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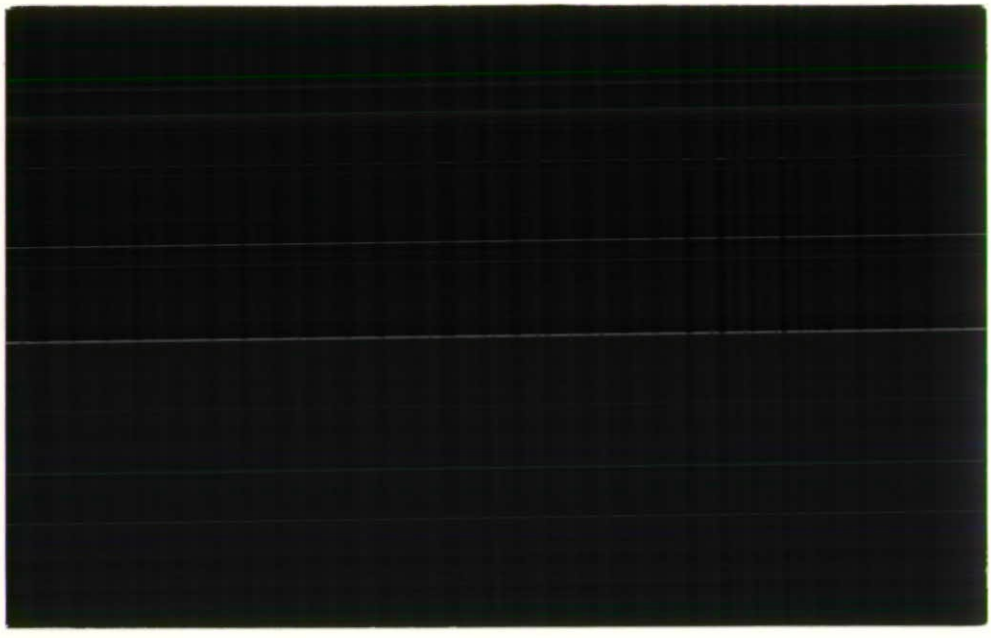

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Hydrological Impact Assessment

A Review of IH Expertise

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Summary

This report reviews IH's current level of expertise in the field of hydrological impact assessment. Hydrological impact assessment, as used here, is defined as the assessment of any changes to the hydrological cycle resulting from modifications to the physical environment associated with a specified set of human activities. In essence this refers to the hydrological component of an environmental impact assessment (EIA) and is thus concerned with evaluating the extent to which new developments may effect aspects of water quantity and quality.

The review demonstrates a high level of expertise in the hydrological impact assessment of a range of types of development, partly through IH's extensive research in relevant fields and partly through commissioned impact studies. These include flood defence, water resource schemes, urban development, forestry, agricultural land drainage and mineral extraction.

Many of the hydrological techniques developed at the Institute are shown to be appropriate for impact study applications. Of particular note are the Flood Studies Report, the Low Flow Studies, the QUASAR water quality model and the IFIM method for assessing the impact of flow changes on aquatic habitat. The review also outlines the way in which experimental catchment and hydrological process studies performed at field stations such as Plynlimon and Balquhidder are of major importance for assessing the impact of certain rural developments.

In addition, the review details IH involvement in a wide range of commissioned impact studies. These studies have involved a range of methods from small scale site investigations to the application of detailed hydrological simulation models. In an example of a major multidisciplinary environmental impact study IH played a central role in providing details of possible hydrological changes for additional studies by experts in fields such as ecology and geomorphology.

The review demonstrates a high level of expertise at the Institute and suggests that this combination of experience and knowledge can be applied in a wide range of environmental impact studies. Where the scope of an EIA is wide, IH is in a position to utilise this specialist knowledge to undertake component hydrological studies.

Contents

1 Introduction

This report attempts to review IH's current level of expertise in the field of hydrological impact assessment. It aims to document both research and commissioned impact studies performed across a wide range of relevant subject areas. The review is intended as the first of several stages in a project to develop guidelines for hydrological impact assessment. Whilst clearly supporting this longer term objective, the review can also can be seen to have additional benefits.

Firstly, it helps to consolidate the findings of many of the programmes of research performed by hydrologists at the Institute and show how the knowledge and experience gained in these studies can be applied to 'real world' problems. Secondly, the review can help in the presentation of IH expertise by its incorporation in subsequent proposals for commissioned hydrological impact studies.

