Defra/Environment Agency
Flood and Coastal Defence R&D Programme

Operations and Maintenance Concerted Action Report

R&D Technical Report W5A-059/3/TR

defra
Department for Environment Food and Rural Affairs

ENVIRONMENT AGENCY

Operations and Maintenance Concerted Action Report

R&D Technical Report W5A-059/3/TR

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Statement of Use
This report provides general information on operations and maintenance of flood and coastal defences. It has been used to guide Flood Defence Managers of future R&D needs. It is available for general use to flood and coastal defence practitioners, but not as formal guidance

Keywords
Operation, maintenance, flood defence, coastal defence, performance

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EXECUTIVE SUMMARY

Operations and Maintenance (O&M) tends to be an under-supported area within the overall flood and coastal defence business. A fundamental review of this subject area was carried out within this study through a concerted action process in order to identify how best R&D might support the improved delivery of O&M benefits. Recommendations for future development of the area and a performance-based management framework for its delivery have been developed as part of this study. This framework fits into the strategic tiered approach to flood and erosion risk management, which Defra and the Environment Agency aim to develop in order to focus investment on the most beneficial areas for risk reduction. It should link with future Defra guidance on performance assessment for defences.

The proposed framework provides a logical process for asset management that allows decisions on management intervention to be based on their effect on performance of the asset or defence system. The broad nature of the framework will enable O&M to be compared on a similar performance baseline as other forms of intervention such as major improvement schemes. Its hierarchical form will also enable the use of a consistent data-set for decision making and reporting through the policy, strategy and delivery tiers of flood and coastal defence management.

The development of the proposed research and development (R&D) involved the consideration of the existing knowledge base and ongoing research. The programme was based on maximising available knowledge and seeking advancements where urgent needs are identified which can accrue significant benefits through R&D. Based on this, the following priorities have been identified for the O&M business:

(i) The development of a performance-based asset management system. This R&D will draw together and trial current R&D and recent developments on the characterisation and performance of defence systems in order to provide a decision-support tool for quantifying the reduction in risk from an O&M management intervention. The development and piloting of such a system will provide a significant step-change in the O&M business by introducing a performance-based decision making process, comparable with that used for improvement works.

(ii) The collation and dissemination of existing best practice tools and techniques for O&M management, to lift the whole of the O&M business to an overall higher level of competence. This higher level of competence will then be subject to a more structured continuous improvement by regular capture of emerging best practices within the O&M business and other sectors. Where possible such work should be done as part of a continuous improvement process by the business.

(iii) Specific step-change R&D projects, which will be targeted at high-need areas where great benefits can be gained by the improvement of

knowledge and techniques in the areas. Such areas include embankment performance, conveyance estimation, asset condition assessment and saltmarsh management. Development in each of these areas will reduce the knowledge uncertainty currently inherent in the ability to manage flood and erosion risk.

This work from the O&M concerted action dovetails with and builds on work in other related themes and subject areas within the joint Defra / Environment Agency R&D programme. A key aspect of this work is that it must be piloted and trialled with practitioners.

Some of the proposed work is already programmed in the joint R&D programme, and some projects (e.g. embankment best practice) are now ongoing. The overall short-term programme is costed at about £2.0M over the next four years - around £500,000 is unbudgeted. This investment in R&D is in addition to the continuous improvement through collation and dissemination of best practice to be funded within the operational budgets of the Operating Authorities.

The short-term programme of research is designed to put O&M interventions on a performance-based footing alongside improvement works and to quantify the reduction in risk that these provide. The proposed programme addresses the most urgent R&D needs. A separate compendium of all the issues that might be supported by R&D or continuous improvement has been produced.

There are significant benefits to be gained by timely investment in the short-term as this will contribute significantly to future O&M business. Once the short-term programme is complete and a performance-based system is in place, future research and development needs could then be prioritised on a performance or risk-reduction basis.

