Hydraulics Research
Wallingford

MORPHOLOGICAL EFFECT OF RIVER WORKS

A review of current practice

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ABSTRACT

This report describes the preliminary assessment undertaken by Hydraulics Research to evaluate the morphological effect of river works.

The execution of a Water Authority survey to assemble information on existing schemes is described. Analysis of the results reveals that Water Authorities are better at judging whether sedimentation problems will occur as the result of a scheme than they are at judging whether erosion problems will result.

The sedimentation and erosion problems which result from river works are described. An outline of the types of maintenance required to counter these problems is given.

Current methods for predicting sediment movement under UK conditions are reviewed.

An Appendix is included which describes the schemes that were visited.

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1 INTRODUCTION

In their natural state rivers are often considered to be in regime. This is a state of dynamic equilibrium where the channel dimensions are determined by sediment supply and type and the magnitude and frequency of occurrence of discharge. River improvement schemes often change the capacity of a channel to transport sediment causing areas of deposition and erosion. These effects lead to a long term maintenance commitment by the drainage authority to retain the design channel capacity.

The purpose of this study is to identify the impact of river improvement schemes on the erosion and deposition of sediments with the aim of reducing the maintenance commitment required to maintain flood defence standards. The problems encountered range from the large scale sedimentation in the river Usk at Brecon where 5 to 8,000 tonnes of sediment has to be removed at least once a year, to bank instability along a 1.25 km river reach as a result of the deepening of the river Derwent at Matlock.

The aim of the study is to produce guidelines for engineers to use so that they can take account of morphological changes at the design stage.

This report describes the preliminary assessment which is the essential first stage of this study.

2 WATER AUTHORITY SURVEY

2.1 Execution

A questionnaire was sent to the Welsh Water Authority and each of the nine English Water Authorities in order to assemble information on completed flood alleviation schemes. The information requested included scheme details, whether or not sediment problems were considered at the design stage and a subsequent history of the scheme including any maintenance requirements. Figure 1 is a specimen of the questionnaire and Figure 2 is an example of a response received from a Water Authority.

Completed questionnaires were received from seven Water Authorities; these covered a total of 41 schemes. Letters were received, in reply to the request for information, from Thames Water Authority and the North West Water Authority. Thames Water do not take account of sedimentation at the design stage of schemes, however, some poorly defined problems have occurred as a result of river works, The North West Water Authority have carried out a large number of schemes in recent years but found it difficult to identify which of these would be of interest to the study. Both letters invited HR staff to visit to discuss the matter further. No reply was received from the Southern Water Authority.

Visits were made to five Water Authorities in order to discuss the authorities' general approach to the consideration of sediment problems at the design stage of schemes and to ascertain the types of problems encountered as a result of river works. The maintenance commitment required to retain design capacities was also discussed. Visits to specific schemes, selected from the completed questionnaires, were combined with the visits to Water Authorities. As wide a range of schemes as possible were visited. Schemes which considered sedimentation at the design stage as well as those that did not were visited. Schemes without subsequent problems as well as those with were studied. The aim of these site visits was to identify schemes which should be studied in more detail later in this project. A report is included in Appendix A on each of the thirteen schemes visited.

Work is still required to complete the Water Authority survey. The invitations from Thames Water Authority and the North West Water Authority should be taken up. Schemes in these two Water Authorities and also in the Northumberland Water Authority should be visited. Yorkshire and Southern Water Authorities should be contacted to establish their approach to considering sediment problems at the design stage of schemes and to investigate the possibility of site visits.

2.2 Results

Tables 1 and 2 are respectively detailed summaries of the schemes that were visited and the schemes that were not visited but for which completed questionnaires were received. In these Tables design considerations have been sub-divided into sedimentation and erosion. Sedimentation considerations usually relate to large-scale sediment deposition whilst erosion is generally only considered as a local phenomenon.

Appendix B describes a statistical analysis of the data collected. It is concluded that the Water Authorities are better at judging whether sedimentation is likely to be a problem than they are at judging whether there will be erosion problems as a result of the river works.

3 PROBLEMS AND MAINTENANCE

A significant proportion of all river works result in some morphological problems. Most of these problems are minor and do not involve the Water Authority in a substantial maintenance commitment. In a few cases a long term and expensive maintenance commitment is required to retain the design standard. It is these schemes that are of particular concern. When the problem is one of large scale sedimentation the reduction in channel capacity between maintenance is also of concern. For the schemes with the most severe problems, further river works are often being considered in an attempt to reduce the level of maintenance.

Problems which were a direct consequence of the river works occurred in 31 of the 41 schemes studied. Vegetation growth, which required a maintenance commitment, occurred in two of the remaining schemes. The problems encountered range from large scale sedimentation in the river Usk at Brecon where 5 - 8 tonnes of sediment has to be removed at least once a year, to bank instability along a 1.25 km river reach as a result of the deepening of the river Derwent at Matlock.

Maintenance is only executed as part of a regular programme on the schemes with the most serious problems. For all other schemes maintenance is ad-hoc; it is carried out when there has been a significant reduction in the design channel capacity. In general, bank protection, to counter erosion, is only carried out, once a scheme has been commissioned, if flood defences are threatened.

Of the water authorities visited, only the South-West Water Authority carry our regular inspections of all completed river works to identify maintenance requirements.

The worst large scale sedimentation problem encountered is that on the river Usk at Brecon (see Plate 1). 5 - 8,000 tonnes of gravel has to be removed from a 500m reach of river at least once a year. The cost of the sediment removal is approximately £40,000. Serious large scale sedimentation problems also occur on a 80 m reach of the river Ecclesbourne at Duffield where 300-600 cubic metres of silt and gravel has to be removed every year (see Plate 2) and, a 1 km reach of the river Colne at East Mill, Colchester, where 10,000 cubic metres of silt had to be removed approximately ten years after the scheme was commissioned. In each of these schemes the channel cross-section had been greatly enlarged either by channel widening or deepening.

Large scale sedimentation occurs in flood relief channels as well as the main river. Approximately 5,000 tonnes of sediment was removed from the Cowley flood relief channel in Exeter in 1982/83. This was subsequently replaced by further sediment which has resulted in a reduction in the capacity of the relief channel. The deposited sediment appears to have stabilised; there are no plans to carry out further sediment removal.

In some cases information on the quantity of sediment that has been removed is uncertain as it is very rare for a survey to be carried out to check that all the intended material was removed at the construction stage and after any subsequent maintenance.

Localised as well as large scale sedimentation occurs as the result of river works. The deposition of sediment on the bed of one of the culverts at the Grimsby Road bridge over Buck Beck is an example of localised sedimentation in bridge and flood relief culverts. The deposited sediment is only removed if there has been a significant reduction in the capacity of the culvert.

Sediment deposition in the stilling basin downstream of a weir is a further example of localised sedimentation. The stilling basin below the side weir at the head of the Trew's weir flood relief channel in Exeter suffers from this problem (see Plate 3). This sediment has to be removed every few years. The South-West Water Authority consider this to be an acceptable maintenance commitment.

Localised sedimentation and erosion can occur at outfalls. The sediment deposited in this case does not usually result in a significant reduction in channel capacity so no maintenance is required. If serious bank erosion problems occur at outfalls some form of bank protection work is carried out (see Plate 4)

Whilst large scale erosion (bed degradation) can result from flood alleviation schemes, it rarely does in the UK because of the type of river works. In general these reduce the flow velocity either by increasing the channel capacity or diverting a proportion of the flood flow from the main channel. Bed degradation could occur downstream of dams or when water is transferred from one river system to another.

Of the schemes reported on the worst bank stability problems were found downstream of river structures, on bends and on reaches of the river which have been realigned. The schemes visited provided examples where erosion of protected as well as unprotected banks has occurred. The failure of interlocking concrete block bank protection downstream of Black Weir on the river Taff at Cardiff is an example of the former (see Plate 5), whilst many examples of unprotected bank erosion can be found on the river Yeo as a result of the Thornford scheme (see Plate 6). The type of bank protection depends on the severity of the problem and the materials available. The most severe problems usually require sheet piles (see Plate 7) or concrete walls: these are not always acceptable to local residents. Minor erosion problems are often countered by stone revetments (see Plate 8). In areas where natural stone is not available building waste is sometimes used to construct these. The Wessex Water Authority have planted willows to counter erosion that occurred as a result of the Thornford scheme. (see Plate 9). Stone gabions have been used to protect part of the River Exe in Exeter. (see Plate 10). Grass has been allowed to grow through these gabions to form what appears to be a natural grass covered bank.

Erosion downstream of river structures such as weirs is widespread; large pools often develop. The Colchester division of the Anglian Water Authority find that erosion in these pools becomes stable and do not carry out bank protection. The erosion behind the sluice gates at the head of the Nayland flood relief channel is a further example of erosion downstream of structures. This erosion may in time result in the failure of the structure. Erosion can also result from flood flows by-passing structures; the erosion at Henney weir, shown in Plate 11, is an example of this problem.

Erosion can occur where flood relief channels rejoin the main river. This is illustrated by the severe bank erosion in the river Stour at the downstream end of the Nayland flood relief channel. (see Plate 12). This occurred because flood flows from the relief channel were allowed to strike an unprotected bank. At the downstream end of the Exwick flood relief channel, in Exeter, this form of erosion was countered by installing baffle blocks at the base of a weir (see Plate 13).

Problems can occur when a scheme results in a lower river level. This usually occurs when an agricultural scheme is carried out to improve land drainage, but it also occurs when an increased freeboard can only be achieved by deepening the channel. The scheme on the river Derwent at Matlock, which lowered river levels by up to 2m, resulted in large scale bank instability; extensive bank protection was used to counter this. The lower water levels that occurred as a result of the Thornford scheme caused a reduction in the water table elevation in the adjacent aquifer. This aquifer is used for water supply; modifications to an abstraction wall were required to alleviate the problem.

The growth of algae, weeds and larger vegetation was considered to be a problem in seven of the schemes studied. River works, by changing the velocity and depth of flow, may encourage or discourage vegetation growth. Vegetation removal is a major component of the maintenance program of all Water Authorities. In small channels reed and weed growth is often removed more than once a year. This cutting and raking will result in the removal of small quantities of sediment. The cutting of grass and larger vegetation on the bed and banks of flood relief channels is essential if the schemes which utilise these are to operate successfully at their design discharge.

The growth of vegetation in channels can cause a reduction in flow velocities; this may encourage sediment deposition. This tends to be a seasonal problem since high winter flows, when the vegetation has died down, will erode deposited sediment.

4 DESIGN CONSIDERATIONS

Sedimentation or erosion was explicitly considered at the design stage of 20 of the 41 schemes for which replies were received. Discussions with the Water Authorities revealed possible explanations for the failure to explicitly consider these processes at the design stage of the other schemes. These explanations fall into two categories, firstly those due to design practice, and secondly, those due to physical setting.

The manner in which a scheme is designed is dependent on the designers' experience. Experienced designers attempt to avoid alterations to the low flow regime of a river so as to reduce the potential for subsequent problems. This can be achieved by the creation of a channel with a compound cross-section which leaves the low flow channel unaltered but increases the channel capacity at flood discharges. A compound cross-section is created by the construction of a flood berm or the raising of flood embankments or walls. (see Plates 14 and 15). The use of flood relief channels which carry a proportion of the flood discharge are another way in which flood alleviation can be achieved without altering the low flood regime of a river (see Plate 16). In urban areas space limitations rarely allow the creation of a compound channel or the excavation of a relief channel. The required capacity can usually only be achieved by altering the channel. In these cases sedimentation and erosion should be considered at the design stage.

