EA - South West
Box 9

ENVIRONMENT AGENCY

REVIEW OF FLOOD DEFENCE PRACTICES ON THE SOMERSET LEVELS AND MOORS

THE REPORT

July 1999

EA-South West/99-48 √

CONTENTS

DOCUMENT 1

THE REPORT

ENVIRONMENT AGENCY
021869

DOCUMENT 2

THE APPENDICES

DOCUMENT 3

MAPS AND FIGURES

REVIEW OF FLOOD DEFENCE PRACTICES ON THE SOMERSET LEVELS AND MOORS

1. EXECUTIVE SUMMARY

1.1 Review Documents and Consultation Process

A commitment to review flood defence practices is a key part of the Environment Agency's Somerset Levels and Moors Water Level Management Strategy. This is the first report to be produced as part of that review. It is in three parts:

i) A scoping document presenting information on current practices
ii) Supporting Appendices
iii) Maps and Figures

This first report sets out the present flood defence practices as understood by the Environment Agency. Comments are invited on the information provided. Once a common information baseline is agreed the review will then proceed to its next stage. This will involve consideration of any changes to flood defence practices and the drawing up of future programmes of work. Suggestions on these aspects of the review are welcome too.

To ensure momentum can be maintained and to allow consideration by the Agency's Flood Defence Committee, it would be helpful for initial responses to be made by 31 October 1999. To aid the consultation process and to help ensure an understanding of the complex issues involved the Agency is happy to respond to requests for further information and to accept invitations to address meetings.

1.2 Basic Principle

The basic principle of Flood Defence in the area is that to protect the urban areas of Taunton, Bridgwater, Langport etc, excess flood waters from rivers or high tides is stored on the low lying moors until it can be evacuated without increasing flood risk downstream.

1.3 Overview

The report first provides a factual overview of the complex drainage system, including a history of the drainage and how it evolved, and the topography and geology that moulded it. The sluices, pumping stations, flood banks and channels are detailed, and their roles in summer water supply and flood defence outlined. Guidelines within which the Agency operate when conditions allow are stated, and the importance of structures to strategic and local drainage highlighted.

The overview section ends with a summary of the roles and responsibilities of the various Operating Authorities affecting flood defence within the Levels and Moors.

1.4 Benefit/Cost Analysis

The Benefit/Cost Analysis looks at all the identifiable benefits of the Agency's flood defence work in catchment, the area which feeds the Levels and Moors. It does this by considering flood damages under the existing standard of service, under a "do nothing" scenario and with a reduced standard of service.

Whilst economic values are calculated for agricultural and urban benefits, no attempt has been made to assign such values to wildlife, habitat, landscape, archaeology, tourism, recreation and socio-economic benefits, but these are described. The Agency's current revenue costs and capital costs over the last ten years are used for annual costs.

The agricultural benefit analysis includes a financial analysis reflecting the impact on farming incomes, including Environmentally Sensitive Area (ESA) payments, and a comparative economic analysis involving net margins under Treasury rules. The economic analysis recognises ESA payments as a measure of the nation's valuation of the land environmentally. With the assumptions made, the benefits to the nation of the current flood defence regime are significantly less than the financial benefit to farmers. The analysis also concludes that agriculture is heavily dependent on flood defence. Reduction in flood defence standards would increase economic benefit to the nation, whilst reducing financial benefit to farmers. If reduced standards of Flood Defence resulted in a significant reduction in agriculture on the Somerset Levels and Moors the economic benefit would not be realised, due to the lack of farmers to manage the land.

The cost of the current standard of service of flood defence can only be justified by the protection afforded to the major urban areas by storage of floodwater on the Moors.

All three scenarios offer some nature conservation interest. There is a need for a consensus as to the relative merits of the different habitats resulting from each scenario. The area's natural assets most highly prized nationally and internationally are reliant on the current standard of flood defence, and would be lost if that service reduced.

1.5 Parrett and Sowy Operational Model

A hydraulic computer model first developed in 1993 has been significantly enhanced to help the testing of options for operating the Parrett, Sowy, Tone and King's Sedgemoor Drain system. Flood events since 1997 have been used to calibrate flows, and observed levels against model simulation results are presented.

Some limited scenarios changing spillway levels, dredging regimes and sluice operations have been tested. Even where these show improvements, further work on the cost effectiveness and economic justification of such changes is necessary. Further calibration during different flood events will give greater confidence in model predictions and updated survey information needs to be collected and input.

1.6 Effects of Development

In July 1995, the Agency presented a series of studies on flooding on the Somerset Levels and Moors. This included a presentation of the insignificance of the runoff from Taunton compared to that from the other 96.5% of the River Tone catchment. To further illustrate this, and the impact of development on other rivers draining to the Levels and Moors, studies have been undertaken using catchment computer models with and without urban areas.

These studies conclude that the total urban area of the River Tone contributes just a 2.8% increase on a 1 in 100 return period flood, rising to 4.1% on an annual flood. Similarly the urban contribution of the River Isle is just 1% for a range of return periods, and for the River Yeo 2% for a 1 in 100 year event. These are so small, that the impact of recent increased development is almost unmeasurable, as all recent developments have included an element of detention as recommended by the Agency.

1.7 Maintenance Summary

The Appendices accompanying this report generally give further detailed information to back up that in the Overview and Benefit/Cost Analysis. However, Appendix F, the Maintenance Summary is a spreadsheet presenting routine grasscutting, weed control and dredging for all main river reaches in the Overview study area, and the specification for this work. It gives a reason for the work being undertaken, and shows changes in specification introduced since the 1980s. These details will help identify current and past practice on lengths where there may be some concern about the impact of the Agency's maintenance work.

2. INTRODUCTION

The 1991 Somerset Levels and Moors Water Level Management and Nature Conservation Strategy, itself reviewed in 1998/99 includes an understanding to review Flood Defence Practices on the Somerset Levels and Moors.

Whilst there are many links between Flood Defence Practice and Water Level Management, in many locations, the same structures being operated for both, it is important to review them separately. They do not need to impact on each other, and their objectives differ. For the majority of the year, levels are maintained for water level management. Only when the volume of flood water down the rivers or level of tide means these levels cannot be maintained does the operation for Flood Defence take over.

The purpose of this report is to present information on the current Environment Agency Flood Defence Practices, their objectives and how they came about. This is vital information to understanding the Agency's work, and will form the basis from which other bodies' perceptions of how the current practices should change can be considered.

The broad aim of flood defence policy is to reduce risks to people and the developed and natural environment from flooding and erosion through a combination of flood warning, flood and coastal defence and development control. Safeguarding of lives and the protection of urban areas are given greatest priority, followed by the continuation of existing rural flood defence and drainage schemes. New rural flood defence and drainage schemes receive least priority.

MAFF's Flood Defence Strategy requires that flood defence measures and warning systems should be technically sound, economically viable and environmentally acceptable.

- Technical soundness requires that a range of options should be considered as part of project appraisal.
- Economic viability requires that flood defence capital and maintenance works should give good value for money, and maximise the benefit:cost ratio from the options available.
- Environmental acceptability requires that the predicted impacts on wildlife, habitats, landscape, archaeology and recreation are not considered unsatisfactory to the bodies (English Nature, English Heritage, Countryside Commission) that represent environmental interests.

The Environment Agency is now required to examine the cost-effectiveness of its operational and maintenance work, with the objective of justifying and prioritising all these activities by April 2001. This requirement is brought into even sharper focus by an annual budget that is decreasing in real terms.

This report refers to the drainage system within the coastal belt, Levels and Moors south of the Mendip Hills, which can be conveniently defined as lying within the Internal Drainage Board boundaries. It has been written with the following objectives:

- To describe briefly the historical development of the topography and drainage systems.

- To explain the function of, and interaction between, the natural river system and man-made drainage channels, structures and pumping stations.
- To explain how the responsibility for the drainage system within the Levels and Moors is divided between a number of bodies.
- To present an overall benefit/cost assessment of operations and work required to maintain current protected flood defence standards. The area covered for this part of the report has been extended to include urban areas at Taunton and Bridgwater,
- To describe a computer model of the river system which incorporates:
    - parts of the Rivers Parrett, Isle, Yeo and Tone
    - the Parrett Flood Relief Channel (Sowy River)
    - King's Sedgemoor Drain and linked channels
    - and present some results of its use in exploring changes in practice
- To present the results of further work on the impact of development on flood flows reaching the Levels and Moors.
- To present a summary of Maintenance operations and their purpose
- To invite comment on the information provided and the practices described.

The basic principle of Flood Defence within the Somerset Levels and Moors is that to protect the urban areas, including Taunton, Bridgwater and Langport, excess flood water from rivers or high tides is stored on the low-lying moors until it can be evacuated without increasing flood risk downstream.

The water level management practices and the associated operational procedures are complex and vary seasonally and in response to weather conditions. The purpose of this report is not to describe the arrangements in detail, as these are more fully discussed in individual Water Level Management plans, to which reference can be made. A list of completed plans is included in Appendix K.

We recognise the size and complexity of the information provided here, and are keen to help you understand the issues. We can provide officers to address meetings if you wish and can answer any questions which you have.

We intend to consider every response and draw up a programme of work to be presented to the Flood Defence Committee as part of our annual planning.

3. HISTORY OF THE REVIEW

In 1991, the National Rivers Authority published the report "The Somerset Levels and Moors Water Level Management and Nature Conservation Strategy" (1). Item 5 of the Strategy was a commitment to review flood defence practices in the Somerset Levels and Moors with the objective of furthering nature conservation.

The results of such a review would be of importance to conservation bodies who were looking for changes in practice to reduce impact on the environment, and landowners and Internal Drainage Boards who felt the Agency should be carrying out more maintenance, and operating differently.

Initially, the National Rivers Authority considered that the Standards of Service Exercise undertaken throughout the North Wessex Area would provide the basis for the Review. During the study, however, it became clear that for the Somerset Levels and Moors only, Standards of Service data was less than appropriate. Standards of Service assumes that work on a length of river relates to the flood risk adjacent to that length only. This is not the case on the Levels and Moors.

A start was made on collecting data for the review, but the floods of winter 93/94 and 95 diverted staff for investigation to answer more immediate questions.

A vital element in analysing the River Parrett, Tone and Sowy system is the development of a computer model. River flows on the Levels and Moors had never been measured, records were of levels only. Because storage is such an important part of the system, calibration of flows through a range of events was necessary. Flow gauging locations were set up in 1996, and it was only with events in winter 97/98 that sufficient calibration was obtained to prove the model, although further events will be needed to give additional confidence in results.

One investigation reported on in July 1995 was the impact of development upstream of the Levels and Moors on flood risk on the moors. Further work using catchment models has reinforced the 1995 findings.

