | Annual cutting autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective | Multiple annual cutting in summer/autumn - selective<br>Biennial cutting - selective<br>Cutting 3-5 yr rotation - selective |

NB: Quality features present are given a numerical code in accordance with those in the riverine feature checklists

**Table 4.12 Best practice for bank vegetation management**

| River | | Best practice options for bank vegetation management |
|---|---|---|
| Dysynni Low Level Drain | Med. 2/3/7 | Light grazing |
| Woldgrift Drain | Med. 1/6/7 | |
| Sir Arthur's Pill | Low | |
| Pilling Water | Low | |
| Dreneuydd/ Broadway Reen | Med. 3/4/7 | Single annual mowing/flailing in autumn /winter leaving a toe strip 1m+ |
| River Sence | Low | Light grazing |
| River Wampool | Low | |
| River Yare | Med. 3/6/7 | Single bank mowing/flailing in spring /summer leaving a toe strip 1m wide |
| River Yarty | High 1/2/3/4/8 | Single bank mowing/flailing in autumn /winter leaving a toe strip >0.25m |
| Hilton Brook | Med. 2/4/6/8 | Mowing/flailing every 3 - 5 years either leaving a toe strip 1m+ or selective cutting (< 20%) |
| | | Light grazing |
| River Arrow | Med. 2/6/8 | Mowing/flailing every 3 - 5 years either leaving a toe strip 1m+ or selective cutting (< 20%) |
| | | Light grazing |
| River Wensum | Med. - High 3/5/7 | Single bank mowing/flailing in spring /summer leaving a toe strip 1m wide |
| | | Single bank mowing/flailing in autumn /winter leaving a toe strip >0.25m |
| | | Mowing/flailing every 3 - 5 years either leaving a toe strip 1m+ or selective cutting (< 20%) |
| | | Light grazing |

NB: Quality features present are given a numerical code in accordance with those in the riverine feature checklists

Generally, maintenance procedures currently practised in the study reaches conform to those identified as 'best practice' by the 'Guidelines for Determining Vegetation Maintenance Best Practice'. The current maintenance options for each of the weedcutting schemes and recommended changes to the maintenance regime to improve wildlife quality of the channel are shown in Table 4.13. Table 4.14 shows similar information for bank maintenance and recommendations to improve wildlife quality. It must be noted, however, that these changes to maintenance regime could affect the SoS provided, possibly to unacceptable levels. It is recommended that the relationship between SoS and best environmental maintenance practice

be identified with a view to formulating maintenance plans which reconcile the two sets of criteria.

**Table 4.13 Current and best practice channel maintenance**

| Study Site | Current Channel Maintenance | Recommended Changes to Maintenance Regime to Improve Wildlife Quality |
|---|---|---|
| Dreneuydd/Broadway Reen | Weed cut every 18 months | Biennial cutting |
| Dysynni Low Level Drain | Annual weed cut in summer, 100 % removed | Biennial, selective cutting |
| River Wensum | Annual weed cut, 60 % removed in summer, uncut strip down each margin | Cut in the autumn |
| Woldgrift Drain | Annual weed cut in summer, 1 m fringe left down each margin | |
| River Yare | Annual weed cut in summer, 60 % removed, desilting every 7 years | Cut in autumn |
| River Sence | Annual weed cut, 60 % removed | Cut every 2 years |
| Sir Arthur's Pill | Weed cut every 18 months, autumn/winter, 100 % removed | Selective cutting |
| River Wampool | Annual weed cut summer/autumn, 100 % removed | Selective cutting, leave margin of vegetation |
| Pilling Water | Annual weed cut in summer/autumn, 100 % removed | Selective cutting |

**Table 4.14 Current and best practice bank maintenance**

| Study Site | Current Bank Maintenance | Recommended Changes to Maintenance Regime to Improve Wildlife Quality |
|---|---|---|
| Dreneuydd/Broadway Reen | Grazed extensively | Increase grazing intensity or simulate grazing through flail mowing |
| Dysynni Low Level Drain | Grazed, cut | Grazing |
| River Wensum | Grazed | Single bank mowing, leaving a toe strip |
| Woldgrift Drain | Flail mown | Light grazing (As arable area, alter flail regime to simulate grazing) |
| River Yare | Grazed | Selective mowing |
| River Sence | Grazed | Reduce grazing intensity, leave toe strip 1 m wide |
| Sir Arthur's Pill | Intensively grazed | Reduce grazing intensity |
| River Wampool | Grazed intensively | Reduce grazing intensity, flail leaving toe strip 1 m wide |
| Pilling Water | Grazed, flail mown | Reduce grazing intensity and abandon flail mowing |

## 4.9 Benefit Assessment and Scheme Evaluation

### 4.9.1 Benefits

Table 4.15 summarises the estimates of value added from agriculture for typical land uses, assuming different drainage conditions and financial and economic prices. The benefits associated with preventing a given deterioration in drainage status are also shown. The values in Table 4.15 are based on examples derived from the study sites.

Table 4.16 shows typical values for annual flood damage costs by land use, drainage and the return period of the event. These flood costs are based on those for a large catchment (> 25 $km^2$) in which flooding occurs mainly during the winter months. Flood costs are not shown for horticultural enterprise as these are not grown on land prone to flooding.

**Table 4.15 Representative net returns according to drainage**

| Land Use | Scheme | Financial Prices (£/ha) | | | Change in Net Return (£/ha) | | |
|---|---|---|---|---|---|---|---|
| | | Good | Bad | Very Bad | Good to Bad | Bad to Very Bad | Good to Very Bad |
| Extensive grass | Dysynni Low Level Drain | 315 | 249 | 194 | 65 | 56 | 121 |
| Intensive grass | River Wampool | 463 | 357 | 285 | 106 | 72 | 178 |
| Grass/arable rotation | River Sence | 264 | 237 | 145 | 27 | 92 | 119 |
| All cereals | Hilton Brook | 399 | 338 | 222 | 61 | 116 | 177 |
| Cereal/oil seed rotation | Woldgrift Drain | 491 | 416 | 314 | 75 | 102 | 177 |
| Cereal/root crop rotation | Pilling Water | 566 | 301 | 74 | 265 | 227 | 492 |
| Horticulture | Sir Arthur's Pill | 1500 | 750 | 150 | 750 | 600 | 1350 |

| Land Use | Scheme | Economic Prices (£/ha) | | | Change in Net Return (£/ha) | | |
|---|---|---|---|---|---|---|---|
| | | Good | Bad | Very Bad | Good to Bad | Bad to Very Bad | Good to Very Bad |
| Extensive grass | Dysynni Low Level Drain | 153 | 110 | 74 | 42 | 37 | 79 |
| Intensive grass | River Wampool | 394 | 321 | 188 | 73 | 133 | 206 |
| Grass/arable rotation | River Sence | 126 | 105 | 46 | 21 | 59 | 80 |
| All cereals | Hilton Brook | 339 | 227 | 154 | 112 | 73 | 185 |
| Cereal/oil seed rotation | Woldgrift Drain | 434 | 357 | 249 | 77 | 108 | 185 |
| Cereal/root crop rotation | Pilling Water | 370 | 307 | 199 | 63 | 108 | 171 |
| Horticulture | Sir Arthur's Pill | 1500 | 750 | 122 | 750 | 628 | 1378 |

**Table 4.16 Typical flood costs**

| Land Use and Drainage Status | Flood Costs (£/ha) According to Flood Return Period (years) | | | | |
|---|---|---|---|---|---|
| | FRP 0.50 | FRP 2 | FRP 4 | FRP 6 | FRP > 10 |
| ***Extensive grass*** | | | | | |
| Good | 19 | 5 | 2 | 2 | 1 |
| Bad | 13 | 3 | 2 | 1 | 1 |
| Very Bad | 11 | 3 | 1 | 1 | 1 |
| ***Intensive grass*** | | | | | |
| Good | 42 | 11 | 5 | 4 | 2 |
| Bad | 31 | 8 | 4 | 3 | 2 |
| Very Bad | 21 | 5 | 3 | 2 | 1 |
| ***Grass/arable rotation*** | | | | | |
| Good | 83 | 15 | 7 | 6 | 3 |
| Bad | 69 | 12 | 6 | 5 | 2 |
| Very Bad | 49 | 10 | 5 | 4 | 2 |
| ***All cereals*** | | | | | |
| Good | 120 | 19 | 9 | 7 | 4 |
| Bad | 105 | 17 | 8 | 6 | 3 |
| Very Bad | 88 | 16 | 8 | 6 | 3 |
| ***Cereal/oil seed rotation*** | | | | | |
| Good | 127 | 19 | 9 | 7 | 4 |
| Bad | 107 | 17 | 8 | 6 | 3 |
| Very Bad | 90 | 16 | 8 | 6 | 3 |
| ***Cereal/root crop rotation*** | | | | | |
| Good | 275 | 48 | 23 | 19 | 9 |
| Bad | 222 | 38 | 18 | 15 | 7 |
| Very Bad | 84 | 15 | 8 | 6 | 3 |

* Flood costs are based on large catchment, predominantly winter flooding

### 4.9.2 Scheme evaluation

The performance of maintenance was assessed on 12 sites. However, on four of these sites (Rivers Arrow, Sence, Wampool and Yarty) the analysis was extended to include different maintenance combinations and/or definitions of the benefit area.

Using the methods described in Chapter 3, expected annual benefits were aggregated at scheme level and set against the average annual cost to determine a benefit cost : ratio (Table 4.17). These benefit and cost estimates are expressed per hectare in Table 4.18 for ease of interpretation. A number of points can be made.

The modelled results generate average annual economic benefits per scheme of between £ 4 and £ 66/ha, with a mean of £ 21/ha. In financial prices, benefits are higher with a mean of £ 30/ha.