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INTRODUCTION

1.1 Background to the O&M Concerted Action

The Operations and Maintenance (O&M) of flood and coastal defences is one of the topic areas within the engineering theme of the joint Defra/Environment Agency research and development (R&D) Programme. Future research and development needs in the area are being scoped using a concerted action process.

A "Concerted Action" is a series of defined activities in a specific subject area which bring together users and researchers with the common objective of developing, through a process of review and assessment, the future programmes of R&D.

The use of the concerted action process to develop future research was part of the recommendations of the MAFF (now Defra)/Environment Agency advisory committee on flood and coastal defence research and development chaired by Professor Edmund Penning-Rowsell (Penning-Rowsell Report – MAFF, 1999a).

Further detail about the thematic structure is contained within the proposals for the implementation of the Penning-Rowsell report by MAFF/Environment Agency.

1.2 Research Objectives

The objective of the O&M concerted action is to carry out reviews and consultations, and produce the following outputs:

- Review of current practice, probably including some consensus on "best practice";
- Review of science base, typically including a literature review and consideration of ongoing research and;
- Prioritised future R&D programme for the O&M Topic Area, and specification of R&D projects.

1.3 Purpose and Scope of Report

This concerted action report is the culmination of a review and consultation process aimed at providing a direction for the future advancement of O&M and a framework for its delivery. The process within the development is summarised in *Figure 1.1*.

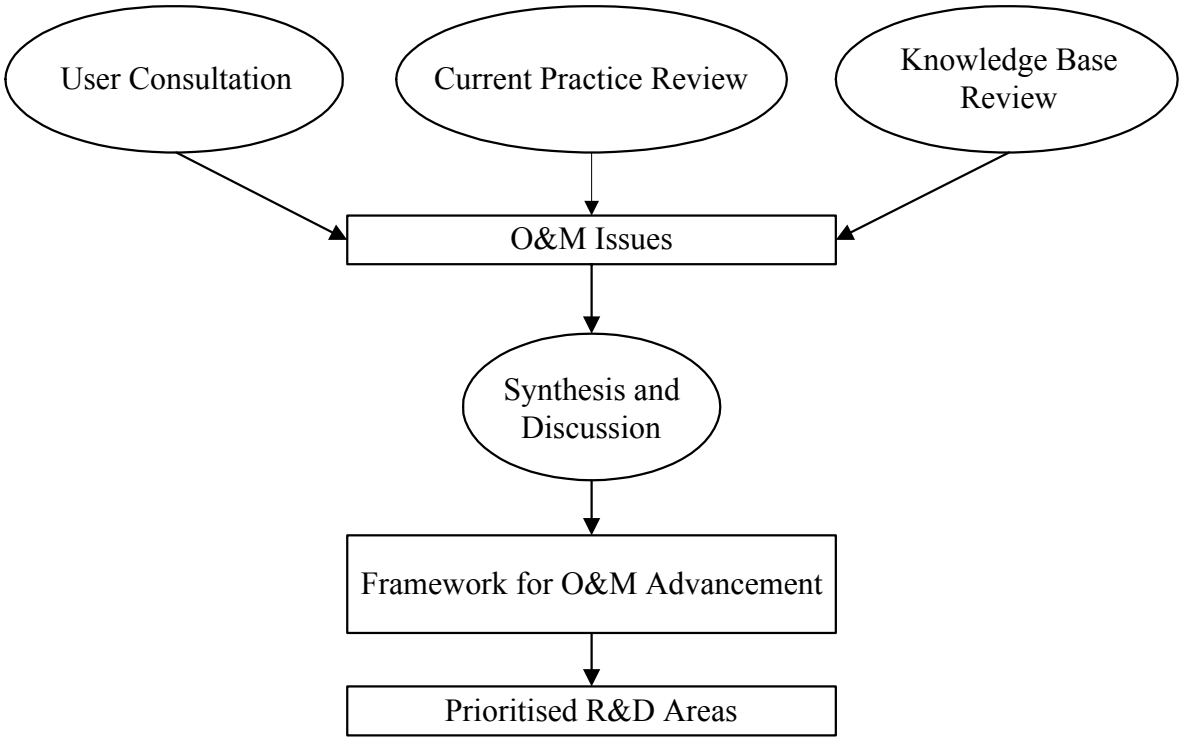

Figure 1.1 O & M Concerted Action Development Process

The purpose of this report is to present a summary of the review of current practice and how advancement can be made within O&M by maximising the use of current good practice and properly targeted research and development.