4. OVERVIEW

4.1 Geology and Topography

The Somerset Levels and Moors are surrounded by a crescent of hills with a variety of geological origins. (See Figure 4.1)

The Mendip Hills to the north are comprised of Carboniferous Limestone and from subterranean passages within the rock, the River Axe emerges at Wookey. The low lying land abutting the Mendips is the red Mercia Mudstone.

The Brue, Cary, Yeo and Parrett rise in the Oolitic Limestone ridges, capped by slowly permeable clayey soils, which run from above Bruton to Crewkerne at the head of the Parrett. The same geology is found in the Polden Hills separating the Brue and Cary catchments and in the Fivehead Ridge between the Isle and Tone catchments. The ridges were left following the general erosion of the Triassic and Jurassic rocks which formed the basin of the Somerset Levels and Moors. This erosion also left the 'islands' of Brent, Glastonbury, Puriton, Meare, Sowy, Burtle and Wedmore, rising above the general Lias, Mudstones and Marls.

The Isle and the southern Tone tributaries rise in the Blackdown Hills, of Cretaceous Upper Greensand. To the west, tributaries of the River Parrett and River Tone rise in the Quantock and Brendon Hills of Middle Devonian Sandstone.

The Levels and Moors themselves have been shaped in more recent geological times, from the end of the last Ice Age some ten thousand years ago. The four distinct glacial advances during this Pleistocene glaciation each froze sufficient water to lower the world sea level by more than 100 metres, thereby causing coastlines to migrate seawards and the rivers to gouge much deeper valleys. At Bridgwater for instance, the valley bottom was left some 15 metres below current ground level. When the ice melted, sea levels rose again, flooding inland, holding back the rivers and causing deep valleys to fill with alluvial deposits.

It is these filled valleys which form the Levels and Moors. Four and a half thousand years ago, the process was largely complete and the rate of rise of sea level slowed considerably. Since then, ground level changes in the area have generally been much more gradual and less dramatic, for as long as the sea was able to flow inland, estuarine silt would have been carried inland and deposited. This process approached equilibrium when the ground reached a sufficiently high level to curtail the ingress of the sea. The ultimate level of deposition approximated to the level of mean high water spring tides, which can still be seen today wherever tidal saltings skirt estuaries or coastlines. Before the construction of sea walls, those parts of the Somerset basin lying closest to the shoreline would have consisted of tidal saltings with their level determined by the mechanism just described. These deposits effectively reduced tidal incursion so that the land level rose faster nearer the coast, giving rise to the raised coastal belt.

Inland extensive marshes developed, with reedbeds, sedges and sphagnum bog. As vegetation accumulated these marshes rose in level faster than the increase in sea level, thereby eventually forming extensive peatlands. As sea level rose again, the coastline and clay belt moved back landwards, leaving exposed peat and submarine forests, which are still present on the foreshore.

Figure 4.2 shows a schematic profile of the strata from Huntspill on the coast, along the line of the Huntspill River and South Drain to Meare. The moors which have peat soils are shown in Figure 4.1.

Commencing in Romano-British times, attempts were made to hold back the sea and by the 14th Century there was a network of sea walls in existence, more or less on the same line as today's defences. These effectively curtailed further significant topographical changes. Inland, away from the influence of tidal water, there are significant variations of ground level between adjacent moors. The lowest moors are generally those that were the first to be protected from frequent flooding.

Perhaps the most consequential effect of the long period of tidal exclusion has been caused by the continuing relative rise in mean sea level. This rise is projected to continue at an accelerating rate, currently estimated to be 6mm per year. This rise is primarily as a result of the general elevation of world sea levels by the melting of the polar icecaps and thermal expansion of the oceans due to global warming. However, a proportion is due to the tectonic lowering of ground levels in the south-west of England as a consequence of the retreat of the last glaciation.

The sea defences have therefore caused sea levels to "leave the land behind" and the lowest ground levels in the basin now lie some 6 metres below extreme high water. It has already been explained that the lowest areas lie well inland from the coast, so that the drainage of these areas now involves not only the passage of water through the higher coastal belt, but also discharge against increasingly adverse sea levels.

The various river and sea defence works that have been carried out in the catchment over the last millennium have been closely constrained by this local topography, surface geology and tidal influences. The flood defence and environmental interests will continue to be influences by these factors in the future, particularly if the higher predictions of sea level rise are realised. Map 3 shows those areas at risk from flooding as defined in Section 5, the benefit/cost section of this report.

4.2 The Uplands

The previous section describes the hills surrounding the Somerset Levels and Moors. The upper reaches of the rivers which rise in these hills are typical of upland rivers, with relatively steep bed gradients and narrow floodplains. Many of the soils are relatively impervious and these characteristics give rise to a flashy response to rainfall.

Annual rainfall in the uplands which enclose the Levels and Moors averages some 1000mm, compared with 700mm in the centre of the Parrett lowlands. The extremes range from an annual rainfall of 2400mm on Exmoor to 450 mm at Langport and Burnham. Many of the highest 24 hour rainfalls in the UK have been recorded on the southern, eastern and western edges of the Somerset rivers' catchments. Bruton, on the River Brue, has experienced a number of extreme rainfall events, up to 250mm in 24 hours. Aisholt and Cannington, at the foot of the Quantock Hills, have also recorded 24 hour falls exceeding 200mm. The high intensity rainfalls have usually been associated with summer thunderstorms. These have not been concentrated in small areas and because the high rainfall has often not been over the whole catchment, flooding on the Levels and Moors has not always occurred.

The upper reaches of the Somerset rivers are relatively short. All the rivers respond to rainfall falling in the upper catchment by flows peaking at points where the floodplain widens out into the Levels and Moors within 12 hours of the rainfall.

The runoff from the uplands will generally be dependent on the soils (which may vary between sands to virtually impervious clay) the slope of the ground, the vegetation and the saturation of the soils from previous rainfall. Despite these variations, rainfall may so saturate the ground that eventually 100% runoff occurs.

For well over a thousand years, the steepish bedslopes of the upper reaches encouraged their modification for milling purposes. By 1960 virtually all the local mills had fallen into disuse, although at many locations the impounding weirs, mill leats and control sluices are still in place. The traditional operation of the control structures associated with the mills was by the miller, who was always available to ensure adequate water levels to meet power requirements, and also to operate the structure to minimise flood risks.

Although disputes occurred between landowners, particularly between the mill owner and those with interests downstream, the law gave rights and protection, recognising the need for water power. Since the abandonment of the mills for their primary purpose, often involving conversion to luxury homes, arrangements have had to ensure that downstream interests in particular are safeguarded. It can no longer be assumed that a mill house owner is always at home and where it is essential that sluices are opened in response to rising river levels, the Agency and its predecessors have reached agreement with the landowners on emergency procedures to be followed.

In response to the flood risks threatening property in the upper reaches, and often in response to previous flood events, a number of flood alleviation schemes have been put in place. Bruton is now protected by a flood detention reservoir upstream of the town, but most schemes which have been constructed have used flood embankments or floodwalls to exclude flood water from populated areas and, in places, the use of channel enlargements or realignments. Major schemes in the upper reaches now protect Taunton on the River Tone and Ilchester on the River Yeo. Table 4.1 lists some improvement schemes undertaken.

Table 4.1 Location of Improvement Schemes

LOCATION	RIVER	TYPE
Ilchester	Yeo	3 ring banks
Sherborne	Yeo	Flood defences
Mudford	Yeo	Flood defences
Yeovilton	Yeo	Flood defences
Cam villages	Cam	Flood defences
Yetminster	Wriggle	Flood defences
Stoford	Barwick Stream	Various villages, flood defences and channel improvements
Kingsbury Episcopi	Parrett	Ring bank
Thomey	Parrett	Ring bank
Ilminster, Horlicks Dairy	Isle	Ring bank
Iford Bridges	Isle	Ring bank to farmhouse
Ashford Mill	Isle	Ring bank
Isle Brewers	Isle	Ring bank
Taunton	Tone	Flood defences and channel improvements – 800 properties protected
Bathpool	Tone	Flood defences
Ruishton	Tone	Food defences
Creech St Michael	Tone	Flood defences
Ham	Tone	Flood defences
Bruton	Brue	Flood detention reservoir
East Lydford	Brue	Ring bank

4.3 The Levels and Moors

The development of the Somerset Levels and Moors, firstly by geological processes and, during the last thousand years, by a series of small and large scale works has resulted in a complex drainage system. The word 'drainage' itself has to be used in its widest sense in this area to include sea and tidal river defences, urban and rural flood protection, flood water evacuation, agricultural drainage and summer water supply. To begin to understand the system and the way it is operated and maintained, it is necessary to appreciate the way the drainage system developed and the influence that this has had on man's activities in the Levels and Moors.

4.3.1 Drainage and Development

A thousand years ago the lowland rivers of Somerset meandered through the moors in river channels more or less untouched by man's influence. The lack of gradient produced shallow, un-embanked natural watercourses subject to severe siltation in their lower reaches due to uncontrolled tidal intrusion. Fluvial flows would have exceeded channel capacity for a large proportion of the time. Even an average winter's rain would have put most of the low-lying basin, between the inner boundary of the coastal belt and the foot of the uplands, under water until the following summer. Furthermore, the fortnightly spring tides would have inundated large areas each side of the river channels, giving salt-marsh conditions far inland.

However, the wetlands were a vital resource for local people. The lowest peat moors, with their extensive areas of open water, reed beds and marsh were exploited as fisheries and wild-fowling areas and where possible peat and willows were harvested. Higher areas, especially where clay soils were found on the surface, were grazed by cattle or geese when water levels permitted. On the islands of higher ground (known as "zoys" in the Parrett basin), some arable cultivation was practised. It should be borne in mind that since the initial construction of the main river embankments, sea levels have risen by about a metre whilst improved drainage has caused land levels to subside slightly, so that today gravity drainage is more difficult than it was in the past.

The catching of fish and eels was also very important. Artificial weirs ("gurgites") were constructed in the main watercourses to hold up water levels to improve the fisheries. Unsurprisingly this practice worsened flooding and caused much local dissent.

Drainage works are known to have been carried out in the time of King Alfred and continued by the ecclesiastical establishments of Muchelney, Glastonbury and Wells. However, before the 13th century the moors were subject to such disorganised commoning arrangements that there was little interest in co-ordinated drainage development. The Statute of Merton in 1235 gave significant new powers to enclose and occupy the moors and began the reclamation activity. Organised land drainage began in 1304 with the first Commission of Sewers, with subsequent commissions from time to time. Flood protection of the land in the river basins started with the piecemeal reclamation of small "polders" sited adjacent to higher clay ground close to the hills, where modest embankments were constructed to reduce the frequency of inundation. The intention was to extend the period during which the land could be used and possibly enable areas previously fit only for fishing and wildfowling to be used for summer grazing.