**Table 4.17 Summary of total maintenance benefits (£)**

| Scheme | Model Economic | Model Financial | Farmer Economic | Farmer Financial | Maintenance Cost | Benefit : Cost Ratio Economic | |
|---|---|---|---|---|---|---|---|
| | | | | | | Model | Farmer |
| | £ | £ | £ | £ | £ | £ | £ |
| River Arrow -TB | 5120 | 7771 | 2562 | 4557 | 5097 | 1 | 0.5 |
| River Arrow - TB/Db | 9720 | 14361 | 2562 | 4557 | 6597 | 1.5 | 0.4 |
| Dreneuydd/Broadway Reen | 4211 | 6208 | 5501 | 8362 | 4650 | 0.9 | 1.2 |
| Dysynni Low Level Drain | 6232 | 17011 | 5789 | 15831 | 11600 | 0.5 | 0.5 |
| River Wensum | 927 | 1589 | 1507 | 2287 | 870 | 1.1 | 1.7 |
| Woldgrift Drain | 3627 | 4076 | 29490 | 31037 | 3464 | 1.1 | 8.5 |
| River Yare | 450 | 929 | 2105 | 2592 | 900 | 0.5 | 2.3 |
| River Sence - W/Db | 5163 | 5800 | 6597 | 8138 | 7380 | 0.7 | 0.9 |
| River Sence -D/W/TB/Db | 5163 | 5800 | 6597 | 8138 | 11490 | 0.5 | 0.6 |
| Hilton Brook | 5052 | 5342 | 6922 | 7767 | 5635 | 0.9 | 1.2 |
| Sir Arthur's Pill | 5009 | 7666 | 2483 | 23571 | 5430 | 0.9 | 0.5 |
| River Yarty -TB | 334 | 384 | 1252 | 1631 | 297 | 1.1 | 4.2 |
| River Yarty -TB/Db | 1000 | 3330 | 1252 | 1631 | 3000 | 0.3 | 0.4 |
| River Wampool - detailed study | 3570 | 2850 | 15414 | 11640 | 3750 | 1 | 4.1 |
| River Wampool - extended study | 20870 | 16660 | 90100 | 68040 | 11890 | 1.8 | 7.6 |
| Pilling Water | 8080 | 13209 | 11737 | 27268 | 11344 | 0.7 | 1 |

NB: Farmer assessment of benefits are based on perceived deterioration in drainage status without maintenance in an average weather year
Modelled estimates show benefits of maintenance weighted by probability of wet, average and dry seasons occurring
TB = Tree & Bush, Db = Debris removal, D = Desilting, W = Weed cutting

**Table 4.18 Summary of maintenance benefits (£/ha)**

| Scheme | Model Economic | Model Financial | Farmer Economic | Farmer Financial | Maintenance Cost | Benefit : Cost Ratio Economic | |
|---|---|---|---|---|---|---|---|
| | | | | | | Model | Farmer |
| | £/ha | £/ha | £/ha | £/ha | £/ha | £ | £ |
| River Arrow -TB | 18 | 27 | 9 | 15 | 17 | 1 | 0.5 |
| River Arrow - TB/Db | 33 | 48 | 9 | 15 | 22 | 1.5 | 0.4 |
| Dreneuydd/Broadway Reen | 13 | 20 | 18 | 27 | 15 | 0.9 | 1.2 |
| Dysynni Low Level Drain | 14 | 38 | 13 | 35 | 26 | 0.5 | 0.5 |
| River Wensum | 27 | 46 | 44 | 66 | 25 | 1.1 | 1.7 |
| Woldgrift Drain | 14 | 15 | 112 | 118 | 13 | 1.1 | 8.5 |
| River Yare | 9 | 18 | 21 | 26 | 9 | 0.5 | 2.3 |
| River Sence - W/Db | 28 | 32 | 36 | 44 | 40 | 0.7 | 0.9 |
| River Sence -D/W/TB/Db | 28 | 32 | 36 | 44 | 62 | 0.5 | 0.6 |
| Hilton Brook | 54 | 57 | 74 | 83 | 60 | 0.9 | 1.2 |
| Sir Arthur's Pill | 21 | 32 | 10 | 97 | 22 | 0.9 | 0.5 |
| River Yarty -TB | 4 | 4 | 15 | 19 | 3 | 1.1 | 4.2 |
| River Yarty -TB/Db | 12 | 39 | 15 | 19 | 35 | 0.3 | 0.4 |
| River Wampool - detailed/extended | 15 | 12 | 66 | 50 | 16 | 1 | 4.1 |
| Pilling Water | 27 | 45 | 40 | 92 | 38 | 0.7 | 1 |

NB: Farmer assessment of benefits are based on perceived deterioration in drainage status without maintenance in an average weather year
Modelled estimates show benefits of maintenance weighted by probability of wet, average and dry seasons occurring
TB = Tree & Bush, Db = Debris removal, D = Desilting, W = Weed cutting
Figures have been subject to rounding

For the most part, farmer assessment of average maintenance benefits are higher than modelled estimates, ranging from £ 9 to £ 112/ha in economic prices, with a mean of £ 33/ha. Farmer estimates tend to be higher because farmers did not distinguish those years when maintenance would have little impact. Responses may have been biased to overestimate rather than underestimate maintenance benefits in order to secure future standards of service.

Maintenance costs varied from £ 3 to £ 62/ha depending on the intensity of maintenance and the size of the benefit area. Average costs were £ 27/ha.

The Benefit : Cost ratios show that, for the assumptions made, the model results indicate that of the 12 schemes (and four variants):

7 schemes gave benefit : cost ratios > 1
3 schemes gave benefit : cost ratios <1 and > 0.8
2 schemes gave benefit : cost ratios < 0.8 and > 0.6
4 schemes gave benefit : cost ratios < 0.6

By comparison, the farmer assessments gave:

9 cost : benefit ratios > 1
1 cost : benefit ratio < 1 and > 0.8
1 cost : benefit ratios < 0.8 and > 0.6
5 cost : benefit ratios < 0.6

In three out of 16 cases, farmer assessment of benefit : cost were lower than modelled estimates. In three cases, farmer assessments were higher by a factor of as much as four or more. These latter cases mainly involved arable production particularly sensitive to changes in drainage status. The results are variable but key factors emerge. Benefit : cost is favourable where:

- benefits/ha are high due to high value land use which is sensitive to changes in standards of drainage service if maintenance is withdrawn;
- average maintenance costs/ha are low because the work is spread over a relatively large benefit area; and,
- the best performing schemes have both these attributes.

## 4.10 Summary

This chapter has reported on results of the study of river maintenance on 12 sites and of methods of analysis which have been developed and applied. These provide the framework for guidelines on best practice which are described in the next chapter.

# 5. GUIDELINES

## 5.1 Introduction

There is increasing pressure to justify river maintenance in terms of the cost of carrying out the work and the benefits of maintaining standards of service. There is also a requirement to adopt the optimum maintenance regime which will enable the provision of adequate SoS whilst maintaining or enhancing existing environmental interest.

The output from this River Maintenance Evaluation Study includes 'Guidelines for the Justification of River Maintenance'. Contained within this document (R&D Note 511) are:

Guidelines for the justification of river maintenance;
Guidelines for determining best practice vegetation management in channel; and,
Guidelines for determining best practice vegetation management on banks.

Further details are presented below.

## 5.2 Guidelines for the Justification of River Maintenance

These guidelines enable the user to determine the appropriate maintenance regime in order to provide a particular standard of service. They are aimed at those with responsibility for determining the type and extent of river maintenance to be performed. They provide a routine for the justification of maintenance regimes in terms of the impact on standards of land drainage service, flood risk and financial / economic benefits and costs of maintenance.

### 5.2.1 Use of guidelines for the justification of river maintenance

The guidelines can be used on rivers / drainage channels which provide a land drainage service to adjacent land or in areas such as the Somerset Moors and Levels which are served by a system of ditches - which drain into a main channel. The guidelines may be used on a catchment wide basis at different levels of resolution. The river sub-reaches may be aggregated into reaches, sub-catchments and catchments according to major differences in drainage condition, flood frequency, soil type and land use.

The guidelines for the justification of river maintenance may be used for a variety of purposes such as:

- to audit the impacts of alternative levels of maintenance;
- to reconcile alternative levels of maintenance and their benefits;
- to study 'what if?' scenarios;
- to compare the benefits of alternative maintenance strategies;
- to determine whether maintenance is required or can be justified; and,
- to justify the flood protection provided by highland carriers.

### 5.2.2 Limitations to use

The guidelines will be revised following further testing by the NRA. Throughout the formulation of these guidelines, comments and modifications suggested by NRA Flood Defence staff (in the Severn Trent, North West, South West and Northumbria and Yorkshire Regions) have been acted upon.

There are some limitations to use of these guidelines. These are listed below:

- they are based on idealised gravel, sand and silt bed channels, the parameters of which were derived from the 12 study sites (Section 4.7.3). Without further testing, the guidelines cannot be applied to channels of all sizes with confidence. They can be applied with confidence to sand channels of bed width 5 to 11 m and to silt channels of bed width 3 to 7 m. Beyond these ranges, the guidelines must be used with caution;
- they are not designed for use on chalk streams;
- they are not to be used to encourage additional maintenance unless the current level of maintenance is deemed to be inadequate to maintain the desired standard of service; and,
- they are not to be used to evaluate the drainage function of highland carriers because highland carriers do not provide an outfall service for field drains and ditches in the adjacent lowland areas.

### 5.2.3 Format of the guidelines for maintenance justification

The user is taken step by step through the guidelines in a logical progression according to the type of river and maintenance regime. These guidelines take the form of tables and charts supported by written instructions. The user is required to complete a record sheet whilst proceeding through the guidelines. The actual information which is required by the user to feed into the record sheet and guidelines has been kept to a minimum. The majority of information required is provided.

To justify the maintenance regime in monetary terms, the user is required to feed into a record sheet average channel parameters of the reach to be maintained (width, depth, freeboard, bankful discharge, dominant land use, soil type and benefit area). At each stage, if knowledge of, for example, land use and soil type is limited, help and information is included in the guidelines. Default values are provided for many parameters. Details of the maintenance regime and costs are required.

By selecting values from various tables and figures, the user is able to determine the impact of widening, deepening and removal of aquatic vegetation on channel capacity, flooding and standard of drainage service in the floodplain for the 'with' and 'without' maintenance situation. Tables are provided which allow the user to determine the financial and economic benefit of the maintenance regime, taking into account the maintenance cost, maintenance interval and longevity of the impacts.

A top copy of each of the record sheets is provided with the guideline document. These need to be retained and photocopied in order for them to be used for each separate evaluation.

## 5.3 Guidelines for Determining Best Practice

Two sets of guidelines have been produced to help determine maintenance best practice in environmental terms. The 'Guidelines for Determining Maintenance Best Practice in Channel and the 'Guidelines for Determining Maintenance Best Practice on Bank', form separate chapters in R&D Note 511. They enable the best practice maintenance option in environmental terms to be determined on the basis of the wildlife quality.

### 5.3.1 Use of guidelines for determining best practice

Their purpose is to facilitate the selection of maintenance practices for channel and bank vegetation which are best for wildlife. They should be used in conjunction with the 'Guidelines for Justification of River Maintenance'.

### 5.3.2 Limitations to use

The 'Guidelines for Determining Best Practice' are based on qualitative data. At the present time, no quantitative data exist on the impact of maintenance regimes on environmental quality. The use of quantitative data may increase the accuracy of these guidelines. These guidelines will be revised following further testing by the NRA. Throughout their formulation, comments and modifications suggested by NRA FRCN staff (in the Severn Trent) have been acted upon.