It is important at this stage to give a clear indication of what is meant by hydrological impact assessment. To some hydrologists it is a very general term; virtually all aspects of hydrological investigation might arguably be referred to as an assessment of the impact of some factor on the hydrological cycle. It is therefore necessary to define more clearly the meaning of hydrological impact assessment as used in this report since this delimits the nature of material which has and has not been included in the review.

Hydrological Impact Assessment, as used here, may be defined as:

> The assessment of any changes to the hydrological cycle resulting from modifications to the physical environment associated with a specified set of human activities.

In essence, the term as used here refers to the hydrological component of an environmental impact assessment (EIA) and is thus concerned with evaluating the extent to which new developments may effect aspects of water quantity and quality. The scope of this review is therefore inextricably linked to the scope of EIAs as defined by EC Directive 85/337 and which was implemented in the UK through the Town and Country Planning Act (Assessment of Environmental Effects) Regulations 1988 (SI No. 1199) and a number of subsequent regulations relating to specific types of project (DoE, 1989). The 'specified set of human activities' referred to in the above definition is equivalent to the list of projects requiring an EIA in the UK of which a broad outline is presented in table 1.1.

Certain of the types of development listed in table 1.1 are emphasised in bold text. These are areas in which the review has been able to demonstrate a high level of IH expertise and which comprise the main areas of coverage in this report. Each area of expertise is described in a separate chapter, firstly through a review of IH research in relevant fields and secondly through a consideration of impact studies of particular development projects. It should be noted that although the review is essentially concerned with studies relating to the categories of project defined in EC and UK legislation it does incorporate coverage of studies in other parts of the world where these are of direct relevance.

Table 1.1 Summary of project types subject to an EIA in the UK.

Schedule	Development	Examples
Schedule 1 - Requiring environmental assessment in every case	Certain industries	Oil refinery, iron and steel, asbestos, chemicals
	Power generation > 300 Megawatts	
	Certain waste disposal and storage	Radioactive waste, special waste
	Certain transport developments	Motorways, long distance railway, inland waterways
Schedule 2 - Requiring environmental assessment where likely to have significant environmental effects	Agriculture	**Afforestation, land reclamation, water management**
	Extractive industry	**Peat, minerals,** coal, gas
	Energy industry	Hydroelectric power, reprocessing of nuclear fuel
	Metal processing	Motor vehicle manufacture, ship yards
	Glass making	
	Chemical industry	Pesticides, pharmaceuticals
	Food industry	Slaughter houses, breweries
	Textile, leather, wood and paper industries	Fibre-dyeing, tanneries
	Rubber industry	
	Infrastructure projects	**Urban development, flood relief, dams, roads,** pipelines
	Other projects	**Waste water treatment,** explosives manufacture

Source (DoE, 1989)

The review begins by considering areas in which the management of hydrological variables is of central concern, either through the development and improvement of infrastructure or through the control of surface and groundwater resources. Chapter 2 reviews IH expertise in the assessment of flood defence and alleviation schemes whilst chapter 3 considers the hydrological assessment of water resource projects. Chapter 4 then reviews IH expertise in the evaluating the hydrological impact of urban development projects.

Following this the review moves on to consider types of project where hydrological impacts may be thought of as more indirect but which never the less can result in major changes to water quantity and quality. In chapter 5 the emphasis is on rural forms of development which involve changes in land use, with particular attention given to forestry and the drainage of agricultural land. Finally, chapter 6 describes further impact studies undertaken by IH which do not fall into one of the four main categories of expertise covered in the previous chapters.

It is evident that in defining the main areas of IH expertise there are many types of development which are subject to an EIA but which are not covered in this report. In some cases these are project types to which the assessment of hydrological changes is not particularly relevant whilst in others they represent areas in which IH has little or no experience in undertaking actual impact studies. It should also be noted that whilst this report is intended to provide a reasonably thorough review of IH expertise it does not claim to be comprehensive. In certain cases it has not been possible to access the relevant reports of studies in this field. In addition there may be in existence reports of studies performed by IH which would be considered by their authors as suitable for inclusion in this review but of which the author of this report has no knowledge.

2 Flood Defence and Alleviation

2.1 Background Research

The Institute of Hydrology has a long history of research in the field of flood estimation. In 1975 the five volume Flood Studies Report (NERC, 1975) was published, providing detailed guidelines for the estimation of floods for both gauged and ungauged river channels. The subsequent updating of the FSR with supplementary reports and the transfer of the methods of estimation to a software package, MicroFSR, have ensured that the report remains the definitive source for hydrologists and engineers involved in flood prediction.