Section 1 provides an introduction to the report.

Section 2 describes the vision for future delivery of O&M, the role O&M plays within flood and coastal risk management, and the framework which is proposed to assist in the delivery of improved O&M and hence improved flood and coastal erosion risk management.

Section 3 presents a summary of the current practice review within the processes outlined in the framework presented in Section 2. This section also provides some consensus on good practices, how they can be maximised within O&M and where improvements are required.

Section 4 discusses the proposed approach to the development of future priority areas for advancement within a performance-based framework and presents an outline of the short-term priority areas.

1.4 Users

The intended readership of this report is the user community. There are two main groups of users within the O&M business.

The first group consists of practitioners. It includes organisations with operational responsibilities for flood and coastal defences under the Land Drainage, Coast Protection, Water Resources and Environment Acts such as the Environment Agency, Internal Drainage Boards, Local Government and Maritime Authorities, their consultants and contractors.

The second group is the research and technical development community. It includes research bodies, universities, businesses and consultants who would be involved in further research and development within the O&M topic area or other related research themes or topic areas.

2 A FRAMEWORK FOR THE IMPROVEMENT OF O&M

2.1 Vision

A vision has been developed within this study which sets the target for effective delivery of O&M. This vision is to attain:

Effective flood and coastal defence management based on the use of best practice, where intervention in natural processes is based on the consideration and optimisation of its effect on performance.

In line with the stated objectives of Defra and the Environment Agency, improved performance would be measured principally in terms of reduction of risk to people and property from flood and erosion. Other indicators will include improved whole life cost-effectiveness, health and safety, environmental performance and sustainability; in summary, the effective long-term management of the processes delivering the principal objective.

2.2 Effect of Maintenance on Flood and Coastal Erosion Risk

For the purposes of this report, maintenance of a flood defence or coast protection asset or system is viewed as comprising all those activities that are required to be carried out on a periodic basis:

- After construction or improvement of an asset or system, or development of a management approach, to ensure that the asset or system continues to provide a target standard of performance over a range of loading conditions during its design life.
- To maintain acceptable standards of flood and coastal erosion defence within systems, which have not had major studies or improvement schemes.

A flood or coastal defence improvement on the other hand is a scheme that provides a positive step change in the delivery of performance over a range of loading conditions. Defence replacement or renewal refers to the re-construction of part or all of a flood or coastal defence at the end of its useful life.

While these different aspects of flood and coastal defence management have been outlined separately for the purposes of analyses, effective management requires their consideration as part of an integrated whole-life performance-based management system.

2.2.1 The Wider Framework of Flood Risk Management

While this report is about O&M, it recognises that O&M is only one of a number of activities that affect flood and coastal erosion risk. The effect of maintenance therefore needs to be understood in the context of these other activities.

If all intervention to a defence asset or system ceases (do-nothing scenario), the probability of damage would increase due to defence deterioration and/or climate change, while the consequence might increase due to development and associated increased runoff. The deterioration in performance over time that occurs in a typical asset/system can be represented as shown in *Figure 2.1*. The exact rate would depend on the type of asset, its state, the loading on it and the environmental condition within which it is located (Environment Agency 2002b).

Figure 2.1 Typical Deterioration Profile for Flood and Coastal Defence Asset System

The behaviour at each of the three stages shown in the figure is dependent on the type of asset/system. The benefit of any intervention can be measured by the reduction in the probability and/or consequence of flooding or coastal erosion as compared to the do-nothing scenario (damage avoided). This concept is illustrated in *Figure 2.2*.