Limitations in the use of these 'Guidelines for Determining Best Practice' are listed below:

- photographs are not always an adequate substitute for site visits due to a variety of reasons. It may be difficult to identify the gradient of the watercourse and the range of photographs available may not fit the observed bank and channel forms and river bed widths, therefore proving difficult to categorise the channel and banks. Generally, site visits will be required;
- if photographs are used, they must be taken at a time of year when it is easy to see and identify the type of aquatic vegetation present and they must enable an assessment to be made of the environmental quality of areas adjacent to the watercourse;
- these guidelines must not be used as a basis for re-engineering managed channels to raise stage levels and under some circumstances potentially reduce or abandon the requirement for vegetation maintenance;
- further testing is necessary to confirm the approach taken by these guidelines; and,
- these guidelines are not designed for use on chalk streams.

### 5.3.3 Format of the guidelines for determining best practice

Both the channel and bank environmental guidelines are based on a decision tree which works through the main factors which influence best environmental practice. The river is initially classified according to width and gradient. Each class is subsequently divided according to the vegetational structure of the bed and bank and the floodplain community. Other parameters such as soil type, landform and freeboard are also taken into account. Based on the classes mentioned above, the channel and bank quality are determined. The guidelines are supported by check lists and a comprehensive set of photographs which illustrate river category, class and quality.

## 5.4 Conclusion

All the guidelines are in a practical form and can be introduced immediately. They can be updated and modified as required in order to reflect appraisal of the techniques and as further environmental information becomes available.

# 6. CONCLUSIONS AND RECOMMENDATIONS

This Chapter summarises the aims and results of the Study and draws a number of conclusions. Recommendations are made for further work.

## 6.1 Summary

The aim of this study was to develop and verify methods and databases which assess the benefits associated with alternative maintenance strategies in rural, predominantly agricultural catchments. For this purpose 12 river sites were selected for study. Maintenance activities involved weedcutting, tree and bush maintenance and desilting. Pre- and post-maintenance surveys were carried out which included:

- farmer surveys which covered farming systems, land use, drainage status, flooding, environment and views on the impact of maintenance;
- drainage surveys which identified the drainage network in the benefit area;
- soil surveys which identified the texture and hydraulic conductivity of soils in the benefit area;
- cross-sections pre- and where maintenance altered channel cross-section, post-maintenance;
- river corridor surveys which identified the environmental features of the channel and river corridor; and,
- a river engineers' survey to examine the decision making-process and current rationale for maintenance.

Routines for data collection and analysis were developed which link maintenance standards in river and arterial drainage systems with waterlogging and flood risk and hence agricultural productivity in the benefit area. These methods were used to evaluate the extra annual financial and economic benefits attributable to maintenance and to set these against annual maintenance costs.

Using modelled estimates of economic benefits, seven of the 12 schemes and their variants are justifiable in economic terms (benefit : cost ratio > 1). A further three are marginal (benefit : cost ratio between 0.8 and 1) and within the confidence of the analysis could be deemed economically viable. Farmer assessment results in nine schemes being economically viable and one marginal.

Guidelines for the justification of river maintenance and determination of vegetation maintenance best practice in channel and on banks have been developed.

## 6.2 Conclusions

The conclusions presented here relate to the study and its findings as a whole. Conclusions specific to each scheme are contained within the individual scheme reports, submitted as Annexes to this R&D Note (Project Records R&D 317/18-22/ST).

### 6.2.1 General conclusions

The main components of river maintenance evaluation are:

- the maintenance activity;
- river and floodplain characteristics;
- flooding and drainage status;
- land use and farming system; and,
- environmental criteria.

### 6.2.2 Research project management

A number of conclusions can be drawn from the research management experience:

- site selection and scheduling of maintenance work and site surveys were critical factors;
- close collaboration between the NRA and the research contractor were essential. Where collaboration was difficult, alternative sources of information were used;
- an initial briefing workshop was beneficial. Regular contact and meetings with Flood Defence Managers throughout the study were invaluable;
- ongoing review and evaluation of research output and best practice guidelines with NRA throughout the project was beneficial; and,

- interest and support by the NRA Project Manager was critical to successful completion of the study.

### 6.2.3 Assessment methods

A number of conclusions can be drawn regarding the methods used to assess maintenance:

- flood risk and drainage status pre- and post-maintenance should be derived from multiple sources;
- farmers' views tend to be subjective, relying on recall with respect to pre-maintenance conditions. They are also influenced by prevailing climatic conditions. Detailed questioning and repeat visits are necessary;
- flood routing and watertable modelling provide objective assessments but require additional data relating to river and floodplain profiles, hydrological and climatic data and information on soil types;
- a positive correlation was shown between drainage assessments derived from farmer sources and watertable modelling;
- using data from farm survey and farmers, it was possible to compile estimates of agricultural benefits associated with different standards of drainage service afforded by maintenance;
- the methods recognised that maintenance benefits vary according to the type of weather year. Estimates of expected average annual benefits attributable to maintenance in wet, average and dry conditions were calculated;
- pre- and post-maintenance environmental impact assessment is an important element of maintenance design, monitoring and evaluation. The 'best practice' maintenance guidelines will enable environmental quality to be monitored;
- there are different ways of achieving the required SoS. Maintenance activities are inter-related: maintenance such as desilting may not be beneficial without subsequent annual weed maintenance, but annual weed maintenance may reduce the need for desilting; and,
- the evaluation methods used in the study have been simplified to provide standard data and simplified routines for river maintenance justification in the form of guidelines.

### 6.2.4 Maintenance evaluation results

A number of conclusions are drawn regarding the results of evaluation:

- agricultural benefits do not necessarily reflect the level of expenditure on maintenance i.e. the results show that a comparatively expensive desilting operation which increases channel capacity and lowers river water levels does not necessarily produce greater benefits than less expensive weed maintenance activities;

- those factors which have been identified as having an influence on the presence or absence of benefits and the scale of the benefits include:

  **river characteristics**, including pre-maintenance freeboard levels and the extent to which the freeboard is changed as a result of maintenance;

  the degree to which the water levels are changed as a result of maintenance activities is partly a function of type of maintenance. For example, desilting may change river water levels by a greater amount than tree and bush maintenance;

  **floodplain characteristics**, the soil characteristics in the benefit area affect the responsiveness of watertable depth to changes in river water level. In particular, the hydraulic conductivity and drainable porosity (specific yield) of the soils influence the speed and extent of movement of water through the soil. Heavy clay soils are less responsive to maintenance than lighter soils;

  the drainage system in the benefit area is also shown to influence the extent to which watertable depth responds to changes in river water level. An intensively drained system (either intensive ditch system or field drainage) is more sensitive to changes in river water levels than a less intensive drainage system;

  the width of the floodplain (or benefit area) has an impact on the degree to which maintenance activities have an impact on drainage status. If the floodplain is narrow (River Yarty), the area deriving benefits from maintenance are small compared to those on a wider floodplain (River Wampool);

**farming system characteristics**, including intensity of land use, responsiveness of land use to changes in drainage status and farmers' perceptions of drainage constraints on field management;

drainage status is not always the dominant factor in determining field management. Farm type affects the type of management on the farm as a whole and the particular land use within the benefit area; and,

the most important variables influencing the justification of maintenance are the agricultural benefits per hectare, the size of the benefit area, and the cost of maintenance activities.

A general conclusion can be drawn. That is, the more intensive the land use, the better is the standard of field drainage (either due to piped underdrainage or freely draining soils), the greater is the sensitivity to standards of maintenance, and, the greater the justification and scope for expenditure on river maintenance.

## 6.3 Recommendations

The recommendations relate to further monitoring and research and to the testing of the guidelines. Specific recommendations for each individual site are contained within the scheme reports (Project Records R&D 317/18-22/ST).

It is recommended that:

- a debriefing workshop is held to disseminate results of this study and use of the guidelines;
- training is provided in the use of the guidelines for maintenance justification and determination of 'best practice' through workshops;
- the guidelines are tested throughout the NRA on channels of various types on which different maintenance regimes are practised;
- the guidelines for the justification of river maintenance are produced in a simple spreadsheet format to aid rapid use and to limit the need for the user to interpret graphs and to read off tables;

- the compatibility of the guidelines for maintenance justification with other systems such as the Flood Defence Management System (FDMS) is assessed;

- 'best-practice' examples of river management should be implemented and monitored as demonstration models to practitioners. This should ideally be on a reach with some high quality wetland/wet grassland habitats, water features such as standing water, ditches in the flood plain and permeable soils. It is recommended that the effect of the maintenance regime on the surrounding habitats is monitored;

- long-term monitoring of the effects of different vegetation maintenance on different environmental components is advised. Some effects occur very quickly, for example, loss of nesting cover for birds, while others will take longer. It is possible to identify a suite of watercourses incorporating the eight river types with moderate wildlife value and run different maintenance regimes on them. Changes in the quality of the wildlife assemblages in response to different practices could then be evaluated over time and the justifications for changing existing practices evaluated in wildlife terms, and, if desired, against economic and technical criteria;

- the relationship between SoS and best environmental maintenance practice be identified with a view to formulating maintenance plans which reconcile the two set of criteria;

- a quantitative method for determining environmental assessment is developed;

- the hydraulic effects of changes from less desirable practices to acceptable and best practice should be monitored;

- to enable the methodology of the guidelines for vegetation maintenance best practice to be assessed and refined, a method of appraising the benefits and disbenefits is required. It will be possible to use the system of quality criteria developed within the guidelines as a means of assessing the impacts of maintenance operations on each environmental component. It is recommended that annual assessment is undertaken to build up a good indication as to the long-term effects of different methods of vegetation maintenance;

- in areas of notable conservation interest or where there is high restoration potential, water level management plans need to be produced. To be formulated effectively, these demand

quantitative estimates of water-regime requirements. Research experience suggests that these are best estimated from an analysis of the distribution of existing vegetation stands and quantified in terms of tolerance to stress. It is recommended that research is undertaken to derive tolerance limits for species or communities which are transferable between sites; and,

- the impact of debris dams on retained water levels, flood risk and flooded area is quantified and their environmental attributes assessed where relevant.

## 6.4 Epilogue

This report has reviewed the aims, objectives, methods and results of river maintenance on 12 sites in England and Wales. The study has combined organisational, hydrological, economic and environmental criteria. It has met the stated objectives of developing data and methods to support the river maintenance management function. These have been produced in the form of guidelines for practitioners with respect to the economic and environmental assessment of proposed maintenance activities.

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# APPENDIX I

## RIVER MAINTENANCE ENGINEERS QUESTIONNAIRE

Note to Engineers/Supervisors: Could you please have a look through the scheme files for the watercourse named below and answer the following questions relating to previous and planned work.