The FSR and its derivatives detail techniques for assessing the likely magnitude of a flood of a given probability or return period by one of two alternative approaches, the statistical method and the rainfall-runoff method. In cases where flow data is unavailable for a given channel flood magnitude can be estimated from catchment characteristics, using relationships derived from the extensive research effort which preceded the publication of the FSR. Research into the application of FSR techniques has continued at IH to the present day, with regular reports (for example Boorman, 1985 and 1990) detailing the results of reviews and recent progress.

The methods of flood estimation developed at the Institute are clearly of direct relevance for the assessment of flood defence and flood alleviation works. Any study of channel improvements is primarily concerned with evaluating the extent to which the works will result in the desired changes to the flood regime of the river. The FSR provides the tools by which this assessment is made.

With the upsurge in concern over environmental issues in recent years there has been a diversification of research at IH from the purely engineering aspects of flooding to encompass ecological factors. Research into the way in which different aquatic species perform under a range of river flows has been carried out using the Instream Flow Incremental Methodology (IFIM). The approach, first developed in the United States, involves the use of the Physical Habitat Simulation (PHABSIM) model which links hydraulic and ecological components to simulate the relationship between streamflow and habitat. This allows the determination of the optimum flow regimes not only for a range of species but also for different stages in the life cycle of any one species.

Initial research at IH into IFIM was concerned with assessing its performance in relation to UK aquatic environments (Bullock et al, 1991) and with the calibration of PHABSIM from flow, habitat and species data collected on two British rivers. This research was able to demonstrate the potential of the approach as a means to quantify the impact of changes in river flow on aquatic ecology, a finding that has been confirmed by subsequent studies.

An important part of this subsequent research has been into the application of IFIM specifically for the assessment of flood defence schemes (Johnson et al, 1993). In case studies involving both the use of PHABSIM and site sampling of the aquatic ecology the research was able to show the way in which the change in flow regime associated with flood defence

works would significantly effect habitats in riffle reaches and mid-stream areas. Although it was concluded that there would be no major reductions in faunal diversity, application of the IFIM approach was able to reveal the way in which particular life-stages would be adversely effected by loss of habitat. The research has demonstrated the suitability of both IFIM and PHABSIM for impact assessment of flood defence and alleviation schemes.

2.2 Impact Studies

IH has been involved in a number of studies to assess the hydrological impact of flood defence and alleviation schemes. These have included studies of changes in both flow regimes and in water quality and in some cases have involved collaboration with experts in other fields.

In a detailed study of proposed flood alleviation in Upper Strathspey changes in the flow regime of the channel and flooding of ecologically sensitive marsh areas were assessed using a hydraulic model of the river system (Johnson et al, 1991). The model, calibrated from historical flood events and a survey of the channel geometry, was able to show the way in which the frequency and distribution of flooding was altered by each of two proposed alleviation schemes. In a series of supporting reports by a multidisciplinary team of experts (IH, 1991) the findings of the hydrological study were assessed in terms of their potential impact on a range of factors including aquatic and terrestrial fauna and flora and the geomorphology of the channel reach.

In another study IH was commissioned to assess the hydrological impact of a proposed barrage across the River Roding, a tributary of the Thames (Acreman, 1991). Although the function of the barrage is to improve the amenity value of the Roding for boating and other leisure activities, the methodology used is equally applicable to a study of a barrage intended as a flood control measure. A hydraulic model was designed to estimate changes in water level at critical cross sections along the Roding. The model was able to take into account influences such as the tidal regime of the River Thames and other factors effecting the operating conditions of the barrage. Methods of flood frequency analysis were then used to assess the extent to which slight increases in the channel water level would represent increased flood risk.

In other studies of flood alleviation schemes attention has been focused on potential changes in water quality resulting from channel modifications. A notable example is the water quality study for the environmental impact assessment of a flood relief scheme on the Maidenhead to Eton reach of the River Thames (Whitehead et al, 1990). The study involved the simulation of a range of water quality variables in a proposed flood relief channel using the model QUASAR, of which more details are given in chapter 3. The results of the model simulation were then used to predict algal growth in the flood relief channel. The study concluded that a constant 'sweetening flow' should be maintained in the channel in order to maintain water quality similar to that in the main river and to prevent the growth of algal blooms.

3 Water Resources Schemes

3.1 Background research

The Institute of Hydrology has been involved in a wide range of water resources projects, both in the UK and overseas. The majority of these studies have involved an assessment of the potential of water resources for exploitation, often as part of a feasibility study or as hydrological analysis providing the basis for engineering design work. Coverage of IH's involvement in projects of this kind falls outside the scope of this review. Instead, attention is focused on studies of water resource schemes where the focus of attention has been not on an assessment of potential for exploitation but on the hydrological impact of proposed schemes.

