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Review of NRA Coastal and Estuarial R&D Related to Flood Defence

R N Bray & M W Owen

Project Report 308/2/HO

NRA

National Rivers Authority

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CONTENTS

LIST OF FIGURES

SUMMARY

This report reviews the NRA's role in the field of flood defence and, in particular, the Research & Development required to support the organisation in providing adequate flood defences in coastal and estuarial areas. The review is carried out against the background of current national and international R & D in this field and in the context of the evolving demands for nationally consistent standards, improved scientific and analytical methodologies, and economic and conservation pressures.

Current programmes and perceived requirements for future R & D are reviewed under the main headings of scientific analysis and design, improvements, maintenance and emergencies. These main headings are then subdivided into component subjects to a level which enables both current and future individual R & D projects to be identified. Recommendations are made for future R & D in these areas together with cost estimates and expected benefits arising from the recommended projects.

During the review certain important themes emerged relating to national consistency, dissemination of R & D results, funding and evaluation of completed flood defence projects. These aspects are discussed in the report and recommendations made where appropriate.

1. INTRODUCTION

This review has been carried out in accordance with the Terms of Reference accompanying the letter from the External Advisers to the National Rivers Authority (NRA) dated 7 March 1991 (Bray/Bramley) and subsequently confirmed by the letter from the NRA to the Advisers dated 15 March 1991. A copy of the Terms of Reference is attached as Appendix A.

2. REVIEW PROCEDURE

The review has been carried out in the following manner:

- Assessment of background documentation and preliminary discussions to assimilate the scope and direction of the current NRA R&D Programme

- Development of a number of integrated topic frameworks and subsidiary headings for data storage, together with some more general subject headings which appeared to be required

- Discussions with interested parties, telephone interviews and attendance at both the 'Ackers' Committee meeting at Watford and the MAFF Loughborough Conference

- Development of a general strategy and proposals for more detailed research by reference to the data assembled within the topic frameworks

- Production of draft final report, circulation to R & D topic leaders for comment and discussion with R & D personnel at Head Office.

It is considered inappropriate to list all the documentation reviewed, but the main organisations and persons consulted are given in Appendix B. In addition to these a considerable number of other persons were consulted informally at gatherings such as the MAFF Loughborough Conference and the Ackers Committee Workshop.

3. R&D SUPPORT SERVICES AND RESPONSIBILITIES

The NRA's aims relating to flood defence are stated as being:

- To provide effective defence for people and property against flooding from rivers and the sea

- To provide adequate arrangements for flood forecasting and warning

Two additional NRA aims also have an influence on the above. These are:

- To develop the amenity and recreational potential of waters and land under NRA control

- To conserve and enhance wildlife, landscape and archaeological features associated with waters under NRA control.

The latter of these has been construed by the Advisers to include land as well as water.

The NRA core Function which undertakes flood defence is supported by Commission C of the R & D Programme which is sub-divided into a number of research topics under the control of designated topic leaders. Those topics having a bearing on coastal and estuarial flood defence are:

C4 Operational management
C6 Coastal and estuarine works/structures
C7 Effects of climate change on flood defences
C8 Response to emergencies

However, it is understood that the intention is now to combine Topics C6 and C7.

In addition to these topic areas, Commissions E and F address the recreational and conservation aspects of the NRA's work, and certain cross-functional aspects are addressed in Commission G.

Research under the above topics is tailored to suit the needs of the NRA in undertaking its statutory responsibilities and duties in flood defence, and will have one or more of the following primary purposes:

- to support its policy development

- to improve its ability to carry out statutory duties

- to improve its efficiency or effectiveness in carrying out its business

- to increase its general knowledge and understanding, particularly relating to the aquatic environment.

In general the R & D carried out falls into the Frascati categories of "Applied Research with Specific Objectives" and "Development".

The manner in which the NRA strives to achieve its objectives in the field of flood defence is by carrying out a number of activities against a background of demands and constraints. This background is composed of:

- Target standards of service
- The assets and organisation of the NRA relating to flood defence
- Current environmental, conservation and amenity requirements
- Environmental boundary conditions

With these components, the background is therefore evolving continually, as society's expectations change, as the NRA improves or extends its assets, and as the environmental conditions are modified by factors such as global warming. However the rate at which the background evolves is slow enough to allow it to provide a framework within which the following activities are carried out:

- Development and improvement of defences
- Maintenance and repair of defences
- Warning of, and responding to emergencies

all of which may involve, to a greater or lesser extent:

- Scientific analysis and engineering design.

The way in which these activities are related to the general background and to each other is illustrated in Figures 1 to 4. It is for assistance in these four activities that the R & D Support Service is called upon. A detailed review of the research status within these activities, and recommendations for developing and improving this research programme are given in Section 5 of this report. However, a number of broader issues came to light during the review and these are discussed in the following section.

4. MAJOR FLOOD DEFENCE ISSUES

4.1 Need for Research and Development

That there is a need for research and development in the field of coastal and estuarial flood defence from a technical viewpoint seems to be in little doubt. Amongst the many persons consulted during the review not one was of the opinion that the NRA R & D effort should in any way be diminished. On the contrary, there were frequent references to areas into which R & D should be extended to enable the operational part of the NRA to carry out its duties in a responsible and cost-effective manner.

As may be seen from the benefits listed against projects in Appendix C, most of the R & D which is recommended is expected to lead to improvements in consistency, quality, risk reduction and cost saving. In the present political climate of 'value-for-money' and 'public accountability' these particular improvements would seem to be of prime importance. The corollary of this is that a lack of R & D, or a reduction in R & D effort, is most likely to result in the organisation being politically more vulnerable than it would otherwise have been.

4.2 Overall framework of flood defence management

It appears desirable for the NRA to develop a nationally consistent overall framework for flood defence management within which regional and site-specific activity programmes can be progressed. For an overall framework to be effective it must contain certain established elements, such as:

- Consistent levels and methods of data storage and retrieval, to ensure that data is not inadvertently lost, can be conveniently retrieved into analytical systems, and is of a consistent quality.

- Agreed frameworks for flood risk assessment, design philosophy, and scheme evaluation.

- Consistent engineering, environmental, conservation and financial approaches on a countrywide basis.

To what extent this framework is developed by the operational divisions of the NRA or through support by the R & D Service is a subject for future decision. However, it would seem prudent for the NRA to determine the key elements required for the establishment of a nationally consistent framework, and for future R & D projects to be integrated into this framework (Proposal 1.1). The frameworks described in Section 3 of this report, and illustrated in Figures 1 to 4, might provide a basis for this development.

4.3 Strategic studies and management systems

A considerable amount of work has been undertaken in various regions to develop flood defence management systems to provide a broad framework within which to take site-specific decisions of an engineering and managerial nature. Many aspects of this work could be transferred and utilised in other regions. For example, it is important that the generic issues arising from the Anglian Region's Coastal Management Study should be extracted in a form which is of use to other regions. However, there is a danger that a multiplicity of transfers of these techniques from different studies might lead to inconsistencies of approach, if this extraction process is not coordinated.

4.4 Information dissemination

4.4.1 Dissemination of R & D results.

There appeared to be a general consensus amongst the organisations consulted that a greater degree of dissemination of information on R & D would be beneficial. In particular it was felt that there was a need to know what research was being carried out, both within the NRA and in allied organisations, and what the results of the research were (i.e. how they could be applied). The point was made that it was better for one person to synthesise the results of a research project than for many busy people to try to read the entire report and extract the relevant results.

It is assumed that all NRA research reports will contain an informative abstract containing a summary of the results of the research and an indication of the use to which they might be put. However, there is still perceived to be a need for synthesis reviews, derived from one or more research projects in related subjects, which would extract the key results of the work and present them for general use in the context of practical engineering applications. These reports could then be built into "state of the art" reviews for various different subjects. The list of subjects to be treated in this way also needs to be defined.

4.4.2 Codes of practice, manuals and guidance notes

Developing the theme of this section of the report further, there would appear to be a general consensus that design manuals, or guidance notes, for capital and maintenance works would be welcomed in this field. There are two reasons for this. Firstly, the consultants employed by the NRA regions would have a better understanding of what was required from them, and competitive proposals submitted by them for work would be judged against a common yardstick.(Something which it is suspected does not always happen at present, thus leading to differing standards of work being carried out at different times and in different regions). Secondly, it would greatly facilitate engineering within the NRA regional offices and assist in the production of working briefs for work put out to consulting firms.

In particular, considerable benefit would be achieved by developing standard codes of practice covering planning and design philosophy, and project evaluation. This would ensure that all regions, and their consultants, would work effectively and consistently. It is therefore recommended that thought be given to how these manuals and codes could be produced, which areas of flood defence engineering and management need to be covered, and to what level of detail they should be drafted (Proposal 1.2).

4.5 Co-ordination of coastal projects

There are many organisations involved in the development of projects in the coastal and estuarial field. Many of these bodies are involved in overlapping areas of work, both in technical and geographical terms. For development to occur effectively in this field a high degree of co-ordination is required. At present there is a fairly high degree of informal co-ordination in some parts of the country, but inevitably some duplication of work will occur, or existing information will be overlooked, due to the lack of a coordinating centre. It is suggested that the R & D Support Service should ensure that they are continually updating their knowledge of the status of current research in this field, possibly in the form of an in-house coastal & esturial R & D database, of past, current and proposed R & D projects.

One advantage of maintaining a database of this type is that it makes it easier for projects suitable for co-funding to be identified. See Section 4.6 below.

4.6 Research funding

There appears to be an ambivalent attitude to co-funding of R & D in the coastal and estuarial field. On the one hand there is the view that, unless projects are fully funded by one organisation, the results are of limited value, because the objectives are a compromise of the needs of the co-funders. On the other hand there is the fact that some projects, particularly those involving long term monitoring of environmental parameters, are too expensive for any one organisation to fund. At least one organisation consulted was of the opinion that any initiative by the NRA to act as co-funders in this field would be welcomed and would encourage others to follow suit.

It is recommended that co-funding opportunities should be actively sought in areas of interest identified in Section 5 below, particularly in the context of European initiatives. However, rather than contributing to the joint funding of a co-operative research project, thought should be given to collaborating by funding of discrete elements of multi-component research programmes.

4.7 Post project appraisal

A number of organisations consulted referred to the lack of feedback from completed schemes, and there was a general agreement that some form of post-project appraisal system would be of great benefit. In particular the need for post project information on such aspects as design risk, mixed beach behaviour, environment recovery rate and maintenance costs were just some of the subjects mentioned.

Clearly, for much of the R & D work currently being implemented a post-project appraisal system is necessary for validation of the new techniques when put into in practice. It is well known that the tail ends of both design and construction projects tend to get overlooked, and that there is a tendency for engineers to want to move on to a fresh project rather than to tie up all the loose ends of the current one. For this reason it is felt that a post-project appraisal system must either be carried out as a separate exercise (i.e. as a project in itself) or must be a mandatory part of the original project.