**1. NRA Region**
**2. Watercourse and reach selected for study**

**3. Details of work previously carried out in the study reach:**

a) capital works

| Maintenance type | Y/N | Brief description | Date performed | Location | Cost |
|---|---|---|---|---|---|
| Regrading | | | | | |
| Resectioning | | | | | |
| Embankments / Revetments | | | | | |
| Structures | | | | | |
| Other (please specify) | | | | | |

b) Maintenance

| Maintenance operation | Date last performed | Method / equipment used | Usual timing | Usual frequency |
|---|---|---|---|---|
| Dredging/desilting | | | | |
| Repairs to structures | | | | |
| Repairs to banks | | | | |
| Tree maintenance | | | | |
| Bush clearance | | | | |
| Debris removal | | | | |
| Weed clearance | | | | |
| Other (please specify) | | | | |

c) If weed removal by use of herbicides:-

- what herbicide was used ? _____

- was the aim complete eradication, controlled growth or occasional control ?

d) If weed clearance is necessary, have environmental and/or biological control methods been considered ? Y / N.

If yes, please outline briefly:-

e) If dredging/desilting or weedcutting has been performed, was the work carried out in an upstream or downstream direction ? _____

**4. Reasons behind decision to perform maintenance:-**

Please rank (1,2,3 etc.), in order of importance, those factors which influenced the decision to undertake maintenance activities on this stretch of river this year (1992). Leave blank those factors which are not relevant.

| Factor | Rank |
|---|---|
| Response to customer demands | |
| Recent inspection highlighting need for maintenance | |
| Part of a regular work schedule | |
| Labour and equipment available | |
| Change in management policy | |
| Change in river condition (e.g. upstream urbanisation) (please state change) | |
| Other (please specify) | |

**5. Please list, in your view, for the stretch of river concerned:-**

a) Beneficial impacts of the proposed maintenance activities.
b) Non-beneficial or negative impacts of the proposed maintenance activities.

| Maintenance operation | Beneficial impacts | Negative impacts impacts |
|---|---|---|

**6. For the maintenance operations carried out on the watercourse concerned in 1992, please identify:-**

the criteria for the standards of maintenance:-

e.g. a) custom & previous practice
b) supervisors inspection
c) engineer's appraisal & survey
d) other (please specify)

and the methods used:-

e.g. a) conditions in the watercourse
b) environmental factors
c) proven suitability
d) cost effectiveness
e) availability of skills/machines
f) other (please specify)

| Maintenance operation | Choice of standard & frequency * (* select from list above) | Choice of method * |
|---|---|---|
| | | |

**7. Before maintenance works are carried out, please indicate the notification procedures followed in the area:-**

| Maintenance operation | Groups notified | Method of notification (e.g. letter, telephone, visit) |
|---|---|---|
| | | |

**8. On completion of maintenance works in the area, is there:-**

a) A follow-up inspection/evaluation ? Yes / No

If yes, who does it ? _____

What form does it take ? _____

b) Follow-up contact with affected parties ? Yes / No

If yes, who does it ? _____

Which parties are contacted ? _____

What form does it take ? _____

**9. List the main operations in the area put out to contractors and indicate, from the following list the main reasons for doing so:-**

a) Peak work loads
b) Specialist skills/machines
c) Cost-effectiveness
d) Emergency work
e) Other (please specify)

| Maintenance operation | Reasons for using contractual labour (* select from the list given) |
|---|---|
| | |

*THANK YOU FOR YOUR TIME AND CO-OPERATION*

# APPENDIX II

## BASELINE SURVEY QUESTIONNAIRE

Date _____ NRA Region _____
Farm code _____ River _____

## FARM / FARMER DETAILS

1 Farm size - total farm _____
- area owned _____
- area tenanted - full _____
- 364 day _____
- summer grazing _____

2. **No. of holdings & relationship between them** _____

3. **No. of workers** - family _____
- regular hired _____
- casual (no. weeks) _____

4. **Management status** :-
sole proprietor / manager / partner / other (please specify)

5. **How many years have you farmed this holding ?** _____

6. **Cropping pattern/rotation** ha/acre

Winter sown cereals (wheat / barley)
Spring sown cereals (wheat / barley)
Potatoes (early / main-crop)
Sugar beet
Linseed / oilseed rape
Forage crops (e.g. turnip)
Field veg. (e.g. vining peas)
Leys & temporary grass
Permanent pasture
Rough grazing
Woodland
Unused
Other (please specify)

7. **How often do you reseed ?** temporary grass / ley _____
permanent grass _____
rough grazing _____

8. **Dairy**

no. of cows _____
no. of followers >1 yr. _____
<1 yr. _____
milk yields / cow (L / Gal.) _____

9. **Beef**

no. of beef cattle <6 months _____
6-12 months _____
1-2 yrs _____
>2 yrs _____
suckler herd - no. of cows _____
system :- _____

10. **Sheep**

no. of ewes _____
no. of lambs reared per ewe tupped _____
breed _____
system :- _____

11. **Pig**

no. of sows _____
no. of weaners _____
indoor or outdoor _____
system - breeding / fattening _____

12. **Poultry**

total no. of birds _____
battery or free-range _____

## FIELD LEVEL INFORMATION

Identify on map those fields whose drainage is influenced by main river. (Where possible, group fields together that are similar in drainage/soil type/land use - number each field group for future identification.)

**13. Field description**

| Field no. | Fragmented or continuous ? | Distance from farm | Tenure status | Years farmed | Drainage status (natural or piped into river or ditch) |
|---|---|---|---|---|---|

Mark on map drain spacing & system (mole/grid):- written plans ?

How old is the piped drainage ? _____

**14. Present land use of each field in benefit area**

**Arable**

| Field No. | Crop type | Years in rotation | Crops in rotation | Yield (kg/ha) |
|---|---|---|---|---|
| | | | | |

**Grassland**

| Field No. | Permanent / temporary | Years in rotation | Stock types | Grazing seasons | Nitrogen applied (kg/ha, (straight or compound) |
|---|---|---|---|---|---|
| | | | | | |

**Grass conservation**

| Field No. | Hay or silage | Date of 1st cut | Date of 2nd cut | Date stock taken off land |
|---|---|---|---|---|
| | | | | |

## KNOWLEDGE / PERCEPTION OF RIVER MAINTENANCE

**15. River maintenance**
Have any of the following been performed on the river ?

| Maintenance operation | Yes / no | Date last done | By whom ? |
|---|---|---|---|
| Dredging/desilting | | | |
| Weedcutting | | | |
| Debris removal | | | |
| Bush clearance | | | |
| Tree felling/removal | | | |
| Repairs to riverbanks | | | |
| Repairs to structures | | | |

**16. Farm drainage systems**
Have you carried out any of the following on your field drainage systems ?

| Operation | Yes / no | Date last done |
|---|---|---|
| Ditching/ditch clearance | | |
| Weeding of channel | | |
| Moling /subsoiling | | |
| Pumping - regular or intermittent | | |
| Tree/bush clearance from channel | | |

## FLOODING

**17. Fields prone to flooding**
(Mark flooded areas on map)

| Field No. | Source of water (river /rain or upland water) | Flooding frequency | Date of last flood | % winter flooding | % summer flooding | Length of flood (days) |
|---|---|---|---|---|---|---|
| | | | | | | |

**18. Associated river conditions at time of flood**

Normal / Silted / Breach / Blockage / Weedy / High water due to excessive rainfall

**19. Consequences of flooding**

Damage to standing crop- decreased yield / reseeding
Loss of livestock (no. of heads)
Damage to fencing/buildings
Litter & debris
Erosion
Pollution
Delayed farming operations

**20. Change in flood risk**

Did you notice a fall in flood risk immediately after the maintenance work ? Yes / No

Has the flood situation worsened over time since maintenance was done ? Yes / No
If yes, what are the change and on which fields ?

| Field No. | Change * |
|---|---|

* Select from following list

Time of year
Duration
Source
Frequency
Area flooded

**WATER-LOGGING**

**21. Field wetness condition**

| Wetness condition | Field No. |
|---|---|

Spring - rarely wet
- occasionally wet
- often wet
- permanently wet

Summer - rarely wet
- occasionally wet
- often wet
- permanently wet

Autumn - rarely wet
- occasionally wet
- often wet
- permanently wet

**22. What factor is mostly responsible for the wet conditions ?** * Select from the list given

* Lack of field drainage / Age or condition of field drainage / limited outfalls into ditch/river/ Submerged outfalls into ditch/river / Weeds in channel / Tree/bush growth restricting channel capacity / Soil type.

**23. Change in wetness condition**

Has there been any change in wetness condition following maintenance ? Yes / No

If yes what was the pre maintenance condition ?

| Wetness condition | Field No. |
|---|---|

Spring - rarely wet
- occasionally wet
- often wet
- permanently wet

Summer - rarely wet
- occasionally wet
- often wet
- permanently wet

Autumn - rarely wet
- occasionally wet
- often wet
- permanently wet

24. Did you notice an improvement in wetness condition of the land following river maintenance ? Yes / No

25. Has the situation worsened with time since the maintenance was done ? Yes / No

## IMPACT OF DRAINAGE STATUS CHANGES

**26. Changes in farming practice as a result of river maintenance**

Has river maintenance resulted in any changes in farming practice ? Yes / No

If yes, how have land use & productivity been affected ?

**27. Views on river maintenance**

Is it necessary ?, Is it beneficial?
What time scale do you recommend for the maintenance

## ENVIRONMENTAL ASPECTS

28. Are any environmental features on your fields affected by river maintenance ? Yes / No

| Feature | Affected by maintenance ? | Impact |
|---|---|---|
| Fisheries | | |
| Wildlife habits - birds | | |
| Flora | | |
| Fauna | | |
| landscape | | |
| Archaeological / Recreational | | |

29. Have you taken any measures to enhance/protect these features? Yes / No

If yes what / where ?

30. Are any areas of your land designated conservation areas, ESA's, SSSI etc.? Yes / No

If yes what/where?

31. Is Set-Aside / Diversification likely to be an attractive option to you ? Yes / No

If yes what plans do you have ?

***THANK YOU FOR YOUR CO-OPERATION AND TIME***

# APPENDIX III

## POST MAINTENANCE QUESTIONNAIRE

Date _____ NRA Region _____

Farm code _____ River _____

**Post Maintenance**

**1. Flooding**

| Field No. | No. of events | Duration | Date | Damage (*select from list) |
|---|---|---|---|---|
| | | | | |

* Crop
Livestock loss
Fencing
Erosion
Litter / debris
Delayed operations
Other (Specify)

Has there been a reduction in flooding following maintenance ? Yes / No

If yes, why ? 1) increased channel capacity as result of maintenance
2) weather conditions
3) result of own flood protection works
4) combination of 1 & 2

**2. Wetness condition**

Drainage status of each field ?

| Month | Field No. | Drainage status * select from list |
|---|---|---|
| February | | |
| March | | |
| April | | |
| May | | |

* Rarely wet
Occasionally wet
Often wet
Permanently wet

Is there an improvement on pre-maintenance wetness condition ? Yes / No

If yes, why ? 1) impact of maintenance
2) weather conditions
3) field drainage installation
4) change in land management

**3. Reaction to maintenance**

What are your feelings on the maintenance work ?