Interest soon extended to the improvement of the leeves (slightly higher ground alongside the rivers formed naturally by the settling out of silt from floodwater). Although the elevation of these levees would have left them comparatively well drained during summer months, the proximity of the river would have meant almost continuous overflow throughout the winter and spring. So by the beginning of the 14th century, long stretches of artificial raised floodbanks had been formed, including the entire reach of the Parrett from the high ground at Langport, to the inland boundary of the higher coastal clay belt at Moorland. Cut-off banks ran back to high ground, which divided the protected area into compartments.

As already mentioned, the levees consist of natural alluvium, a material well suited to embankment construction, and are significantly higher than general moor levels. Where possible the new embankments were built on top of the levees, thereby gaining the twin advantages of a ready source of material and a reduced height requirement. These extensive works must have made a tremendous improvement to conditions in the moors they protected – possibly greater than any other measure carried out before or since. For instance it is recorded that there were extensive crops of barley, peas, beans and oats in Earlake (North of Burrow Mump) in 1311.

The isolation of the Levels and Moors from the direct influence of the arterial rivers enabled large areas of land to be available for summer grazing on a commoning basis. At this time the rectilinear network of drainage rhynes, which is so prominent in these areas today, was not present. A much less dense mixture of natural and artificial drainage channels conveyed surplus water from these zones to their outlets into the arterial rivers, where simple clyses (one-way flaps) provided some isolation from river conditions. During the winter, floodwater would overtop the river banks and could not be fully evacuated until the river levels fell below ground level, which in wet years might not occur until the early summer.

4.3.2 Compartmentalisation

A clear understanding of the effects of the compartmentalisation of the Levels and Moors is required to understand many of the local drainage developments and schemes in the area. In general, the cut-off banks were provided as local initiatives and safeguarded newly embanked zones such as Earlake and Weston Level from their less well protected neighbours. However in some locations the establishment of separate flood compartments was taken as an opportunity to provide a reduced susceptibility to flooding at the expense of adjacent areas.

The construction of Balt Moor Wall is a notable example of this and is discussed in more detail in Appendix C. The wall acts as a barrier across the northern floodplain of the River Tone and it effectively prevents any floodwater which has left the Tone's embanked channel and is moving down the floodplain, from passing further east to disperse in Salt Moor and North moor. It should come as no surprise to learn that Balt Moor Wall was constructed by the principal ecclesiastical landowners in these latter areas and that the scheme caused great dissent when carried out in the late 14th century. Balt Moor Wall has been retained and reinforced to continue its isolating function and indeed can now be regarded as essential because the area it protects has been developed with farms, other commercial enterprises, houses and the A361 road, most of which would otherwise have been untenable.

By way of contrast Beer Wall, which runs from the Isle of Sowy to High Ham and which used to isolate King's Sedge Moor from the very flood-prone Aller Moor, has been allowed to deteriorate. This is partly as a result of its reduced importance following major flood alleviation works carried out over the last 40 years.

Maps 1 and 2 show the location of dividing walls and banks, which create compartments in the Levels and Moors. Many of these barriers incorporate connections between the areas, either as sluice gates on open channels, or as culverts incorporating valves. These give some flexibility in the movement of summer water supply and, to a lesser extent, of floodwater.

4.3.3. High Level Carriers

Once continuous lengths of embankment had been formed on both sides of the rivers, the channels became "high-level carriers". This concept of constraining floodwaters to an embanked channel at a level above that of the adjacent land is used world-wide and has great advantages from a flood protection viewpoint.

- Assuming that the channel is made large enough, floods that would otherwise spread out over the floodplain can be contained and passed downstream without inconvenience.

- The higher water levels give a more effective discharge through the lower reaches, and where applicable, against high tides. As long as the river is contained within its floodbanks, water levels in adjacent moors are not directly affected by those in the river.
- In the case of un-embanked channels, a small rise in river level, perhaps even insufficient to cause any overland flooding, will immediately be transmitted into the floodplain and may well induce waterlogging in the lowest lying areas.

High level carriers are especially effective in Somerset because the tidal reaches of the rivers have always been too small to deal effectively with flood flows from the uplands. Maps 1 and 2 show by colour coding, the embanked rivers which convey flood waters through the Levels and Moors, either to the coast or to the coastal clay belt, where higher ground levels meant that embankments are no longer required.

4.3.4 Internal Drainage and the Pumping Station

During the 17th and 18th centuries, improving economic conditions encouraged the further improvement of the Levels and Moors areas. Ambitious privately-funded schemes were promoted to cut the rectilinear rhyne networks and main drainage channels, and construct new outfall structures. In the Axe and Brue areas, major schemes to improve the capacity of the main rivers were carried out concurrently. These ambitious schemes were generally carried out under private Acts of Parliament, Local Enclosure and Drainage Acts, thus avoiding the necessity of obtaining the agreement of every landowner and commoner affected.

These schemes greatly improved the general field drainage conditions and usually incorporated elaborate arrangements for feeding and distributing "summer water" for wet-fence and cattle drinking during the grazing season. The recovery of the land from winter flooding was also assisted, but many of the schemes did little to reduce the susceptibility to initial flooding. Wet springs, with their consequentially high river levels, still often seriously delayed the onset of grazing. This was particularly the case in those areas such as Curry Moor, which had been adapted in the past to act as initial "sacrificial" flood storage areas.

Following these major improvements, every effort was made to take full commercial advantage of the drier conditions. Large areas were transferred to arable farming. In King's Sedge Moor for instance, it was reported that the majority of the improved area, including the lowest peat ground, was soon ploughed up and used for cereal crops. However problems with low soil fertility and continuing severe winter flooding caused this development to be abandoned and within a further thirty years extensive grazing was once again the norm.

The progressive farming interests were not to sit idle for long, however. The development of steam power resulted in the installation of the first scoop-wheel pump at Westonzoyland in 1830. However, both the Westonzoyland pump and the one installed seven years earlier on the left bank of the Parrett draining East Saltmoor were not only seriously undersized but also very inefficient and were soon abandoned. The invention of Appold's new centrifugal pump in 1851, led to a spate of new pumped drainage schemes, again centred in the lower Parrett area and the early scoop-wheel pumps were also replaced. This time their main purpose was more properly identified as flood evacuation, allowing the ground to return to production earlier each Spring.

It was not until the Second World War that any further new pumping schemes were promoted using diesel powered pumps. The food shortages at this time prompted the new schemes and the installation of diesel power machinery at existing stations. Then, during the 1950's, 60's and 70's further pump schemes were carried out, extending the area covered to include the moors upstream of Langport, the north side of the lower Brue valley, and the lowest ground in the Axe catchment. Electric pumps took over from the diesel installations, improving efficiency and allowing for automation and better control of water levels.

4.3.5 Constraints on the Efficiency of Pumping Stations

Although all these initiatives provided much needed benefits to the agricultural community, areas like Curry Moor enjoyed little more than earlier evacuation of winter floods and better control of the water table during the growing season. The pumping station did almost nothing to prevent initial flooding by overtopping from the adjacent arterial river. Some other areas are not affected in this way and where no "foreign" floodwater normally enters a particular zone, then the pumps have significantly reduced the incidence of overland flooding. Stan Moor is a typical example of this case, where any residual liability to flooding is simply due to the limited pump capacity.

However, another problem can arise, and West Sedgemoor is a good example of this. Even though it is protected from the Parrett's flood water by a substantial embankment, the operation of the pumping station is constrained by the water level in the River Parrett, into which the pumps discharge. Should, as is often the case, the river overspill its other bank into Aller Moor, the pumps have to be shut down to avoid pumping one area out at the expense of another. Under these conditions, the station is said to be "locked out". Until the flood in the main river subsides, the pumped area is clearly at the mercy of any rainfall falling within its own catchment. The areas and pumping stations affected by this constraint are described in more detail in the Appendices.

Only Gold Corner Pumping Station, with its generous installed capacity and a dedicated outlet channel to the sea can truly be regarded as a "full blown" pumping scheme in the East Anglian tradition. Its performance speaks for itself. In nearly sixty years of operation, and despite having the lowest ground levels in Somerset, the pumped area has never been seriously flooded, and water tables have been closely controlled throughout the period. Before the scheme the moors along the south side of the lower Brue, which the station serves, used to flood deeply almost every winter.

4.3.6 The River and Drainage System

The systems within each catchment are described in the Appendices, which should be referred to for more detail. In this section it is appropriate to summarise some of the characteristics of the overall river and drainage system within the Levels and Moors.

- The general elevation of the moors is 3 to 4 metres above Ordnance Datum, with lowest levels at less than 2 metres above Ordnance Datum in the Brue Valley.
- The lower reaches of the main rivers have very flat gradients, typically between 1 in 5,000 and 1 in 10,000. In some places the bed levels of the arterial rivers are nearly equal to that of the adjacent land.

- Moors in much of the Parrett, Yeo, Isle, Axe and Brue valleys are pumped into the arterial rivers and channels. The King's Sedgemoor Drain is notably the only main channel discharging to the Bristol Channel from the Levels and Moors without the use of any pumping stations to drain its moors.

The topography of the area has been modified by the compartments that have been created over the centuries, together with the embankments to the highland carriers. This has led to differences between the vulnerability of moors to overtopping from main rivers or other moors and the extent to which pumping may be restricted because of the need to avoid worsening of flooding in other areas. These aspects are discussed in more detail in the Appendices and the table 4.2 summarises the constraints for each pumped area.

Table 4.2 Details of Individual Moors

Pumping Station	% of Catchment as Upland	Risk of Overspill from Other Moors	Risk of Overtopping from Main River	Pumping Constrained by High River Levels
Stockmoor [SPS1]	50	Nil	Low	No
Northmoor [SPS2]	36	Low	Low	Tidal Parrett >7.5m
Westonzoyland [SPS3]	2	Low	Low	Tidal Parrett >7.5m
Saltmoor [SPS4]	0	Adjacent to Northmoor	Low	Tidal Parrett > 7.5m
Stanmoor [SPS5]	20	Low	Low	Parrett > 7.5m
West Sedgemoor [SPS6]	71	Nil	Low	Parrett > 7.46m
Westover [SPS7]	84	Moors on left bank of Parrett connected	High	Parrett > 8.1-8.31m
Huish Episcopi [SPS8]	66	Connection between moors in catchment	High	Yeo > 8.84m
Midelney [SPS9]	71	Connection between moors in catchment	Medium	Isle > 8.73m
Curry Moor [SPS10]	63	Connection to Hay Moor	High	Tone > 7.4m
Long Load [SPS11]	57	Connection between moors in catchment	High	Yeo > 9.8m
Cross Moor [NPS1]	60	Low	Low	Cheddar Yeo > 5.8m
Clewer [NPS2]	74	Connection between moors in catchment	Medium	Axe levels > 5.94 m
Blackford Moor [NPS5]	0	Connection between moors in catchment	Low	High Shipham Rhyne
Gold Corner [NPS6]	84	Connection between moors in catchment	Low	No
North Drain [NPS7]	65	Connection between moors in catchment	Low	Brue levels > 3.7m

4.3.7 Summer Water Supply

From the early development of the drainage system in the Levels and Moors, the supply of water in the summer to the rhyne network has been an important requirement. The main purpose has been to provide stock watering and wet fencing rather than water for irrigation and this remains the same today. The supply of summer water relies on a number of installations and maintenance activities.