There are at least two types of post-project appraisal:

- an appraisal of the results of an R & D project to determine its usefulness

- an appraisal of the effectiveness of a flood defence scheme, and validation of the engineering and conservation principles inherent in its design and operation

It is understood that the former of these two types is now a normal procedure within the NRA. The latter requires to be carried out during the lifetime of the project. What seems to be required now is a research project to define how the flood defence scheme appraisals are to be implemented, and to develop the procedural framework for carrying them out (Proposal 1.3).

5. DETAILED RESEARCH AND DEVELOPMENT ISSUES

The main headings which were used for the compilation of the comprehensive framework of subjects or issues related to the NRA's responsibilities in coastal and estuarial flood defence were:

- Improvement (Development)
- Maintenance and repair
- Emergencies
- Scientific analysis and design

Each of these headings was further subdivided at the beginning of the review into possible themes and specific subjects where further research might be necessary. During the course of the consultations with the various organisations other themes were suggested which it was thought were sufficiently distinct to warrant separate headings. Most of these additional headings related to general considerations in the execution of the NRA's responsibilities in flood defence, and have been discussed in Section 4 above. In this section only those themes or issues which fall clearly under the headings mentioned above are discussed. It should be noted that the category 'Scientific analysis and design' also contains the subjects of 'Sea level rise' and 'Climate change'.

5.1 Improvement

The coastline of England and Wales is extremely variable, with many different landforms and coastal regimes, population densities and flood defence requirements. Therefore it is highly unlikely that standard designs could be adopted for the development and improvement of flood defence works. However, as a national body the NRA should be adopting a standard and consistent philosophy for the design of flood defence works. At present there is a widespread feeling that this is not the case, with different approaches being used in the different regions. Although some aspects of the NRA's existing research programme are clearly aimed at developing some consistency, several aspects still need consideration.

An overall philosophy for the design of improvement works can be broken down into four main themes:

- Definition of standards of service
- Design constraints
- Probability and consequences of failure
- Cost/benefit considerations

and these are discussed in the following sections.

5.1.1 Definition of standards of service

The target standards of service are part of the overall background against which the NRA carries out all of its activities, as outlined in section 4.2 of this report, and as illustrated in Figures 1, 2 and 3. However they generally receive the most detailed examination when flood defence improvements are being considered.

At present the only guidance which is available for the designers of flood defence works is contained in the report of the Waverley Committee appointed by MAFF in the wake of the North Sea floods of 1953. Although slightly revised in later years, this report basically concluded that the defences should be designed to withstand the worst recorded water level, with a suitable freeboard to allow for wave action. Some broad indications were also given of situations where greater or lesser standards of service could perhaps be justified.

Clearly the Waverley recommendations are open to widely different interpretations, one of the reasons for the regional differences already mentioned. Another disadvantage of the Waverley report is that it relates the standard of service to one cause of the event (i.e.the extreme water level) rather than to the event itself (flooding). The flooding could in fact be the result of a wide variety of causes, for example extreme wave action or seawall collapse. The required standard of service therefore must be related to the frequency of flooding which can be tolerated at a particular site, whatever the causes of that flooding.

Within its current research programme, the NRA already has a project "to develop through pilot studies a national system for examining standards of service" (for flood protection), being undertaken by Robertson Gould Consultants under the supervision of the NRA Anglian Region. The main thrust of this research is towards river flooding, and the aim has been to define the required standards of service in relation to various land use categories. Building on this work, a new project should be started with the objective of defining standards of service for protection against estuarial and coastal flooding (Proposal 2.1). It should be recognised that both the type of flood event and the consequences of flooding are very different for estuarial and coastal situations, and the required standards of service are therefore likely to demand quite different methods of definition compared to river flooding.

5.1.2 Design constraints

All proposed flood protection works are likely to have their own site-specific design constraints, for example a requirement to use components of the existing defences, or a practical limitation on the maximum height of embankment which can be constructed. However, almost all schemes are constrained by the need to conserve and, if possible, to enhance the environment without detracting from the engineering performance of the scheme. Again this is part of the overall background against which the NRA carries out all its activities. The NRA is therefore already putting considerable effort into conservation, and three projects related to flood defence are in the current or proposed research programme on conservation issues (Commission F):

- Conservation enhancement of flood defence works
- Coastal wildlife database
- Conservation value of sea defences

In these and other research projects on similar lines the aim should be to develop general guidelines on the treatment of conservation issues in the design of flood defence works. These guidelines could then be used both by the NRA's in-house design engineers and perhaps more importantly by its consulting engineers also.

One of the problems which was mentioned on several occasions during the consultations was the wide disparity in attitudes between the numerous conservation organisations. There was a widespread feeling that the conservationists should also be encouraged to research and develop a consistent approach to the environmental impacts and opportunities of flood defence works, to match the efforts already being made by the NRA. In this respect, joint research projects between the NRA and various conservation bodies would seem to offer advantages (Proposal 2.2).

5.1.3 Probability and consequences of failure

In Section 5.1.1 of this report it has been pointed out that the required standard of service must be related to the frequency of flooding which can be tolerated. The flooding itself can be caused by a wide variety of factors, each with its own chance of occurrence, and its own consequences of failure. For example a seawall built with its crest level too low might be subject to overtopping by wave action during a severe storm, but the duration of the flood event is likely to be rather short, being limited to the peak of the storm tide. In contrast, a seawall which is weakly constructed might be breached: large quantities of flood water will probably discharge through the breach on each tide until at least temporary repairs are carried out.

Even if overtopping of the seawall and the breaching of the seawall have exactly the same chance of occurrence, their consequences are therefore very different. The full and proper evaluation of the level of protection provided by a particular flood defence scheme should therefore take account of all possible causes of flooding, and of their consequences.

In continental Europe, and in the Netherlands in particular, major coastal engineering works (including flood defence schemes) are increasingly being designed using probabilistic and risk assessment methods. These methods usually result in a much more cost-effective solution, because they involve a more realistic estimate of the danger of failure.

Some consulting engineering firms in this country use probabilistic methods to a limited extent in the design of flood defence works, but no standards or guidelines exist. As the national body responsible for the majority of flood protection in England and Wales the NRA should take the lead in developing standard procedures or guidelines for appropriate probabilistic design and risk assessment methods for flood defence works.(Proposal 2.3)

In probabilistic design methods, there are five main stages of work:

- identifying the possible modes of failure (flooding)
- identifying the environmental parameters (such as water levels or wave conditions) or the structural parameters (such as crest elevation or revetment block thickness) which cause that mode of failure to develop
- estimating the probability of occurrence of each failure mode
- estimating the magnitude and the rate of development of failure
- predicting the resulting flood damage

For most so-called "hard defences" (e.g.seawalls and revetments), identifying the possible modes of failure is relatively easy. A minor research task would be to draw up a checklist for typical structures, which can then be referred to by designers.(Proposal 2.3a) Defining the possible failure modes for soft defences such as saltings or renourished beaches is more difficult, but can probably still be prepared as a checklist.

Again for hard defences, identifying the environmental and structural parameters which cause that particular failure mode to develop is relatively straightforward. However for beaches and saltings this is often extremely difficult. For example, low beach levels could be due to short but severe storms, or to persistent moderate storms, or to persistently high water levels, or to untypical wave directions. In many existing cases the exact cause is never known. Clearly it will not be possible to make much progress in this area until a much better understanding of coastal sediment transport is available.(Proposal 2.3b and see Section 5.4.3)

It is very likely that most of the failure modes which have been identified will depend on several different parameters: for example, overtopping of a seawall might depend on water level, wave height and wave period: the depth of toe scour might depend on wave height, period and persistence. The probability of occurrence of each failure mode will therefore depend on the joint probability of occurrence of all the governing parameters. Improved methods for predicting extreme water levels, based on the joint probability of occurrence of high tides and severe storm surges, have recently been developed through research funded by MAFF.

Further research is necessary to develop similar methods for predicting the joint probabilities of extreme water levels and wave conditions, and the work should also be extended to cover a wide range of different parameters (Proposal 2.3d). None of these methods, however, can work in the complete absence of any data, and the routine measurement of parameters such as wave conditions, beach levels etc. is urgently needed to complement existing data collection on water levels, wind conditions, fresh water flows etc. This data needs to be collated nationally, and to be readily available for use by design engineers. However, the data will be of use to many different organisations, and the NRA should therefore seek collaboration with others to set up this collection, collation and archiving system (Proposal 2.3c).

For some of the failure modes, estimation of the magnitude and extent of failure can be based on standard formulae or prediction methods. However there are several other failure mechanisms which cannot yet be quantified in these terms. For embankment type seawalls it is very difficult to predict the rate of damage to the front face armour or to the rear face cover layer, and hence to predict the likelihood of a breach developing during the period of the storm. Once the initial breach has formed, it is then extremely difficult to estimate how quickly its width will grow in comparison with the timescale of a tidal cycle.

Further research is necessary on these issues, perhaps based on a detailed analysis of past breaches in sea defences, both in the UK and elsewhere within Europe (Proposal 2.4). Predicting the failure of soft defences depends crucially on the ability to predict accurately the reaction of the defence, for example a renourished beach, to each and every wave and tidal condition over long timespans. Although mathematical models are available which can give some indications in this respect, there is still considerably more research needed. (see Section 5.4.3)

Prediction of flood damage resulting from failure of the sea defences depends upon estimating the quantity of water stored in the flood plain, and its velocity of ingress. Both of these values depend on the sea defence structure and on its mode of failure, but they also depend on the geographical form of the flood plain itself. Unfortunately existing maps are usually insufficiently detailed to give the required information on contour levels, roadway elevations etc. which would allow floodwater paths, flooding depths etc. to be calculated accurately. As a long term aim, the NRA should consider commissioning a detailed mapping exercise of all coastal flood plains, with contours at close intervals - perhaps 0.25m (Proposal 2.5).

5.1.4 Cost/benefit considerations

Significant research is under way at present into the estimation of both the benefits and the costs of sea defence schemes. However there are a number of issues which still need to be studied.

On the cost side, estimation of the capital cost of the scheme is well understood. However estimation of future maintenance costs is very uncertain, and tends to be based on the personal experience and subjective judgement of the design engineer. In the main this is because very few organisations keep detailed records of past maintenance costs on particular sea defences or types of defences.

Because of the uncertainty in maintenance costs, schemes tend to be selected on the basis of least capital cost rather than lowest "whole life" cost, with the possibility that the optimum scheme in the long term has been overlooked. As a result of increasing pressure from the public, softer solutions to coastal defence problems have to be considered. Such solutions almost always demand a significant amount of routine maintenance, and estimation of the associated costs therefore plays an important role in comparing the soft and hard defence options.