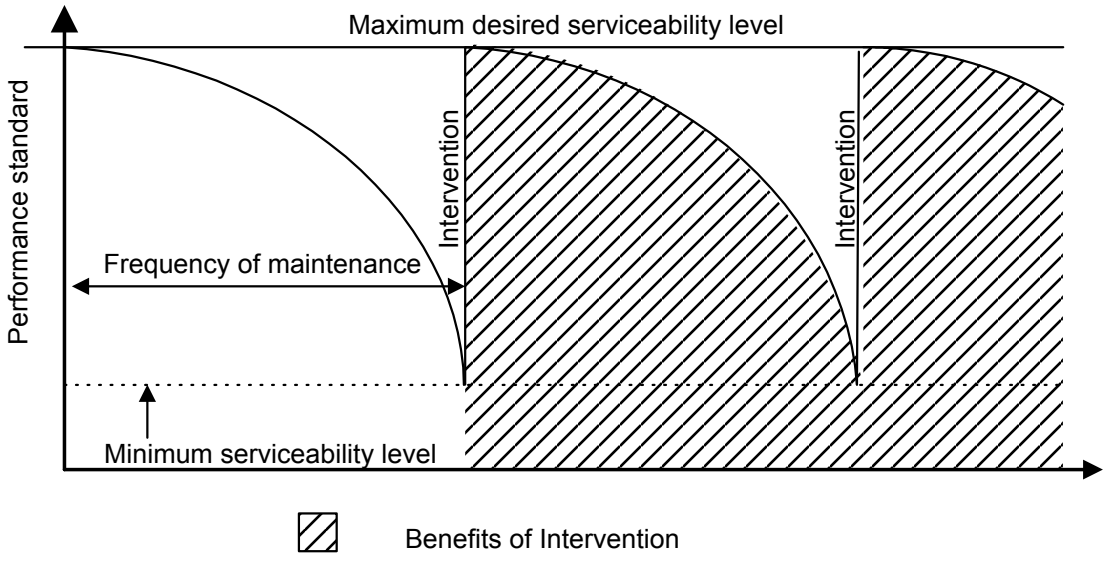

Figure 2.2 Effect of Intervention on Performance

The principal contribution that maintenance makes to reduce the risk of damages occurring, alongside other flood or coastal erosion risk-reducing activities is illustrated in *Figure 2.3*. While the other activities tend to push the future risk to a new position, maintenance tries to keep the probability of flooding or coastal erosion at an acceptable level over the range of expected loading. Maintenance normally has no effect on the consequence of flooding or coastal erosion, apart from in the way it influences the mode of failure and hence the time-scale or severity of the consequence.

Where maintenance levels are "adequate" then the probability of damages occurring remains unchanged. A reduction or increase in the level of maintenance from the present level will result in a consequential increase or decrease in the probability of flooding or coastal erosion as illustrated in *Figure 2.3*.