Certain Water Authorities do not explicitly consider sediment problems at the design stage because of the nature of the majority of rivers in their region. This is usually because of the low natural sediment concentrations in the rivers. Any problems resulting from schemes on these rivers will take a long time to develop. The South-West Water Authority do not consider sediment problems because, typically, their rivers are steep and fast flowing. On these rivers erosion should be considered at the design stage and sedimentation should be considered if a scheme will result in a reduction in flow velocity.

A wide range of approaches has been used for considering sedimentation at a schemes design stage. At one extreme mobile- and fixed-bed hydraulic models and numerical mobile-bed river models were used whilst at the other the fact that a problem will exist as the result of a scheme is identified but no attempt is made to quantify the magnitude of the problem. This latter approach is worse than failing to consider potential sediment problems. Once a problem has been identified its magnitude must be ascertained so that the maintenance required to retain the design channel can be estimated. Ideally the reason for the problem should be identified and, if possible, it should be countered by modifying the planned scheme.

Mobile-bed hydraulic models are used to investigate both large scale and local sedimentation and erosion. They have been used to identify areas of potential scour and accretion and also to assess ways in which the capacity of a channel can be increased e.g. by channel widening or the use of a flood relief channel. At the design stage of the Exwick flood relief channel, Exeter, a mobile-bed hydraulic model was used to study the distribution of flow between the river Exe and the planned relief channel. The model illustrated that a Crump weir constructed across the river and a side spill weir controlling flow into the relief channel would not provide a satisfactory distribution of flow. During flood periods the sediment load in the river channel downstream of the river structure would be unchanged whilst flows would be diminished. Accretion would occur in the river downstream of the weir. These accretion problems were minimised by the adoption of a revised scheme in which flow, in the river channel, is controlled during flood periods by automatically closing sluice gates. One difficulty with mobile-bed hydraulic models is obtaining scaled bed sediment which both adequately represents and behaves in a similar manner to that in the prototype.

Fixed bed hydraulic models have been used to identify potential erosion problems related to a planned scheme. At the design stage of the Cardiff flood relief scheme a hydraulic model was used to investigate the effect of different channel modifications on the hydraulic jump downstream of Black weir. A design was chosen which ensured that the hydraulic jump was stable within the stilling basin in order to reduce downstream erosion. The hydraulic model used at the design stage of the Trew's weir scheme in Exeter illustrated that flow over the side weir into the flood relief channel took the form of a powerful stream which would result in erosion. Ways of diffusing the flow by using baffle blocks at the base of the weir were investigated using the model.

Flow velocities can be measured at all points within a fixed-bed hydraulic model. Using these measurements the locations most susceptible to erosion can be identified and decisions on the strength of bank protection required taken. In the Trew's weir scheme, Exeter, different strengths of bank protection in the stilling basin at the head of the relief channel were based on hydraulic model velocity measurements. Just downstream of the side weir, where the highest velocities were recorded, sheet piling was used whilst further downstream the bank protection consisted of stone revetments. (see Plate 17).

Numerical mobile-bed river models divide the length of river covered by a scheme into a number of reaches; within each reach the flow and sediment transport is calculated. They allow changes in both the bed elevation and the composition of bed material to be predicted. In the case of agradation these models allow the size of maintenance commitment to be ascertained. Localised effects such as erosion round bridge piers and bank instability cannot be predicted using numerical mobile-bed river models.

The use of physical and numerical models complement each other. Physical models are appropriate for local erosion and accretion problems whilst numerical models are appropriate for large scale bed agradation or degradation problems. Physical models allow the locations at which bank protection is required to be identified. The size of a sediment removal maintenance commitment can be ascertained using numerical models.

The effect of a planned scheme can also be estimated by predicting the effect it has on the tractive force on the river bed. The tractive force is a measure of the pull of the water on the bed in the direction of the flow; an increase in tractive fore results in an increase in the potential for erosion whilst a decrease results in an increase in the potential for deposition. The tractive force is dependent on the hydraulic radius and the bed slope; by knowing how a scheme will effect these parameters the effect on the tractive force can be calculated. Sediment transport rates can be obtained from the tractive force by using a bed load formula such as that developed by Du Boys. The effect on tractive force of the scheme designed for the river Usk at Brecon was calculated. It was shown that the tractive force would increase upstream of Llanfaes bridge and decrease downstream of the bridge. No estimate of the effect these changes would have on sediment transport rates was however made. It was accepted that maintenance would be required as a result of the scheme but due to shortcomings in the modelling approach the magnitude of this commitment was not quantified. Detailed monitoring of river morphology was proposed in order to estimate the size of the maintenance commitment. As with numerical mobile-bed river models, tractive force calculations only allow large scale sedimentation and erosion effects to be ascertained.

At the design stage of some schemes flow velocity calculations are made so that the locations where bank protection is required can be identified. The South-West Water Authority always uses this method for ascertaining the strength of required bank protection when a scheme alters the low flow regime of a river.

In the Colchester division of the Anglian Water Authority schemes are designed with the aim of limiting the maximum velocities in order to reduce the potential for subsequent large scale erosion. This is usually achieved by the construction of new weirs. Potential energy losses, and thus erosion problems, are concentrated at these structures. These localised erosion problems can be countered by bank protection.

In some cases sedimentation and erosion are considered in a very crude way without doing any calculations. The decision not to realign a channel is an example of this approach. The Buck Beck improvement scheme involved the deepening and widening of the channel to increase its capacity. Channel re-alignment was not carried out in an attempt to avoid subsequent problems. In the case of Buck Beck this approach appears to have been successful.

At the design stage of some schemes the large scale effect of the scheme on the river channel is not considered but the local effect at structure is analysed. This can be done both numerically and by making scale models of the structure and testing them in a flume.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Sediment problems created as a result of river works can lead to large and unexpected maintenance commitments. These problems could in many cases have been anticipated and in some cases avoided.

2. Sedimentation or erosion was explicitly considered at the design stage of 20 of the 41 schemes studied.

3. Problems which were a direct consequence of the scheme were identified in 31 of the 41 schemes studied.

4. These problems ranged from large scale sedimentation to bank instability over a long river reach.

5. Water Authorities are better at judging whether sedimentation problems will occur as the result of a scheme than they are at judging whether erosion problems will result.

6. Sediment considerations, at the design stage of river works, usually relate to large scale sediment deposition whilst erosion is only considered as a local phenomenon.

7. The major reason sedimentation or erosion is not considered is because the scheme is designed so as not to alter the low flow regime of the river or because of the nature of the majority of rivers in an area.

8. For some schemes sedimentation was identified as being a problem but no attempt was made to estimate its magnitude.

9. Both large scale and localised sedimentation problems result from river works. The most serious large scale sedimentation problems are associated with schemes in which the channel cross-section is greatly enlarged.

10. When large scale sedimentation problems occur a significant, and very expensive, maintenance commitment is often required to retain the design standard.

11. Because most UK river works result in a reduction in flow velocities large scale bed degradation is rarely a problem.

12. Maintenance, of all schemes except those with the most severe problems is in general, 'ad-hoc'.

13. Only the South-West Water Authority regularly inspect completed schemes.

14. Techniques ranging from the use of physical and numerical models to very crude consideration of sedimentation are used at the design stage of schemes.

15. Physical models allow local effects to be identified whilst numerical models are appropriate for the consideration of the large scale effects of a scheme.

5.2 Recommendations

1. The Water Authority survey described in Section 2.1 should be completed.

2. Sedimentation should be considered at the design stage of any scheme which results in alterations to the low flow regime of a regime.

3. If sediment deposition is identified as being a potential problem the magnitude of the problem and the maintenance commitment required to retain the design capacity should be estimated.

4. Completed schemes should be inspected regularly.

5. A post-construction survey of each scheme should be carried out to provide a baseline for future surveys.

6. When sediment removal is carried out the affected reach should be surveyed.

7. Some of the schemes described in Appendix A should be studied in more detail. Field work is required to better define the problem. The morphological behaviour of the schemes should be modelled and methods of reducing the maintenance commitment investigated.

6 ACKNOWLEDGEMENTS

The provision, by the Water Authorities, of the data from which this report is compiled is gratefully acknowledged.

TABLES.

TABLE 2: Detailed Summary of Schemes for which Questionnaire reply was received but were not visited

Scheme	River	Water Authority	Urban (U)/ Agricultural (A)	Date	Designed standard		Design Considerations Y/N		Scheme Details	Subsequent Problems	Maintenance
					Discharge (cumecs)	Return Period (Years)	Sedimentation	Erosion			
Ely-Ouse: Ten mile Rivers	River Ouse	Anglian Water Authority Ely Division		1954-62			N	N	Widening and deepening Flood embankments Re-alignment	Local problems where pumping stations release suspended sediments	
Reconstruction of Castle Mill lock and sluice, Goldington, Bedford	River Ouse	Anglian Water Authority		1978			N	Y	Dredging Replacement of flood gates and locks	Sediment accumulation Bank erosion	Sediment removal
Watton Brook, Richmond. Road to Candlesprings	Watton Brook	Anglian Water Authority		1980			N	N	Channel & bridge improvements	Siltation Erosion	Silt removal Bank stabilisation
Mardyke improvement scheme		Anglian Water Authority Colchester division		1985	17		N	Y	Channel enlargement Flood embankments		
Middle Mill Improvement scheme	River Colne	Anglian Water Authority Colchester Division	U	1986	70		N	Y	Channel enlargement Flood embankments		
River Witham through Grantham	River Witham	Anglian Water Authority Lincoln Division	U	1974-78	40		N	N	Channel enlargement & deepening. Reconstruction of weirs and bridges	Severe erosion at one bend	Cutting of banks
River Bain - Dogdyke to Coningsby Lock	River Bain	Anglian Water Authority Lincoln Division		1984-85	59	100	N	Y	Flood embankments and walls. Vegetation planting		Weed cutting and raking
Barlings Eau Improvement Scheme		Anglian Water Authority Lincoln Division		1978	28	10	N	N	Channel enlargement and deepening	Bank erosion - especially on bends	Weed cutting Minor revetment work
River Gipping Comprehensive Scheme	River Gipping	Anglian Water Authority Norwich Division		1970-83			Y		Bank protection New control structures		
River Tas Flood Alleviation	River Tas	Anglian Water Authority Norwich Division		1978			N	N	Channel improvement Bank protection Flood relief channel		Weed cutting
River Ise - Wellingborough	River Ise	Anglian Water Authority Oundle Division		1980-83	21		N	N	Channel graded and re-aligned. Weir reconstructed		
Harpers Brook Improvement Scheme	Harpers Brook	Anglian Water Authority	U and A	1974	300(A) 600(U)	2 50	N	Y	Channel enlargement Bridge reconstruction Small on-stream detention basin	Siltation Localised erosion	Dredging
River Welland, Stanford to Market Harboro'	River Welland	Anglian Water Authority		1972			N	N	Channel enlargement Localised re-alignment Structure improvement	Sediment accumulation	Dredging

TABLE 2 (continued)