For soft defences estimation of the maintenance costs is likely to improve as more accurate models of coastal sediment transport are developed. For hard defences, all available data on past maintenance should be collated, and guidance notes should be prepared for the benefit of design engineers. Steps should also be taken to ensure that accurate records of maintenance expenditure are routinely assembled in future (Proposal 2.6a).

In terms of estimating the value of the benefits of flood defence schemes, several items of research are still required. In particular, more work is needed to develop straightforward methodologies for estimating conservation and amenity values (Proposal 2.6b). For example it is extremely difficult at present to estimate the value of a natural beach, or to compare the relative costs and benefits of a sand or a shingle beach renourishment scheme, or to compare any soft defence scheme with a hard defence scheme.

With regard to estimating agricultural values, there is a need to update existing methods, in particular to take account of the substantial changes taking place in the European Community's Common Agriculture Policy. The updated methods should also allow the economic and environmental consequences of coastal retreat to be included in the assessment. In this context, there is a need to investigate the political and legal mechanisms for the compensation of land and property owners where the coastal retreat option is selected, and for grant aiding these payments (Proposal 2.6c).

5.2 Maintenance and repair

The maintenance and repair of flood defences should really form part of an integrated 'Asset management system', which would address the following aspects:

- the standard of service required

- the associated risks and uncertainties

- the condition of the existing defence

- the level and frequency of maintenance required

- the assignment of priorities for capital works

The first two of these aspects will also be part of the overall design philosophy, as discussed in Section 5.1 of this report. However, their special relevance to maintenance and repair will be discussed further below, together with the other aspects.

Research on the design of new flood defence works is largely funded by MAFF at present, because most of the capital costs of these works are provided by MAFF through grant-in-aid. However, the maintenance and repair of existing structures is the sole responsibility of the owner of the defence. Therefore R&D on maintenance and repair of the NRA's defences should be funded by the NRA itself.

5.2.1 Standards of service

The standard of service which should be supplied by a particular flood defence should have been set at the time of the original design and construction of the defence. However, at the time when maintenance is being considered the required standard of service may have changed, either because of a change in land use, or simply because society's expectations of safety have increased or decreased.

In addition the standard of service actually provided by the defence may have changed due to degradation or improvement to the structure or its foundations, or to a fundamental change in the local environmental boundary conditions. Research is needed to develop straightforward methods for back-analysis of existing structures, to be applied routinely over many miles of defences to identify the standard of service actually being provided (Proposal 3.1).

5.2.2 Maintenance philosophy

The maintenance philosophy for a particular defence depends on evaluating the existing condition of the structure, determining the level of protection which it provides, assessing its remaining life, and estimating the costs and benefits of maintenance/repair. In each of these aspects, methods are required which are sufficiently straightforward to be applied at regular intervals over many miles of defences (Proposal 3.2a). In the Netherlands for example legislation has recently been passed which requires all flood defences to be re-assessed every five years: the assessments are the responsibility of the owners of the defences, but all the reports have to be submitted to a central agency for examination and approval.

Codes for evaluating the condition of river flood defences have recently been produced under the existing R&D programme, but these need to be extended to coastal defences. In addition they are based very largely on the physical condition of the defence, rather than on its engineering integrity (Proposal 3.2b).

The level of protection currently provided by the defence may have changed, either because the environmental loadings have increased, or because the condition of the defence has deteriorated. The risks associated with this change have to be calculated, again using cost-effective methods.

Perhaps the most difficult aspect of the maintenance philosophy is the assessment of the remaining life of the defence. Based on a detailed analysis of existing structures, guidelines should be produced for carrying out this assessment (Proposal 3.2c).

Estimating the costs and benefits of maintenance or repair should be relatively straightforward, once the risks associated with the existing level of protection have been estimated. Again, for river and estuarine flood defences a report has recently been completed on the prioritisation and programming of flood defence works, based on a weighted rating system. This was undertaken under the current R&D programme, and now needs to be extended to coastal defences (Proposal 3.2d).

5.2.3 Inspection and monitoring

The efficient implementation of the maintenance programme depends on a systematic monitoring programme which involves not only careful inspection and measurement of the behaviour of the defences, but also of the environmental conditions which govern that behaviour. Normally the defences should be inspected at regular intervals, and after major storms. However, because the NRA is responsible for very many kilometres of defences, the methods for inspection and monitoring have to be quick and effective. There is a need to develop cost-effective methods for monitoring the environmental conditions and the behaviour of defences during extreme events, and also for the routine measurement of beach contours. For example, the Anglian Region of NRA have recently initiated a monitoring programme involving:

- shoreline inspections during storm seasons
- beach profile surveys at 6-month intervals
- annual aerial surveys to give beach contours, salt marsh levels, cliff lines etc.
- quinquennial hydrographic surveys to give nearshore seabed levels and sub-littoral beach profiles.

In addition wind and water level data from existing recording stations will be available, allowing possible correlations between defence response and environmental parameters to be investigated.

These and other suitable procedures now need to be established on a countrywide basis (Proposal 3.3a). Similarly there is still no reliable non-destructive technique for detecting voids in seawalls or holes made by vermin in embankments, leaving a major problem in the planning of preventative maintenance (Proposal 3.3b).

5.2.4 Repair

The planning of the repair or maintenance works themselves includes the selection of the techniques and the materials to be used, estimation of the costs involved, and also determining the frequency of the work. There is a widespread feeling that research is needed to identify more cost-effective methods for carrying out repair works on sea defences, and there is already a proposal in the R & D programme entitled 'Rehabilitation of structures - guidelines on refurbishment and replacement'. This research should include an examination of whether there are any economies of scale which can be of benefit to the NRA, and whether there are any new techniques which can be employed. These may include steps which should be taken at the design stage to ensure ease of future maintenance, such as guaranteed access, or the use of standard components to build up the site-specific design solution (Proposal 3.4a).

As mentioned earlier, estimation of the maintenance and repair costs for sea defences is very important in evaluating the whole-life cost of a scheme, and also for budget planning purposes. There is very little useful information for engineers on this subject, and a data base of actual capital and maintenance costs through the project life should be produced for a variety of existing sea and estuarial defence schemes. This data should also be used to establish the optimum balance between the frequency and extent of maintenance/repair, in terms of the long term costs involved (Proposal 3.4b).

5.3 Emergencies

Emergencies are likely to arise as a result of extreme events, which produce environmental conditions more severe than those specified in the defence's standard of service, or due to failure of the defences, resulting in a lowering of this standard. Clearly, therefore, there is a direct link between defined standards of service and requirements for emergency response, the latter being, in part, defined by the former.

However, standards of service defined for the flood defences only determine the frequency and extent to which emergency services may be required. There is also a need to define other standards of emergency services, relating to warning services, response times and the degree of self-sufficiency required within the NRA prior to the involvement of other emergency services. A number of these matters are being addressed in the current research project being undertaken by the Flood Hazard Research Centre.

Essentially the NRA's emergency service requirements consist of:

- analysis of likely emergency scenarios and prediction of the effects of such emergencies, to determine emergency frequency and possible resources needed

- development of real time emergency prediction techniques

- development of warning systems and establishment of warning trigger levels

- installation of adequate resources and response procedures to provide the standard of emergency service required

5.3.1 Resources

Emergency scenarios, and the prediction of their effects, have to be analysed by consideration of the defence service standards and the probability of their being exceeded, or lowered by defence failure. In both cases research into standards and reliability of service is required before further work can be carried out. However, there may be a case here for a small research project to define the input requirements for such an analysis (Proposal 4.1).

5.3.2 Real time prediction

Reliable real time prediction depends on an adequate amount of data being fed to the predictor, and on a prediction technique being in place which is sufficiently accurate. Current developments of the Storm Tide Warning Model and the inclusion of waves in this model are all moving in the right direction. In particular, the improvement of this service to give better data on surges in west coast estuaries, mentioned elsewhere in this report, will assist in this respect. There is thus a further reason for NRA to support this research.

Extension of national surge and wave models to give predictions of inshore site specific environmental conditions is less advanced (although it is currently being discussed as a proposed project in the NRA R & D programme), as is the requirement to transform this data into a form where it can be used to predict potential emergencies. The need for more site-specific data for model validation has been mentioned elsewhere in this report. Research will, in due course, be needed to determine the best way of relating this local data to the flood defences and thereby producing a convenient emergency prediction system. Local look-up tables have been suggested. (Proposal 4.2).

5.3.3 Flood warning

The introduction of comprehensive flood warning systems, based on predicted conditions and defence responses, is generally related to resources, since techniques for transmitting data and issuing warnings are relatively advanced. What is not so clear is the assessment of the effectiveness of the warning systems and the benefits derived from the warnings. Response to emergencies is not wholly an NRA responsibility since the local authority and the emergency services are also involved, particularly the police, who have numerous other duties.

There appears to be a need for research to be carried out into the effectiveness of local warning procedures, in order to justify the investment required in installing and maintaining them. The research needs to investigate whether the procedures can be improved (either within the NRA or externally), and also needs to develop methods to quantify the cost-effectiveness of the overall warning systems (proposal 4.3).

5.3.4 Response to emergencies

A number of authorities commented on the practical response required in the event of an emergency, in particular there is a need for guidance on emergency repair methods for breached defences. This guidance needs to be of two types; firstly to address the question of whether it is practical and effective to attempt to repair a breach in the particular emergency situation being experienced, and secondly, having established that repairs are needed, to evaluate the reliability and cost-effectiveness of methods for carrying out these repairs expediently (Proposal 4.4).

5.4 Scientific analysis and design

Almost every aspect in the overall management of coastal and estuarine flood defences includes a certain degree of scientific analysis and design. In general, the scientific analysis carried out for a particular flood defence can be divided into three main areas (see also Figure 4):

- determination of environmental boundary conditions
- evaluation of nearshore processes
- calculation of loads on the defence, and of its responses

and these are discussed in the following sections.

For emergency warning procedures it will often be necessary to carry out the analysis in real time, to give accurate forecasts of extreme environmental conditions, and of the expected response of the defences, (see Figure 3). However, in evaluating the condition of existing flood defences, (Figure 2), and in the design of any improvements which may be necessary, (Figure 1), determination of the environmental boundary conditions and of the nearshore processes will usually be based on scientific analysis of past records, extrapolated if necessary to predict the design storm conditions. The response of the structure will then be determined for these predicted loads.

In all these case, the exact extent of the scientific analysis will depend upon both the overall importance of the flood defence, and on its complexity. For some types of defences, and for some environmental parameters, the scientific knowledge is already far advanced, allowing a full technical analysis to be carried out. For others, considerable further research is needed.