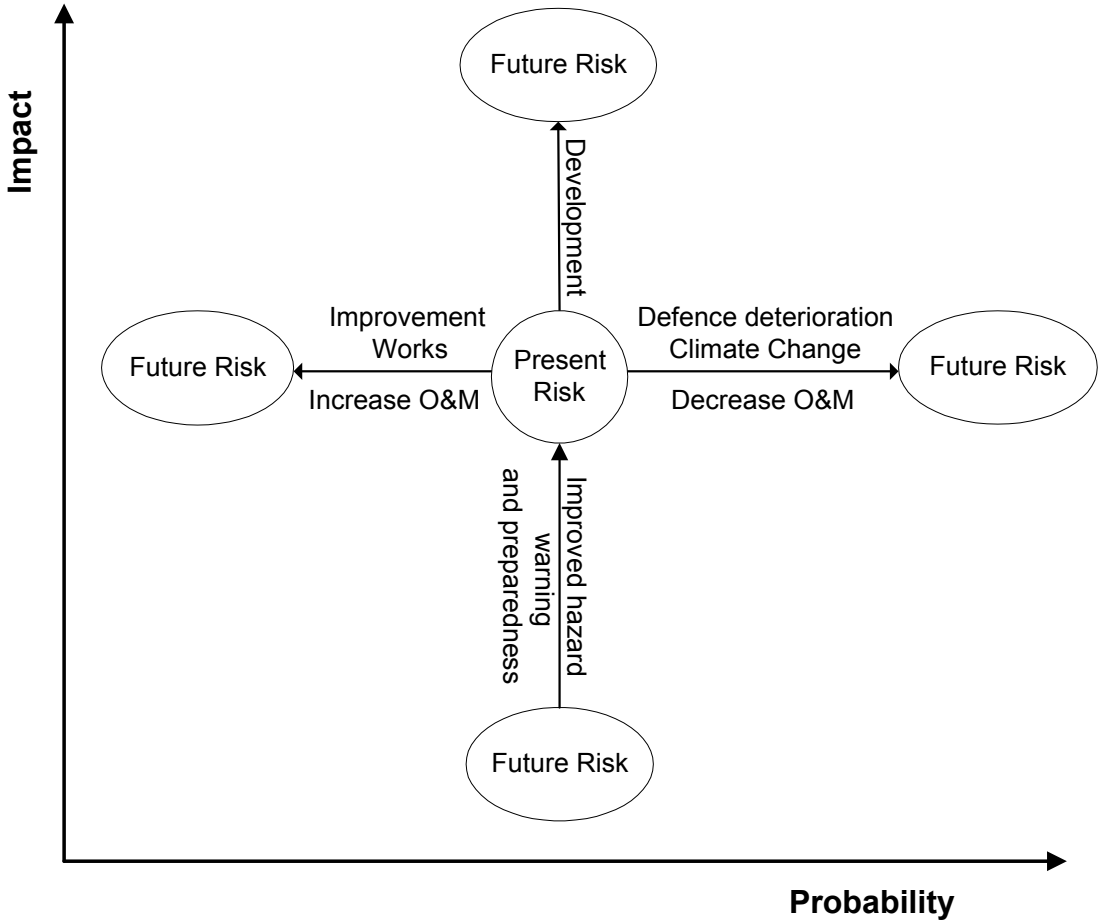

Figure 2.3 Factors which may Influence Future Flood Risk
(Reproduced from Defra, 2002)

Alongside maintenance activities, improvement works are carried out which decrease the likelihood of flood damages. In addition, flood warning and action taken on their receipt reduce the consequence of flooding. Similarly, development control activities on new development have bearing on the number of new properties falling into the "at risk" category.

While the distinctions above have been necessary to position O&M within other activities that affect flood and coastal defence risk, inevitable overlaps between the functions in the management of all interventions from simple maintenance through to complete replacements occur. Fundamentally however, the focus of O&M remains on maintaining a level of performance over a range of loading conditions, through maintaining and amending as necessary the level of O&M activities.

The ability to represent all interventions that affect flood and coastal erosion risk in this form allows a consideration of their effects on performance on a similar basis (such as average annual or present values of damage avoided or increased) by any of the interventions.

2.3 The O&M Framework

Developing from the discussions in Section 2.2, it is clear that there is a need for a system for managing O&M that is performance based. To this end, a generic framework for considering the current state and the future development of O&M has been developed, and is presented as *Figure 2.4*. This framework comprises a number of discrete process activities. It represents the logical process, which needs to be followed in the management of any asset or system.

This framework will enable all interventions to be based on their effect on performance. The broad nature of the process activities puts it on a similar baseline to other interventions and will allow the comparison of various types of intervention from routine maintenance, improvement, flood warning through to replacement on the same performance baseline. This will also assist in bedding O&M better within Defra' Project Appraisal Guidance on Performance (FCDPAG 6).