River Nene (Whilton Branch). Long Buckby to Daventry	River Nene	Anglian Water Authority	U	1972			N	N	Re-sectioning	Siltation	Dredging
River Trannon	River Trannon	Severn-Trent Water Authority: Upper Severn Division	A	1977-78		10	Y	N	Flood bank construction Dredging Limited drainage improvements	Erosion of banks	Gabions placed to check bank erosion
River Dove at Tutbury	River Dove	Severn-Trent Water Authority: Derwent Division		1978			Y	Y	Weir lowered overflow blocked	Bank erosion sedimentation	Bank protection Sediment removal
River Don Scheme	River Don	Northumbrian Water Authority Tees Division		1986		10	N	N	Regrading Re-sectioning	Slips and erosion	
Mainsforth Scheme		Northumbrian Water Authority Tees Division		1985		10	N	N	Pumped drainage Scheme	Slips and erosion	
Stokesley Flood Protection Scheme		Northumbrian Water Authority Tees Division		1979		40	N	N	Re-alignment Flood banks	Sedimentation Vegetation growth	
Morden Carrs Scheme		Northumbrian Water Authority: Tees Division	A	1980		10	N	N	Pumped drainage scheme	Sedimentation Vegetation growth	
River Glen Flood protection scheme Abeld bridge to Coupland	River Glen	Northumbrian Water Authority: Northumberland and Tyne division	A	1984	78		Y		Channel re-sectioning Flood bank construction Construct outfall sluice	Gravel deposition	Gravel removal
River Hull tidal surge barrier	River Hull	Yorkshire Water Authority		1977-80			N	N	Construction of tidal surge barrier. Narrowing of channel	Siltation in tidal channel	Dredging
Bradpole Flood Alleviation Scheme near Bridport		Wessex Water Authority Avon and Dorset Division		1981-83	51	100	N	N	Two stage channel Flood berms Flood embankments and walls. Flood relief culvert channel revetment	Sediment deposition in flood relief culvert	Sediment removal
Tone Valley scheme near Taunton	River Tone	Wessex Water Authority Somerset Division	U	1967			Y	Y	Major channel improvements		
River Frome, Bristol	River Frome	Wessex Water Authority Avon and Dorset Division		1983-86			Y	Y	Diversion channel		
Tellisford Flume, River Frome, Somerset	River Frome	Wessex Water Authority Avon and Dorset Division		1960-63			N	N	Diversion of earth channel. Construction of flow measuring flume	Erosion of large pool downstream	
Midford Flume		Wessex Water Authority Avon and Dorset Division		1960-63			N	N	Construction of flow measuring flume	Erosion of bank downstream	
River Avon, Chippenham to Malmesbury	River Avon	Wessex Water Authority Avon and Dorset Division		1955-64			N	N	Re-grading Widening Re-alignment	Bank erosion	

FIGURES.

FIGURE 1

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Scheme	
Date	
Type of work carried out	
Were sediment problems considered during design?	
If so, in what way?	
Has maintenance been necessary?	
If so, what was the nature of the problem?	
Further information on design of scheme, if available	
Who to contact for further information	

FIGURE 2

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MORPHOLOGICAL EFFECTS OF RIVER WORKS

Scheme	BRECON FLOOD ALLEVIATION SCHEME
Date	1983
Type of work carried out	Channel enlargement and re-grading and construction of flood embankments and walls
Were sediment problems considered during design?	Yes
If so, in what way?	Morphological analysis of river Usk at Brecon by Consultants and analysis of effects of proposed scheme.
Has maintenance been necessary?	Yes, twice since completion of scheme in 1983
If so, what was the nature of the problem?	Excessive accumulations of gravel in river channel within the extent of the scheme.
Further information on design of scheme, if available	Consultants report available.
Who to contact for further information	A. Abrams, Area Land Drainage Engineer, WWA South East Division, Nelson.

PLATES.

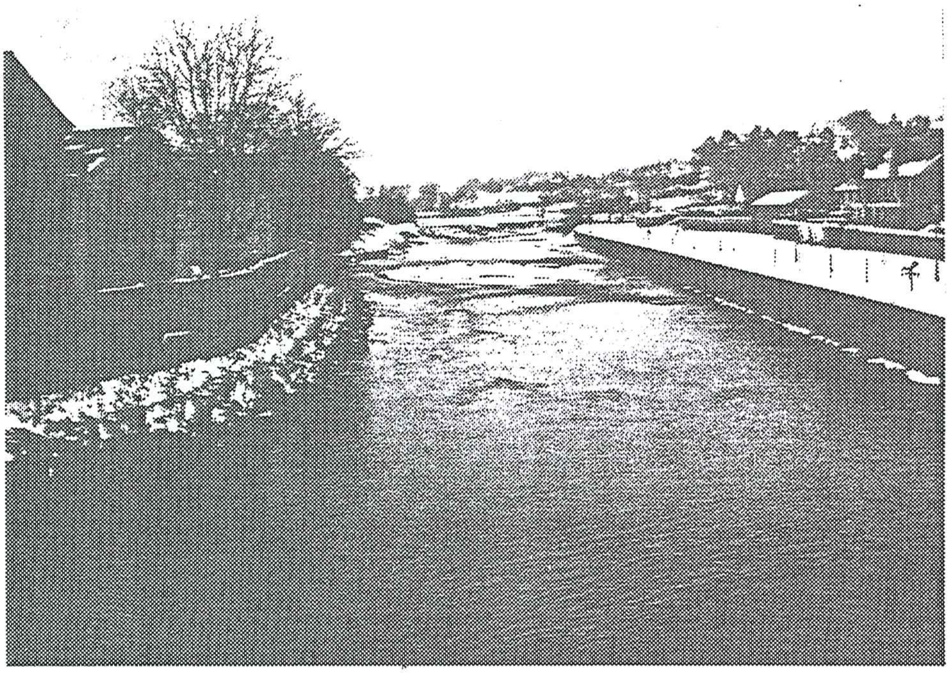


PLATE 1

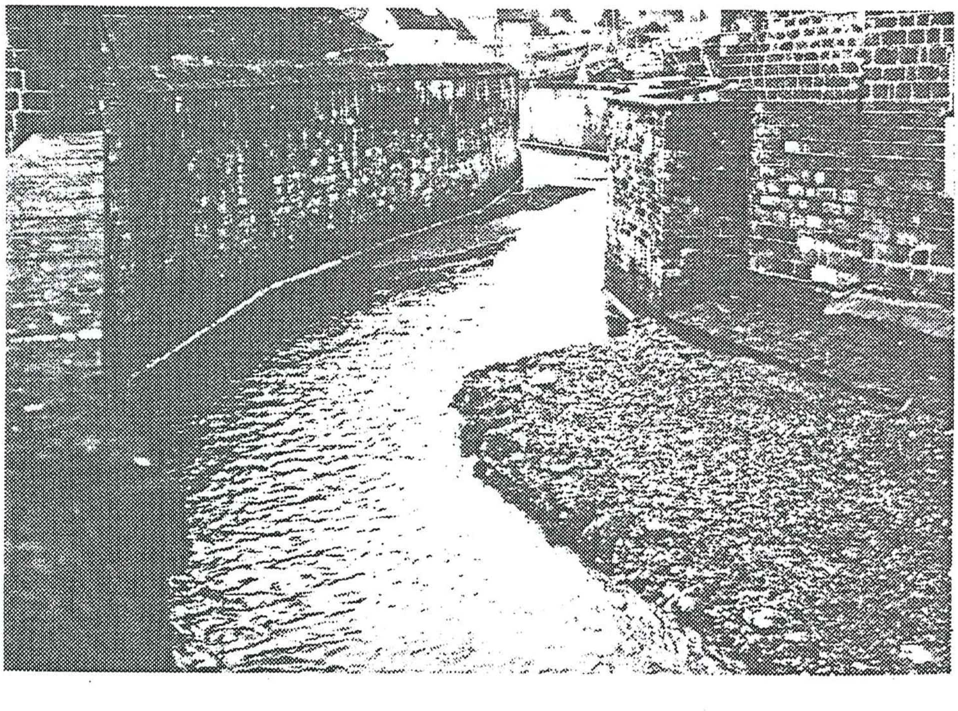
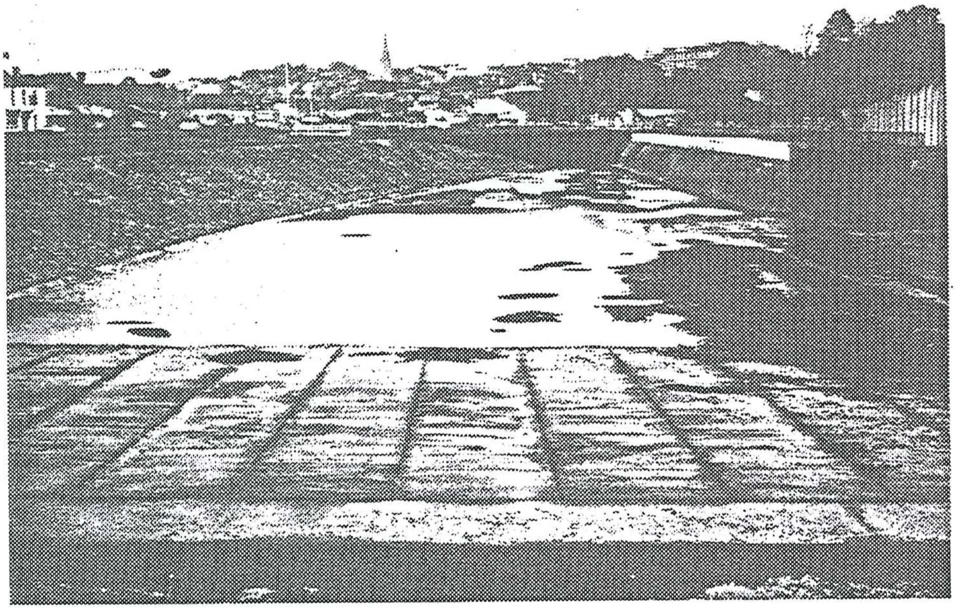


PLATE 2



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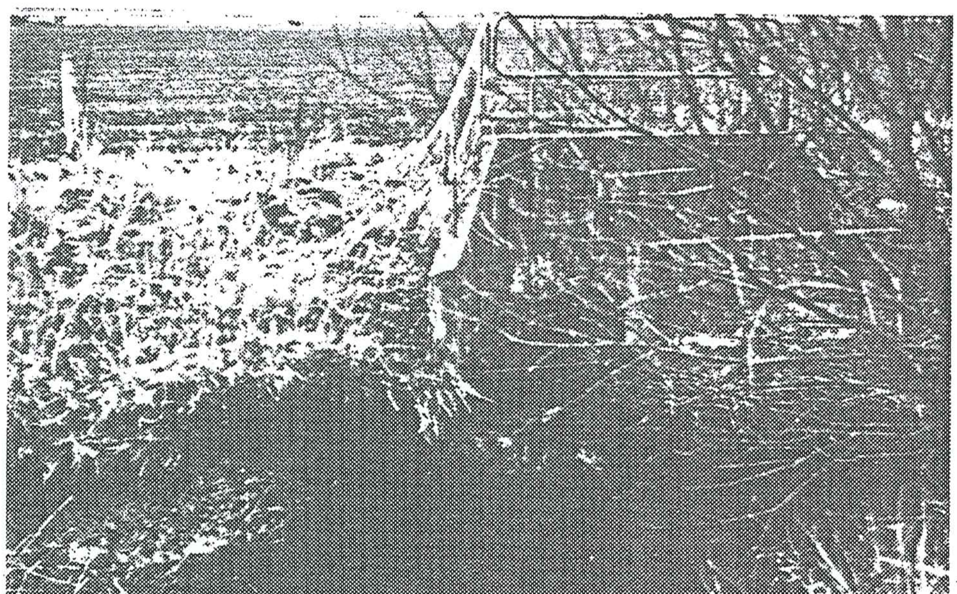