- Unnecessary
- Too severe
- About right
- Not sufficient

Do you feel alternative measures could have been taken ? Yes / No

If yes, please comment.

What are your feelings on the consequences of maintenance activities ?

e.g. Machinery on land, spoil etc.

- Accept as part of the job
- Strongly oppose
- Other (please specify)

Do you feel alternative measures could be taken ? Yes / No

If yes, please comment.

**4. Field drainage**

If the drainage condition deteriorated through lack of river maintenance what would the effect be on:

Land use:-

Stocking rate:-

Grass conservation:-

Nitrogen inputs:-

Grazing seasons:-

Estimate of field drainage costs? - with / without permeable fill _____

Have any new field drains been installed since the last visit ? Yes / No

If yes, what and where ?

Has any ditching, moling or subsoiling been done since the maintenance ? Yes / No

If yes, what, where and what were your reasons ?

**5. Weather**

What has the weather been like during :-

| | | |
|---|---|---|
| February | _____ | 1) No rain |
| March | _____ | 2) Limited rain |
| April | _____ | 3) Average rain |
| May | _____ | 4) High rainfall |

**6. Arable Land**

| Field No. | Crop | Yield (expected and actual) |
|---|---|---|
| | | |

**7. Grassland**

| Field No. | Stock type | Grazing season | Level of Nitrogen applied | No. of cuts hay and silage |
|---|---|---|---|---|
| | | | | |

**8. Livestock Systems:-**

Beef system: suckler / 18 month beef / 24 month beef

Stocking rates:

Age & weight when buy & sell

Spring / autumn calving

Feeding regime

**9. Environment**

**Environmental features affected by maintenance**

Has river maintenance had a positive or negative effect (good or bad) on

| | |
|---|---|
| fish | good / bad |
| birds | good / bad |
| fauna | good / bad |
| trees | good / bad |
| landscape | good / bad |
| recreation | good / bad |
| archaeological | good / bad |

***THANK YOU FOR YOUR CO-OPERATION AND TIME***

# APPENDIX IV

## COMPUTATION OF MANNING'S 'N' ROUGHNESS COEFFICIENT

Manning's 'n' = $(n_0 + n_1 + n_2 + n_3 + n_4)\, m_5$, where:

$n_0$ = material involved $n_1$ = degree of irregularity $n_2$ = variations of channel cross-sections $n_3$ = relative effect of obstructions $n_4$ = vegetation $m_5$ = degree of meandering

(range of values in parentheses)

**Material involved**

This simply reflects the predominant bed material - earth (0.02) to coarse gravel (0.028)

**Degree of irregularity**

The degree of irregularity is considered smooth (0.000) for surfaces comparable to the best attainable for the materials involved; minor (0.005) for good dredged channels; moderate (0.010) for fair to poorly dredged channels, moderately sloughed or eroded side slopes of canals or drainage channels; and severe (0.020) for badly sloughed banks of natural streams, badly eroded or sloughed sides of canals or drainage channels and unshaped, jagged, and irregular surfaces of channels excavated in rock.

**Variations of channel cross-sections**

The character of variations in size and shape of cross-sections is considered gradual when the change in size or shape occurs gradually, altering occasionally when large and small sections alternate occasionally or when sharp changes cause occasional shifting of main flow from side to side, and alternating frequently when large and small sections alternate frequently or when sharp changes cause frequent shifting of main flow from side to side.

**Relative effect of obstructions**

This value is based on the presence and characteristics of obstructions such as debris deposits, stumps, exposed roots, boulders, and fallen and lodged logs. Conditions considered in other steps must not be re-evaluated or double-counted in this selection. In judging the relative effect of obstructions, the following should be considered: the extent to which the obstructions occupy or reduce the average water area, the character of obstructions (sharp-edged or angular objects induce greater turbulence than curved, smooth-faced objects), and the position and spacing of obstructions transversely and longitudinally in the reach under consideration. Values range from negligible (0.00) to severe (0.04-0.06).

**Vegetation**

Values for vegetation range from 0.005-0.01 for low vegetation growth to 0.05-0.1 for very high vegetation growth. Vegetation includes in-channel and bankside growth. The value is also influenced by the size and shape of the channel which can influence the effect that vegetation has on channel roughness.

**Degree of meandering**

Values range from 1 for minor to 1.3 for severe meandering.

# APPENDIX V

# WATERTABLE MODEL

## 1.I Introduction

A watertable model has been developed at Silsoe College to measure watertable levels in fields adjacent to river channels. This non-steady state model identifies the likely equilibrium field watertable height for specified climatic conditions. Data is input for each block of land within the benefit area.

Data required by the model takes two separate forms:

- continuous data for the survey period at weekly intervals (rainfall (mm), evapotranspiration (mm) and river water level (m AOD); and,
- in-situ field data relating to field variables and channel features. The data include ditch/pipe spacing (m), hydraulic conductivity of topsoil and subsoil (m/day), soil boundary depth (m), ditch base and land surface elevation (m AOD).

The field data relates to the specific block of land under consideration whilst the river channel information refers to the nearest cross-section. A complete list of the in-situ data required and example values are presented in Table 1.1.

**Table 1.1 Field and channel data required for the watertable model**

| | |
|---|---|
| Ditch spacing (m) | 25 |
| Depth to impermeable layer (m) | 1.4 |
| Geometrical factor for ditch system | 1 |
| Initial water table depth (m) | 0.2 |
| Hydraulic conductivity of topsoil (m/day) | 0.83 |
| of subsoil (m/day) | 0.3 |
| Soil boundary depth (m) | 0.9 |
| Specific yield of topsoil (m/m) | 0.155 |
| of subsoil (m/m) | 0.03 |
| Unsaturated hydraulic conductivity exponent | 8 |
| Surface elevation (m AOD) | 88.43 |
| Ditch base elevation (m AOD) | 87.06 |

Example data taken from the River Arrow

The output produced by the model contains results for a particular block of land affected by the cross-section for which the data was input. It takes the form of two columns of data (Table 1.2) which indicate the river water level and the modelled watertable height.

**Table 1.2 Input and output from the watertable model**

| Block Number | 901 | |
|---|---|---|
| Cross-section | 5 | |
| | Input Data | Output Data |
| | River height (m AOD) | Watertable height (m AOD) |
| Week 1993 | | |
| 1 | 1.44 | 1.69 |
| 2 | 1.37 | 1.66 |
| 3 | 1.44 | 1.61 |
| 4 | 1.44 | 1.51 |
| 5 | 1.37 | 1.44 |
| 6 | 1.37 | 1.39 |
| 7 | 1.37 | 1.38 |
| 8 | 1.43 | 1.37 |
| 9 | 1.43 | 1.35 |
| 10 | 1.40 | 1.32 |
| 11 | 1.40 | 1.37 |
| 12 | 1.40 | 1.34 |
| 13 | 1.40 | 1.46 |
| 14 | 1.40 | 1.40 |
| 15 | 1.40 | 1.35 |
| 16 | 1.37 | 1.22 |
| 17 | 1.37 | 1.18 |
| 18 | 1.28 | 1.24 |
| 19 | 1.28 | 1.37 |
| 20 | 1.40 | 1.30 |
| 21 | 1.40 | 1.69 |
| 22 | 1.40 | 1.69 |
| 23 | 1.40 | 1.40 |
| 24 | 1.60 | 1.28 |
| 25 | 1.60 | 1.35 |
| 26 | 1.60 | 1.69 |
| 27 | 1.60 | 1.62 |
| 28 | 1.51 | 1.67 |
| 29 | 1.51 | 1.52 |
| 30 | 1.60 | 1.49 |
| 31 | 1.60 | 1.41 |

## 1.2 Rainfall Probability

Long term monthly rainfall data were collected form the nearest meteorological station to each study site. These records spanned a period of 11 to 33 years. The data were used to assess the probability of dry, average and wet seasons occurring. The probabilities associated with these type of seasons for each watercourse are presented in Table 1.3.

## 1.3 Sensitivity Analysis

As stated in Section 1.2, the probability of wet, dry and average seasons has been determined. Sensitivity analysis was carried out on the watertable model to determine the effect of this varying rainfall distribution within each month of the spring, summer and autumn seasons on watertable levels.

Throughout the sensitivity analysis, data for a seven year period was used. The value for the total rainfall within each month of each season under consideration was kept constant. The rationale for this was that monthly rainfall records were used and there were no grounds for altering the distribution between months. All other data required by the model was kept constant in order to isolate the impact of rainfall distribution on the watertable.

**Rainfall scenarios**

The distribution of rainfall within a given month cannot be predicted accurately. However, the rainfall may fall in one of various patterns. The month could be dry or wet, rainfall may be evenly distributed throughout the month or it may all fall in a short space of time as a peak event. It is the sensitivity of the watertable model to these rainfall patterns which has been analysed.

Each season was treated as a separate entity and the watertable model was run for each season using different rainfall distributions. Only the rainfall for the particular season concerned was changed, the remaining seasons contained the actual data. The rainfall scenarios used are listed below.