5.4.1 Environmental boundary conditions

For the design of a coastal or estuarial flood defence scheme, the environmental boundary conditions which have to be determined may include:

- water levels (tides, surges, mean sea levels)

- waves (winds, local waves, swell)

- currents (tidal, wave-induced,oceanic)

- sediment regime (sediment type, transport rates, seabed and coastal geology)

Considerable work is already being carried out on behalf of MAFF by the Proudman Oceanographic Laboratory (POL) and by the Meteorological Office to assist in the prediction of water levels. Development of the national tide gauge network is continuing, and the long term measurements from the Class A gauges are being analysed to provide the best possible estimates of trends in mean sea levels, of tidal components, and of extreme water levels.

However, there are many existing tide gauges which are not linked in to the national network, which could provide useful data. On the Humber Estuary, an exercise has recently been completed by consultants for the NRA Anglian, Severn-Trent, and Yorkshire Regions to set up a tidal database through the collation of all available recorded tide levels, using data from both the networked and the local tide gauges. This was found to be extremely valuable in the strategic planning of the flood defences in the area. A report should be produced giving guidance on the methodology used for this type of study, and outlining the associated costs and benefits (Proposal 5.1). This will then enable other regions of the NRA to give consideration to similar exercises in other areas, e.g.the Severn Estuary or Morecambe Bay.

Apart from the measurement and statistical analysis of water levels, the MAFF-funded work on water levels also includes the development and routine operation of storm surge forecasting models. At present these models are reasonably accurate on the East Coast, but on the West Coast there are still considerable problems. On the whole the magnitudes of the surges are reasonably accurate, but the prediction of their timing relative to the tidal phase is rather wayward. It is hoped that present research to develop a combined surge/tide/wave model will help to overcome many of these problems.

The present models are operated routinely by the Met.Office, with the forecast conditions being transmitted to the NRA Regions, and to some of the Coast Protection Authorities. Since NRA is the main beneficiary of these forecasts, consideration should be given to joint funding of this routine operation of the models, allowing the NRA the opportunity to tailor the output to its own requirements (Proposal 5.2). In particular, it would be useful to give more localised predictions, e.g. at various locations up important estuaries. However, for these predictions to be validated, measurements would be necessary, possibly by some form of maximum water level recorder rather than a conventional tide level recorder.

In complete contrast to the situation for water levels, there are at present no national arrangements for the measurement of either locally generated or swell waves. The committee appointed by MAFF to oversee the programme of tide gauge recording has recently been given revised terms of reference to include wave recording. The committee seems likely to recommend the setting up of a few strategically located offshore wave recorders for long term measurements, with the possibility of deploying one or two additional recorders at various other locations for relatively short terms (perhaps one or two years) to provide comparisons, and to allow for the calibration of local wave forecasting models. The NRA should support this initiative, and should try to ensure that any wave measurements which are carried out for its own operational purposes are linked into this programme to the greatest extent possible (Proposal 5.3). For example, wave and water level data from the newly installed tower off Boygrift, Lincolnshire, should be available to the national programme.

With regard to the forecasting of offshore waves, the Met.Office has its own model for routine operation, but the predictions are based on a rather coarse grid spacing for flood protection requirements. Other more localised wave models are available (e.g. the HR model HINDWAVE), but they are not generally available on a routine forecasting basis. In areas where the waves are predominantly locally generated (e.g.Liverpool Bay) models such as HINDWAVE could easily be adapted for routine forecasting. Where the wave climate is a combination of locally and distantly generated waves, some consideration should be given to refining the Met.Office model to give more localised predictions on a routine basis (Proposal 5.4).

As mentioned, the Met. Office wave model predicts offshore wave conditions, rather than the conditions inshore at the site of the defences. At most locations there will be significant differences between the inshore and offshore conditions, because of the effects of various nearshore processes. Forecasting of the offshore conditions is therefore of rather limited value, serving mainly to warn of the onset of storms. The problems of forecasting inshore wave conditions on a routine basis are discussed further in the next section (5.4.2 Nearshore processes)

At most coastal sites the existing <u>currents</u> are best established by direct measurement, since they are highly site specific. Tidal currents can be modelled to some extent, but it is still extremely difficult to predict wave induced currents. This is also discussed further in Section 5.4.2 of this report.

An examination of the <u>sediment regime</u> at the site of proposed flood defence works can pay useful dividends. This should include an examination of the available data on the geology of the coastline and the seabed, and also of any available evidence for sediment transport paths and trends. For example several areas of the coastline of England and Wales are protected to some extent by offshore sandbanks: it may be useful to set up either national or regional research projects to examine the historical behaviour of these banks, in order to determine their influence on the long term flood defence strategy in those areas (Proposal 5.5).

5.4.2 Nearshore processes

For most flood defence schemes, the environmental conditions predicted offshore are influenced to a large extent by various nearshore processes, and a full understanding of these processes is therefore very important. By far the most important are those processes which affect the wave conditions at the defences, and the processes of sediment transport. Sediment transport is discussed more fully in Section 5.4.3 in relation to the prediction of the loads and the responses of beaches used as flood defences.

As the waves propagate from offshore to inshore they are affected by several processes including:

- friction losses
- refraction and diffraction
- shoaling and breaking

The available methods for calculating the effects of these processes range from simple nomographs of refraction and shoaling, to complex mathematical models which incorporate all of these processes, at least to the extent to which this is possible with existing knowledge. Shoaling, refraction and diffraction are essentially linear processes which are well understood, although methods of modelling them in areas of complex bathymetry are still being developed. Friction losses and breaking are highly non-linear processes which are not yet fully understood, and all the available models use empirical formulae for their treatment.

Nevertheless, from the limited amount of data which is available, the various methods appear to give reasonable estimates of the wave heights and periods at inshore locations, provided they are used in the appropriate circumstances. Virtually no data has been available to check on the accuracy of wave direction predictions, which is very important in sediment transport calculations. For the design of flood defence structures it would be useful to develop guidelines for the most appropriate wave transformation methods to be used in particular circumstances. (Proposal 5.6)

When it comes to forecasting of inshore wave conditions at a particular site on a routine basis, the practicalities depend to a very large extent on the complexity of the nearshore processes which are actually important at that site. Where only linear processes are important, it should be possible to derive simple mathematical models or even look-up tables which would allow the forecast offshore wave conditions to be converted rapidly into inshore conditions. However when the important processes at the site are non-linear, more complex mathematical models are required which, on the face of it, would probably have to be operated as an extension of the Met Office offshore wave forecasting model. Nevertheless, a research project should be carried out to determine the feasibility of deriving forecasts of inshore wave conditions from offshore conditions for different types of inshore locations (Proposal 5.7a).

Considerable research on the actual processes of wave transformation is still continuing, for example as part of the MAST G6-M research project on Coastal Morphodynamics (involving research institutes from the UK and 10 other European countries). However, there is a marked shortage of data to calibrate and validate the new models which are being developed. Measurements are required of both offshore and inshore wave heights, periods and directions, at several locations where the various processes have different degrees of importance. However the measurements at each location need only be of fairly limited duration, typically one to two years. Clearly these measurements are likely to have several uses, and the NRA should collaborate with others to set up a research project to carry out the necessary work (Proposal 5.7b).

5.4.3 Defence loads and responses

The enormous variety of coastal and estuarial flood defence schemes can be divided into "hard" and "soft" defences. Soft defences are those which involve substantial or total utilisation of natural systems as an integral part of the scheme. Soft defences thus include such schemes as beach nourishment, beach re-cycling, formation and maintenance of saltings and mudflats, formation and protection of sand dune belts etc. Hard defences include the more traditional structures such as seawalls and revetments. Structures such as groynes and offshore breakwaters are generally associated with beach control, and therefore are usually part of a soft engineering solution. For convenience, this discussion on the loads on flood defences, and on their responses is divided into the two subjects of hard and soft engineering.

As mentioned, soft engineering involves mainly beaches, dunes, saltings and mudflats. In particular, flood protection schemes based on the maintenance of adequate beaches have a wide appeal, based partly on their ability to dissipate wave energy in a relatively harmless fashion, and partly to their amenity value. However, in areas where flood defence has traditionally been based on substantial seawalls there is a widespread lack of confidence in the ability to predict accurately the behaviour of the beach, both in the long and the short terms.

In terms of beach design it is important to predict both the profile and the plan shape. Prediction of the profile of shingle beaches has been researched extensively in recent years through MAFF funding, resulting in the development of empirical methods. However, this research has largely ignored mixed sand and shingle beaches, or the situation where a shingle beach is fronted by a sandy foreshore, both of which are fairly common occurrences. Some progress is presently being made on predicting profiles in front of a range of seawalls, again for shingle beaches only.

For sandy beaches, there are some methods available in the literature, but there is a noticeable lack of confidence in their use. Accurate methods of predicting the profiles of sandy beaches are likely to require considerable research on the processes associated with cross-shore sediment transport.

Prediction of the plan shape of beaches has been based so far on relatively simple models, which can be used over many kilometres of coastline and over timespans of many years. However these models ignore any associated changes in the beach profile, and therefore are rather inadequate for predicting short term changes, or for predicting the plan shape close to beach control structures.

Recently the NRA Anglian region have been the client for the development of a so-called "integrated sediment dynamics model". This model includes sections to calculate the changes to both the plan shape and the profile of the beach, but the two sections are not fully interactive. In other words, changes to the plan shape and the profile do not occur simultaneously. This would require the development of a fully three-dimensional model, in which the various cross-shore and longshore processes are fully described, and are fully interactive. However, this will require a much better understanding of both the hydrodynamic and the sediment transport processes involved, especially for mixed sand/shingle beaches, and for beaches with complex profiles (Proposal 5.8).

Where beach control structures are involved, the basic understanding of their effects on the hydrodynamics and sediment transport processes is generally rather poor. This is true not only for the more recent structures such as fishtail or other groynes having diffraction features at their ends, but also for more traditional timber or rock groynes, and for offshore breakwaters. This means that the design of beach control schemes is still rather more of an art than a science, and it also means that the exact evaluation of the cost/benefit of such schemes is not possible.

Further research is necessary to understand these structures, and to develop the methods for their incorporation into the mathematical models of the short term and long term behaviour of beaches (Proposal 5.9). As always however detailed post-project monitoring will be required to provide the data for the calibration and validation of these models.