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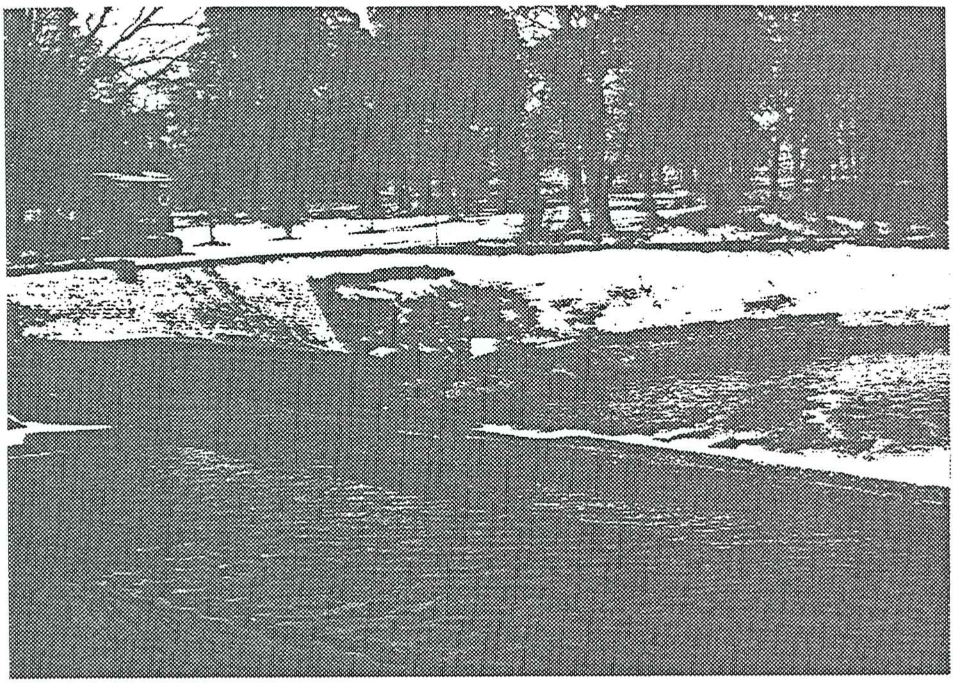

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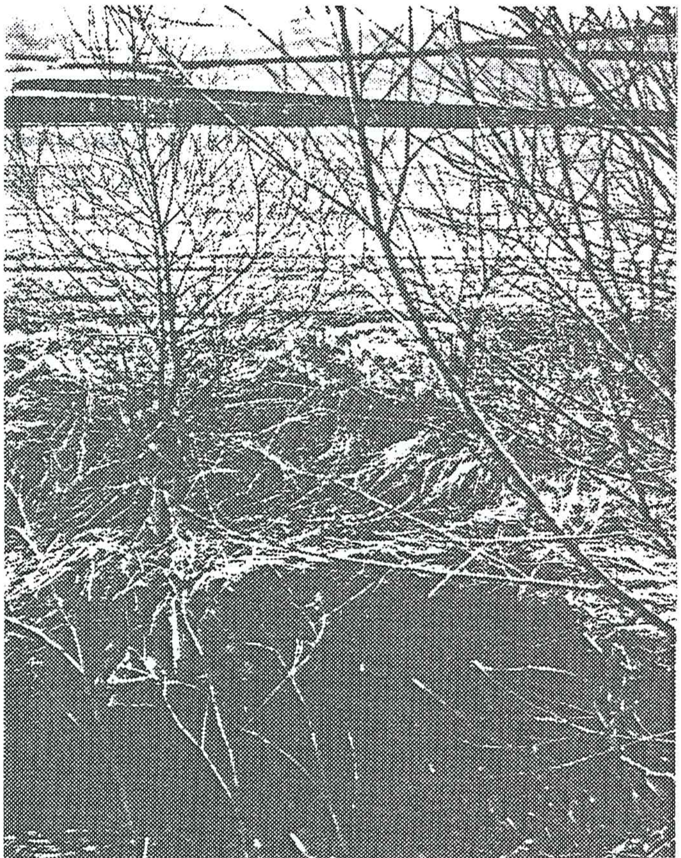

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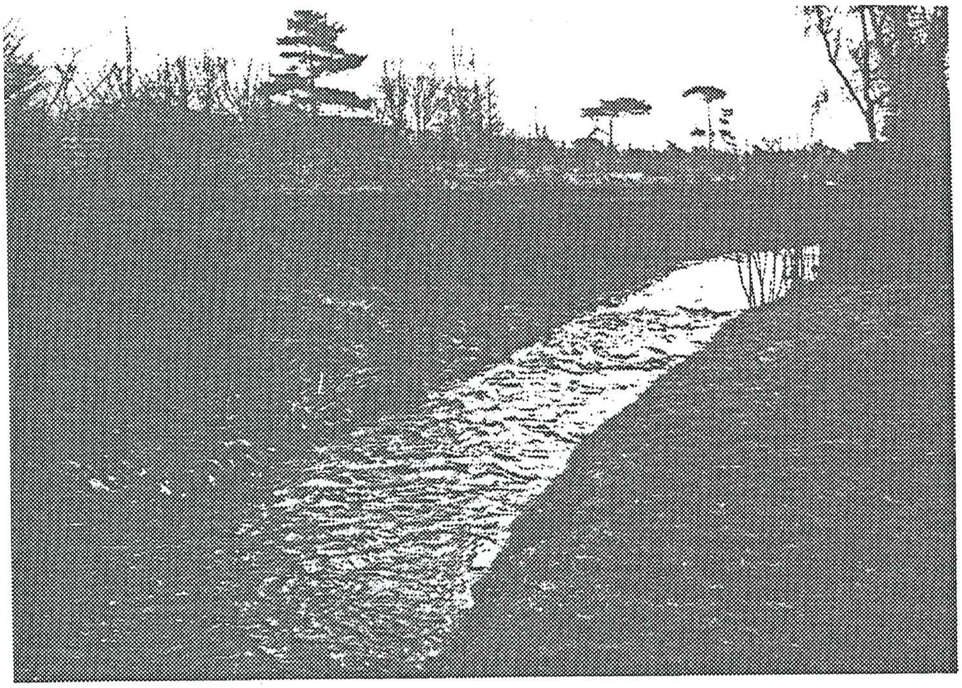


PLATE 7

PLATE 8

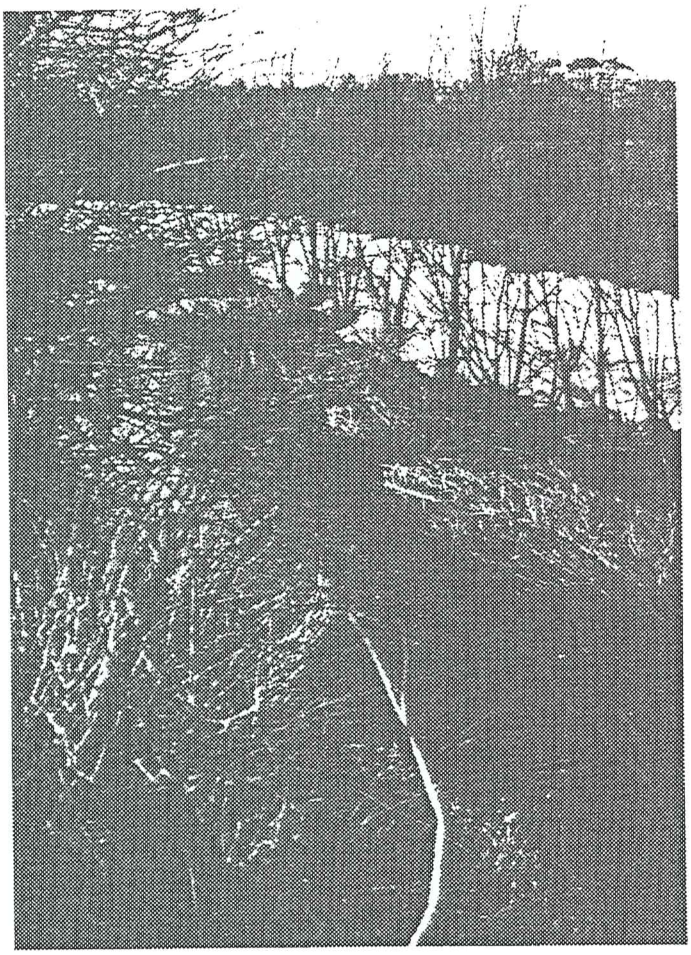
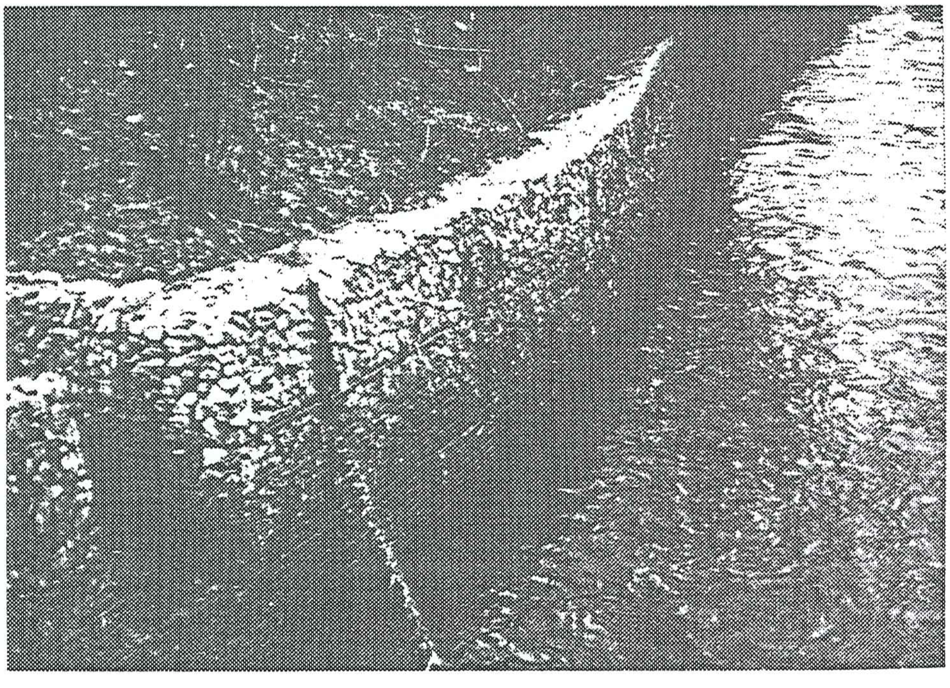