1. Dry season - actual rainfall values * 0.75
2. Wet season - actual rainfall values * 1.25
3. Peak event
4. Uniform distribution

**Table 1.3 Probability of dry, average and wet seasons**

| Watercourse | Met. Station | Season Type | Spring | Summer | Autumn | Year |
|---|---|---|---|---|---|---|
| River Arrow | Lyonshall | Dry | 0.08 | 0.21 | 0.29 | 0.21 |
| | | Average | 0.75 | 0.71 | 0.63 | 0.71 |
| | | Wet | 0.17 | 0.08 | 0.08 | 0.08 |
| Dysynni Low Level Drain | Aberdyffi Golf Club | Dry | 0.13 | 0.13 | 0.26 | 0.39 |
| | | Average | 0.7 | 0.78 | 0.65 | 0.57 |
| | | Wet | 0.17 | 0.09 | 0.09 | 0.04 |
| Dreneuydd/ Broadway Reen | Redwick, Usk | Dry | 0.12 | 0.211 | 0.17 | 0.31 |
| | | Average | 0.75 | 0.71 | 0.71 | 0.52 |
| | | Wet | 0.13 | 0.08 | 0.12 | 0.17 |
| Woldgrift Drain | Alford Well | Dry | 0.29 | 0.18 | 0.24 | 0.17 |
| | | Average | 0.59 | 0.53 | 0.58 | 0.44 |
| | | Wet | 0.12 | 0.29 | 0.18 | 0.39 |
| River Wensum | Hope House | Dry | 0.15 | 0.22 | 0.18 | 0.16 |
| | | Average | 0.73 | 0.75 | 0.73 | 0.69 |
| | | Wet | 0.12 | 0.03 | 0.09 | 0.15 |
| River Yare | Norwich Water Works | Dry | 0.24 | 0.24 | 0.27 | 0.25 |
| | | Average | 0.73 | 0.67 | 0.64 | 0.59 |
| | | Wet | 0.03 | 0.09 | 0.09 | 0.16 |
| River Sence | Kilby Bridge | Dry | 0.17 | 0.14 | 0.35 | 0.48 |
| | | Average | 0.76 | 0.65 | 0.62 | 0.45 |
| | | Wet | 0.07 | 0.21 | 0.03 | 0.07 |
| Hilton Brook | Claymills Waste Rec. Works | Dry | 0.18 | 0.08 | 0.33 | 0.36 |
| | | Average | 0.73 | 0.58 | 0.50 | 0.37 |
| | | Wet | 0.09 | 0.33 | 0.17 | 0.27 |
| River Yarty | Twist | Dry | 0.07 | 0.21 | 0.21 | 0.64 |
| | | Average | 0.715 | 0.43 | 0.57 | 0.22 |
| | | Wet | 0.215 | 0.36 | 0.22 | 0.14 |
| Sir Arthur's Pill | Chivenor | Dry | 0.22 | 0.46 | 0.21 | 0.54 |
| | | Average | 0.62 | 0.39 | 0.65 | 0.38 |
| | | Wet | 0.16 | 0.15 | 0.14 | 0.08 |
| River Wampool | Wiggonby School House | Dry | 0.38 | 0.06 | 0.06 | 0.06 |
| | | Average | 0.56 | 0.63 | 0.56 | 0.69 |
| | | Wet | 0.06 | 0.31 | 0.38 | 0.25 |
| Pilling Water | Abram House | Dry | 0.25 | 0.25 | 0.06 | 0.25 |
| | | Average | 0.12 | 0.5 | 0.69 | 0.69 |
| | | Wet | 0.63 | 0.25 | 0.25 | 0.06 |

The wet and dry seasons were determined following the methodology of the FAO (Food and Agricultural Organisation). For the peak event, for each month in the season, the rainfall was taken as falling all within the third week of a five week month and the second week of a four week month. In the case of uniform distribution, the monthly total of rainfall for each month in the season was distributed equally between each week within the particular month.

**Model runs**

The model was initially run using the actual rainfall data of a particular site in order to provide a baseline from which to assess any changes in watertable depth. The model was then run for a dry season, wet season, peak event and uniform distribution. Because the soil type varies between the 12 river sites under consideration, repeated model runs were then made using the same meteorological data but with soil data relating to the different soil types found within the 12 sites. The input data for the soil types considered is presented in Table 1.4.

**Table 1.4 Watertable model data for various soil types**

| Soil type | | Clay | Silt/clay loam | Sand/silt |
|---|---|---|---|---|
| Hydraulic conductivity of | topsoil (m/day) | 0.11 | 0.40 | 4.59 |
| | subsoil (m/day) | 0.50 | 0.30 | 2.57 |
| Soil boundary depth (m) | | 0.40 | 1.00 | 0.55 |
| Specific yield of | topsoil (m/m) | 0.07 | 0.13 | 0.27 |
| | subsoil (m/m) | 0.30 | 0.28 | 0.21 |

**Results and conclusions**

The effect of the various rainfall distributions on watertable levels were determined through data distribution using the three watertable level classes (< 0.3 m from ground surface i.e. very bad drainage, 0.3 - 0.5 m i.e. bad drainage and > 0.5 m from ground surface i.e. good drainage) which are described and explained in the main text (Section 3.5.2). The number of weeks in each season in which the watertable level was in each of the three classes was determined. These results were then compared to the watertable level distribution using the actual rainfall data. The results of the model runs are presented in Table 1.5. Figures in parenthesis indicate the number of weeks difference in watertable class when compared to the values using the actual rainfall data.

**Table 1.5 Sensitivity analysis of watertable model to rainfall distribution**

| Soil type | Watertable depth (m below surface) | No. weeks watertable at various depths under different rainfall distribution scenarios | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Actual | Dry years | Wet years | Peak spring | Peak summer | Peak autumn | Constsnt spring | Constant summer | Constant autumn |
| Silty/clay loam | > 0.5 | 286 | 360 (+74) | 253 (-33) | 289 (+3) | 284 (-2) | 284 (0) | 286 (+2) | 288 (+2) | 287 (+1) |
| | 0.3 - 0.5 | 64 | 3 (+61) | 86 (-22) | 57 (-7) | 66 (-2) | 65 (-1) | 65 (-1) | 63 (+1) | 64 (0) |
| | < 0.3 | 14 | 1 (+13) | 25 (-11) | 18 (-4) | 14 (0) | 15 (-1) | 13 (+13) | 13 (+1) | 13 (+1) |
| Clay | > 0.5 | 347 | 363 (+16) | 317 (-30) | 344 (-3) | 348 (+1) | 348 (+1) | 347 (0) | 346 (-1) | 347 (0) |
| | 0.3 - 0.5 | 14 | 0 (+14) | 37 (+23) | 17 (+3) | 13 (-1) | 13 (-1) | 14 (0) | 15 (+1) | 14 (0) |
| | < 0.3 | 3 | 1 (+2) | 10 (-7) | 3 (0) | 3 (0) | 3 (0) | 3 (0) | 3 (0) | 3 (0) |
| Sandy/ silt | > 0.5 | 363 | 363 (0) | 363 (0) | 362 (-1) | 363 (0) | 363 (0) | 363 (0) | 363 (0) | 363 (0) |
| | 0.3 - 0.5 | 0 | 0 (0) | 0 (0) | 1 (-1) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| | < 0.3 | 1 | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) | 1 (0) |

The main conclusion which can be drawn from the results are as follows:-

1. the distribution of rainfall has limited effect on the drainage status of sandy/silt soils;

2. dry years resulted in an improvement in drainage status on all three soil types when compared to results using the actual data;

3. wet years resulted in a deterioration in drainage status in each case when compared to the results from the actual data;

4. the drainage of clay soils is slightly susceptible to both peak events and constant levels of rainfall resulting in only a small change in the number of weeks the drainage status is under each category. For example, peak rainfall events in each month of the spring result in an improvement in drainage status from three weeks under the very bad condition to no weeks classed as very bad. These three weeks are now classed as bad; and,

5. silty/clay loam soils are the most responsive to the changes in rainfall distribution and quantity. The greatest change in drainage status occurs with the peak events in the spring. This results in a deterioration in drainage status for 11 weeks and an improvement for three weeks.

As already describes in the main text (Section 3.5.2) the drainage status is classed as good, bad or very bad only if 80 %, 50 % and 50 % respectively of all the weeks fall into these categories. Through varying the rainfall distribution on the three soil types, some changes did occur in the number of weeks under each drainage condition. However, these changes were insufficient to cause a change in the percentages outlined above.

It can be concluded therefore, that drainage status is insensitive to rainfall distribution in areas with a clay, sandy silt or silty/clay loam soil type. It must be noted however, that weekly rainfall data were used. If daily rainfall records were studied, variations in rainfall distribution at this higher level of resolution may be seen to exert more influence upon drainage status.

# APPENDIX VI

## MORPHOLOGICAL CHANGE AND MAINTENANCE IMPACT LONGEVITY

**Table 1 Widening**

| Plan Form | River Gradient | Bed Material | Discharge Capacity | Flow Velocity | Morphological Impact | Timescale of Change |
|---|---|---|---|---|---|---|
| Straight / meandered | Gentle | Sand | + | - | Potential deposition on inside of meanders | L |
| Straight / meandered | Gentle | Sand / loam | + | - | " " | L |
| Straight / meandered | Gentle | Sand / silt | + | - | " " | L |
| Straight / meandered | Gentle | Silt / loam | + | - | " " | L |
| Straight / meandered | Steep | Sand / gravel | + | - | Potential deposition. Moves & deposits sediment in flood. Returns to equilibrium relatively quickly. | M / S |
| Straight / braided | Steep | Sand / gravel | + | - | Deposition. Unstable & liable to change river characteristics during flood. | M/S |

**Table 2 Deepening**

| Plan Form | River Gradient | Bed Material | Discharge Capacity | Flow Velocity | Morphological Impact | Timscale of Change |
|---|---|---|---|---|---|---|
| Straight / meandered | Gentle | Sand | + | - | Potential deposition occurs more rapidly than with widening. Deposition downstream. | M |
| Straight / meandered | Gentle | Sand / loam | + | - | " " | M |
| Straight / meandered | Gentle | Sand / silt | + | - | " " | M |
| Straight / meandered | Gentle | Silt / loam | + | - | Potential deposition occurs more rapidly than with widening. Bank instability may cause deposition downstream. | M |
| Straight / meandered | Steep | Sand / gravel | + | - | Potential deposition occurs more rapidly than with widening. Bank instability may cause deposition downstream. | S |
| Straight / braided | Steep | Sand / gravel | + | - | Deposition likely to occur swiftly especially in flood conditions. | S |

Key : L = Long term (> 20 years) M = Medium term ( 10 - 20 years) S = Short term ( < 10 years)
+'ve = Increase - 've = Decrease

**Table 3 Vegetation cutting**

| Plan Form | River Gradient | Bed Material | Discharge Capacity | Flow Velocity | Morphological Impact |
|---|---|---|---|---|---|
| Straight / meandered | Gentle | Sand<br>Sand / loam<br>Sand / silt<br>Silt / loam | + | + | Potential erosion as bank/bed roughness reduced & bank stability decreased. Deposition of eroded material downstream. Erosion reduced if cut in summer with lower flow & faster growth recovery. |
| Straight / meandered | Steep | Sand / gravel | + | + | " " |
| Straight / braided | Steep | Sand / gravel | + | + | " " |

Key = +'ve = Increase

**Table 4 No vegetation cutting**

| Plan Form | River Gradient | Bed Material | Discharge Capacity | Flow Velocity | Morphological Impact |
|---|---|---|---|---|---|
| Straight / meandered | Gentle | Sand<br>Sand / loam<br>Sand / silt<br>Silt / loam | - | - | Potential deposition on bed as roughness increases & bank stability decreases. Erosion downstream as sediment trapped by vegetation. |
| Straight / meandered | Steep | Sand / gravel | - | - | " " |
| Straight / braided | Steep | Sand / gravel | - | - | " " |