From the above it can be seen that considerable research is needed on beach modelling, in order to promote beach management schemes as an alternative to more traditional means of flood defence. The results of this research will be of interest to a wide variety of organisations, and co-funding of the research amongst both national and European authorities is likely to be the most cost-effective way forward. Two significant opportunities for such collaboration exist at present. Firstly the European Community's Marine Science and Technology programme (MAST), where Coastal Zone Science and Engineering is a designated topic. The UK is already well represented in this programme, with several universities and research organisations participating in research into coastal morphodynamics and coastal structures. For this research the EC provides up to 50% of the funding, and the remainder has to be found from national sources. The NRA could make a useful contribution to this research, particularly with regard to the interaction between coastal structures and coastal morphology, which is not well covered in the present programme. It is felt that the NRA should respond most positively to the current proposal for research into this topic which has been put forward to the EC by HR Wallingford in collaboration with organisations in Spain and the Netherlands.
The second opportunity arises from the recent decision of the Science and Engineering Research Council (SERC) to fund the construction of a large coastal wave basin to be operated as a national facility for research into nearshore processes and sediment transport. Much work of direct relevance to the NRA could be carried out in this new basin, including research to develop improved models of beach behaviour, and also testing of various beach control structures to obtain a much better understanding of the basic processes involved, thus leading to improved design guidance. The NRA should keep in close contact with this research, and should be ready to take advantage of this facility when planning its R & D programme.

Apart from these possible collaborative ventures, there are some more practical aspects of beach renourishment schemes which could be investigated by the NRA acting largely on its own. These include less costly methods of handling and placing the materials, the effects of bimodal size gradings in the replenishment materials, and the availability of suitable sediments (Proposal 5.10).

Over many lengths of the coastline of England and Wales, flood defence is either provided or is greatly enhanced by the presence of extensive widths of saltings and mudflats. It has been reported that many of these saltings are eroding, but in many cases the evidence is rather sparse. Therefore, wherever the saltings are considered to be an important component of the flood defences, a programme of routine measurements of the width and level of the saltings and mudflats should be initiated as soon as possible. Guidelines should be produced on the best methods of obtaining this data, and also on the methods of storing and analysing the data (Proposal 5.11).

In those areas where erosion of the saltings is known to be occurring, the exact causes have so far been extremely difficult to determine. Coordinated studies are required by a multidisciplinary team to investigate the various processes involved in the growth and decay of saltings, and to develop and verify models for the prediction of their behaviour. Based on the results of this research it should be possible to develop schemes for the regeneration of the saltings which are rather more scientifically based than hitherto. Any field trials of these schemes must include a detailed programme of monitoring - a recent review of saltings as a sea defence carried out as part of the current R&D programme has found that virtually no data exists on the performance of past regeneration schemes.

Clearly research on salting and mudflats is an area where collaboration with other organisations is essential for success. Bodies such as English Nature are known to be interested, especially if the research includes some aspects of the creation of new saltings as part of a strategy of managed retreat of the flood defence line.

There are very few areas around the coastline of England and Wales where sand dunes play an important role in the flood defences, and amongst those consulted there has been no call for further research on their behaviour. Extensive research has been carried out by Dutch engineers, but much of this is not relevant to the UK situation, where the planning controls on development in the dune belt have been very much less restrictive.

Traditionally the flood defences of the coastlines of England and Wales have been based on hard engineering structures, such as seawalls and revetments. In many areas such structures will continue to be necessary, and existing structures will need maintenance and repair. Compared to soft defences, there is a considerable knowledge of the behaviour of coastal structures. For both seawalls and revetments the preparation of design guidelines has been under way for about three years, and the resulting volumes should be published shortly, by CIRIA in the case of seawalls, and by PIANC in the case of revetments. Both of these guidelines attempt to summarise the current state of the art, and they should prove to be useful references for the NRA's flood defence engineers. Nevertheless some items of research still remain.

For seawalls, considerable information now exists on the overtopping discharges to be expected under given environmental conditions for a wide range of seawall geometries. However, there are some types of seawall for which model tests are still the only way of estimating overtopping. This is particularly true for seawalls incorporating wave return walls, and for seawalls which experience oblique wave attack. For these seawalls generic model studies should be carried out to develop empirical design methods for overtopping (Proposal 5.12).

A second major problem in the design of seawalls is the estimation of the depth of scour at the toe, which controls the selection of the foundation level. The review of the performance of seawalls, carried out by CIRIA in 1986, showed that undermining of the toe constituted the most common cause of failure of seawalls. Since that time, considerable research has been funded by MAFF on toe scour on shingle beaches fronting seawalls of various designs, and empirical methods of estimation are now available. However further research is necessary to extend this work to sand beaches, and to mixed sand/shingle beaches (Proposal 5.13). The existing information for shingle beaches also needs to be published and used more widely.

Where toe erosion is shown to be a serious problem, some method of toe protection is required, usually involving either a rockfill blanket or a concrete mattress. However, the dimensioning of the toe protection is rather uncertain. Some guidance is given in a report to be published shortly on the use of rock in coastal engineering, but further research is necessary to develop firm guidelines on this subject (Proposal 5.14). In a related subject, a project on the foundations of rockfill structures is in the NRA's current regional research programme, and it is intended to extend this work as part of the national R&D programme to all types of armourstone foundations.

A further problem with the design of seawalls is the estimation of the wave impact forces. Several formulae exist for calculating the forces, but the results can be substantially different. Because of the process of air entrainment which takes place in the very violent zone close to the seawall, model tests at small scale also do not necessarily give correct estimates of the forces. Therefore it is likely that progress towards better estimation methods can only be achieved by large scale model and field measurements. Because of the cost of such research, collaboration with other organisations is probably necessary, especially in Germany and the Netherlands where very large testing facilities are available (Proposal 5.15). The MAST programme would provide an opportunity for such collaboration.

For revetments, the principal unknowns which remain concern the stability of the front face armour. Traditional revetments were designed and built using the knowledge and experience of the local engineering staff, and using locally available materials in a relatively labour intensive operation. Usually the revetments were also built in a relatively sheltered environment. However with the demise of inexpensive labour, new materials and new methods of construction are being used, often with little reliable information on their future performance. As existing saltings are eroded, many of the revetments are also now located in a more hostile environment, where their design is more critical.

As part of the current R&D programme, a project to investigate revetment systems and materials, and to examine their effectiveness, attributes and costs, is now underway. The current project is essentially a review of available information, and to some extent it duplicates the forthcoming report from PIANC. For rock faced revetments, firm guidelines are now available, but it is likely that further research involving model tests and field trials will be required for many of the other armour systems. This is particularly the case for new systems and new materials, but it may also apply to some traditional systems, for example the grass faced embankments which form the flood defences in many estuaries (Proposal 5.16).

Grass is also the most common facing for the rear slope of revetments. At present the design guidance for the rear face is extremely general: for example, it does not take into account the slope of the face. In many of the countries bordering the North Sea there are extensive lengths of revetments, and it is believed that research to investigate the stability of the crest and rear face is underway in both the Netherlands and Denmark. Clearly it would be useful if the NRA could participate in this research.

Occasionally, offshore breakwaters are used as a direct means of flood defence, rather than as a means of controlling beach behaviour. In the design process, the wave conditions in the lee of the breakwater can be estimated reasonably accurately, but prediction of the stability of the armour can be a problem. This is because all of the prediction methods assume that the front face of the breakwater extends well above the water line. For offshore breakwaters the crest is often close to the water line, and may even be submerged at extreme high water levels. Further research is needed to investigate armour stability under these conditions,and to develop design guidelines (Proposal 5.17).

5.4.4 Climate change

During the past few years there has been considerable discussion and research concerning the possible changes to the world's future climate as a result of the increasing quantities of the so-called "Greenhouse gases" in the atmosphere. The consensus view, as expressed in the reports of the Intergovernmental Panel on Climate Change (IPCC), is that there will be an accelerating trend of rising globally averaged mean sea levels. However, there will be significant regional variations in this pattern, and there is as yet no agreement on the rise in mean sea level which can be expected around the UK coastline.

In addition to sea levels, several climatological research workers have suggested that there will be changes in the wind climate, possibly leading to more severe and/or more frequent storms. Again, however, there is not yet any agreement within the scientific community about the magnitude and distribution of this effect. Precise estimates of the changes in sea level and storminess around the UK coastline are unlikely to be available for the next ten years or so, despite considerable international research on the subject. In the meantime the design of sea defences has to continue.

a) Sea level rise

Although the rise in sea level has received considerable media attention, its direct influence on the design and performance of sea defences will in fact be relatively minor if the current predictions are approximately correct. Most coastal engineers would feel that it is insignificant compared to all the other uncertainties in the design. However, a rise in mean sea level may cause other changes which may be more significant in some locations. For example, increased water depths following a rise in sea level may cause an increase in tidal amplitude in some estuaries, leading to significant changes in High Water levels. On coastlines with a shallow foreshore, increased water depths will allow larger waves to reach the sea defences, thus increasing the wave run-up elevation by an amount greater than the rise in sea level.

It is not considered necessary for the NRA to contribute to the major international research programmes now underway to predict more precisely the effects of greenhouse warming, although the NRA should use its influence to ensure that regional variations in sea level rise are one of the issues being studied. Instead the NRA should be using its resources to research the consequential changes resulting from changes in sea level. The subjects which should be addressed include:

- an assessment of the effect of rising sea levels on the return periods of extreme water levels (Proposal 5.18)

- an assessment of the effect of rising sea levels on tidal propagation in estuaries (Proposal 5.19)

In both cases studies based on various assumed rises in sea level will be required, and for several example locations around the coastline. The aim should be to examine the sensitivity of these parameters to possible future changes in sea level, rather than to produce definitive design data. That will have to await the accurate predictions of the local sea level changes.

At many locations around the UK coastline sea levels have already been rising for many decades. In parallel with the above research efforts, the existing data bank on tidal levels etc. should therefore also be studied, to determine what changes in return periods, High Water levels etc have been recorded, and how they relate to the recorded changes in mean sea level (Proposal 5.20).

b) Storminess

Changes in the frequency and severity of storms could have a much more significant effect on the performance of coastal flood defences than would a change in sea level. Again the NRA should use its influence with the Hadley Centre to ensure that local predictions of changes in storminess are one of the outcomes of the international research efforts. Other than an analysis of the historic records of wind and wave conditions, it is difficult to see what further research can be done on this specific subject until these more accurate predictions are available. Several studies to analyse historical trends have already been carried out (e.g. for the Severn Estuary by HR Wallingford, and for the southern North Sea by Halcrow and the University of East Anglia), generally showing large variations from decade to decade, but with little or no apparent trend. Further studies along these lines could be carried out as the need/opportunity arises

c) Effects on defences

Studies to examine the effects of possible changes in sea levels and storminess on the performance of flood defence structures such as seawalls and revetments have already been carried out on NRA's behalf, both by HR Wallingford as part of the R & D programme, and by Halcrow as part of the Anglian Region's Coastal Management Study. Further generic research (as opposed to site-specific studies) on this subject is probably not necessary at this stage, pending more accurate predictions of the future.

The effects on soft defences, such as beaches and saltings, are much more difficult to determine. An existing project within the R & D programme is to assess the future effect on beaches, mainly by an examination of historical changes and relating these to recorded changes in sea level and storminess (Proposal 5.21). This project should be duplicated for saltings, to compare the behaviour and development of saltings in areas of the country where sea level is presently rising, with those where sea level is essentially static (or possibly even falling slightly) (Proposal 5.22).