PLATE 9



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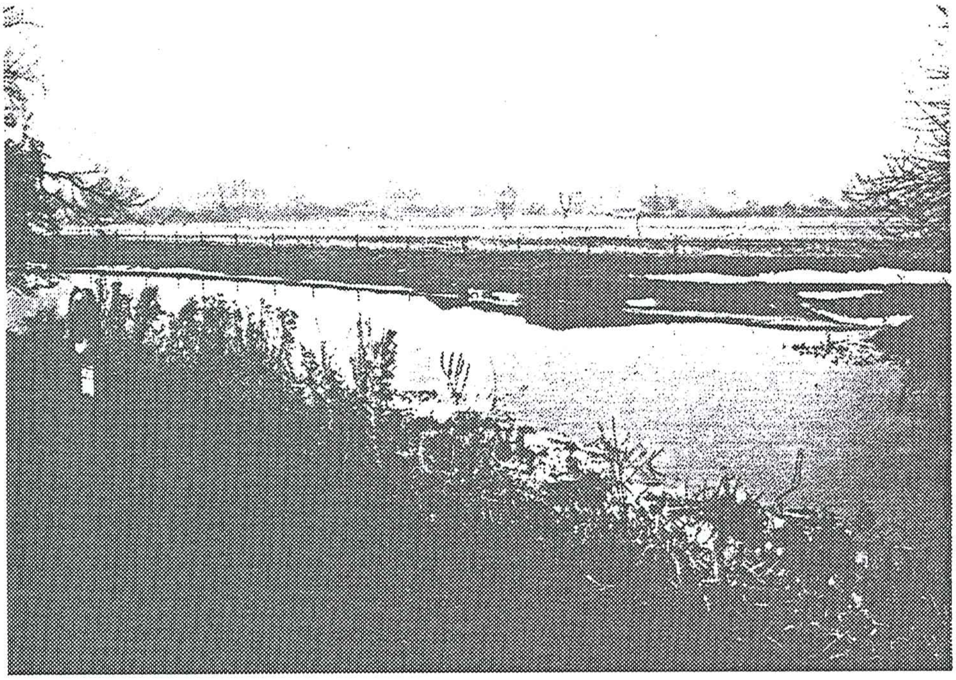

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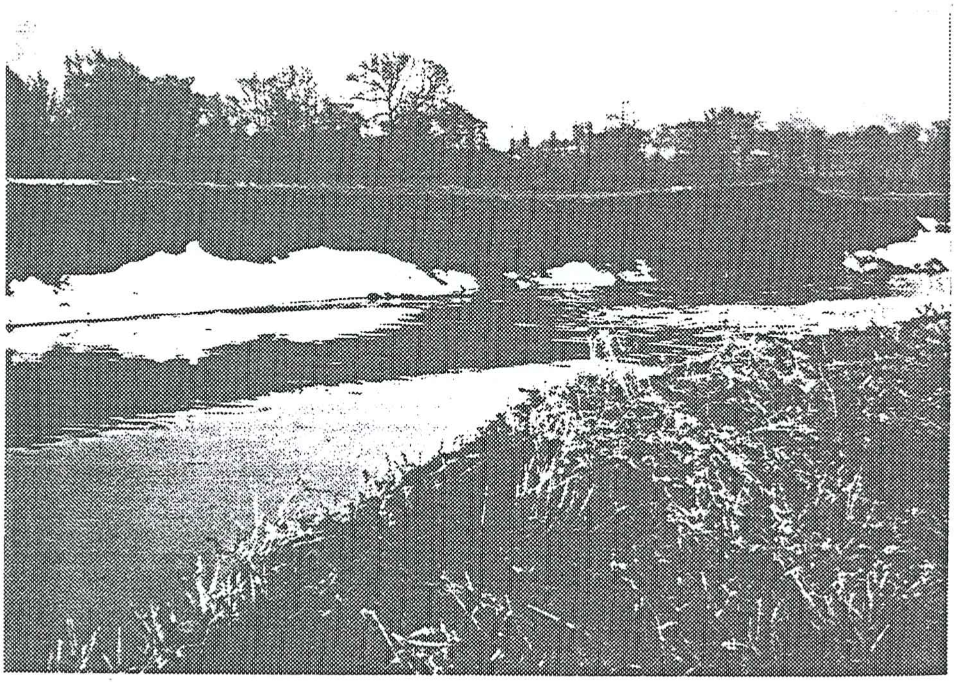

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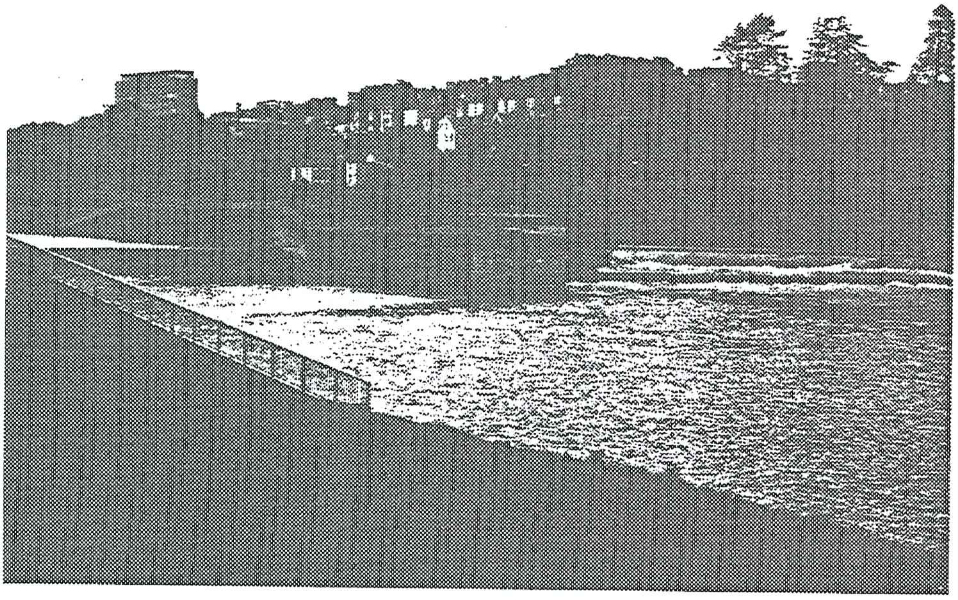

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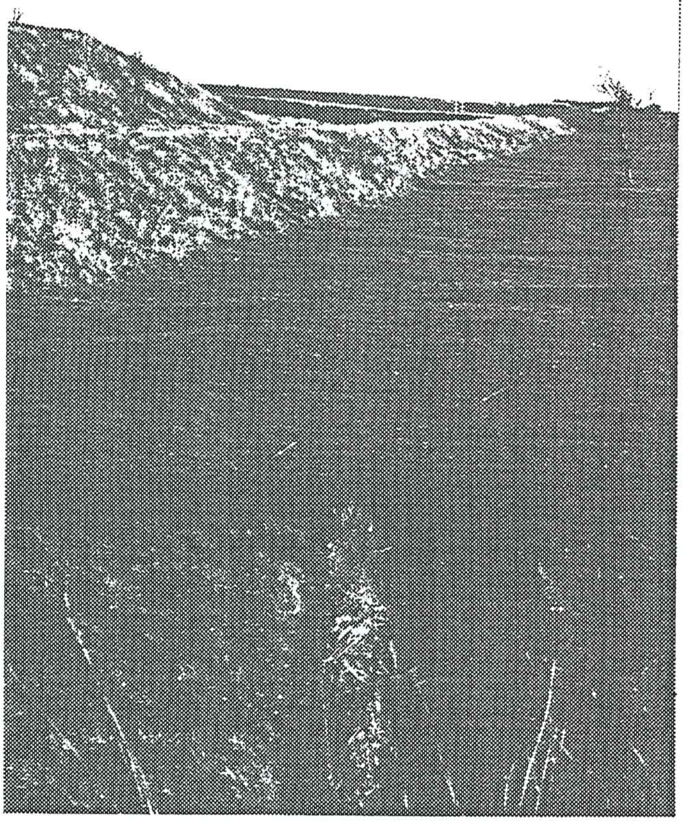

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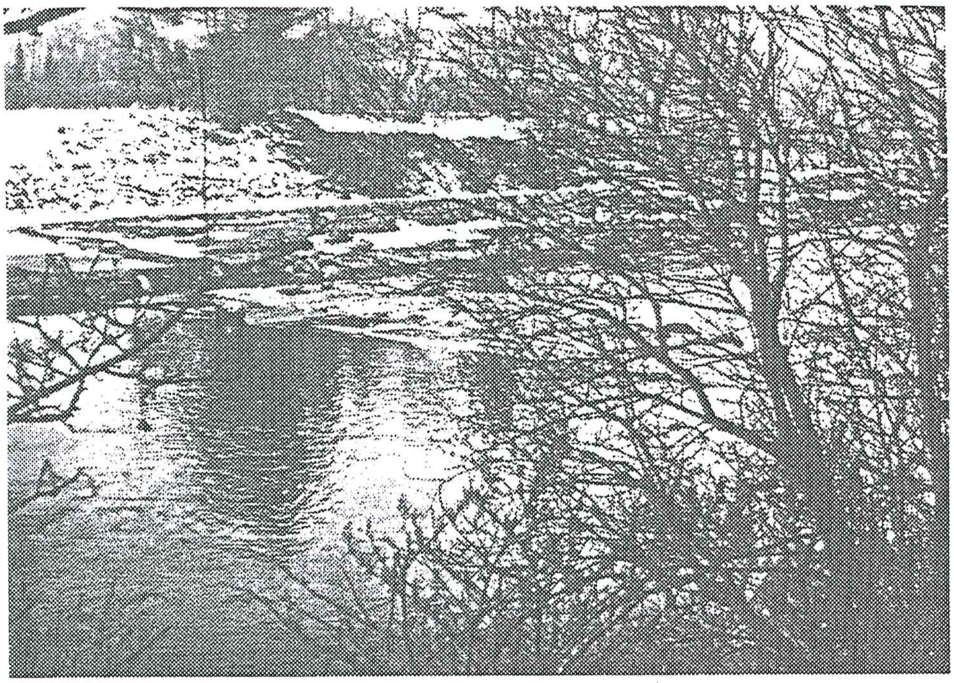

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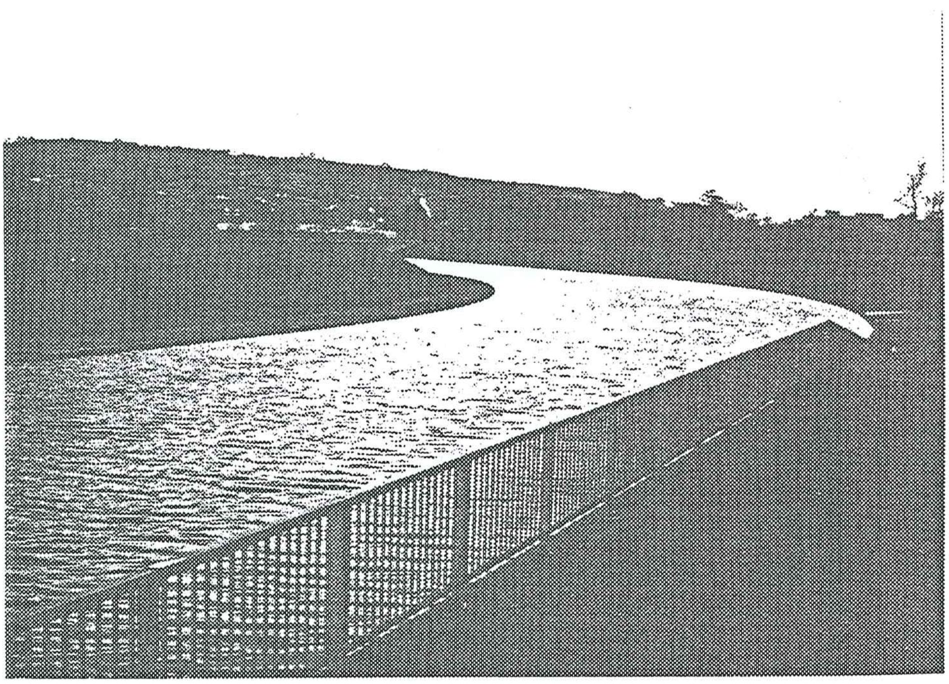