- Penning sluices on main rivers, to provide high water levels in the arterial channels to allow gravity flow through the rhyne network.
- Sluices or tilting gates to control flow to the rhyne network. These are usually closed during high flows to keep flows within the arterial network.
- Control structures within the rhyne network, normally operated by the Internal Drainage Boards (IDB), to distribute water through the system.
- Maintenance of the rhyne system involving dredging and weed cutting. With the very flat gradients available within the Levels and Moors, water will not reach some parts of the network without this work, which is undertaken to prevent head losses in the system.

Maps 1 and 2 show many of the structures which control this summer water supply. Fuller details are included in the Water Level Management Plans that have been prepared for many of the areas. The maps show, by green arrows, the direction of flow of the water in summer. Often the flow direction is reversed when the rhyne network is used to evacuate floodwater or is acting as a normal drainage system. The blue arrows on the map illustrate the flow direction for drainage and floodwater evacuation.

4.4 The Coastal Belt and Sea Defences

The topography of the coastal belt has been explained in Section 4.1. Its most significant characteristic is its elevation, ground levels are consistently around 6.5 metres above Ordnance Datum, which is some 4.5 metres above the lowest moor levels. This permits effective drainage by gravity and any problems in this respect can be attributed to the local inadequacies in various secondary drainage networks.

From a strategic viewpoint, the Environment Agency's principal flood defence concerns in this zone are restricted to safeguarding it from tidal inundation by overtopping or breaching of the sea defences and, to a lesser extent, providing an adequate supply of fresh summer water for agricultural purposes.

4.4.1 Sea Defences

Some 56km of the Somerset coastline are sufficiently low-lying to require artificial sea defences to exclude the highest tides. The Bristol Channel has one of the highest tidal ranges in the world at some 13m and although natural ground level is about the same as mean high water spring tides, extreme tides can rise a further 2 metres above this. Furthermore, depending on the degree of exposure, and the type of sea defence, a further 2 metre allowance can be needed to give adequate protection from overtopping or damage by wave attack.

Because the lowest ground levels in the basin lie well inland, these raised sea defences are paramount to the security of the whole of the Levels and Moors. Without the tidal defences some 20% of the county would be subject to occasional tidal intrusion and would thus become uninhabitable. The zone extends inland as far as Glastonbury, Ilchester and Martock. The eastern side of Bridgwater, the Midlands-West Country main railway line and the M5 motorway all rely absolutely on these defences. In Roman times no effective sea defences were present and this is why the Fosse Way, which was the main north-south communication route through the county, was situated so far east.

The surge tide on 13 December 1981 overtopped many sea defences along the Somerset coastline. The volumes which poured over, and in some instances through the defences, caused salt water flooding of land and properties up to 3.5km inland. The severe damages experienced in this event gave added impetus to the programme of improvements to the sea defences. The Agency's sea defences have now generally been brought to a 1 in 200 year standard and a repeat of the 1981 event would now result in limited overtopping. Map 3 shows those areas protected from tidal flooding.

The sea and tidal defences incorporate a number of outfalls and tidal exclusion structures on the arterial rivers and drains. The tidal exclusion structures are listed in Appendix A and reference should also be made to Maps 1 and 2 for the location of structures and outfalls.

A vigilant watch is kept on all sea and tidal defences and outfalls through them, to ensure their structural integrity and correct operation in the case of tidal flaps or gates. The consequences of failure would be serious, with ground levels some 2 metres below highest tide levels. In the case of tidal exclusion structures the tide level can be some 8m above river bed levels.

4.4.2 Summer Water Supply

The supply of summer water (for stock watering and wet fences rather than for irrigation) is a major Agency Flood Defence activity throughout the Levels and Moors. However, it is only on the coastal belt that the topography requires this water to be provided by pumping to a satisfactory system. Pumping is needed here for two reasons. Firstly, because the coastal belt is for the most part isolated from higher ground, it is not possible to divert the upland streams for this purpose. Secondly, water levels in the main arterial rivers that cut through the coastal strip are too low to provide direct feed to the adjacent land , having been set to permit the gravity drainage of the lowest Moors during summer months. By way of an example the River Brue at East Huntspill is "penned" at 1.8 metres above Ordnance Datum Newlyn (ODN). This is about 200mm below the lowest ground in Catcott Moor, but over 4 metres below the local field levels at East Huntspill.

It is for these reasons that large areas of the coastal belt in the Axe and Brue valleys have been provided with small pumping stations to lift the arterial river water up into elaborate distribution networks. Table 4.3 lists the locations of these pumping stations.

Table 4.3 Summer Supply Pumping Stations

PUMPING STATION	MAP REFERENCE	GRID REFERENCE	PROVIDING WATER TO:
South Hill	NPS3	ST34565	Bleadon Level
White House	NPS4	ST363552	Mark Yeo Inlets
Whithy Drove	NPS8	ST327441	Puriton Level
Sloway Lane	NPS9	ST303452	Huntspill Level
Henley	SPS12	ST435327	Somerton Moor

The pumping station at Henley has been included for completeness in this list of pumping stations providing a water supply, although it is not on the coastal belt.

4.5 Operating Authorities

The roles and responsibilities of the organisations involved with drainage and flood defence issues in the UK are not straightforward. In the Somerset Levels and Moors, the inclusion of Internal Drainage Boards and the provision of summer water supply may further confuse those who are not directly involved in the work.

The organisations with drainage and flood defence roles are:

- The Environment Agency
- Internal Drainage Boards – 18 Boards cover the Somerset Levels and Moor
- Local Authorities – District, Unitary and County Councils (LA's)
- The Ministry of Agriculture Fisheries and Food (MAFF)
- Riparian landowners

Rivers and watercourses are divided into two legal categories, "main rivers" and "ordinary watercourses". Main rivers are shown on statutory maps held by the Environment Agency and MAFF. All other rivers, streams, watercourses, rhynes and ditches are ordinary watercourses. Main rivers are highlighted on Maps 1 and 2.

Generally the Environment Agency has responsibilities for sea defences, which protect against flooding of low lying land from the sea and estuaries and LA's have responsibilities in respect of coast protection, which relates to erosion of land not normally subject to flooding. On the Somerset coastline, there are variations to this simple guideline. The responsibility for each length has been agreed between the LA's and the Agency. The effect of this is that some lengths in urban areas, which are strictly sea defences, fall within the remit of LA's. This resulted from the need to integrate the defences into other LA interests, particularly of amenity and tourism.

The roles discussed below are usually based on permissive powers rather than a definite responsibility for undertaking any particular work. Whilst a duty of care responsibility applies when work is undertaken, the powers do not confer any statutory obligation to provide protection from flooding. The following sections briefly explain the roles of the bodies involved in drainage and flood defence on the Somerset Levels and Moors.

4.5.1 The Environment Agency

The Environment Agency's roles include the following:

- Supervising all matters relating to flood defence in England and Wales, including powers to direct where other drainage authorities fail to carry out their own duties
- Carrying out improvement and maintenance works to reduce the risks of flooding from designated main rivers and the sea
- Clearing obstructions from main rivers which may cause a flood hazard
- Operation of pumping stations and tidal and fluvial control structures on main rivers
- Advising planning authorities on the implications of development proposals on flood risk issues and the environment
- The production of Local Environment Agency Plans (LEAP's)
- Issuing flood warnings
- Using powers to regulate works that may affect flood risk. Consent from the Agency is required for structures in, over or under main rivers, and for obstructions in non-main river watercourses
- Surveys of flood risk areas

The flood defence powers of the Agency are generally permissive, and are complemented by the wider planning powers of Planning Authorities to control development in flood risk areas. The Agency's flood defence function is undertaken through the Regional Flood Defence Committee with delegation of certain matters to the Somerset Local Flood Defence Committee.

The Agency's Land Drainage byelaws generally apply to main rivers and their floodplains, and to areas within particular distances from flood and coastal defences. Typically, Agency consent is required for the erection of structures, excavations, planting and mooring etc, in these areas.

The Agency also has a duty to further conservation in the exercise of any of its Flood Defence powers or duties and it has specific responsibilities as a competent authority under the Habitats Regulations. The Agency has prepared Water Level Management Plans for those areas for which MAFF have defined the Agency as the Operating Authority. The Agency has also contributed to other Water Level Management Plans for which Drainage Boards are the designated Operating Authority. The Agency has assisted in the promotion of Raised Water Level Areas in partnership with the MAFF Environmentally Sensitive Areas Scheme.

Some of the work now undertaken by the Agency, particularly relating to operation and maintenance activities has evolved by custom through the historical development of the Levels and Moors. Nationally, the Environment Agency under the Environment Act 1995 has a requirement to justify its expenditure on operational and maintenance work, and is now proceeding to analyse the costs and benefits of each element of expenditure. This may lead to proposals to change current practices and the consideration of this will form part of the Review of Flood Defence Practices, of which this Overview is an element.

4.5.2 Internal Drainage Boards

Eighteen Internal Drainage Boards operate within the lowland areas of the Somerset Levels and Moors catchments. The first Boards were formed in 1830 to manage the drainage of the lowlands bordering the arterial watercourses. The areas in which the Boards operate are shown on Maps 1 and 2.

Internal Drainage Boards have powers in relation to adopted or "viewed" rhynes. The adoption of these rhynes is by resolution of the Board, and finance is raised by the collection of a drainage rate on land and property in the Board's area. The roles of the Drainage Boards are:

- Permissive powers to improve and maintain viewed rhynes
- Powers to construct, operate and maintain control structures and pumping stations. In Somerset, the Environment Agency operates all major pumping stations.

Similar to the Environment Agency the Internal Drainage Boards have a duty to further conservation in the exercise of its powers and duties, and also specific responsibilities as competent authorities under the Habitats Regulations.

4.5.3 Local Authorities

Local Authorities (LA's), whether as County, District or Unitary Councils, have roles and powers in relation to flood defences and coast protection.

- LA's may carry out works on watercourses, other than "main rivers" and those in Internal Drainage Board areas, in order to alleviate flooding from rivers or the sea. LA's also have certain powers of enforcement on ordinary watercourses.