Water resource schemes can arguably have as blatant an impact on the hydrology of a catchment as any form of development. Direct abstraction of water from a river or the damming of a channel to create a reservoir has the unavoidable consequence of reducing flows for all or some of the time. The drilling of wells or boreholes for abstraction of groundwater carries with it the potential for a fall in the height of the water table and a change in the pattern of groundwater flow. The reduction of river flows and over abstraction of groundwater can both result in a deterioration in water quality.

There are many areas of IH research which are of direct relevance to the assessment of changes of this nature. The Low Flow Studies report (IH, 1980) details the findings of the Institute's research into the estimation of river low flows in the UK. The report, in comparable fashion to the Flood Studies Report, contains detailed descriptions of techniques for the characterisation of river low flow regimes and for the estimation of low flows in ungauged catchments.

IH research into low flows has continued since the publication of the Low Flow Studies. In particular it has been possible to build on the findings of earlier research with the analysis of flows during the particularly extreme drought that occurred in the late 1980s and early 1990s throughout southern England (Gustard et al 1992). This research has also seen progress in the use of the Hydrology of Soil Types (HOST) map developed at the Institute in the analysis of low flows and the development of Micro Low Flows software which implements the main components of IH research to allow the estimation of low flows at any site in the UK.

The methods of analysis developed in the Low Flow Studies and subsequent reports can be used to assess the way in which river flow regimes change as a result of abstraction or the construction of reservoirs. This allows the determination of the impact on other users and, perhaps more importantly from the point of view of an environmental assessment, on water quality and river ecology.

Application of the Instream Flow Incremental Methodology (IFIM) and use of the Physical Habitat Simulation Model (PHABSIM) described in chapter 2 represent a more direct approach to the assessment of the impact of flow changes on aquatic ecology. In a case study forming part of the research into the application of IFIM in the UK the approach was

adopted to assess the hydrological impact of two water resource schemes in central England (Bullock et al, 1991). In both cases the schemes had involved the impoundment of rivers to create reservoirs but with different impacts on the respective flow regimes. Whereas in one case the full range of discharges had been reduced in the other high flows had been reduced but low flows increased. The study was able to show the way in which the varying impact of impoundment had reduced the available habitat for adult brown trout in the former case whilst increasing it in the latter.

Water resource schemes can have a significant impact not only on flow regimes but also on water quality either as the dilution of pollutants decreases or through the discharge of effluent into river channels. One of the major components of water quality related research at IH has involved the development of models to simulate the way in which river water quality responds to changes in flow or effluent discharges.

The Quality Simulation Along Rivers (QUASAR) model has been designed to model flow and water quality in a river on a reach by reach basis (Whitehead, 1992). Water quality variables simulated in the model include nitrate, ammonia, dissolved oxygen, BOD, pH and water temperature. QUASAR is able to simulate the way in which these variables change in conjunction with various inputs to and outputs from the river channel such as tributaries, groundwater inflow, storm and effluent discharges and abstractions for public water supply.

3.2 Impact Studies

IH has been involved in studies to assess the impact of water resource schemes on both water quantity and quality. The methods of analysis developed in the Low Flow Studies and implemented in Micro Low Flows have been used to assess the impact of both direct abstraction from a river (Bullock, 1991) and of river impoundment (Gustard et al, 1991). In the latter case the study involved the comparison of three alternative schemes in Northern Ireland by way of a simulation model of the river and lake systems involved. This enabled an assessment of the way in which the flow regime under each option would be altered by analysis of flow-duration curves.

In a study of a proposed abstraction from the River Thames the impact assessment not only involved a consideration of changes in the flow regime but also in water quality (IH, date unknown). The river reach in question was modelled using the Institute of Hydrology Quality Model (IHQM - a forerunner of QUASAR) which demonstrated that abstraction was unlikely to have a significant impact on water quality except in the unrealistic scenario of abstraction during extreme low flows. QUASAR was also used in a study of river water quality at Bursa in Turkey (Piper, 1991). This involved simulation of the existing river water quality and of the improvement under the operation of a proposed water treatment plant.

IH has also been involved in studies to assess the impact of water resource development in other overseas locations. In a study of the impact of small dam construction in Botswana a user-friendly computer model, HYDAM, was developed to simulate the effect of river impoundment for irrigation by local farmers (Meigh et al, 1992). The model was has been able to demonstrate that the construction of a large number of small scale reservoirs has a significant impact on the yields of larger reservoirs supplying urban demand.