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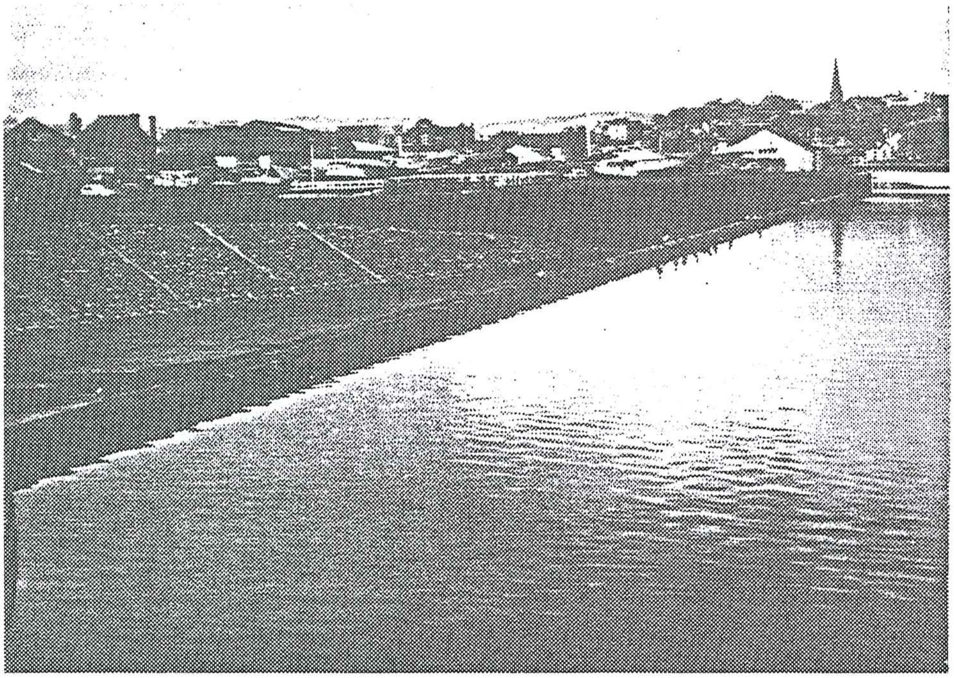

PLATE 17

APPENDICES.

APPENDIX A

Report on schemes visited

A.1 Buck Beck improvement scheme

Anglian Water Authority: Lincoln Division

Aim

Intensive urbanisation of the catchment was planned over the 25 year period from 1975 to 2000. The scheme was designed to increase the channel capacity, over that part classed as main river (6.8km), to contain the 100 year flood from the urbanised catchment. The 100 year flood discharge, once urbanisation is complete, was estimated as approximately 28 cumecs.

Design considerations

Sedimentation

Not considered at the design stage. It is not perceived to be a problem in this or any other of the rivers covered by the Lincoln division of the AWA.

Bank stability

Considered at the design stage. Bank protection of different kinds was installed at bridges and on bends e.g. stone revetment (Grimsby Road bridge), sheet metal piles (Louth Road bridge) and timber planking (Kings Road bridge). River realignment was not carried out in order to avoid erosion and bank stability problems.

Scheme details

The existing tidal doors were modified and a new set installed. These close at high tides to stop tidal flow up the river. High river discharge can force the doors open at any tidal level. Throughout its length the river was deepened and widened to increase its capacity. A compound cross-section was created by constructing flood berms and raising flood embankments. Several new bridges with associated concrete culverts were constructed. The scheme was both designed and constructed by the AWA. Construction started in 1975; the river works were completed by 1979 and the bridge works by 1983. The scheme costs approximately £1m. Two-thirds of the money was provided by Cleethorpes council and one-third by MAFF.

Subsequent problems

Very few problems are evident. The bed of one of the two culverts at Grimsby Road bridge has been covered with sediment but this is not significantly reducing the culverts capacity. There is weed growth throughout the channel.

Maintenance

Regular weed cutting and raking is carried out - this will result in the removal of a small amount of sediment.

A.2 River Usk at Brecon

Welsh Water Authority: South Eastern Division

Aim

A flood in December 1979 caused extensive flooding in Brecon. This flood had a discharge of 610 cumecs and a return period of 45 years. Analysis revealed that existing flood defences would only protect against the 15 year flood which has a discharge of 490 cumecs. A scheme was designed to reduce the frequency of flooding to once every 100 years. The 100 year flood has a discharge of 685 cumecs.

Design Considerations

Both sedimentation and erosion were considered at the design stage by analysing the effect the scheme had on the tractive force at the river bed. It was concluded that there would be erosion upstream and deposition downstream of Llanfaes bridge as a result of the scheme. No attempt was made to quantify the volume of material involved in these processes. It was accepted, at the design stage, that some maintenance would be needed. Detailed monitoring of river morphology was proposed to decide the form and frequency of the maintenance.

Scheme details

The scheme was designed by Sir M Macdonald & Partners engineering consultants. There is a significant difference between what was proposed and the work actually carried out - this was mainly due to pressure from environmentalists who did not want a shoal, with established vegetation growth, removed from downstream of the bridge. As a result of this pressure no channel works were carried out downstream of the bridge. The invert at Llanfaes bridge was lowered by 0.75m and the bridge piers were strengthened. The bed and banks upstream of the bridge were excavated to create a new cross-section and bed gradient. This work was carried out as far as the weir; a distance of approximately 500m. Floodwall height, both up and downstream of Llanfaes bridge was increased by up to 0.8m. New flood walls and flood embankments were constructed at some locations. The river Honddu was retrained and the river Afon Tarell re-aligned at their confluences with the river Usk. The scheme was constructed by Welsh Water and external contractors. It cost approximately £0.9m and was commissioned in 1983.

Subsequent Problems

Gravel shoals form in the channel upstream of Llanfaes bridge causing a significant reduction in the design channel capacity. The source of this gravel is not clear - some must come over the weir (possible only during the highest floods), some is probably eroded from the island downstream of the weir and some must be brought into the Usk by its two tributaries.

Maintenance

Gravel has been removed from the channel, both up and downstream of Llanfaes bridge, twice since the scheme was commissioned. Each time 5-8,000 tonnes of gravel were removed at a cost of £40,000. The scheme was visited about four months after gravel removal - at this time most of the shoals had been re-established indicating that gravel removal at least once a year will be required. Small groynes have been constructed in an attempt to prevent shoal formation. In order to be successful these would have to be so large as to themselves cause a reduction in channel capacity. The shoals cause the flow to be deflected against unprotected banks - revetment work has been carried out to counter the resulting erosion. Because of the significant maintenance commitment a further study is being carried out with the aim of modifying the scheme to reduce the maintenance. It is expected that this study will propose channel works downstream of Llanfaes bridge.

A.3 Cardiff flood relief scheme

Welsh Water Authority: South Eastern Division

Aim

In 1960 Cardiff was inundated by a flood in the River Taff. Subsequent analysis, done as part of, but prior to, the scheme design, revealed that this flood had a discharge of 850 cumecs with a return period of in excess of 100 years. A scheme was designed to protect Cardiff against a similar size flood.

Design Considerations

An hydraulic model was used to test alternative designs for the flood alleviation scheme.

Sedimentation

This was not considered within the hydraulic model.

Erosion

The effect of different channel modifications on the position of the hydraulic jump downstream of Black Weir was analysed. The scheme was modified to ensure that the hydraulic jump was stable and confined to the stilling basin in order to minimise downstream erosion.

Scheme Details

River works were carried out from Penarth bridge to upstream of Radyr weir; a distance of approximately 9km. The channel was graded to create a uniform bed slope. Widening was used to increase the channel capacity. As part of the widening some channel re-alignment was carried out. The modified channel had a regular trapezoidal cross-section. Different forms of bank protection were used to stabilise the modified channel e.g. gabions, concrete matting. In places vertical banks had to be used - at these locations sheet piles fronted by concrete blocks were used as protection. New flood embankments were constructed and existing ones modified. In places these flood embankments were away from the river to allow for offstream flood water storage on the floodplain. Obstructions under bridges were removed to ensure the maximum possible area of flow. The scheme was designed by the Hydraulics Research Station in 1979.

Subsequent Problems

Gravel shoals are deposited in the reach between Cardiff bridge and the Wood Street road bridge and also downstream of the Wood Street rail bridge. The concrete matting apron at the Wood Street road bridge failed and had to be replaced by a solid concrete apron. Bank failures have occurred downstream of Black Weir both where concrete block bank protection exists and in areas where there is no bank protection.

Maintenance

4,500-5,000 tonnes of sediment is removed every five years from the reach between Cardiff bridge and the Wood Street road bridge. As far as the Water Authority is concerned this is an acceptable level of maintenance. This quantity of material is equivalent to a depth of approximately 0.75m across the channel width throughout the reach. Material up to 12" in diameter has been removed. The sediment is removed from the river by the Water Authority. A gravel contractor provides transportation to carry the material away from the site. The gravel shoal downstream of the Wood Street rail bridge is pushed to the bank when maintenance is carried out upstream, however, the gravel is not actually removed. Armouring is carried out, when required, at sites of bank failure. Weed growth between the blocks in the concrete block bank protection has to be kept under control to prevent it becoming unsightly.

A.4 TREFOREST ESTATE FLOOD PROTECTION SCHEME, RIVER TAFF, GLAMORGAN

Welsh Water Authority: South Eastern Division

Aim

In December 1960 a flood occurred which resulted in damage costing approximately £3m. The peak discharge of this flood was estimated to be 715 cumecs. A comprehensive flood relief scheme was designed with the object of containing a flood discharge of the 1960 magnitude.

Design Considerations

A fixed-bed hydraulic model of the complete scheme was developed to ascertain the performance of the recommended design. At the upstream end of the scheme bed configuration and bed-load behaviour in the vicinity of power station intakes were especially important. A mobile-bed hydraulic model was developed for this part of the scheme. Using this model alternative ways of increasing the channel capacity adjacent to the power station were investigated. The efficiency of channel widening and a by-pass channel were analysed. It was concluded, from the mobile-bed model studies, that a flood berm would achieve the same objective with no significant change in bed configuration at the power station intakes. The mobile-bed model illustrated that a proposed bend realignment would result in bank scour. Based on the model results bank protection was proposed.

Scheme Details

The weir at Taff's Well was removed and the bed in the vicinity of the weir was regraded. The bed slope was regraded throughout the scheme. A new weir was constructed near the power station intakes at Nantgarw. Channel realignment was carried out. A trapizoidal channel was created by channel widening and modification of bank slopes - this resulted in a slight increase in cross-sectional area. The modified channel was stabilised by using sheet pile and concrete mat bank protection. Flood banks, up to 2.5m high, were constructed. A flood berm was created and service bridges removed close to the power station intakes. A single track railway bridge was raised by 0.5m. Channel modifications close to bridges resulted in the opening of arches which were not previously used. The multi-arched Gwaelod-Garth bridge was replaced by a single-span structure. The scheme was designed and tested by the Hydraulics Research Station in 1968.

Subsequent Problems

Gravel accumulation occurs within the central part of the scheme. On one bend sheet pile bank protection has failed - these have been replaced by longer sheet piles but the problem has not been solved.