- Maritime District Councils (district councils which adjoin the sea) have powers to protect the land against erosion or encroachment by the sea (coast protection). These powers extend to some defences protecting flood risk areas in Burnham on Sea and Weston super Mare.

- LA's produce contingency plans for civil emergencies and work with the emergency services to co-ordinate a response. They also respond to the local effects of flooding, including assistance to those at risk from or affected by flooding.

- LA's have powers under the Town and Country Planning Acts to regulate land use within England and Wales. Planning Authorities are responsible for protecting the flood defence interests of people whose property may be affected by development proposals.

- LA's can make byelaws that apply to non-main rivers to ensure the efficient working of the drainage system, and to the coast.

- Local Authorities as **highway authorities** are responsible for draining highways. This includes preventing water from flowing onto the highway, together with certain responsibilities for bridges and culverts under the Highways Act 1980.

Again in carrying out any work, the Local Authorities have a duty to further conservation.

4.5.4 The Ministry of Agriculture Fisheries and Food

MAFF powers and responsibilities include the following:

- Assessment of and award of grant aid for capital improvement works
- Administration of agri-environmental schemes including Countryside Stewardship, ESA's and Habitat Scheme
- Guidance and priorities for Water Level Management Plans
- Overall policy for Flood Defence in England and Wales
- Powers of direction in cases of dispute

4.5.5 Riparian Landowners

Riparian landowners are owners of land adjacent to watercourses. They have responsibilities for maintenance of watercourses. These include clearance of blockages, and cutting of bankside vegetation, although in many cases both activities may be undertaken by statutory bodies.

5. BENEFIT/COST ANALYSIS

5.1 Aim

The aim of this section is to determine, in broad terms, the benefits and costs of Flood Defence on the Somerset Levels and Moors, and, in this respect, the extent to which the current standards of Flood Defence serve the strategic objectives of sustainable development in the area. The output of the study will feed into the Environment Agency's consultation process for strategic planning.

The specific objectives of the study were:

- to determine the type and value of assets and activities dependent on Flood Defence, the degree to which they are sensitive to standards of Flood Defence, and the compatibility of Flood Defence requirements across major asset/activity types, with particular reference to agricultural and conservation interests;

- the benefits to these assets/activities of retaining current standards of Flood Defence service, and the benefits and costs to these interests of a change (mainly a reduction) in these standards;

The review focused on three main elements relating to flood defence standards of service in the Levels and Moors, namely: agricultural impacts, urban and related property impacts, and nature conservation. Impacts on other interests, such as tourism, recreation, fisheries, archaeology, and the peat and withy industries were also briefly examined.

5.2. The Study Area

The study area comprises that part of the Flood Plains of the Rivers Axe, Brue, Parrett and Tone which lie within the boundary of the 100 year flood event envelope (inclusive of the areas that are defended against the 100 year event within this area) (Map 3). These areas fall within the jurisdiction of a number of Internal Drainage Boards that lie within the geographical area known as the Somerset Levels and Moors. At this stage no attempt has been made to consider costs of IDB and other external bodies in providing the benefit considered.

5.3 Flood Defence Project Appraisal Procedures

The procedures for the appraisal of Flood Defence projects submitted to MAFF for grant-aid are contained in MAFF's Flood and Coastal Defence Project Appraisal Guidance Notes (MAFF PAGN2 1993). This Guidance focuses on techniques of economic assessment with a view to delivering projects that constitute best value and generate benefits greater than costs by a satisfactory margin

For the purpose of this report, a number of aspects contained in the Guidance are particularly relevant:

- indicative standards of Flood Defence depend on land use, namely relatively high standards of service for commercial and residential areas and relatively low standards for agricultural land use;
- Flood Defence schemes should be compared with the '*without project*' or '*do nothing*' option, literally meaning ***no*** active Flood Defence expenditure whatsoever.
- Strategic reviews of Flood Defence should consider alternatives to the 'do-nothing' option, such as:

  a continuation of the *existing* system,

  a *minimum* level of expenditure to maintain a system (such as breach repair, bank strengthening), a change to a higher or lower expenditure, and

  some *other alternative* scheme such as managing flood defence and water level for environmental purposes.

PAGN guidelines refer to methods for assessing Flood Defence benefits associated with urban land use (damage to property, loss of commercial and industrial activity, disruption to communications and public services), impacts on agriculture and the rural economy, and recreation and tourism. The Guidance makes reference to the importance of environmental benefits, though observes that precise monetary quantification is difficult. Where alternative schemes deliver significantly different environmental qualities, the guidance suggests that it may be possible to determine the value of changes in environmental quality that would be needed to choose one alternative over another. It observes that payments to farmers to deliver environmental benefits, such as ESA payments, indicate a willingness to pay for and a benefit derived by society for incremental environmental quality (and not just as a transfer payment as in the case of subsidised or protected agricultural prices).

With respect to agricultural benefit assessment, the Guidance distinguishes three agricultural flood defence scenarios: complete land loss due to permanent inundation, occasional flooding, and permanent increase in flooding. The first could apply if land is lost to agriculture, for example if land reverts to marsh or swamp. The second could apply if failure to adequately rehabilitate a scheme led to occasional failure with the need to make good "as and when". The latter might apply where, for a variety of reasons, a decision is made to permanently reduce the standard of flood protection or drainage service. All three PAGN agricultural scenarios could apply to future circumstances in the Somerset Levels and Moors. For reasons explained later, the analysis uses the third agricultural scenario, the impact of a permanent reduction in standards of service, as the basis for analysis.

MAFF Guidance advises on the use of adjustment factors to remove the effect of government subsidies on the valuation of agricultural outputs. PAGN is currently under review. Given the reduction in support to agriculture and the downward movement of agricultural commodity market prices towards unprotected international levels, the adjustment factors may be out of line with the current and medium term price predictions. Furthermore, changing priorities towards the environment, evident in incentivised agri-environment schemes such as ESA and Countryside Stewardship, change the relative benefits and costs of scheme options in favour of different and in some cases lower standards of service than those required for intensive commercial farming. These are likely to be important issues for Flood Defence appraisal in the future, but at the time of writing, the PAGN2 remains in place.

Whereas PAGN refers to grant aided capital schemes, on-going operation and maintenance expenditure is subject to the Environment Agency's Guidelines on the Evaluation of Non Grant Aided Works, recently superceded by the Flood Defence Maintenance Manual

(FDMM) and System (FDMS) (Dunderdale and Morris, 1998). These methods are consistent with those applied to capital works. They justify maintenance of a given standard of service against the 'do nothing' option, require best value, positive benefit:cost ratio, and increasingly accommodate environmental criteria in the design and implementation of works (Dunderdale and Morris, 1996).

This Review of Flood Defence practices on the Somerset Levels and Moors has been conducted with due regard to the above Guidance on the appraisal of capital and maintenance works.

5.4 Approach

For the purpose of analysis, three flood defence scenarios have been identified:

- *Scenario 1*: continuation of existing standards of service.
- *Scenario 2:* do nothing, implies a reversion to pre-drainage conditions.
- *Scenario 3*: an intermediate standard, somewhere between the Scenarios 1 and 2.

Flood impact analysis focuses on agricultural, conservation and urban interests. Scenarios 1 and 2 are relatively easy to define, although doing nothing is in reality unlikely to be a pragmatic option. Scenario 3 is more of a concept of an alternative standard rather than a specific standard at this stage of enquiry. Scenario 3 for agriculture and conservation is considered as a 'third way' with opportunities for reconciling the two interests. Scenario 3 for urban interests, considers a "mend as it breaks" approach to retaining the 100 year protection standard. Because hydraulic conditions, assets and land use vary so much within the study area, scenario 3 can only really be defined on a site/hydraulic unit basis. This goes beyond the scope of the present broad based review.

The following assumptions were made.

Table 5.1 Assumptions

Event	Standard	Flood	Duration	Definition and Source
		Non urban	Defended areas	
Annual	Current	4 weeks	0	Env Agency
	Do nothing	12 weeks	2 days	Records
30 year	Current	6 weeks	0	Flood area from Section 24(5)
	Do nothing	16 weeks	4 days	Survey
100year	Current	10 weeks	0	Flood area from Section 105
	Do nothing	24 weeks	1 week	Survey

Flooding is predominantly a winter event. More than 90% of peak flows which reach 'flood stage' tend to occur during October to March inclusive, and almost 90% of these during November to February inclusive (Williams 1970). Summer flooding is relatively infrequent, but tends to occur in early or late summer when it does (Morris and Hess 1987). For the purpose of analysis, it is assumed that the events in table 5.1 occur in winter. Summer flooding is assumed to occur approximately every 15 years under the existing regime, but would occur approximately every 8 years in the do-nothing situation.

The approach to benefit cost is consistent with MAFF PAGN guidance. It compares the benefits and costs of alternative flood defence regimes, and derives the net benefits attributable to the flood defence function (Table 5.2).

Table 5.2 - Framework for Benefit Cost Assessment

	A **Existing Flood Defence Regime**	**B** **Alternative Regime: either Do-nothing or Intermediary Regime**	**A-B** **Difference between Existing and Alternative Regime**
Benefits			
Agriculture	Value added from farming	Value added from farming	Extra value added from farming
Urban	Flood damage costs	Flood damage costs and reduction or loss in asset values	Extra flood damage and asset loss
Nature Conservation	Inventory of natural assets, bio-diversity, wildlife, habitat, landscape	Inventory of natural assets, bio-diversity, wildlife, habitat, landscape	Change in natural assets, bio-diversity, wildlife, habitat, landscape, particularly on 'critical' quality and quantity
Other	Assets and activities, eg archaeology, tourism, recreation	Assets and activities, eg archaeology, tourism, recreation	Changes in assets and activities, and related values.
Costs			
	Capital and operating costs (all operators)	Capital and operating costs (all operators)	Extra capital and operating costs (all operators)
Net Benefits	Benefits minus costs	Benefits minus costs	Extra benefits minus extra costs

The agricultural and urban assessments derive monetary estimates of flood defence benefits. The conservation assessment undertakes a qualitative impact analysis. Details of these analyses are presented in Appendices G-J.

Annual costs to compare with benefits were assessed from budget Revenue costs for 99/00, and average capital costs 89/90 to 98/99. Revenue costs include the cost of operations detailed in Appendices A to E, and maintenance costs detailed in Appendix F.

5.5 Agriculture Results (From Appendix G)

Table 5.3 summarises the results of the financial analysis of the Scenarios, reflecting the impact on farmer incomes. The following comments are made:

> Farmers obtain significant financial benefit from the present defence regime (an average £271/ha inclusive of ESA payments, £185/ha exclusive of ESA payments). It is emphasised that these are not farm profit estimates: they do not include charges for rent and rates (and drainage charges), financing, and general business expenses. They are net returns for the purpose of estimating the incremental impact of alternative drainage standards.