In addition to studies concentrating largely on surface water resources IH has undertaken investigations into the impact of proposed groundwater abstraction schemes. One such study focused on the likely impact of borehole abstraction on the upward seepage of groundwater to a nearby SSSI (Gilman, 1992). From an analysis of borehole observations and a site water balance the study was able to show that the scheme was likely to reverse the direction of seepage and suggested the design for a sub-irrigation scheme to mitigate this effect.

4 Urban Development

4.1 Background Research

IH has a long record of research in the field of urban hydrology. Research reports have been published on the impact of urban development on catchment hydrology (Lowing, 1977), on urban rainfall-runoff processes (Kidd, 1978) and on the effects of urbanisation of flood magnitudes and frequency (Packman, 1980).

Much of this research has focused on the way in which the increase in impervious area associated with urban development increases the volume and speed of surface runoff when compared to a vegetated catchment. This, combined with the more efficient transport of runoff via artificial drainage and sewerage systems, has been found to cause a reduction in the response time to rainfall and increased peak flows.

A major theme of IH's research has been the way in which changes such as these may increase flood risk in newly urbanised catchments. In general urbanisation has been found to increase both flood magnitudes and flood frequency (Packman, 1980). On the basis of findings such as these the methods for flood frequency analysis developed at the Institute and presented in the Flood Studies Report (NERC, 1975) have been supplemented with revised procedures specifically designed to cater for urbanised catchments (IH, 1979). These procedures have also been incorporated into an in-house catchment flood model known as SCHEME, which has been used to assess the impact of urban development in a number of consultancy studies.

An alternative approach to the problem of assessing flood risk in urban areas has involved the development of sophisticated rainfall-runoff models of urban drainage such as WASSP and WALLRUS. These are models which are widely used by hydrologists and engineers to simulate the behaviour of urban drainage systems. Following a detailed research effort IH provided the hydrological components of both WASSP and WALLRUS (IH, 1979-80) and has since continued to investigate the performance of them through a comparison with other catchment models such as SCHEME and the Australian produced RORB.

Whilst urbanisation can increase flood risk it has also been associated with falling groundwater levels and reduced river flows during periods of dry weather. This is caused by a reduction in the proportion of rainfall infiltrating the ground surface. The Institute's research into low flows has resulted in the development of analytical methods which can help to characterise and investigate changes of this nature (IH, 1980).

4.2 Impact Studies

IH has performed several studies to assess the hydrological impact of proposed urban developments ranging from basic flood risk assessment to detailed site investigations and analysis. In the case of the more straightforward studies, such as that assessing proposed housing development on the River Tinney at Calenick (Acreman, 1991b), the use of existing

data for flood frequency analysis has been sufficient to gauge likely impacts.

Where the demands of a project are more substantial it has been necessary to undertake various field studies. The assessment of flood risk associated with a new light industry development in St Lucia involved the surveying and estimation of rating equations (Acreman, 1992) for a local river channel. The lack of historic records at the site also necessitated the synthetic generation of data before flood frequency analysis could be performed.

Studies of proposed floodplain developments have also been performed for sites in mid-Wales (Hudson and Leeks, 1989). These investigations involved not only consideration of hydrological variables but also of aspects of site geomorphology which exerted an influence on the floodplain and the river channel.

Other studies have been more concerned with assessing the way in which urban development may effect the overall hydrological regime and water quality of a catchment. The study of a proposed housing development at Cransley Lodge, Kettering involved detailed monitoring of surface water and groundwater flow and quality in order to assess the possible impact on a neighbouring SSSI (IH, 1992b). Through these investigations and further flood frequency and low flow analysis the study was able to conclude that the development would have minimal impact.

5 Forestry and Other Rural Development

5.1 Background research

Much of the Institute's extensive research into the hydrological effects of land use change has been concerned with forestry, and in particular the impact of coniferous afforestation in areas of upland Britain on water resources. In 1967 the Institute established a pair of experimental catchments at Plynlimon, mid-Wales (Kirby et al, 1991). A programme of research was designed which would compare the hydrology of the mainly grassland catchment in the Upper Wye valley with that of the headwater catchment of the River Severn, 70% of which was forested. Although the initial objective of research at Plynlimon was to assess the impact of afforestation on yields, the scope of the study has expanded greatly over the past 25 years. Whilst the assessment of catchment water balances continues this work has been supplemented with detailed studies of hydrological processes and water quality involving a comprehensive programme of field monitoring.