Maintenance

During scheme construction gravel was removed every 2-3 years. Following commissioning this interval increased to once every 4-5 years. The gravel removal takes approximately four weeks and involves 2-3,000 tonnes of material. This material is transported from the site by a gravel contractor. Gravel is only removed from an 800m reach in the central part of the scheme.

A.5 EAST MILL IMPROVEMENT SCHEME, RIVER COLNE, COLCHESTER

Anglian Water Authority: Colchester Division

Aim

The scheme was designed for water supply. It was planned to impound river discharge and exclude tides so that water could be extracted and treated for water supply. The impoundment created a severe man-induced flooding problem which had to be alleviated. Naturally there is no flooding problem associated with the river Colne in Colchester. A scheme was designed to contain floods with discharges up to 114 cumecs. This flood had a return period in excess of 100 years.

Design Considerations

Sedimentation was not considered despite the fact that river discharge was being impounded which would result in a reduction in flow velocities and thus increase the potential for deposition. The fact that erosion was not considered was reasonable since the reduction in flow velocities would decrease the erosion potential.

Scheme Details

The scheme extends for 2.75km from the tidal limit of the river Colne at East Mill to Middle Mill. A new set of automatic sluice gates were installed at East Mill. These were designed to exclude all but the very highest tides (higher than the 1953 surge). The sluice gates automatically open at high river discharges. Adjacent to the downstream part of the scheme the floodplain is heavily developed resulting in no potential for offstream flood storage. Here the channel was massively enlarged (by a factor of two) to create a channel capacity of 71 cumecs. A compound channel cross-section with a capacity of 114 cumecs was developed by constructing flood embankments up to 2.5m high. Further upstream there was potential for offstream flood storage. In this area the channel was not modified and the flood embankments were merged into higher ground. The scheme was designed and constructed by AWA. The scheme cost approximately £100,000.

Subsequent Problems

Silt accumulates in the part of the scheme where the channel was massively enlarged. This accumulation was first noticed by anglers whose fishing lines were fouled by the silt. Erosion has occurred in the pool just downstream of Middle Mill. This appears to be stable and no bank protection is planned.

Maintenance

Approximately ten years after the scheme was commissioned 10,000 cubic meters of silt (and some gravel) was removed from the enlarged channel at the downstream end of the scheme. The silt was pumped from the channel to form a mound at a nearby leisure centre.

A.6 RIVER STOUR IMPROVEMENT, BURES TO CORNARD

Anglian Water Authority: Colchester Division

Aim

The object of the scheme was to protect agricultural land from flooding over a distance of approximately 7km. A beneficial side effect was that it reduced the flooding risk in Bures. At its upstream end the scheme merges with the Sudbury urban flood alleviation scheme. A channel with a compound cross-section and a capacity of 50 cumecs was designed. It was originally

25 years but it has subsequently proved that the return period for this flood was 5-10 years.

Design Considerations

Sedimentation was not considered at the design stage. Potential erosion problems were combated by limiting the maximum flow velocities. This was achieved by constructing new weirs to reduce velocities and therefore erosion. Any erosion that does occur will be concentrated at the weirs where bank protection can be carried out.

Scheme Details

To achieve the flood alleviation it was planned to obtain a 4' freeboard by channel deepening and the raising of flood embankments. No channel widening was carried out. The water level at Bures mill was dropped by 2' and bed material removed from upstream of the mill. At places where a 4' freeboard already existed new weirs were installed. The modified channel had a capacity of 25 cumecs which is the mean annual flood. A further advantage of the lower water levels is that it improves the drainage of adjacent agricultural land. Spoil removed from the channel was used to create a compound cross-section by the construction of flood embankments. The capacity of the channel to the top of the flood embankments is 50 cumecs. The flood embankments are largest in the centre of the scheme; up to 5'. At some locations, where the farmer did not want flood protection, there are no flood embankments. At these locations spoil from the channel was thinly spread over adjacent farmland. At Rookery bend, just downstream of Bures, sheet metal revetment work was carried out. This was to enable the construction of new landing stages compatible with the new river level rather than as bank protection. The scheme was designed and constructed by AWA at a cost of £65,000.

Subsequent Problems

There is erosion upstream of Henney weir where the river by-passes the weir at high discharges. Weed growth is visible within the channel at Henney. Coypu holes may result in the destabilising of flood embankments. A re-survey approximately ten years after the scheme was commissioned revealed silt deposits. This silt may not have been removed during the schemes construction.

Maintenance

The only maintenance has been grass cutting on the flood embankments.

A.7 NAYLAND FLOOD RELIEF CHANNEL

Anglian Water Authority: Colchester Division

Aim

The scheme was designed to carry flood flows beneath the improved Sudbury to Colchester road. The work was carried out as part of the improvement scheme for this road. At Nayland the road crosses a wide floodplain which occassionally carries a large volume of shallow flood water. Since the construction of a viaduct is extremely expensive it was decided to construct a bridge for the river flow and a relief channel for the flood flow.

Design Considerations

Little information is available about the scheme but it is very unlikely that sedimentation would have been considered at the design stage. Potential erosion problems were considered since substantial foundations were used for the footbridge which crosses the relief channel.

Scheme Details

A 600m relief channel with grass banks and bed was constructed linking the river Stour up and downstream of Nayland. The relief channel is a wide, shallow feature with gently sloping banks and a gentle bed gradient. On the bed of the relief channel there is a ditch. Automatic gates, at the upstream end, control the flow into the relief channel. These gates are controlled by the river level - they gradually open as bankfull discharge is approached.

Subsequent Problems

There has been erosion immediately behind the sluice gates. The eroded material has been deposited in the relief channel. The ditch on the relief channel bed has been greatly enlarged since the scheme was commissioned and there is still evidence of active erosion. A large scour has been formed in the bank of the river Stour opposite to where the relief channel rejoins. Excessive weed growth occurs within the relief channel - reeds several feet high were present at the time of the visit.

Maintenance

There is no evidence of any maintenance since the scheme was commissioned.

A.8 RIVER YEO - THORNFORD SCHEME

Wessex Water Authority - Somerset Division

Aim

The scheme had two independent objectives; firstly to alleviate floods up to 30 cumecs and, secondly, to lower river levels in order to improve the drainage of adjacent agricultural land. Very little flow data was available at the design stage. A 30 cumec flood was believed to have a return period of 5 years. Subsequent monitoring has illustrated that the return period for this flood is much longer than 5 years. This may in part be due to the improvement work carried out at Sherborne Lake. This has resulted in the lake attenuating floods by acting as a storage reservoir. The work at Sherborne Lake was part of a water supply scheme and was carried out independently of the Thornford scheme.

Design Considerations

Neither sedimentation or erosion were considered at the design stage.

Scheme Details

The scheme extends for 7km downstream of Sherborne. Throughout this length the river was deepened by approximately one metre. Channel widening was also carried out - this was greatest at the upper and lower ends where the channel width was approximately doubled. At three locations meanders wee straightened to increase flow velocities and thus transit times. There appears to have been little logic to this straightening. Large meander loops have been left which could easily have been straightened - this may have partly been due to pressure from farmers who did not wish to lose land. Spoil from the channel was used to create very low, gently sloping flood embankments on the right bank. Old farming structures were removed from the channel. A bridge was modified by strengthening its foundations and another bridge was reconstructed. A throttle and bank was constructed towards the bottom end of the scheme to prevent undesirable effects on the river downstream. The scheme was designed and constructed by WWA at a cost of £150,000.

Subsequent Problems

In reaches where the channel was widened and/or straightened a meandering low flow channel has been established. Silt banks and gravel shoals have been deposited to create a compound cross-section - the deposited material becomes coarser towards the bottom end of the scheme. Vegetation is established on the deposited material - willows up to 15' high indicate that some of this material was deposited very shortly after the scheme was commissioned. There is evidence of erosion where the channel has been straightened. A particularly bad scour can be observed where a straightened reach meets meander infill. One surprising result of the scheme was on groundwater levels. In places the river is cut into floodplain gravels. The drop in river level resulted in a reduction of the water table elevation. An abstraction well had to be deepened to counter this effect.

Maintenance

The only maintenance has been willow planting and stone revetment work for bank protection. The removal of the larger vegetation from the channel, especially willow growth on deposited material, is urgently required. The Water Authority is not concerned about the loss of design capacity due to deposition since the channel appears to have originally been over enlarged.

A.9 RIVER ECCLESBOURNE AT DUFFIELD

Severn-Trent Water Authority: Derwent Division

Aim

The scheme was designed to protect Duffield against a 100 year flood in the river Ecclesbourne.

Design Considerations

Sedimentation was not considered at the design stage. Erosion was considered and extensive bank protection was planned as part of the scheme.

Scheme Details

River works were carried out on a 1km reach of the river Ecclesbourne through the centre of Duffield. In the central part of the scheme the river was confined to a concrete channel with vertical banks. Vertical banks had to be used to obtain the required capacity and concrete was used for stability. Both up and downstream of this concrete channel stone revetment work was carried out to protect the banks of the natural channel. At the downstream end of the scheme a meander bend was straightened and sheet piling was installed to protect the railway. For approximately 100m upstream and 50m downstream of the A6 road bridge the natural channel width was approximately doubled. Originally the widened channel was split into a low flow and flood channel by sheet piles. These had to be removed after the scheme was commissioned due to pressure from local residents. Bridges over the widened channel were strengthened by underpinning. Flood walls which merge into higher ground were constructed at the up and downstream ends of the scheme. The scheme was designed and constructed by STWA.

Subsequent Problems

Sediment accumulates in the concrete channel upstream of the A6 road bridge. The stone revetment bank protection is being eroded - this is especially bad where the revetment abutts the sheet piles that protect the railway.

Maintenance

In September/October each year 300-600 cubic metres of sediment are removed from the concrete channel upstream of the A6 road bridge. An access ramp had to be constructed to allow this sediment removal. The quantity of material removed is equivalent to a 1 metre depth evenly spread over the channel width for a distance of 80m. The material is mainly silt but gravel up to 2" in diameter has also been removed. The sediment that is removed is dumped by the Water Authority. The sediment problem at Duffield is the worse in the division that has been generated by river works. The Water Authority is looking at ways of reducing its maintenance commitment. It believes that the source of sediment is the river Ecclesbourne just upstream of Duffield and plans to carry out bank protection work in this area in the near future. A site upstream of Duffield was visited - very bad erosion was visible but the sediment appeared to be of a smaller size than that deposited in Duffield.

A.10 RIVER DERWENT AT MATLOCK

Severn Trent Water Authority: Derwent Division

Aim

The scheme was designed to protect Matlock against a 100 year flood in the river Derwent. This flood has a discharge of 320 cumecs.

Design Considerations

Neither sedimentation or erosion were considered at the design stage. Sediment transport was not considered since the river is steep and fast flowing so it was not perceived to be a problem.

Scheme Details

It was planned to achieve the protection by increasing the channel capacity over a distance of 1.25km and by constructing flood walls. Throughout this length the river is cut into rock (limestone). On one side of the river there is a vertical rock face whilst on the other the A6 has been constructed. The only way the required capacity could be achieved was by deepening the river - this would cause a reduction in water level and thus an increase in freeboard. The channel was deepened by blasting, and then removing the rock (material that had fallen from the adjacent rock face was also removed). The material removed was dumped at the side of the river near the downstream end of the scheme. A man-made and natural rock weir were removed at the downstream end of the scheme and the channel was deepened throughout. The bed level was reduced by approximately 3m at the downstream end of the scheme and by 1m at the upstream end. A service bridge was removed and at another bridge a pipe was moved from beneath to beside the bridge. Existing flood walls were strengthened by adding mortar to dry stone walls.