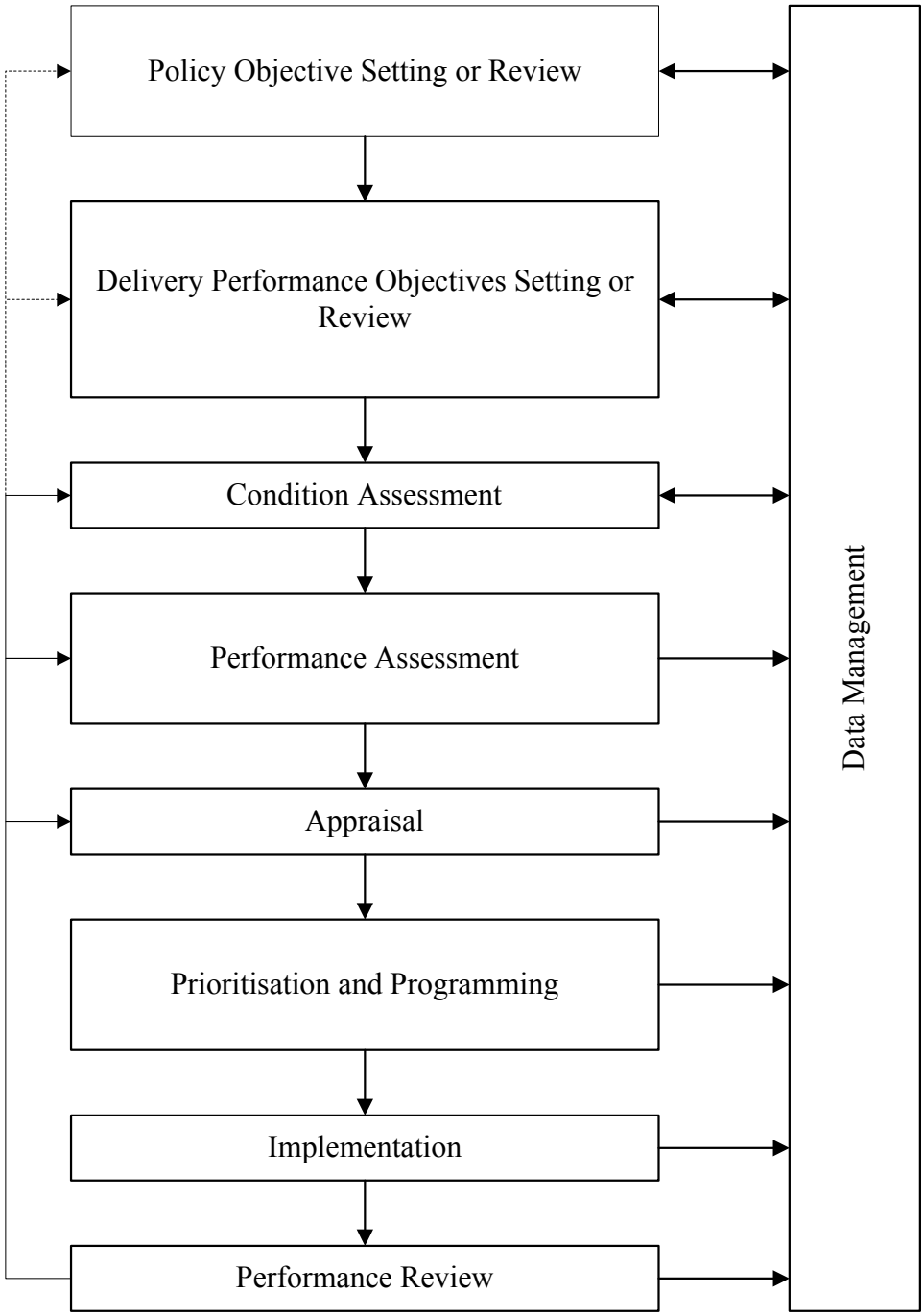

Figure 2.4 Framework for Delivery of O&M

Two aspects of this framework are critical to its success.

- The effective consideration and management of the processes within each of the activities;
- The effective flow of information and outputs from one activity onto the other.