Table 5.3 - Financial Analysis: Net Margins by Flood defence Scenario and Catchment

1999 values, £'000 for each Catchment , (figures in brackets show £/ha)

	Axe	Brue	Parrett	Tone	Total
Scenario 1					
Net Margins, including ESA payments	621 (283)	2313 (287)	3488 (263)	625 (250)	7047 (271)
Net Margins excluding ESA payments	419 (191)	157 (195)	2382 (179)	452 (180)	4821 (185)
Scenario 2					
Net Margins, including ESA payments	498 (227)	32456 (403)	3908 (294)	622 (248)	8273 (318)
Net Margins excluding ESA payments	-118 (-53)	-57 (-7)	-473 (-36)	-120 (-48)	-767 (-29)
Scenario 3					
Net Margins, including ESA payments	889 (405)	3617 (449)	5904 (445)	1027 (410)	11437 (439)
Net Margins excluding ESA payments	273 (125)	958 (119)	1569 (118)	286 (114)	3087 (119)
Summary					
Scenario 1-2	123 (56)	-993 (-116)	-420 (-31)	-3 (-2)	-1226 (-47)
Scenario 1-3	-268 (-122)	-1304 (-162)	-2416 (-182)	-402 (-160)	-4390 (-168)

Assumes land uses qualify for ESA tier payments at 1999 rates

Net margins are not profits, they do not include land charges, finance charges and general business expenses

> The impact of an abandonment of flood defence on farm income depends much on whether the flooded peat areas and wet grassland qualify for ESA type payments. If they do qualify over the entire area, farm incomes could increase from £271/ha to an average £318/ha (an increase of £47/ha). If they do not, it would not be worth farming at all in the Moors: average net margin falls by £300/ha to minus £29/ha (and this is attributable to grazing of the non-peat area only).

> Similarly the attractiveness of the intermediary option to farmers depends on eligibility for ESA payment. In the absence of ESA payments, Scenario 3 would result in income losses to farmers. Assuming peat and non-peat areas qualify for the

relevant tier payments, Scenario 3 could deliver enhanced incomes, an increase of £168/ha for the assumptions made.

Table 5.4 summarises the economic analysis of the three Scenarios, assuming PAGN economic adjustment factors that reflect the value to the national economy of agricultural production. ESA payments to farmers are included as they provide a measure of the environmental benefits accruing to the nation. The following comments are made.

The economic analysis shows that, for the assumptions made, the benefits to the nation of the current flood defence regime (at an average net margin of £23/ha) are significantly less than those accruing to farmers (£271/ha), inclusive of ESA payments.

The abandonment of flood defence (Scenario 2), assuming economic benefits based on ESA rates for preserved peat land (at £430/ha), and wet grassland for summer beefstock grazing (at £230/ha), would increase economic benefits substantially by £250/ha to £273/ha. This assessment is entirely dependent on the economic value ascribed to wetland re-creation and retention.

Scenario 3, which assumes that peats and wet grassland are managed in order to reconcile agricultural and environmental objectives, has the potential to significantly increase economic benefits by an additional £279/ha over the existing flood defence regime for the assumptions made. The option appears to deliver greater economic benefits than complete abandonment, although the option does require that selected flood defence infrastructure and operations remain in place.

Table 5.4 - Economic Analysis: Net Margins by Flood defence Scenario and Catchment
1999 values, £'000 for each Catchment, (figures in brackets show £/ha)

	Axe	Brue	Parrett	Tone	Total
Scenario 1					
Net Margins, including ESA payments	81 (37)	279 (35)	272 (20)	-31 (-13)	600 (23)
Net Margins excluding ESA payments	-121 (-55)	-464 (-58)	-836 (-63)	-204 (-82)	-1626 (-62)
Scenario 2					
Net Margins, including ESA payments	319 (145)	3158 (392)	3188 (240)	440 (176)	7105 (273)
Net Margins excluding ESA payments	-296 (-135)	-145 (-18)	-1193 (-90)	-302 (-120)	-1936 (-74)
Scenario 3					
Net Margins, including ESA payments	558 (254)	2534 (315)	4116 (310)	657 (262)	7865 (302)
Net Margins excluding ESA payments	-563 (-26)	-124 (-15)	-220 (-17)	-85 (-34)	-486 (-19)
Summary (inc. ESA)					
Scenario 1-2	-238 (-108)	-2879(-357)	-3161 (-220)	-471 (-189)	-6505 (-250)
Scenario 1-3	-477 (-217)	-2255 (-280)	-3844 (-290)	-687 (-272)	-7265 (-279)

Assumes PAGN economic price reduction factors of 10% cereals, 25% beef, and 35% sheep, dairy area treated as wheat crop, and inclusion of ESA payments at 1999 rates as an economic benefit.

The preceding analysis of agricultural and environmental economic benefits adopts a broad strategic viewpoint. A number of key messages emerge:

- Existing agricultural land use and farming practice in the Levels and Moors are very dependent on the flood defence and land drainage. Under present circumstances the financial benefits to farmers appear to exceed the benefits to the nation.

- A discontinuation of flood defence would (in the absence of environmental payments) lead to financial losses to farmers and the likely abandonment of farming in the Levels and Moors.

- Assuming that ESA payments broadly reflect the value to the nation of the environmental benefits of wetland recreation and retention, and that the unit value of these exceeds that from incremental farm output (which, given policy reform, is likely to continue to be the case for sites like the Levels and Moors) the 'do nothing' option can deliver economic benefits associated with a switch from agricultural to environmental goods in the flood risk areas.

- The 'do nothing' option would have significant environmental impacts, not all of which would be positive (see section 5.6). Many important environmental features of the Levels and Moors are dependent on a managed water regime, and are particularly influenced by the timing and duration of flooding, and ditch and field water levels. Uncontrolled flooding would result in a deterioration of some features, especially those relating to unimproved wet grassland and habitats. Furthermore, a number of features of traditional grassland management practices such as grazing and hay cutting are beneficial to habitat, landscape and amenity.

- An intermediate option that retains the basic infrastructure of flood defence but operates a lower standard of service than at present could help to reconcile the interests of farming and environment. It could potentially offer a framework for sustainable resource use and development in the Moors, especially in the surface peat areas. This option could deliver a range of biodiversity, tourism, recreational and archaeological benefits. The economic analysis suggests that an intermediary option could offer a potentially preferred development path. The details and costs of delivering this option need further study.

5.6 Wildlife and Conservation Results (From Appendix H)

The impact of changes in flood defence management needs to be studied on a site by site basis, but this analysis aims to give a general over-view. At present (Scenario 1), public money is used to provide low water tables over much of the study area and at the same time engineer high water tables in isolated blocks in the name of nature conservation. The efficiency of such a system needs to be reviewed, especially as there are still some questions over the nature conservation benefits of the existing Raised Water Level Area initiative.

The option of abandoning flood defence structures and operations (Scenario 2) would create a wholesale change to the landscape and to its flora and fauna. Many of the current assets of nature conservation value would be at risk, in particular the remaining areas of species-rich grassland, the potential habitat for breeding waders, and aquatic communities which rely on regularly managed ditches and rhynes. These would be replaced by more extensive swamp communities such as reedbed, the exact nature of which would be dependent on the response of the land managers to the new hydrological situation. Such habitats would bring new opportunities for other species of conservation interest such as Bittem, Marsh Harrier and Otters. Reedbeds may ultimately be allowed to succeed to stands of wet woodland, which itself is a scarce habitat in the U.K., and a feature of the pre-drained moors.

The reduced flood defence management of Scenario 3 offers a compromise between the two preceding options. Whilst creating wetter conditions for the benefit of breeding waders and discouraging the further intensification of farming practice, it retains the capacity to manage the area for pastoral agriculture, which may be viable if appropriate grant aid is available or attractive market conditions are present for its products. This option would require the continued maintenance of the arterial drainage system within the Moors and the retention of pumping capacity in some cases. The financial benefits over the existing situation would have to be reviewed on a site by site basis.

In summary, all three scenarios offer some nature conservation interest. It is recognised that some of the area's current natural assets, which are highly prized and unique within the U.K., are reliant on continued flood defence management and would be lost if a more natural hydrological system were allowed to prevail.

5.7 Urban Results (From Appendix I)

The benefits accruing to each scenario are summarised as follows.

Table 5.5 - Estimate of Present Value of Damage Avoided (Benefits) of Each Scenario

Flood Scenario	Damages	Damages Avoided (Benefits)
Do Nothing (DN)	DN	0
Do Minimum (DM)	DM	DN-DM
Maintain Existing (ME)	ME	DN-ME

Inserting PVd/PVb gives the Benefits associated with the three selected scenarios:

Table 5.6 - Actual Present Value of Damage Avoided (Benefits) of Each Scenario

Flood Scenario	Damages (£ millions)	Damages Avoided (Benefits) (£ millions)
Do Nothing (DN)	739	0
Do Minimum (DM)	220	519
Maintain Existing (ME)	161	578

In conclusion, it is seen that the benefits of preventing the 'Do Nothing' scenario when compared with the existing standard of service are £ 578 millions. Even the delayed maintenance scenario of only maintaining defences as and when they breach, still gives a PVb of in excess of half a billion pounds, illustrating conclusively the significant economic impact on the Levels and Moors, and Bridgwater, in particular of reverting back to pre-flood defence/land drainage conditions.

This study has not looked at the impact of road closure as a consequence of the 'Do Nothing' scenario. Economic losses will be small in comparison with other built assets.

The main arterial road traversing the Levels and Moors - the M5 - acts as a barrier to the ingress of flood water under the 'Do Nothing' scenario.

The study does not include the socio-economic impact of properties above the level of tidal encroachment but which would become isolated as islands or perched on narrow peninsulas under the 'Do Nothing' scenario. The impact on the regional economy as a result of permanent flooding and tidal ingress should, however, be considered during a more in-depth appraisal.

5.8 Other Results (From Appendix J)

Links between flood defence on the Levels and Moors and sectors such as tourism, recreation, fisheries (including angling), archaeology, and the peat and withy industries have also been reviewed. Dependency on standards of flood defence vary. Tourism and recreational activities would probably be enhanced by a flood regime that served to enhance the wetland characteristics of the area, as indeed would the preservation of archaeological remains. The traditional rural industries of peat abstraction and withy production rely on protection from long duration flooding or permanently high water levels.

5.9 Costs

Current Agency expenditure on the Somerset Levels and Moors is best expressed by this year's revenue budget of £1.106 million, and an average capital expenditure between 89/90 and 98/99 of £1.011 million.