Key = -'ve = Decrease

# APPENDIX VII

## LONGEVITY OF MAINTENANCE IMPACTS

**Table 1 Gravel bed river, percentage change in bankful discharge capacity**

| | Deepening | | | | | Widening | | |
|---|---|---|---|---|---|---|---|---|
| Year | 40 % | 25 % | 20 % | 10 % | 5 % | 5 % | 10 % | 50 % |
| 1 | 84 | 16 | 21 | 11 | 6 | 4 | 8 | 41 |
| 5 | 56 | 21 | 16 | 9 | 5.5 | 0.7 | 0.4 | 19 |
| 10 | 46 | 14 | 13 | 7 | 5 | -5 | -5 | -13 |
| 20 | 31 | 18 | 15 | 8.5 | 5 | -3 | -9 | -44 |
| 30 | 21 | 12 | 9 | 2 | -2 | -7 | -17 | -64 |

**Table 2 Sand bed river, percentage change in bankful discharge capacity**

| | Deepening | | | | | Widening | | |
|---|---|---|---|---|---|---|---|---|
| Year | 40 % | 25 % | 20 % | 10 % | 5 % | 5 % | 10 % | 50 % |
| 1 | 26 | 21.5 | 19 | 10.5 | 6 | 2.5 | 5 | 20 |
| 5 | 25 | 20 | 17.5 | 10 | 5.5 | 2 | 4.5 | 19.5 |
| 10 | 25 | 18 | 16 | 9 | 5 | 2 | 5 | 19.5 |
| 20 | 25 | 8 | 6 | 3 | 2 | 0.6 | 1 | 8 |
| 30 | 24 | 5 | 4 | 2 | 1 | 0.2 | 0.5 | 5 |

**Table 3 Silt bed river, percentage change in bankful discharge capacity**

| | Deepening | | | | | Widening | | |
|---|---|---|---|---|---|---|---|---|
| Year | 40 % | 25 % | 20 % | 10 % | 5 % | 5 % | 10 % | 50 % |
| 1 | 31 | 21.5 | 19 | 10.5 | 6 | 2.5 | 5 | 20 |
| 5 | 31 | 20 | 17.5 | 10 | 5.5 | 2 | 4.5 | 19.5 |
| 10 | 30 | 18 | 16 | 9 | 5 | 2 | 4 | 19.5 |
| 20 | 29 | 15 | 14 | 8.5 | 5 | 2 | 4 | 19 |
| 30 | 29 | 13 | 12 | 8 | 4 | 2 | 4 | 19 |

**Table 4 Gravel bed river, percentage change in water depth**

| | Deepening | | | | | Widening | | |
|---|---|---|---|---|---|---|---|---|
| Year | 40 % | 25 % | 20 % | 10 % | 5 % | 5 % | 10 % | 50 % |
| 1 | 32 | 16 | 13 | 7 | -2 | -2 | -5 | -19 |
| 5 | 20 | 13 | 10 | 5 | -2 | -0.1 | 0.2 | -7 |
| 10 | 16 | 8 | 7 | 4 | 2 | 3 | 4 | 8 |
| 20 | 12 | 4 | 3 | 1 | 6 | 7 | 10 | 24 |
| 30 | 9 | 2 | 3 | 7 | 13 | 11 | 16 | 32 |

**Table 5 Sand bed river, percentage change in water depth**

| | Deepening | | | | | Widening | | |
|---|---|---|---|---|---|---|---|---|
| Year | 40 % | 25 % | 20 % | 10 % | 5 % | 5 % | 10 % | 50 % |
| 1 | -24 | -16 | -13 | -7 | -2 | -2 | -5 | -15 |
| 5 | -17 | -11 | -9 | -5 | -2 | -1 | -2 | -11 |
| 10 | -12 | -8 | -6 | -3 | -2 | -1 | -2 | 0 |
| 20 | -9 | -6 | -5 | -3 | -2 | -1 | -1 | -4 |
| 30 | -7 | -5 | -4 | -2 | -2 | -2 | -1 | -1 |

**Table 6 Silt bed river, percentage change in water depth**

| | Deepening | | | | | Widening | | |
|---|---|---|---|---|---|---|---|---|
| Year | 40 % | 25 % | 20 % | 10 % | 5 % | 5 % | 10 % | 50 % |
| 1 | -18 | -10 | -9 | -5 | -3 | -1 | -2 | -9 |
| 5 | -17 | -10 | -9 | -5 | -3 | -1 | -2 | -9 |
| 10 | -16 | -9 | -9 | -5 | -2 | -1 | -2 | -9 |
| 20 | -14 | -8 | -7 | -4 | -2 | -1 | -2 | -9 |
| 30 | -12 | -7 | -7 | -4 | -2 | -1 | -2 | -9 |

**Vegetation Cutting**

**Table 7 Gravel bed, percentage change in water depth**

Original vegetation cover 5 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 0 | -1 | -1 | -1 |
| 5 | 0 | -0.6 | -0.6 | -0.6 |
| 10 | 0 | -0.2 | -0.2 | -0.2 |
| 20 | 0 | -1 | -1 | -1 |
| 30 | 0 | -1.4 | -1.4 | -1.4 |

**Table 8 Gravel bed, percentage change in water depth**

Original vegetation cover 10 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 0 | -1 | -1 | -1 |
| 5 | 0 | -0.6 | -0.6 | -0.6 |
| 10 | 0 | -0.2 | -0.2 | -0.2 |
| 20 | 0 | -1 | -1 | -1 |
| 30 | 0 | -1 | -1 | -1 |

**Table 9 Gravel bed, percentage change in water depth**

Original vegetation cover 15 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | -2 | -2 | -2 | -2 |
| 5 | -1 | -1 | -1 | -1 |
| 10 | -0.4 | -0.4 | -0.4 | -0.4 |
| 20 | -1 | -1 | -1 | -1 |
| 30 | -2 | -2 | -2 | -2 |

**Table 10 Gravel bed, percentage change in bankful discharge**

Original vegetation cover 5 % and 10 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 0 | 2 | 2 | 2 |
| 5 | 0 | 1 | 1 | 1 |
| 10 | 0 | 0.5 | 0.5 | 0.5 |
| 20 | 0 | 3 | 3 | 3 |
| 30 | 0 | 3 | 3 | 3 |

**Table 11 Gravel bed, percentage change in bankful discharge**

Original vegetation cover 15 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 4 | 4 | 4 | 4 |
| 5 | 2 | 2 | 2 | 2 |
| 10 | 1 | 1 | 1 | 1 |
| 20 | 2 | 2 | 2 | 2 |
| 30 | 3 | 3 | 3 | 3 |

**Vegetation Cutting**

**Table 12 Sand bed, percentage change in water depth**

Original vegetation cover 10 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | -2 | -2 | -2 | -3 |
| 5 | -1 | -1 | -1 | -2 |
| 10 | -0.6 | -0.6 | -0.9 | -1 |
| 20 | -0.6 | -0.6 | -0.9 | -1 |
| 30 | -0.7 | -0.7 | -1 | -1 |

**Table 13 Sand bed, percentage change in water depth**

Original vegetation cover 30 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | -3 | -5 | -6 | -8 |
| 5 | -3 | -4 | -5 | -6 |
| 10 | -2 | -2 | -3 | -4 |
| 20 | -1 | -2 | -2.5 | -3 |
| 30 | -1 | -2 | -2.5 | -3 |

**Table 14 Sand bed, percentage change in water depth**

Original vegetation cover 50 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | -5 | -7 | -9 | -11 |
| 5 | -5 | -7 | -9 | -11 |
| 10 | -4 | -6 | -7 | -9 |
| 20 | -3 | -4 | -5 | -6 |
| 30 | -2 | -3 | -4 | -5 |

**Table 15 Sand bed, percentage change in bankful discharge**

Original vegetation cover 10 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 3 | 3 | 4 | 5 |
| 5 | 2 | 2 | 3 | 3 |
| 10 | 1 | 1 | 2 | 2 |
| 20 | 1 | 1 | 2 | 2 |
| 30 | 1 | 1 | 2 | 3 |

**Table 16 Sand bed, percentage change in bankful discharge**

Original vegetation cover 30 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 6 | 8 | 12 | 14 |
| 5 | 5 | 7 | 10 | 12 |
| 10 | 4 | 5 | 7 | 9 |
| 20 | 2 | 3 | 5 | 6 |
| 30 | 2 | 3 | 5 | 6 |

**Table 17 Sand bed, percentage change in bankful discharge**

Original vegetation cover 50 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 10 | 14 | 18 | 22 |
| 5 | 9 | 13 | 18 | 22 |
| 10 | 8 | 11 | 15 | 19 |
| 20 | 6 | 8 | 11 | 14 |
| 30 | 4 | 7 | 9 | 11 |

**Vegetation Cutting**

**Table 18 Silt bed, percentage change in water depth**

Original vegetation cover 20 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | -5 | -7 | -9 | -12 |
| 5 | -5 | -7 | -9 | -12 |
| 10 | -5 | -7 | -9 | -11 |
| 20 | -5 | -7 | -9 | -11 |
| 30 | -5 | -7 | -9 | -11 |

**Table 19 Silt bed, percentage change in water depth**

Original vegetation cover 50 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | -6 | -9 | -12 | -14 |
| 5 | -6 | -9 | -12 | -13 |
| 10 | -6 | -9 | -11 | -13 |
| 20 | -6 | -9 | -11 | -13 |
| 30 | -6 | -9 | -11 | -13 |

**Table 20 Silt bed, percentage change in water depth**

Original vegetation cover 80 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | -6 | -9 | -11 | -13 |
| 5 | -6 | -9 | -11 | -13 |
| 10 | -6 | -9 | -11 | -13 |
| 20 | -6 | -9 | -11 | -13 |
| 30 | -6 | -9 | -11 | -13 |

**Table 21 Silt bed, percentage change in bankful discharge**

Original vegetation cover 20 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 15 | 24 | 31 | 38 |
| 5 | 15 | 24 | 30 | 37 |
| 10 | 15 | 23 | 30 | 37 |
| 20 | 15 | 23 | 29 | 36 |
| 30 | 15 | 23 | 29 | 36 |

**Table 22 Silt bed, percentage change in bankful discharge**

Original vegetation cover 50 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 20 | 29 | 38 | 45 |
| 5 | 19 | 29 | 37 | 43 |
| 10 | 19 | 28 | 37 | 42 |
| 20 | 19 | 28 | 36 | 42 |
| 30 | 19 | 28 | 36 | 41 |