The results of research at Plynlimon have demonstrated that the yield for water resources in upland areas is significantly lower in forested catchments, mainly due to greater evapotranspiration of water from coniferous trees when compared to open grassland. Flood peaks are also reduced, a result of greater interception by mature forest stands. In contrast, sediment yield has been found to be greater in the forested catchment as a result of enhanced soil erosion of forest drains and ditches. Analysis of other aspects of water quality data collected at Plynlimon has provided new insight into the way in which different runoff processes contribute to streamflow.

Recent research into water quality at Plynlimon has focused not on the impact of afforestation but on the way in which the harvesting of conifers may cause a deterioration in some aspects of stream water quality (Neal et al, 1992). In particular, levels of nitrates and aluminium have been found to increase following logging. With the loss of canopy, stream water temperatures have also been found to increase, but in contrast with other changes in water quality this may be of potential benefit for stream ecology.

In addition to the programme of research performed at Plynlimon the Institute has undertaken catchment studies in other areas of the UK subject to afforestation. In the late 1970s a similar dual catchment experiment was set up at Balquhidder in the Scottish Highlands in response to a perceived need for research in an area which differed from Plynlimon in terms of both climate and vegetation (Whitehead and Calder, 1993). Whereas the pre-afforestation vegetation at Plynlimon is dominantly grassland, that found at the Balquhidder catchments consists of a much rougher mix of heather and other moorland species. The Balquhidder catchments are also located in more rugged terrain and are subject to a harsher climate, with a greater proportion of precipitation falling as snow. Research at Balquhidder has been broadly along the same lines as that at Plynlimon, with particular emphasis on process studies involving the estimation of evapotranspiration from the varying types of vegetation.

Both the Plynlimon and Balquhidder catchment studies have involved a comparison between a catchment of mainly open moorland vegetation and a one in which mature coniferous forest

is the dominant land use. In another study at Coalburn in northern England attention has been focused on the hydrological impact during the early stages of afforestation (Robinson, 1980; Robinson et al, 1994). The experimental area at Coalburn was instrumented from the late 1960s on to allow monitoring of changes in water quantity and quality during the phases of pre-planting drainage and early tree growth. The results of this research have been able to demonstrate the way in which the hydrological impacts during drainage and the initial stages of growth differ quite markedly from those relating to mature plantations. Of particular significance is the way in which the ploughing and drainage of land before the trees are planted results in higher peak flows, higher low flows and more rapid response times. These characteristics have been found to become less marked as the plantation matures although persisting for 20 years or more before the effects associated with afforestation supersede those resulting from ploughing and drainage.

Whilst the majority of IH studies have been concerned with the impact of coniferous forests on the hydrology of upland areas recent proposals for the afforestation of lowland areas with broadleaf species have also provided opportunities for research. In an experimental study conducted in lowland England the water use and water quality of a broadleaf site was compared with that of an area of grassland (Harding et al, 1989; 1992). The data collected in the field was also used to model hydrological processes over the longer term. The findings of the study showed that the planting of broadleaf woodlands has little impact on water use, with evapotranspiration lower than from areas of open grassland. In terms of water quality the research was able to demonstrate the way in which broadleaf woodlands can increase solute concentrations by atmospheric scavenging. This and other effects were found to vary in degree between different species of tree.

In addition to the wide ranging research into the effects of various aspects of forestry practice, IH has been involved in studies to investigate the hydrological impact of other forms of rural land use change. Various studies have examined the impact of land drainage and grassland improvement for agriculture. In a detailed programme of research involving the field monitoring of plots of artificially drained land and catchments attention was focused on assessing the impact of land drainage on river flows and in particular on flood magnitude (Robinson, 1990). The scope of the study was wide ranging, covering sites of different soil type, drainage systems and land management practices. The impact of drainage over a range of conditions was simulated using the model DRAINMOD, based on the empirical findings of the field investigation.

The main findings of this research indicate that soil type is a very significant factor in determining the hydrological impact of drainage. At the field scale, drainage of clay soils tends to reduce peak flows whilst increasing them in permeable soils. At the catchment scale many other factors are also of importance and the research indicated that whilst drainage may lower peak flows at the field scale the increased velocity of flow to a main river channel may increase flood magnitudes downstream.

In a separate study based on the monitoring of sites in the Plynlimon catchments attention was focused on the impact of grassland improvements on stream water quality (Roberts et al, 1986). The study involved a comparison of nutrient losses from two drained areas of land, one of which was also subject to cultivation and the application of fertiliser. The main findings of the study related to an increase in nitrate concentrations in water draining from

the improved land from which, on the basis of modelling studies, it was estimated that a grassland improvement at the catchment scale would result in a fourfold increase nutrient losses .