A new flood wall was constructed round a park towards the upstream end of the scheme. A previously unused arch under the main road bridge was opened by the construction of a ramp and flood wall. Automatic gates and pumps were installed at the mouth of a tributary. The gates were to prevent flood waters flowing up the tributary from the Derwent. The pumps enabled flood water to be pumped from the tributary into the Derwent when the water level in the Derwent was higher than that in the tributary. The scheme was designed by STWA using an hydraulic model. The Water Authority constructed the scheme.

Subsequent Problems

The 3-5' drop in water level that resulted from the channel deepening caused bank instability. Very shortly after the channel was deepened extensive bank protection work had to be carried out. This was done by both the Water Authority and the Council (to protect the A6). Stone revetments and stone gabions were used to create stable banks. A lot of protection had to be carried out round the bridge piers.

Maintenance

No maintenance, other than the bank protection described above, has been carried out since the scheme was commissioned.

A.11 RIVER EXE IMPROVEMENT SCHEME, EXETER TREW'S WEIR FLOOD RELIEF CHANNEL

South-West Water Authority

Aim

The scheme was designed to alleviate flooding in Exeter due to an event of similar magnitude to the 1960 flood. This flood had a discharge of approximately 715 cumecs and a return period of 50 to 100 years.

Design Considerations

An hydraulic model was used at the design stage. Sedimentation was not considered within this model. Using the model a stilling basin, in the relief channel downstream of the side weir, was designed to ensure that the hydraulic jump was stable thus reducing the potential for erosion downstream. Based on velocities measured in the hydraulic model bank protection of different types was proposed. The model illustrated that flow over the side weir was a powerful stream of water which could result in erosion problems in the relief channel. Baffle blocks at the base of the side weir were proposed to diffuse this flow.

Scheme Details

A flood relief channel approximately 1km in length was excavated - the material removed was spread over adjacent land. Water enters the relief channel over a side weir just upstream of Trews Weir. The height of the side weir is such that two-thirds of the design discharge is carried by the river and one-third by the relief channel. Downstream of the side weir, adjacent to Trews Weir, a side channel ,with automatic gates, was constructed to minimise the amount of flow that goes into the relief channel. A new fish pass for

Trew's Weir was constructed. In the relief channel downstream of the side weir there is a large stilling basin with bank protection of different types - these were based on velocity measurements at the design stage. The relief channel has grass banks and bed. The scheme was designed so that there is only flow in the relief channel when the river discharge is greater than two-thirds the design flood. At the sides of the relief channel there are two small drainage ditches. The scheme was designed by the Hydraulics Research Station.

Subsequent Problems

Stone pitching was originally used as bank protection at the downstream end of the stilling basin. Vandals pushed these stones into the stilling basin so they were replaced by a grouted stone revetment. A small quantity of sediment accumulates in the stilling basin.

Maintenance

The grass bed and banks of the relief channel are regularly cut - grazing sheep have also been used for this purpose. The sediment from the stilling basin is removed every few years. This removal is considered to be an acceptable level of maintenance by the Water Authority. Structure maintenance is carried out. The drainage channels in the relief channel are cleaned out. A re-survey of the river in 1986 revealed that there had been no significant change in river morphology since the scheme was commissioned.

A.12 RIVER EXE IMPROVEMENT SCHEME, EXETER EXWICK FLOOD RELIEF CHANNEL

South-West Water Authority

Aim

The scheme was designed to protect the Exwick area of Exeter against a flood of similar magnitude to that which occurred in December 1960. This flood had a peak discharge of 715 cumecs and a return period of 50 to 100 years.

Design Considerations

Fixed bed and mobile hydraulic models were used at the design stage. The mobile bed model was used to investigate potential areas of scour and accretion and also to study the distribution of sediment load between the river and the relief channel. Based on the results of his model it was decided which types of bank protection to use and a set of automatic flood gates were designed.

Scheme Details

A flood relief channel from Exwick Mill to Blackaller Weir, a distance of approximately 1.5km, was excavated - the material removed was spread over adjacent parkland. The relief channel has a compound cross-section; the lower part is a concrete channel whilst the upper part has natural grass banks. A constant flow is maintained in the concrete part of the relief channel by water fed from the river upstream of Exwick Mill; this flow does not pass over the side weir at the upstream end of the relief channel. The flow depth is one metre at the upstream end and two meters at the downstream end of the relief channel. At the upstream end of the relief channel there is a side weir and stilling basin. The strength of the bank protection in the stilling basin was based on velocity measurements made in the hydraulic models. At its downstream end the relief channel rejoins the river Exe by way of a weir; baffle blocks have been placed at the base of this weir to diffuse the flow and thus reduce the potential for erosion. Flow into the relief channel is controlled by automatic gates in the river. These close at bankfull discharge (approximately 240 cumecs) to force flow over the side weir into the relief channel. Approximately one-third of the design discharge will remain in the river whilst two-thirds will pass down the relief channel. All flows up to bankfull discharge must remain in the river to prevent the deposition of sediment. The control gates were constructed on land at the inside of a bend. When they were completed the river was realigned to pass through them. The scheme was designed by the Hydraulics Research Station.

Subsequent Problems

Excessive weed growth, below the water surface, in the relief channel sometimes occurs - this is only a minor problem since it can easily be removed.

Maintenance

Structures are regularly maintained and the grass banks of the relief channel are cut. A re-survey of the river in 1986 showed that there had been no significant change in channel morphology since the scheme was commissioned.

A.13 RIVER EXE IMPROVEMENT SCHEME, EXETER. WORKS AT COWLEY

South-West Water Authority

Aim

The scheme was designed to protect the Cowley region, on the outskirts of Exeter, against floods with discharges up to 700 cumecs. The return period of a 700 cumec flood is 50 to 100 years. Hydraulically this area is very complex since flooding results from the interaction of two rivers, the Exe and the Creedy, which have different flood regimes. Weirs and bridges further add to the complexity.

Design Considerations

An hydraulic model was used at the design stage. Sedimentation was not considered within this model. Bank protection was proposed at locations where high velocities were measured in the model. The model reduced the cost of the scheme since it illustrated that a side weir at the upstream end of the flood relief channel was not required.

Scheme Details

A short flood relief channel was excavated to link the Exe with the Creedy. The channel has a natural bed and banks. There is not a weir at either end of the relief channel. A constant flow approximately one metre deep is contained within the channel. The crests of Exwick Weir, on the Creedy, and Cowley Weir, on the Exe were reduced by 2 feet. The right hand arch of the road bridge over the Creedy was opened. High points on the floodplain between the two rivers, downstream of the road bridges, were removed. Stone revetment bank protection was carried out at locations where the greatest velocities were measured in the hydraulic model. The scheme was designed by the Hydraulic Research Station.

Subsequent Problems

Erosion has occurred in the Exe upstream of the relief channel. This may in part be due to the post-scheme installation of water supply pipes beneath the river bed which are having a weiring effect. Erosion is occurring on the bank of the Exe, downstream of the road bridge, due to overland flow from the Creedy. Sediment has been deposited on the nose of land between the Exe and the relief channel. This is surprising since stone revetment work was carried out at this location because high velocities were measured in the hydraulic model. There is evidence of sedimentation (excessive reed growth) at the left hand side of the relief channel. The river Creedy is attempting to close the bridge arch which was opened as part of the scheme.

Maintenance

5,000 tonnes of sediment were removed from the nose of land between the Exe and the relief channel in 1982/83. Material was quickly re-deposited at this location and subsequently appears to have stabilised. It was decided not to remove this material in the future. One metre high stone gabion groynes have been placed at the sides of the relief channel to increase the flow velocity at the centre of the channel for the fish. It is unclear what, if any, effect these will have on the efficiency of the scheme.

APPENDIX B

Statistical analysis of scheme information

Table B.1 is a numerical summary of schemes for which information was assembled. It relates the number of schemes with sedimentation and erosion problems to whether or not these processes were considered at the design stage. This survey is not, and was never intended to be, comprehensive so it is very difficult to draw any conclusions from the components of Table B.1 which relate to individual Water Authorities. However, the totals can be used for further analysis since they are summaries of schemes with different design considerations and problems from a number of physical regions. A difference of means test was used for this analysis. In order to use this test two random samples are assumed to have been drawn from two normal (or approximately normal) populations. The hypothesis that is tested is that these populations have the same mean and standard deviation. In order to do this the T statistic is used, where:

$$T = \frac{\bar{X}_1 - \bar{X}_2}{\sigma \sqrt{\frac{1}{n_2} + \frac{1}{n_2}}} \quad \text{and} \quad \sigma = \sqrt{\frac{n_1 s_1^2 + n_2 s^2}{n_1 + n_2 - 2}}$$

$\bar{X}_1$, s_1, n_1 and $\bar{X}_2$, s_2, n_2 are respectively the mean, standard deviation and size of the two random samples. T is distributed as students t with $n_1 + n_2 - 2$ degrees of freedom. For both sedimentation and erosion the hypothesis tested was that it makes no difference whether or not the process is considered at the design stage to the number of schemes with problems. Table B.2 shows the details of the statistical analysis. The hypothesis is rejected for sedimentation and accepted for erosion. It can be concluded that the Water Authorities are better at judging whether sedimentation is likely to be a problem than they are at judging whether there will be erosion problems as a result of the river works.

TABLE B.1: The relationship between design considerations and subsequent problems

Water Authority	Total number of schemes	Number with sediment problems	Sedimentation: Considered at design stage		Sedimentation: Not considered at design stage		Number with erosion problems	Erosion: Considered at design stage		Erosion: Not considered at design stage	
			Total number	Number with problems	Total number	Number with problems		Total number	Number with problems	Total number	Number with problems
Anglian	18	7	1	0	17	7	8	7	3	11	5
Wessex	7	2	2	0	5	2	4	2	0	5	4
Northumbrian	5	3	1	1	4	2	2	0	-	5	2
Severn-Trent	4	2	2	1	2	1	4	2	2	2	2
Welsh	3	3	2	2	1	1	2	3	2	0	-
South-West	3	2	1	0	2	2	1	3	1	0	-
Yorkshire	1	1	0	-	1	1	0	0	-	1	0
Totals	41	20	9	4	32	16	21	17	8	24	13

TABLE B.2: Statistical Analysis

Sedimentation

Hypothesis: It makes no difference, to the number of schemes with problems, whether or not sedimentation is considered at the design stage.

Sample 1 (Sedimentation considered): 0,0,1,1,2,0,0

$\bar{X}_1 = 0.57$, $s_1 = 0.79$, $n_1 = 7$

Sample 2 (Sedimentation not considered): 7,2,2,1,1,2,1

$\bar{X}_2 = 2.29$, $s_2 = 2.14$, $n_2 = 7$

$\sigma = 1.74$, $T = -1.85$, $\nu = 12$

T is significant at the 95% level. Hypothesis rejected.

Erosion

Hypothesis: It makes no difference, to the number of schemes with problems, whether or not erosion is considered at the design stage.

Sample 1 (Erosion considered): 3,0,0,2,2,1,0

$\bar{X}_1 = 1.14$, $s_1 = 1.21$, $n_1 = 7$

Sample 2 (Erosion not considered): 5,4,2,2,0,0,0

$\bar{X}_2 = 1.86$, $s_2 = 2.04$, $n_2 = 7$

$\sigma = 1.81$, $T = -0.74$, $\nu = 12$

T is not significant at the 95% level. Hypothesis accepted.