6. SPECIFIC PROPOSALS

6.1 Research subjects and priorities

Specific research subjects within the headings listed above are shown in Appendix C. Priorities have been given on a scale of 1 to 3, 1 being the most urgent and 3 the least. An estimate of the duration of each project has also been given in terms of short (1 to 2 years), medium (2-3 years), long (more than 3 years) or continuous. It should be noted that short term projects will give immediate spin-off to the NRA and will generally be less expensive than the longer term ones. Costs are based on mid-1991 rates. For projects where collaboration with other organisations is suggested, the quoted costs indicate the level of investment which would be appropriate from the NRA.

The table also gives a very brief description of the benefits which would be obtained from the proposed project. Most of the projects which are recommended will lead to

a) Improvements in the consistency of standards and methodologies applied throughout the NRA

b) Improvements in the quality of service in carrying out all the NRA's flood defence activities

c) Reductions in the risk of flooding

d) Savings in the costs of providing flood defences

Some of the projects also provide the information to enable the NRA to evolve its policies regarding flood defence issues, and to be able to demonstrate the derivation of these policies to the general public. This applies particularly to projects involved with standards of service and to the possible effects of global warming.

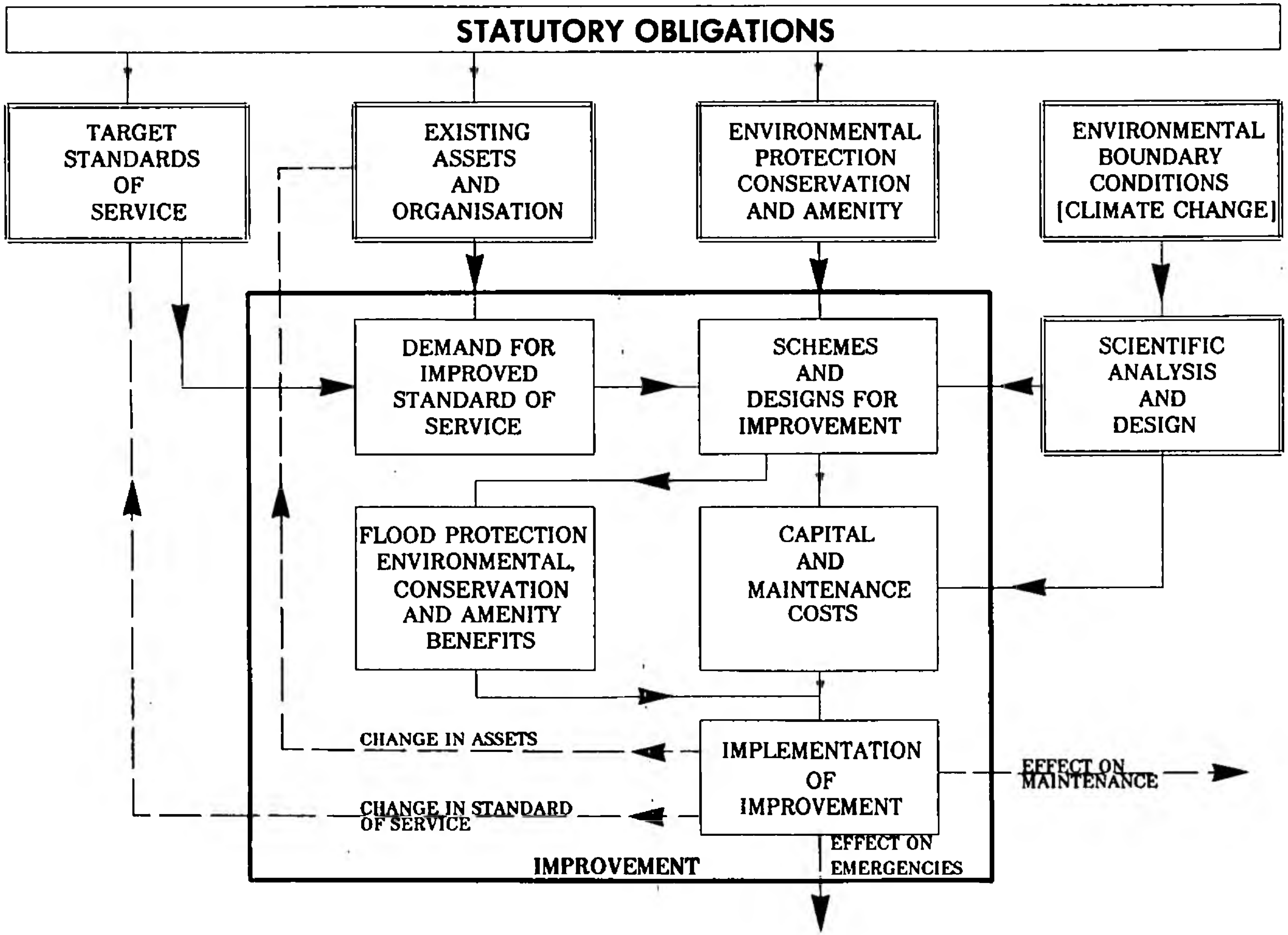
6.2 Other recommendations

In addition to the recommendations for research projects mentioned above a number of further recommendations arise out of the discussion in Section 4. These are:

- that the NRA should continue to keep track of all research in the field of coastal and estuarial R & D, and that, in line with this, consideration should be given to developing a database of past, current and proposed R & D projects in this field

- that the NRA should actively seek out opportunities for collaboration of R & D work in this field, particularly with other European nations, with a view to benefitting from a wider academic and practising catchment, and to take advantage of the knowledge gained and data collected from major initiatives which have been adequately funded

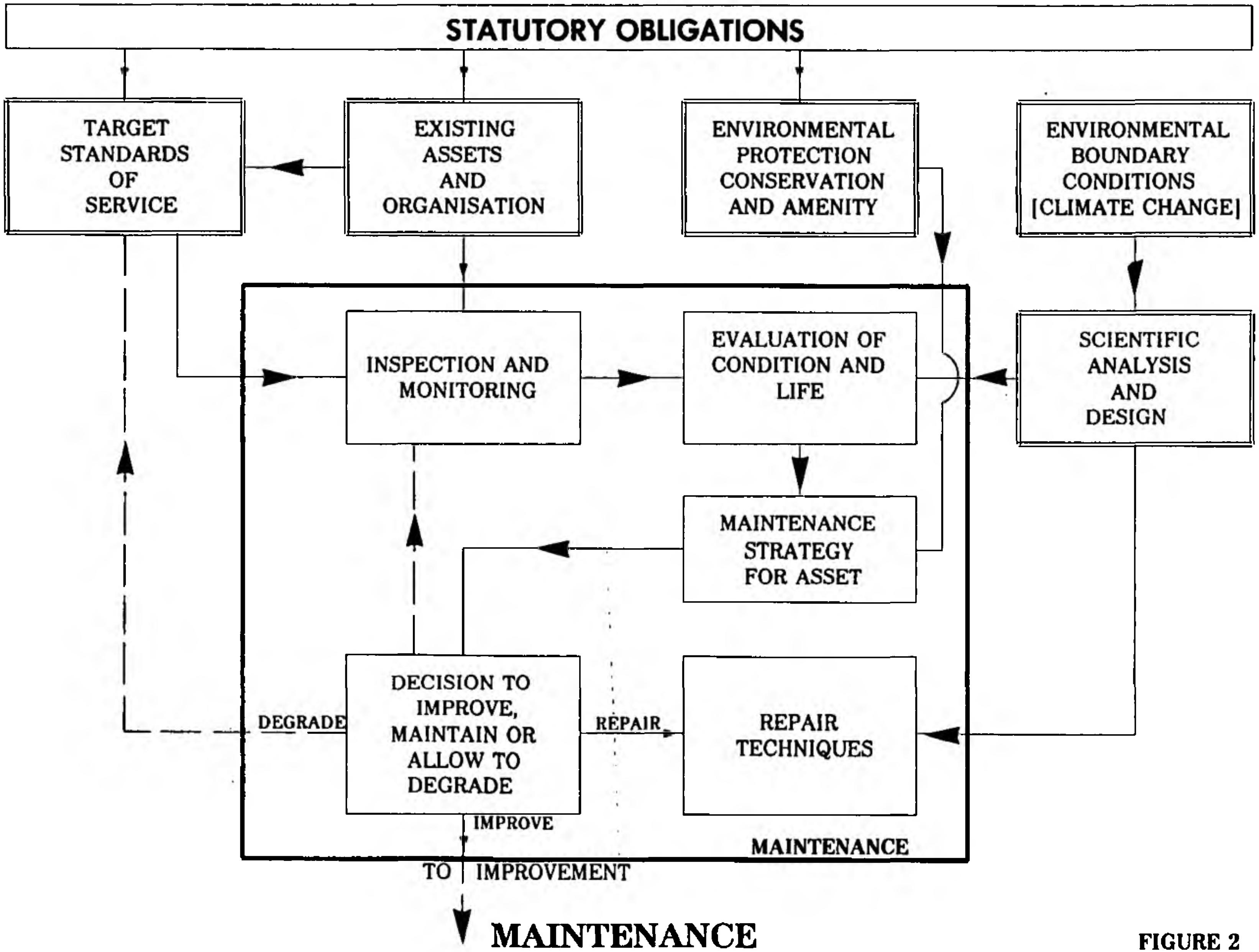
- that consideration should be given to producing synthesis reports of the results of NRA research projects for practising flood defence managers and engineers