IH has also been involved in research into the hydrological impact of peat cutting and wetland conservation. In a multidisciplinary study of peat extraction in Northern Ireland a comparison was made of the positive and negative impacts of alternative methods of extraction (Bayfield et al, 1991). Studies of wetland conservation have involved assessment of the impact of digging drainage ditches and the influence of water level variations on evapotranspiration (Gilman, 1992).

In addition its extensive research programme within the UK IH has also been involved in studies of the hydrological impact of land use change in other countries, notably in East Africa. Experimental catchments were established in Kenya, Tanzania and Uganda in the 1960s to assess the effects of deforestation and overgrazing (Blackie et al, 1979) on water yield and flow characteristics. The results of this research suggest that the hydrological impacts of deforestation for both plantation and subsistence agriculture are limited, with significant increases in runoff occurring only during an initial period following clearance and also varying with soil type. In contrast, overgrazing has been shown to result in significant increases in peak flows during flash flooding due to the loss of vegetation and reduced infiltration capacity of the soil.

5.2 Impact studies

Although the major part of IH's experience in the hydrological assessment of forestry and other land use change has been gained through the field investigations described in section 5.1, the Institute has also been involved in a number of related impact studies.

In a study to assess the implications of a proposed community forest for water resources the authors were able to draw upon previous research into the hydrological impact of planting broadleaf forest in lowland England (Cooper and Kinniburgh, 1993). Using a model to simulate the uptake of soil moisture under various types of rural land use the study found that the proposed afforestation scheme could, as a result of reduced evaporation, lead to increased groundwater recharge. In addition, an analysis of water quality changes suggested that quality would improve, particularly in terms of nitrate levels.

Other studies have been concerned with the impact of rural development on the hydrology of environmentally sensitive areas. These have included a study of the impact of peat extraction on the hydrology of a nature reserve (Bromley and Robinson, 1991) and several investigations into the effect of land drainage on adjacent SSSIs. Studies of this nature have generally involved some form of site investigation, often involving soil and water quality sampling and topographic surveying. Whilst in some cases the impact of land drainage proposals has been assessed as insignificant (Gilman, 1990), in others it has been necessary to recommend measures to ensure that the proposed drainage is effective (Gilman, 1989).

In a more detailed study of the hydrological impact of a proposed land drainage scheme near the River Severn in Gloucestershire a mathematical model was employed to simulate the

historical pattern of flooding recorded in winter 1989-90. The model allowed estimation of the rate at which the flood water would drain from the floodplain under alternative drainage options. The study demonstrated that the impact of any drainage proposal would represent only a limited change from the existing situation, with flood waters controlled largely by the level of flow in the main river.

6 Other Impact Studies

Chapters 2 to 5 describe the way in which the findings of major IH research efforts have been applied in hydrological impact studies. In addition, the Institute has performed a number of other impact studies which have not benefited directly from past or current research at IH but which have, never the less, relied on the application of detailed specialist knowledge and expertise.

6.1 Mineral Extraction

Mineral extraction has, perhaps more than most other activities, the potential to inflict significant changes on the surrounding environment. In particular, the removal of a sizeable volumes of rock and deposits can have a major influence on groundwater levels and patterns of groundwater flow. IH has undertaken several studies both to assess the potential impact of proposed mineral extraction and to monitor hydrogeological conditions during the operational phases of such developments.

In many cases the studies have been commissioned where a proposed development is adjacent to land of particularly sensitive ecology, often designated as SSSIs (Bradford, 1988 and 1989b; IH, 1987 and 1990). Typically these studies have involved a detailed site investigation in order to assess linkages between the hydrology and hydrogeology of the development site and that of the neighbouring area. Such investigations have been aimed at assessing the degree to which mineral extraction will alter the level of the water table and groundwater flow to the detriment of the ecology of the SSSI areas.

In certain studies, the impact assessment has involved the detailed collection and analysis of surface water flow data and groundwater levels (Bradford, 1988; IH, 1987 and 1988). This data has then been used to model the behaviour of groundwater at the site and the impact of the proposed development.

In many of the impact studies of proposed quarrying and gravel extraction it has been possible to demonstrate that adverse impacts are insignificant or could be minimised by appropriate engineering solutions. However, in other cases the studies have identified potential hydrological and hydrogeological changes which could prove harmful to neighbouring SSSIs. In these cases the Institute has been able to advise on and contribute to more extensive field investigations, such as that at Burnham Beeches, (IH, 1988), or to longer term monitoring during the mineral extraction operations, for instance at Worton Rectory Farm (IH, 1987).