The advantages of using a process based framework for all O&M are as follows:

- It allows the development and use of a consistent data-set for decision making and reporting through the policy, strategy and delivery tiers for flood and coastal management;
- The processes are generic enough to be used in other forms of intervention such as improvement works. This sets a good baseline for the comparison and optimisation of O&M and improvement works, and enables maintenance to be compared to other forms of intervention such as major improvement and replacement;
- It considers the entire processes involved in the management of an asset or system and the links between them, thus reducing the risk of considering interdependent activities as independent "pigeon holes";
- It provides a framework for setting targets, measuring against those targets, and taking well considered action based on the risk of doing nothing, the reduced risk due to a intervention and the cost of the intervention;
- It allows the consideration of the input into processes within and output from each stage in a methodical manner;
- The individual activities are specific enough to allow a proper review and consideration of the processes within them and their interaction with other activities;
- The links between each activity shows the flow of information in and out of it, which should improve data management among the processes.

For a given scenario, the level of analysis carried out for a given management scenario needs to be compatible with the completion of the processes within it. Each of the activities within the framework is considered below:

2.3.2 Policy Objective

This is the starting point for any O&M or other intervention. The aim of any intervention should be clearly linked to a policy objective. If not, the rationale for the intervention should be questioned. The policy objective should have clear links to the higher-level policy objective of Defra for flood and coastal defence in England and Wales, and that of the Operating Authorities.

2.3.3 Performance Objectives

Performance objectives are individual standards which assets or systems are managed to attain and maintain. For consistency, the setting of these objectives are guided by overall policy documents (such as indicative standard of protection based on the consequence of flooding of the protected area). This links the performance objectives to the overall policy objectives and provides indicators by which the adequacy or current-state of the asset or system can be assessed. This two-way link is illustrated in *Figure 2.5*.

In line with more probabilistic methods, the performance objective could be a range of indicators relating to a range of loading or exposure conditions or standards, be allowed to vary over time to account for temporal variations or be risk based.

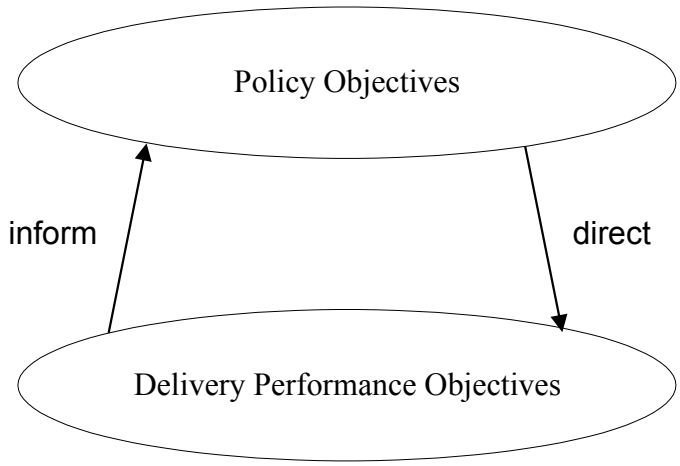

Figure 2.5 Interlinks between Policy and Delivery Performance Objectives

2.3.4 Condition Assessment

This is the process of determining the present condition of an asset or system by survey, inspection or testing. This can be represented by condition grades. The typical processes within the condition assessment will normally involve one or a number of tiered processes for obtaining information about the state of the asset or system and providing reliable assessment of its condition. The output from this activity is one of the key inputs required for the assessment of the performance of the asset or the system it forms a part of.

2.3.5 Performance Assessment

This is the assessment of the present performance of an asset or system. It is based on the comparison of the performance of the asset, given its present condition, to the expected performance defined in the performance objective. This assessment would consider the effect of the condition of an asset on its performance and how critical this performance is to the performance of the whole system or sub-system, which it forms a part of.

Understanding the link between the condition of an asset and the behaviour (response) of the asset under a range of loading conditions is key to the performance assessment. Other useful outputs from this stage are the probability of failure and residual life.

The performance assessment of an asset or system is crucial to the ability to measure the change in performance due to an intervention, or making management decision based on risk. It is fundamental to the broader emerging philosophies on risk management generally and in performance evaluation being considered within the forthcoming guidance FCDPAG6.