IMPROVEMENT

FIGURE 1

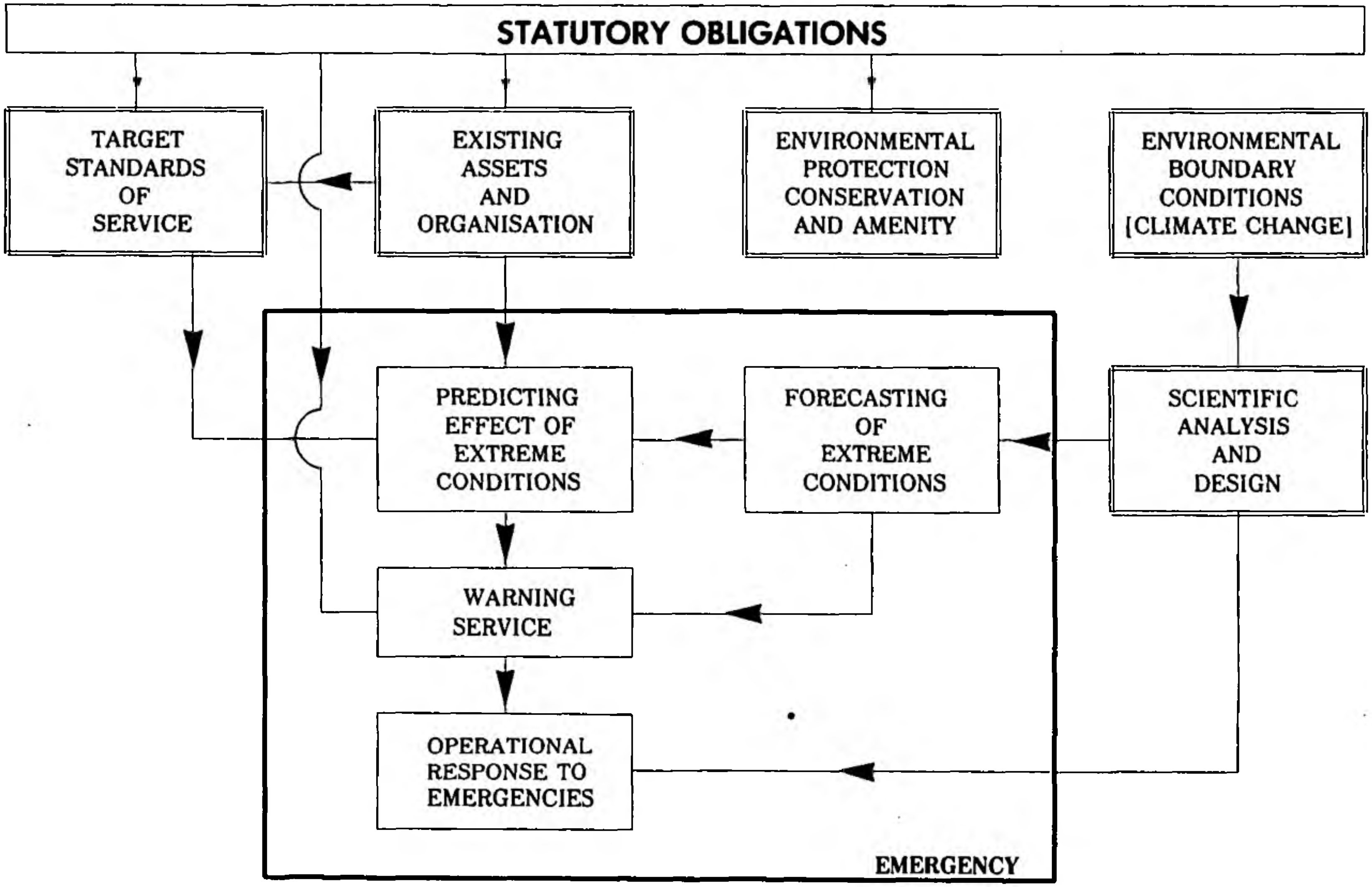
REVIEW OF COASTAL AND ESTUARIAL R& D RELATED TO FLOOD DEFENCE



MAINTENANCE

FIGURE 2

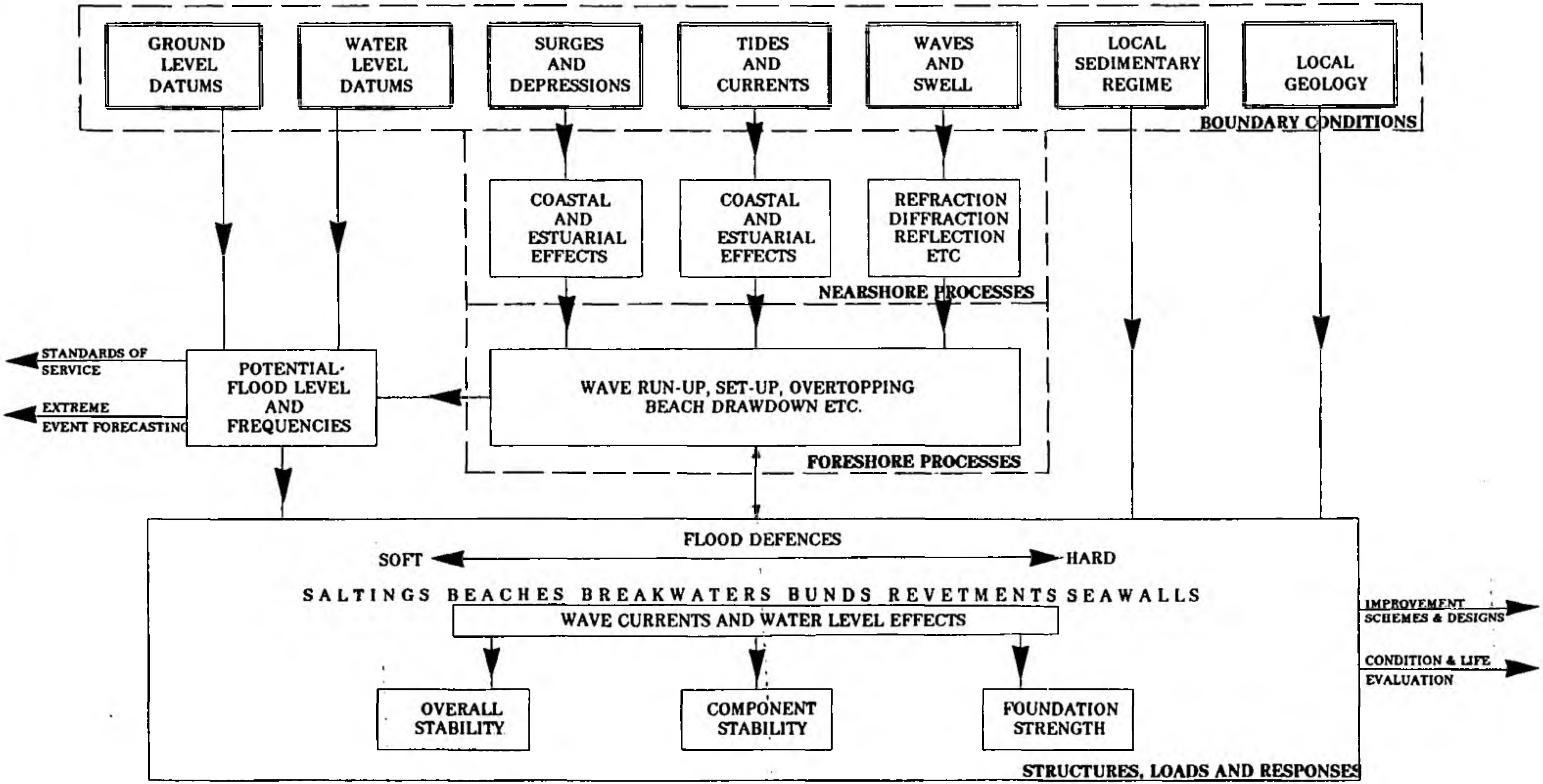
REVIEW OF COASTAL AND ESTUARIAL R & D RELATED TO FLOOD DEFENCE



EMERGENCY

FIGURE 3

REVIEW OF COASTAL ESTUARIAL RESEARCH DEVELOPMENT RELATED TO FLOOD DEFENCE



SCIENTIFIC ANALYSIS AND DESIGN

FIGURE 4

APPENDIX A

External Advisors to NRA on Coastal/Estuarial R & D related to Flood Defence

Terms of Reference

The programme of studies will include the following core activities:

A. NRA Responsibilities

Reading of background documents to determine how the NRA interpret their statutory responsibilities in the area of flood defence.

B. Areas of Interest

Leading on from (A) above, identification of the NRA's interest in each area regarding such items as structures, engineering design, data, management and maintenance.

C. Subject Headings

Development of a comprehensive matrix or network of subject headings to include data, techniques, procedures etc. and the linkages between them. This is seen as a particularly important task as it enables one to place every R & D item in context and to assess its importance and relevance with respect to the known state of the art and other on-going or programmed research.

D. Assessment of Current Knowledge and Worldwide R & D

A broad appraisal of UK and overseas state of knowledge on the relevant subjects, and the research programmes being undertaken or projected for these subjects.

E. Determination of NRA Gaps in Knowledge

This would involve determining both the actual and perceived gaps in knowledge, which would result in recommendations for research or, in the case of imaginary gaps, identifying where dissemination of information or training might be appropriate.

F. Determination of Priorities

A review of the recommendations for research, cost/benefit aspects of recommended items and assignment of priority.

In carrying out this programme of work, there will be the need for widespread consultation both within and outside the NRA.

Reporting:

It is envisaged that there will be three reporting stages as follows:

- A brief report at the end of May, 1991, giving preliminary conclusions on future research areas.

- A draft final report at the end of August, 1991.

- A final report in October, 1991.

Babtie Dobbie, Mr K Riddell
British Geological Survey, Mr R Arthurton
British Maritime Technology, Mr J Graff
Bullen & Partners, Mr C Davies
Coastal Engineering Research
Advisory Committee, Dr P Kemp
Halcrow, Dr C Fleming
Hydraulics Research Ltd, Dr S Huntington
MAFF, Mr A Allison
Meteorological Office, Mr I Pratt
NRA Anglian, Mr M Child
NRA North West, Mr W Rushden, Mr G Noonan
NRA Southern, Mr M West
NRA Severn Trent, Mr J Fitzsimons
NRA Thames, Mrs L Pickles
Posford Duvivier, Mr R Thomas
Proudman Oceanographic Laboratory, Dr G Alcock

Review of coastal and Estuarial R & D Related to Flood Defence - Proposed Future R & D Projects

Area of Research	Project Number	Proposed Project	Priority	Time Scale	Estimated Cost (£'s x 1,000)	Benefits
1. Major Flood Defence Issues	1.1	Development of nationally consistent flood defence procedures, building on generic aspects of completed regional projects (where applicable), and development of a broad R & D framework consistent with this.	1	Medium	40	Improved consistency of approach to flood defence schemes. Improved co-ordination of R & D .
	1.2	Definition of requirements for production of design codes, manuals and guidance notes.	1	Long	15	Improved consistency in design and project evaluation. Higher quality of design, hence reduction of risk. Fairer competition between consultants.
	1.3	Definition of requirements for post-project appraisals for flood defence schemes, and guidance on implementation procedures.	1	Short	40	Improved evaluation of the actual benefits of implemented schemes. Early detection of poor performance and subsequent savings from improved techniques.
			Total Costs		95	

Area of Research	Project Number	Proposed Project	Priority	Time Scale	Estimated Cost (£'s x 1,000)	Benefits
2. Improvement	2.1	Defining standards of service for protection against estuarial and coastal flooding, taking into account different types of flood event and consequences of these.	1	Short	20	Demonstrably consistent standards of service across the country and interpretation of these.
	2.2	Development of guidelines for the treatment of conservation issues in flood defence works.	1	Medium	80	Consistent approach to the consideration of conservation issues.
	2.3	Development of guidelines for the use of probabilistic design methods in flood defence: a) Identification of possible modes of failure for hard defences b) Identification of parameters causing failure in soft defences c) Collection of data to assist in the prediction of joint probabilities of concurrent extreme events (Joint funding?) d) Development of probabilistic design procedures	1	Long	200	Accurate assessment of the probability of failure, and of its consequences. Usually leading to more cost-effective schemes (less conservative). Proposed project for 1992/93
	2.4	Analysis of past defence failures and development of methods of predicting modes and severity of failure, particularly for soft defences.	1	Short	60	Accurate assessment of the degree of damage to the defences, hence allowing more accurate assessment of flood damage. Eliminates the usual assumption of total damage if the design loading is exceeded. Proposed project for 1992/93
	2.5	Production of detailed coastal maps to facilitate the prediction of flood damage resulting from sea defence failure or overtopping.	3	Long	200	Allows detailed assessment of the areas at risk, based on possible flow paths. Eliminates the usual assumption that all ground below a certain elevation will be flooded.