Capital expenditure on the Somerset Levels and Moors dropped considerably in 97/98 and 98/99 due to the concentration of funds on Minehead sea defences. The average between 89/90 and 96/97 was £1.19 million, compared with 97/98 and 98/99 of £0.3 million.

5.9 Conclusion

The preceding analysis sums up the basic difficulty the Agency faces in justifying work on the Somerset Levels and Moors. Whilst drainage improvements increase financial benefits for farmers, they do not increase benefit for the nation, and this is the required measure under MAFF treasury rules. Only the significant benefit to urban property can justify continued Agency expenditure. Indeed, a reduction in drainage leading to an increase in ESA payment increases benefit to the nation.

However, if the Agency was to decrease significantly financial benefit to agriculture, this would result in the cessation of farming practices, and a reduction in benefit to the nation due to the cessation of management of the land.

Such difficulties should be kept in mind when considering the Sowy model results, where many of the options with significant cost still give considerable problems in economic justification.

Detailed justification of individual operations and maintenance practices could only produce comparative results for prioritisation. Attempts to separate out operations for absolute benefit cost analysis would have to include a complex proportioning of the benefit to the urban areas. The Agency intends to use this holistic exercise for overall justification, and other exercises for prioritisation only.

6 PARRETT AND SOWY OPERATIONAL MODEL

6.1 Introduction

The Environment Agency (formerly the National Rivers Authority) undertook a review of its water management operations within the River Parrett system following increased public interest as a result of the 1993/1994 flooding. As part of this review the Agency developed a computational model to undertake initial investigations to assess the maintenance practice of the channel of the River Parrett and the operation of the River Sowy (Parrett Flood Relief Channel).

In November 1996, Posford Duvivier were commissioned to provide guidance to the Agency on the best way forward to optimise this existing model for wider use as a tool for assessing the operational practice of the River Parrett system. As part of this commission an inception report was produced detailing the suitability, limitations and deficiencies of the existing model and making recommendations for an enhanced model which would give an increased level of confidence in water level and flow predictions.

Work commenced on the model enhancement in November 1997. The model was substantially developed using new and existing survey data and was calibrated for within channel and out of channel events. The model is now at a stage where it can be used within reasonable confidence limits as an interpretative tool to test operational practice and model the impacts of change throughout the system.

6.2 Description of the Model

The model of the River Parrett system has been constructed using the computer program ISIS, which is the principal river modelling tool used and accepted by the Industry. The ISIS computational package models open river channels and overbank flows in any nature of channels and includes bridges, culverts, weirs, sluices, pumping stations and reservoirs. The model allows for the tide and river flows to be represented over time and also allows for different gate settings and pump controls at structures such as sluices and pumping stations.

The model developed of the River Parrett system includes the Main River channels of the Rivers Parrett, Tone, Sowy, Cary and King's Sedgemoor Drain (KSD). Specifically, the River Parrett extends from the confluence with the River Isle to the estuary downstream of Combwich at the sea; the River Tone from upstream of Newbridge Sluice to the confluence with the River Parrett; the River Sowy from the confluence with the Parrett to the KSD; the River Cary from the Somerton gauging station to Henley Bridge and the KSD from Henley Bridge to Dunball. In addition, the model extends for a short length along the River Yeo from Huish Episcopi pumping station to the confluence with the River Parrett.

During the model construction detailed site visits and consultation were undertaken to assess the hydraulic significance and characteristics of each structure to ensure their appropriate representation in the model. In addition, detailed quality checks were carried out on the existing survey drawings of each structure.

The River Parrett system model includes all key control structures which have a significant effect on the water levels and flows throughout the system. At structures with gates, such as Dunball Sluice Newbridge Sluice and Oath Lock, the model allows for different gate settings and operation to be modelled over time. All pumping stations within the boundaries of the model have been included and allowance is made for different pump operating conditions to be modelled. The model also includes Hook Bridge, Allermoor and Beazley Spillways and the various moors are represented in the model as a series of storage areas.

6.2.1 Calibration

The River Parrett catchment has a particularly complex system of rivers, hydraulic structures, spillways and relief channels which all impact on the performance of the system as a whole. Robust calibration is essential to ensure that the model accurately represents the conditions in the river system. The model was calibrated using records made of previous flood events and extensive efforts were made to ensure that the model closely reproduced these observed events.

The model was calibrated for a single tidal event, which occurred on the 10 May 1993, and two further events in December 1994 and 1997. These events represent both in bank and out of bank conditions. Model simulations of these events gave excellent agreement with observed levels and for the most part simulated levels were within 100mm of those observed. Figures 6.1 and 6.2 show observed levels against the model simulation for selected sites within the river system.

6.2.2 Model Capabilities and Limitations

The development of such a robust computational model of the River Parrett now allows the Agency to examine the effects of major capital work and changes in maintenance or operational practice prior to them being carried out. The major advantage of the model is that proposed schemes or changes to current practice can be looked at in isolation or in combination and the effects on all parts of the river system can be evaluated. The model, however, is only an interpretative tool and must be used with appropriate care and judgement by personnel with experienced knowledge of the complex River Parrett system and the data on which the model is based.

6.3 Operating Scenarios

Following the completion of the model calibration, the model was used to assess the effects of some works proposals and possible changes to the current operation of the system. To maintain consistency and ensure that the effects of each scenario could be compared against each other, river levels and flows within the River Parrett System were based on the 1st to 3rd January 1998 and various operating scenarios were applied to this baseline condition. To date the following operating scenarios have been investigated:

6.3.1 Allermoor and Beazley spillways were modelled, raised and lowered by 200mm. Figure 6.3 shows the effects of these adjustments to the spillways on the levels at Oath Lock, Westover and Pathe. In addition, the graph shows the effect of shutting Monks Leaze Clyse on flow going over Beazley spillway. Water levels in the River Sowy and peak water levels in the River Parrett are sensitive to the level of Beazley spillway. The influence of the Beazley spillway is particularly important when the Monks Leaze Clyse is closed.

The effect of Allermoor spillway on river levels in the River Parrett depends on the operation of Monks Leaze Clyse. If Monks Leaze Clyse is closed or opened so that only peak flows enter the River Sowy by the Beazley spillway, its impact on the water levels in the River Parrett is negligible.

6.3.2 Two dredging scenarios were examined for the River Tone from Newbridge to the confluence with the River Parrett. Firstly, a full redredge of the channel to the original design profile was assumed. Secondly, the River Tone was partially dredged to create an access berm on the right hand bank and the original design profile on the left hand bank. Figure 6.4 shows the effect of these dredging scenarios against the existing condition. There is negligible difference between the two dredging scenarios, however, there are differences from the existing condition. Dredging the River Tone would help to lower the water levels in the River Tone but would not have a significant effect on water levels in the River Parrett. In addition bankfull capacity within the River Tone would be increased.

6.3.3 The River Parrett was assumed to be dredged from downstream of Oath Lock to 2.5km below Burrowbridge allowing for 1:2 side slopes for the dredged section. Figure 6.5 shows the effect of dredging on levels and flows in the River Parrett. For this case dredging the River Parrett has limited effect on reducing peak levels in the Parrett downstream of the confluence with the River Tone, but leads to a decrease of up to 200mm in levels upstream of the confluence with the River Tone. Bankfull capacity is also increased which would allow less water to spill over Beazley spillway at the start of an event.

6.3.4 The operation of Dunball Sluice has a significant impact on the water levels in the King's Sedgemoor Drain and River Sowy. Figure 6.6 shows the effect of different gate operation at Dunball Sluice on levels at Bradney and Beerwall Sluice. It was found that the operation of Dunball Sluice has limited influence on the water levels in the River Parrett under fluvial flood flow conditions.

6.3.5 The capacity of King's Sedgemoor Drain is dependent on the tidal condition within the River Parrett which prevents water from discharging from the KSD during high tide. The capacity at Dunball Sluice is more than sufficient to release water into the River Parrett and therefore is not a limiting factor. The bankfull capacity of the King's Sedgemoor Drain downstream of the confluence with the River Sowy is less than the 17.5 cumecs 1970 design capacity.

6.3.6 Hook Bridge spillway was raised by 200mm. Figure 6.7 shows the effects on river levels at Currymoor Pumping Station and downstream of Hook Bridge. Raising Hook Bridge spillway results in increased water levels of 100mm downstream of the spillway in the River Tone.

6.3.7 Various gate openings for Monks Leaze Clyse were examined. Figure 6.8 shows the results of closing Monks Leaze Clyse on water levels at Westover, West Sedgemoor, West Quay (Bridgwater) and Pathe.

6.3.8 The operation of Beerwall Gate has a significant impact on the water levels in the upper reach of the River Sowy and the impounded flood water levels in North Moor and Allermoor. The operation of Beerwall Gate has limited influence on restricting flows through Monks Leaze Clyse. The flow capacity of the River Sowy is approximately 17.5 cumecs.

6.4 Future Programme

The impacts of the scenario results in 6.3 now need further consideration. Where options suggest improvements, their cost effectiveness and cost benefit needs to be analysed before any programme of work can be proposed for funding approval.

Work is currently being undertaken to produce a manual detailing the full extent of the model, including the structures, pumping stations, spillways and moors.

With regard to recommendations for future model enhancements, new topographical survey should be undertaken to replace sections in the model which have been taken from relatively old historic survey data. In addition, further calibration of the model should be undertaken when sufficient data becomes available from flood events as and when they occur. Additional calibration would further enhance the model's reliability and give even greater confidence to model predictions. In order to do this greater emphasis needs to be placed on obtaining appropriate level and flow measurements throughout the system as a whole during flood events.

7. EFFECTS OF DEVELOPMENT

7.1. Introduction

In response to public concern that the flood risk on the Levels and Moors has been increased due to the urbanisation of the upland catchment, a study was undertaken by the Environment Agency to ascertain the effects of development on river flows.

Hydrological analysis was also undertaken to compare the flood flows with and without the major urban areas.

7.2. Hydrology and Flooding

When rain falls on bare ground, several physical processes take place. Firstly, depending on how wet the soil was before the rain commenced, rainwater passes into the soil where it is stored. Over time, this water either passes further into the soil, is removed by plants and by evaporation or flows slowly to the river. Secondly, if enough rain falls such that the soil becomes waterlogged, or the rainfall is so intense that the rain water cannot enter the ground quickly enough, the excess rain runs over the land and drains directly into rivers and streams. The speed at which this rain, known as run-off, reaches the river therefore depends on the following main factors:

- How easy it is for water to enter the ground. The more difficult it is for water to enter the ground, the faster the water will reach the river.
- How wet the ground was before the rain started. The wetter the ground, the faster the water will reach the river.
- How far away the rain is from the river. Rain that falls next to the river will obviously reach the river faster than rain that falls on top of a hill.