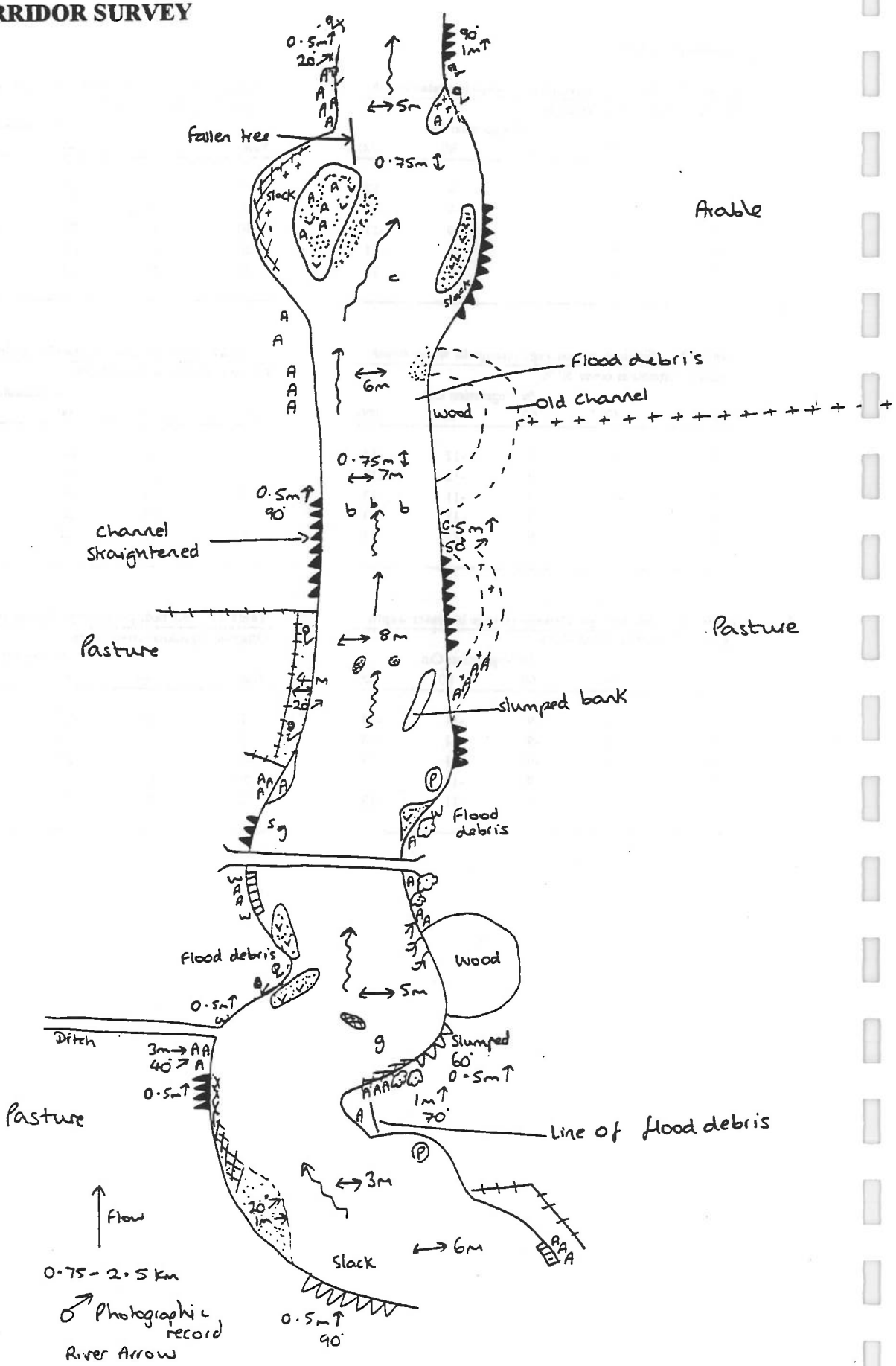
**Table 23 Silt bed, percentage change in bankful discharge**

Original vegetation cover 80 %

| | % Vegetation Cut | | | |
|---|---|---|---|---|
| Year | 40 | 60 | 80 | 100 |
| 1 | 17 | 25 | 31 | 36 |
| 5 | 17 | 25 | 31 | 35 |
| 10 | 17 | 25 | 30 | 33 |
| 20 | 17 | 25 | 30 | 32 |
| 30 | 17 | 25 | 30 | 32 |

# APPENDIX VIII

## RIVER CORRIDOR SURVEY



RIVER RIVER ARROW
Km No. 0·75 – 2·5 km
Date 25/3/92
Surveyor JALD

| | LG | RB |
|---|---|---|
| **A. WOODLAND & SCRUB %** | | |
| 1. Broad-leaved semi-nat. plantation | | 2 |
| Coniferous semi-nat. plantation | | |
| Mixed semi-natural plantation | | |
| 2. Scrub – dense | | |
| scattered | | |
| Carr – alder | | |
| willow | | |
| 3. Parkland | | |
| 4. Recently felled wood | | |
| **B. GRASSLAND & MARSH %** | | |
| 1. Acidic unimproved | | |
| semi-improved | | |
| Neutral unimproved | | |
| semi-improved | | |
| Calcareous unimproved | | |
| semi-improved | | |
| 4. Improved/reseeded | 100 | 98 |
| 5. Marsh/marshy grassland | | |
| **C. TALL HERB & FERN %** | | |
| 1. Bracken | | |
| 2. Upland spp. rich veget. | | |
| 3. Other – tall ruderal | | |
| non ruderal | | |
| **D. HEATHLAND %** | | |
| 1. Dwarf scrub – dry | | |
| wet | | |
| 3. Lichen/bryophyte | | |
| 4. Montane | | |
| 5. Heath/grassland – dry | | |
| 6. wet | | |
| **E. MIRE, FLUSH AND SPRING %** | | |
| 1. Mires – bog | | |
| Fen – reed | | |
| sedge | | |
| sweet-grass | | |
| mixed | | |
| 2. Bog flushes | | |
| **F. SWAMP/INUNDATION %** | | |
| 1. Swamp – single sp. dom. | | |
| Tall mixed assemblage | | |

| | LB | RB |
|---|---|---|
| **G. OPEN WATER** | | |
| 1. Standing – canal + (% of adj. land in each stretch) | | |
| canal = | 1 | |
| ditch | | |
| dyke | | |
| pond, pool, cut-off % | | |
| lake % | | |
| gravel pit % | | |
| reservoir % | | |
| marina %. | | |
| 2. Running | | |
| stream < 1m wide | | |
| 1·5m | | |
| 5·10m | | |
| >10 | | |
| **I. ROCK** | | |
| 1. cliff | | |
| scree | | |
| limestone pavement | | |
| cave | | |
| other | | |
| 2. artificial/waste | | |
| **J. MISCELLANEOUS** | | |
| arable | | 40 |
| amenity grassland | | |
| ephemeral/short herb | | |
| hedge + | | |
| hedge = | | |
| fence on bank | 2 | 2 |
| fence set back | | |
| wall | | |
| building | | |
| caravans | | |
| fish farm | | |
| silage clamp | | |
| sewage works | | |
| garden | | |
| stock pile | | |
| flood debris | 1 | 1 |
| road | | |
| railway disused | | |
| used | | |
| other | | |

| **BANK FEATURES %** | LB | RB |
|---|---|---|
| shell % | | |
| solid earth cliff 1M↑ | 2 | 3 |
| soft earth cliff >80° | 1 | 1 |
| rock cliff | | |
| artificial | 1 | 1 |
| FB flood bank adj | | |
| FB flood bank set back | | |
| levee | | |
| Height <1m | 100 | 60 |
| 1·<2m | | 40 |
| >2m | | |
| Width <1m | 5 | |
| 1·<2.5m | 95 | 100 |
| 2.5·<5m | | |
| >5m | | |
| Slope <30° | 87 | 50 |
| 30·<60° | 3 | 50 |
| 60·<90° | | |
| >90° | | |
| mud | 2 | 1 |
| sand | | |
| bare shingle | 2 | |
| vegetated shingle | 1 | 1 |
| earth | 95 | 98 |
| natural cobbles | | |
| natural boulders | | |
| **BANK VEGETATION** | | |
| Conifer | | |
| Oak, Ash, Sycamore | | |
| P Willow recent pollard | | |
| W Willow old, not pollard | 3 | 1 |
| S Standard willows | | |
| A Alder | 19 | 16 |
| Other trees | | 5 |
| Young trees | | |
| Thick Scrub/shrubs %. | | |
| Sparse Scrub/shrubs %. | | |
| Reed/Sedge %. | 5 | 2 |
| Dense open %. | 10 | 1 |
| Sparse open %. | | |
| Reseeded or mown %. | | |
| Exposed tree roots | | 3 |
| **ISLANDS** | | |
| Rocky, vegetated | | |
| rocky, + bare | | |
| shingle and rock | | |
| shingle, rock + veg | | |
| earth – maturing | | |
| earth – with trees | 1 | |
| developed | | |

| **RIVER HABITATS** | | RIVER |
|---|---|---|
| | bridges/500m | 1 |
| | weirs/500m | |
| | locks/500m | |
| | inlet/500m | 1 |
| Depth | <.25m % | |
| | .25·<.5 | |
| | 0.5·<1.0 | 100 |
| | >1.0m | |
| Width | <1 | |
| | 1·<5 | |
| | 5·<10 | 100 |
| | 10·<20 | |
| | >20 | |
| **Substrates** | | |
| BR | bed rock | |
| b | boulders | 5 |
| c | cobbles | 20 |
| p | pebbles | |
| g | gravel | 70 |
| s | sand | 5 |
| si | silt/mud | |
| cl | clay | |
| pe | peat | |
| **Habitats and Flow** | | |
| | pool | 2 |
| | slack | 20 |
| | riffle | |
| | rapids | 2 |
| | run | 76 |
| | waterfall | |
| | protruding rocks | |
| **Margins** | | |
| | shingle ± bare | |
| | shingle, vegetated | 2 |
| | mud | 5 |
| | sand | |
| **FLORA %** | | |
| | emergent veg < 1m wide | |
| | emergent 1·2m wide | |
| | emergent >2m wide | |
| | total veget. area | 0·5 |
| B | bryophytes | |
| E | emergents | |
| A | submerged | 100 |
| F | floating | |
| | algae % of stretch | |

total to 100%



https://dspace.org/

# River maintenance evaluation

**Dunderdale, J. A. L.; Morris, J.**

**1996**
National Rivers Authority
https://dspace.lib.cranfield.ac.uk/handle/1826/20741
Dunderdale JAL, Morris J. (1996) River maintenance evaluation, R&D note 456

Downloaded from a DSpace repository. https://dspace.org/