2. Improvement (Continued)	2.6	Further research on cost/benefit methods for flood defence schemes, including:				
		a) Development of standard methods of evaluating "whole life costs" of defence schemes with improved assessments of maintenance costs for both hard and soft defences.	1	Medium	40	Enables far more realistic comparisons to be drawn between different flood defence options. Allows better planning of maintenance and repair work.
		b) Development of straightforward methodologies for assessing the conservation and amenity benefits of flood defence schemes	2	Medium	80	Enables realistic comparisons to be drawn between benefits of hard and soft engineering solutions.
		c) Updating of methods of valuing agricultural land, taking into account changes in the EC Common Agricultural Policy, and also in the context of managed coastal retreat, including investigation of political and legal mechanisms for compensating land and property owners.	3	Medium	120	Provides more accurate assessment of agricultural values, and allows accurate assessments to be made of the economics of coastal retreat as an option for flood defence
			Total Cost		800.00	

Area of Research	Project Number	Proposed Project	Priority	Time Scale	Estimated Cost (£'s x 1,000)	Benefits
3. Maintenance and Repair	3.1	Development of routine methods of establishing Standards of Service of existing structures by back-analysis.	1	Medium	25	Allows the Standard of Service of existing structures to be evaluated efficiently and consistently throughout the regions. prevents the proliferation of differing analytical techniques, thereby saving cost and making comparison easier.
	3.2	Development of a nationally consistent philosophy for maintenance and repair of flood defences, including:-				
		a) Development of standard methods of evaluating the characteristics of discrete lengths of existing defences.	1	Medium	40	Improved efficiency and consistency in developing a maintenance policy for long stretches of coastline.
		b) Development of condition coding for coastal defences taking account of both physical condition and engineering integrity.	1	Short	40	Makes condition coding more consistent and useful as a guide to the need for maintenance.
		c) Development of guidelines for assessing the remaining life of a structure, based on a detailed analysis of existing structures.	2	Medium	60	Fills in an important gap in the economic analysis procedure for evaluating the best maintenance philosophy for a particular type of defence. Could lead to significant savings in capital expenditure.
		d) Extension of the work on prioritisation and programming of flood defence maintenance and repair works into the coastal sector.	1	Short	40	Improves the decision-making process and will lead to more rational distribution of funds to maintenance projects. Builds on previous work on river maintenance.

3. Maintenance and Repair (Continued)	3.3	Development of rapid and effective methods for the routine monitoring of the condition and behaviour of defences, including:-				
		a) Methods for data collection of environmental conditions and behaviour of defences during extreme events.	2	Medium	60	Improves the quality and usefulness of data collected and provides more data for the study of the behaviour of structures during extreme events.
		b) Methods for detecting deterioration of the internal fabric of sea defence structures by non-destructive methods.	1	Long	80	An essential component to give confidence in the evaluation of condition of certain types of structure. Feeds into Proposal 3.2c in certain cases.
	3.4	Extension of the existing programme of research into the repair of flood defences, including such items as:-				
		a) The maintenance implications of new designs, economies of scale etc.	2	Short	25	Cost savings in future repair and rehabilitation works.
		b) Establishment of a data base of maintenance and repair costs for a wide variety of different types and costs of defence structure.	1	Medium	60	Improved confidence in the results of cost-benefit analysis involving the whole life costs of schemes (Proposal 2.6a). Possible short term spin-off in terms of improved data for selection of alternative defence schemes.
			Total Cost		430.00	

Area of Research	Project Number	Proposed Project	Priority	Time Scale	Estimated Cost (£'s x 1,000)	Benefits
4. Emergencies	4.1	Definition of input requirements for analysis of emergency scenarios and required resources.	3	Short	20	Ensures that the output of other research projects will be suitable for future research into resources, thereby enabling research to be carried out at reduced costs.
	4.2	Development of procedures for relating real time predicted environmental conditions to site specific emergency situations.	2	Long	80	Enables the improved outputs of STWS model and similar to be used to predict local emergencies and hence warning reliability and response will be enhanced.
	4.3	Assessment of effectiveness of warning systems and development of cost-benefit techniques for assessing their value.	2	Medium	40	Leads to cost savings where it is found that warnings are of little use, and will make the warning system more cost-effective.
	4.4	Development of guidance notes on practical emergency engineering measures for repairs to breached defences.	1	Short	40	More effective temporary repair techniques and less wastage of emergency funds on ineffective operations. Proposed project for 1992/93
			Total Cost		180.00	

Area of Research	Project Number	Proposed Project	Priority	Time Scale	Estimated Cost (£'s x 1,000)	Benefits
5. Scientific analysis.	5.1	Establish procedure and methodology for collation of data on tides and water levels from both national and local gauge networks in specific regions.	1	Short	10	Improved estimates of local tide and surge levels, valuable for strategic planning of flood defences.
	5.2	Development of joint funding of storm surge model in specific areas to provide more localised predictions, e.g. in important estuaries.	1	Medium	210	Improved forecasting of local surge levels, giving better warnings of flooding.
	5.3	Support to MAFF initiative to extend tide gauge recording programme to include wave recording. Need for NRA to link into this programme wherever feasible.	1	Medium	237	Ongoing project.
	5.4	Refinement of Met. Office offshore wave forecasting model to include inshore wave transformation component giving more localised forecasts on a routine basis.	1	Long	230	Improved forecasting of local waves, giving better warnings of flooding.
	5.5	Development of national or regional programmes to examine offshore sediment regimes and the historical behaviour of sandbanks.	3	Long	120 per regional study	Allows better understanding of regional coastal processes, giving estimation of future behaviour of sandbanks, hence of degree of wave exposure at the coastline.

5. Scientific analysis (continued)	5.6	Further research and development on methods of transforming offshore wave conditions to inshore sites, including:-				
		a) Development of guidance notes describing existing methods and their range of application.	1	Short	20	Consistent application of best and most appropriate technology.
		b) Determination of the feasibility of deriving forecasts of inshore wave conditions from offshore conditions for different types of inshore location.	1	Short	40	Calibration and validation of new and improved inshore wave transformation models and possible forecasting techniques associated with these, giving more economic methods of forecasting and more reliable modelling methods.
		c) Collaboration with others to set up measurement programmes for collecting data on offshore and inshore wave conditions for calibration and validation of wave transformation models.	1	Long	80	
5. Scientific Analysis (continued)	5.7	Further research into the understanding of hydrodynamic and sediment transport processes associated with mixed sand/shingle beaches and beaches with complex profiles, to provide input to a fully 3-dimensional beach model.	1	Long	80	Better and more confident predictions of the long term behaviour of soft flood defence schemes.
	5.8	Further research into the behaviour of beach control structures and development of methods of incorporating them into models of short and long term beach behaviour.	1	Long	220	More scientific design of beach control schemes. Better and more confident prediction of the long term behaviour of beach management/nourishment schemes.
	5.9	Investigation of less costly methods of beach replenishment, including methods of handling and placing materials, effects of bimodal size gradings and availability of suitable materials.	1	Medium	40	Ongoing project.
	5.10	Development of guidelines for, and initiation of programmes of, the monitoring of saltings and mudflats. Storage and analysis of data obtained. Possible co-funding with conservation organisations.	1	Long	200	Collection of hard data on behaviour of saltings. Allows better understanding of existing behaviour, and enables estimates to be made of future behaviour. Important for strategic design of flood defences. Research proposed for 1992/93
	5.11	Generic model studies to develop empirical methods for assessment of overtopping of seawalls, with particular reference to oblique wave attack and wave return walls.	2	Medium	85	More accurate assessment of performance of wide range of existing seawalls, without recourse to expensive model tests.

5. Scientific analysis (continued)	5.12	Further research on the toe erosion of seawalls, including:-				
		a) Development of methods of predicting depth of erosion on sand and mixed sand/shingle beaches, and the dissemination of existing information on shingle beaches.	1	Medium	200	Better prediction of toe scour. Encourages better design of hard defences, hence less repair costs. Allows interactions between existing hard defences and proposed soft defences to be evaluated.
		b) Development of guidelines on selection of appropriate toe protection materials and design of schemes incorporating them.	2	Short	40	Encourages application of best and most appropriate technology. Relates to ongoing project on armourstone foundation.
	5.13	Collaboration in international research to derive better methods for the structural design of seawalls and revetments, including:-				
		a) Improved methods for estimating wave impact forces on seawalls.	2	Medium	80	More accurate assessment of wave forces on seawalls, taking account of the dynamic response of the wall and its foundations.
		b) Model testing and field trials of proprietary and other methods of armouring revetments, including the assessment of grass-faced slopes.	2	Long	80	Selection of the most cost-effective methods of revetment re-construction, based on non-commercial research.
		Possible collaboration with Dutch, Danish and German Authorities.				
	5.14	Research into the stability of armouring of offshore breakwaters.	3	Short	85	Development of more cost-effective methods of offshore breakwater construction.
	5.15	Continuing research on the effect of rising mean sea levels on design water levels, including:-				
		a) Sensitivity analysis of the effects on the return periods of extreme water levels.	1	Short	40	Assists in establishing design criteria and scheme benefits. Proposed project for 1992/93.
		b) Sensitivity analysis of the effects on tidal propagation in estuaries.	2	Medium	130	Better understanding of climate change effects in estuaries, and hence of implications for flood defence levels.
		c) Assessment of historic trends in tidal parameters, and determination of their relationship with mean sea level trends.	1	Medium	80	Provides data on past behaviour, and gives indication of possible future trends.

5. Scientific Analysis (continued)	5.16	Assessment of historic changes in beach conditions, and their relationships with changes in mean sea level and storminess.	1	Long	-	Ongoing project nearing completion.
	5.17	Assessment of historic changes in saltings, and determination of their relationship with changing climate.	1	Long	included in 5.11	Better understanding of the effects of climate change on saltings.
			Total Cost		2,307.00	