All these factors act together to determine the speed at which the flow builds up in the river and hence how quickly flooding occurs.

7.3 Catchment Descriptions

7.3.1 River Tone

The River Tone rises to the north west of Clatworthy Reservoir and flows south before turning east through Taunton and discharging into the River Parrett at Burrowbridge. The area of land that drains to the Tone, the catchment, covers 405 km^2, and is predominantly relatively impermeable clay, with a fairly rapid run-off response to rainfall.

On the basis of current information available from existing and emerging Local Authority Development Plans, the Tone catchment is an area of development growth. In the Draft of the Somerset Structure Plan published in February 1995, a housing allocation of 12,900 dwellings was made for the Tone catchment over the Plan period of 1991 to 2011. The Agency carry out frequent detailed negotiations with Local Planning Authorities to ensure that proposed new development allocations are assessed and that they are not at risk from flooding or create a flood risk.

The major urban area within the catchment, and hence the focus for building development, is the town of Taunton. Taunton currently has an area of about 14 km², which is only 3.5% of the total catchment. This has increased from 2% in 1959. By 2001, planners predict this to have increased to 4% of the total catchment area. 75% of the Tone catchment is upstream of Taunton.

Because Taunton is an urban area, the ground is predominantly covered with impermeable materials such as roads, footpaths and buildings. This means that relatively little water passes into the ground, but flows over the surface into drains and then into the river, and as Taunton is built on the River Tone, the water does not have far to travel to reach the river. Because Taunton is so near to Curry Moor, the water flows very quickly past that area and on to Burrowbridge. Furthermore, because Taunton is so small compared to the rest of the catchment, the volume of water and the peak of water arising from the town are also relatively small and would not on their own be capable of causing flooding in Curry Moor.

It is Environment Agency policy (since the 1980's) to insist that all new development in Taunton drains to a detention reservoir. This stores a volume of water in the same way that a green field would, overflowing when full during a prolonged event in the same way that saturated ground would , and storing when empty just like dry permeable land.

The rest of the catchment, mostly upstream of Taunton, is predominantly undeveloped agricultural land and hills. Water soaks into the ground and the furthest points are 20 miles or more from the river. It therefore takes the rain much longer to reach the river and even longer for it to reach Taunton and Curry Moor. Indeed, by the time the upper areas of the catchment have drained as far as Curry Moor, the flow generated by the impermeable ground of Taunton has generally long since gone. Records from Bishops Hull Gauging Station upstream of Taunton going back to 1961 show no increase in the speed of run-off to the gauge.

To be able to compose the catchment's response to rainfall now and in the past, it is necessary to consider similar rainfall events falling on catchments with the same level of saturation. Two such events occurred in December 1958 and November 1994, when continual rainfall eventually led to over-topping of Hook Bridge Spillway. For both events, the period between the start of rainfall and overtopping just beginning was 48 hours. If the Tone catchment had been saturated this period would have been shorter. During many events in the 90's heavy rain after a day or two's pause in rainfall brings an already full River Tone back up to overtopping the spillway in 6 or 7 hours. This is not a result of any change in land use in the catchment but dependant on the preceding catchment conditions.

The area upstream of Taunton is very large compared with Taunton itself, and so the volume of water flowing from this area and the maximum flow are both very large. It is the flow from this area that causes flooding to Curry Moor.

In recent years, there has been a series of extreme flood events on Curry Moor, mostly occurring during the winter months. These have been characterised by medium to heavy rainfall occurring at regular intervals over two or three months prior to the start of flooding. The frequent rain ensured that all of the soil storage capacity was taken up and so the entire catchment was waterlogged and behaving as though it were a developed area. The rain entered the river very quickly and because it was already full from the previous prolonged rain, flooding occurred very quickly.

In this situation, with the River Tone already high, rain falling on Taunton is more likely to have been the initial cause of flooding on Curry Moor simply because it is nearer than most of the rest of the catchment. However, it would still not be correct to say that increased development increases the flood risk, as in these circumstances, the whole catchment is behaving as though it were covered with an impermeable material such as roads, footpaths and buildings.

7.3.2 River Isle

The River Isle is 16 km in length and rises in the Blackdown Hills north of the town of Chard, and flows via Ilminster to its confluence with the River Parrett just west of Langport. The total catchment area is 164 km^2 (16,400 hectares). The catchment is roughly a broad triangle in shape with the base of the triangle reaching a height of 250m above ordnance datum in the Blackdown Hills in the south west, and running across to Chard in the south east. The apex of the triangle is south of Muchelney, approximately 3km south of Langport, where ground levels are approximately 8m above ordnance datum. The catchment is predominantly clay and is therefore relatively impermeable with a fairly rapid run-off response to rainfall.

Mixed farming is pursued in the catchment with the more frequently flooded land given to grass, but cereals are sometimes grown in areas that can suffer flooding. The only major urban settlements are Chard and Ilminster. The growth of these settlements was in the order of 70 hectares in the ten years from 1976 to 1986, and a similar rate of development took place between 1986 and 1996. Assuming a catchment area of 60 km^2 (6,000 hectares) above Ilminster, the urbanisation represents an increase of approximately 0.1% per annum. The increase in urbanisation over the past 20 years has therefore been in the order of 2% of the catchment area above Ilminster, or 0.7% of the total catchment area.

Whilst such development does not pose a serious threat to the capacity of the catchment drainage in general, since the 1980's, the Environment Agency and its predecessors have insisted that all new development is controlled so as to not increase the flood risk in the catchment. For example, the improvements to the A303 trunk road with the construction of the Ilminster by-pass incorporated surface water storage facilities where uncontrolled discharges would have exacerbated existing or created new flooding problems.

There is a gauging weir on the River Isle at Ashford Mill, north of Ilton. Over the twenty year period from 1966 to 1985, there was no evidence from the flow records that either the frequency or level of peak flows had increased. The average number of events where peak flows have exceeded arbitrary limits of $5m^3/s$ and $20m^3/s$ have been plotted for the two periods 1966 to 1975, and 1976 to 1985. No significant difference in frequency can be seen. Indeed, the more recent period gives slightly lower mean figures. Further work will be programmed on extending this analysis to 1999, but cannot be given a high priority at present.

7.3.3 River Yeo

The River Yeo is a major tributary of the upper reaches of the River Parrett; the confluence being located approximately 1 km upstream of Langport and about 3.5 km downstream of the confluence of the Rivers Parrett and Isle. The gradient of the Yeo for its last 12 km, up to Ilchester, is approximately 1 in 4600, and from Ilchester up to Pen Mill, Yeovil, 29km from the confluence, the average gradient is approximately 1 in 1100. The total catchment area is 398 km^2, and river catchment extends to between 3 and 4 km from the channel on both banks along this reach, with the floodplain itself being more than 3 km wide in places.

Between Hainbury Mill, just upstream of Ilchester, and its confluence with the Parrett, the Yeo is artificially embanked with the bank top levels rising up to 3m above the lowest land in the adjacent moors, which flood regularly and extensively. The whole area floods every three to five years and two or three times per year, a considerable proportion of this moorland is affected. Although pumps drain this low-lying land, much of the flooding is caused by the Yeo overflowing onto the moors. Pumping back into the river has to await a fall in river level and evacuation of the floodwater can take one to two weeks.

Although recent flood alleviation schemes have been constructed to protect the towns of Sherborne and Ilchester, and farmland between Sherborne and Yeovil, other extensive areas of farmland and several villages are still at risk of flooding. The main physical constraint on any flood protection scheme for the Yeo is the inability of the River Parrett through and below Langport to accept large flood flows. Flow capacity at Langport is below that considered a reasonable standard of flood protection (1 in 25 years). This obviously warrants further consideration by the Agency in any review of current standards of protection.

7.4 Hydrological Analysis

To illustrate the effect of urbanisation within the catchments, river flows generated by varying intensities of rainfall on the catchment were calculated by hydrological software for two scenarios:

- the existing catchment;
- the existing catchment with nearly all the major developed land areas deleted to reflect the situation where urbanisation has not occurred.

The hydrological computer programme output gives flood flows in the rivers for a wide range of return periods (probability of occurrence) and rainfall events. The output is given for each defined reach, or sub-division, of the catchment and at both the upstream and downstream extents of the reach.

By comparing flood flows for the existing catchment with those obtained for the catchment with nearly all the developed land deleted, the effect of urbanisation of the catchment on flood flows can be established.

7.4.1 River Tone

It is clear from the hydrology results shown in table 7.1 that urbanisation has little effect on the River Tone main river flood flows anywhere in the catchment. Total urbanisation of the catchment to date has caused a maximum increase in flow downstream of Taunton of 2.8% for the 1 in 100 year return period.

This comparative analysis does not take account of any local on site attenuation which is a requirement of the Environment Agency for development within the catchment, and therefore the maximum 2.8% increase in flood flow can be considered as conservative.

Table 7.1 - Percentage increases in flood flow for the River Tone at its confluence with the Galmington Stream.

Return Period (Probability Of Flood Event In Any One Year)	Storm Duration		
	13 Hours	17 Hours	22 Hours
1 in 1	4.1	4.1	4.0
1 in 5	3.6	3.7	3.6
1 in 20	3.2	3.2	3.1
1 in 100	2.7	2.8	2.7

7.4.2 River Isle

Similar analysis of the River Isle catchment shows that previous urbanisation has had little effect on the flood flows in the River Isle. Total urbanisation of the catchment to date has caused a typical increase in flow of approximately 1% on the lower reaches on the Somerset Levels and Moors for the entire range of return periods

The head reach of the Isle catchment shows the most sensitivity to urbanisation as the flood flow increases by approximately 3%. Flood flows downstream of the Chard Reservoir increase dramatically for the 1 in 100 year event due to the capacity of the reservoir being attained.

7.4.3 River Yeo

The hydrology model indicates that the maximum impact of the urban area on flood flows is in the upper reaches of the River Yeo at just less than 5% for the 1 in 100 year event. The flood flows in the lower reaches of the catchment on the Somerset Levels and Moors are affected by approximately 2% for the 1 in 100 year event due to the urban area.

7.5 Conclusions

The maximum impact that any of the urban areas above the Somerset Levels and Moors has on flows reaching the Levels and Moors is that of Taunton and Wellington on the River Tone, and that is only an increase of 4.1% on an annual event. The impact of an increase in these urban areas is almost unmeasurable, as all recent urban developments have included detection as recommended by the Agency.

Any perceptions of runoff reaching the Levels and Moors quicker than in previous years is not confirmed by analysis of timing of events recorded.

The Agency can find no evidence to alter its conclusion that recent urbanisation has not increased flood risk on the Levels and Moors, and the Agency will continue its policy of recommending detention to balance increased runoff where appropriate.