6.2 Road Construction

The construction of roads can have significant hydrological impact on both surface water and groundwater regimes. The laying of an impervious surface might be expected to have all the effects described in relation to urban development in chapter 4. In addition road construction can involve cutting through geological barriers and the creation of embankments to ease gradients. Operations such as these can disrupt the movement of groundwater and cause

changes in the height of the water table. Whilst groundwater levels upslope of a new cutting, for instance, might be expected to fall, those downslope of an earth embankment can rise. Changes such as these, when combined with the increased volume of runoff from the road surface, can contribute significantly to increased flood risk and changes in the area most liable to flooding.

There are also potential water quality impacts of road construction, particularly through the risk of pollution from spills on the road surface. This can not only result in the pollution of surface water but also of groundwater via soakaways in the roadside.

IH has been involved in a number of studies to assess the hydrological impact of road construction schemes. Similarly to the assessment of mineral extraction developments this has involved site inspections to assess likely changes to the surface and groundwater hydrology (IH, 1992). In the case of the Westhampnett by-pass near Chichester (Bradford, 1989a) the assessment was able to isolate the areas in which a water table rise was likely and suggest possible options to ameliorate this effect.

In a study of the hydrological impact of the proposed A34 Newbury by-pass concern was not only focused on possible changes in the pattern of groundwater flow but also on the way in which salt spay from the road surface might harm plant species of an adjacent area of heathland. Although the investigation suggested that the belt of land contaminated by salt spray would be relatively narrow it was recommended that tolerant tree species were planted along the roadside to protect less hardy species in the SSSI.

7 Concluding Summary

This report reviews IH's current level of expertise in the field of hydrological impact assessment. Hydrological impact assessment, as used here, is defined as the assessment of any changes to the hydrological cycle resulting from modifications to the physical environment associated with a specified set of human activities. In essence this refers to the hydrological component of an environmental impact assessment (EIA) and is thus concerned with evaluating the extent to which new developments may effect aspects of water quantity and quality.

The review has been able to demonstrate a high level of expertise in the hydrological impact assessment of a range of types of development, partly through IH's extensive research in relevant fields and partly through commissioned impact studies. Some of these project types, such as flood defence, water resource schemes and urban development involve the modification of certain hydrological variables through the development and improvement of infrastructure. In other cases the impact on the hydrological cycle can be less direct and results from the exploitation of land and other natural resources for economic benefit. This group of activities includes forestry, agricultural land drainage and mineral extraction.

Many of the hydrological techniques developed at the Institute have been shown to be appropriate for impact study applications. Of particular note are the Flood Studies Report, the Low Flow Studies and their related software products MicroFSR and Micro Low Flows. Other software, such as QUASAR, have also been shown to be valuable tools, in this case for evaluating changes to water quality. In addition, the review has highlighted areas of research involving the application of methods of assessment developed elsewhere to hydrological studies in the UK, notably the IFIM method for assessing the impact of flow changes on aquatic habitat.

The review has also outlined aspects of IH's field based studies, emphasising the way in which these studies have helped to improve understanding of the way in which land use change can effect hydrological systems. The catchment and process experiments at Plynlimon, Balquhidder and Coalburn have been shown to provide information to further the high level of expertise at the Institute in areas of forestry and other rural land use change.

The Institute has been involved in a wide range of hydrological impact studies, most of which have involved the application of knowledge or methods developed as part of IH's programme of research. Several of these studies have relied mainly on site investigations, often where mineral extraction or land drainage has been seen as a threat to the hydrological regime of environmentally sensitive areas. In others the site investigation has been more extensive and has involved detailed monitoring of hydrological and water quality variables.

In addition to largely field based investigations the Institute has undertaken a range of studies involving the evaluation of hydrological impacts of proposed developments by the use of simulation models. In a major study of this kind (Johnson et al, 1991) IH performed detailed modelling of river and marsh water level changes under alternative options for a flood alleviation scheme. This information was then used in supplementary investigations by a

team of experts from a range of fields including aquatic and terrestrial ecology and fluvial geomorphology, providing an example of the way in which IH has played a central role in a multidisciplinary environmental impact assessment.

It is evident from table 1.1 (chapter 1) that there are several types of development subject to environmental assessment with which IH has had little or no experience. On the basis of this review it is clear that IH has sufficient expertise in a wide range of techniques of hydrological analysis to undertake impact studies in many of these areas, for example in the assessment of waste disposal, hydroelectric power schemes, inland waterways and chemical manufacture. Whilst the scope of an environmental impact assessment in these and other fields may extend beyond IH's subject area, the high level of expertise at the Institute never the less provides a firm basis from which to undertake component hydrological studies.

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