2.3.6 Appraisal

This stage involves the investigation of required management action based on the performance assessment. Possible actions include cease maintenance, continue as present, increase or decrease level of maintenance, carry out improvements, renew or replace asset or parts of a system.

The various options for intervention and their relative cost effectiveness or value for money would be reviewed at this stage. The ability to assess the benefit of any intervention on an asset or system is dependent on the understanding of the way it deteriorates under a do-nothing scenario and the effect of the intervention on the systems' performance. The rate of deterioration, benefit and cost of intervention are all relevant when considering the timing and frequency of intervention. The goal is to provide the optimum level of service within the defined policy objective. The effect of different frequencies or types of intervention on the performance of a naturally deteriorating asset is illustrated in *Figure 2.6*.

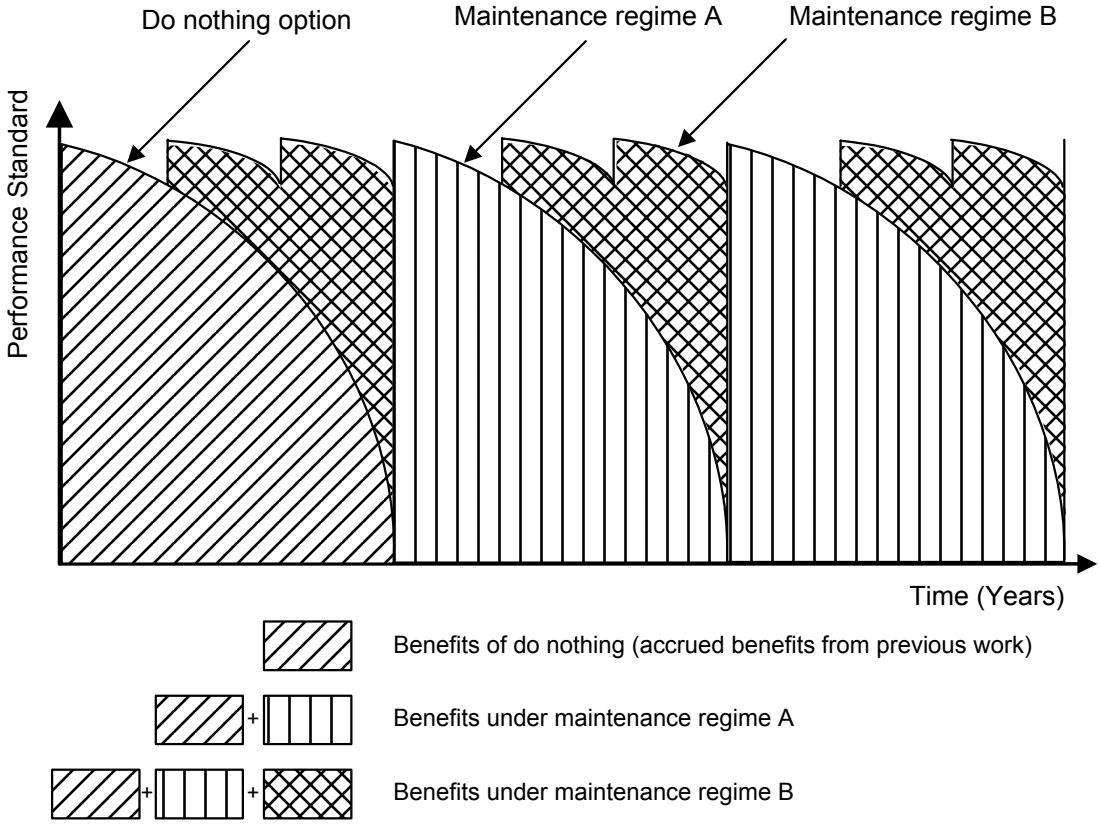

Figure 2.6 Relative Benefits of Various Options or Frequencies of Intervention

The profile shows the standard of performance over time, while the area under the curve shows the benefit (damage avoided) by carrying out the intervention, the most economical schemes will depend on the optimisation of the value added. This is illustrated in *Figure 2.7*.

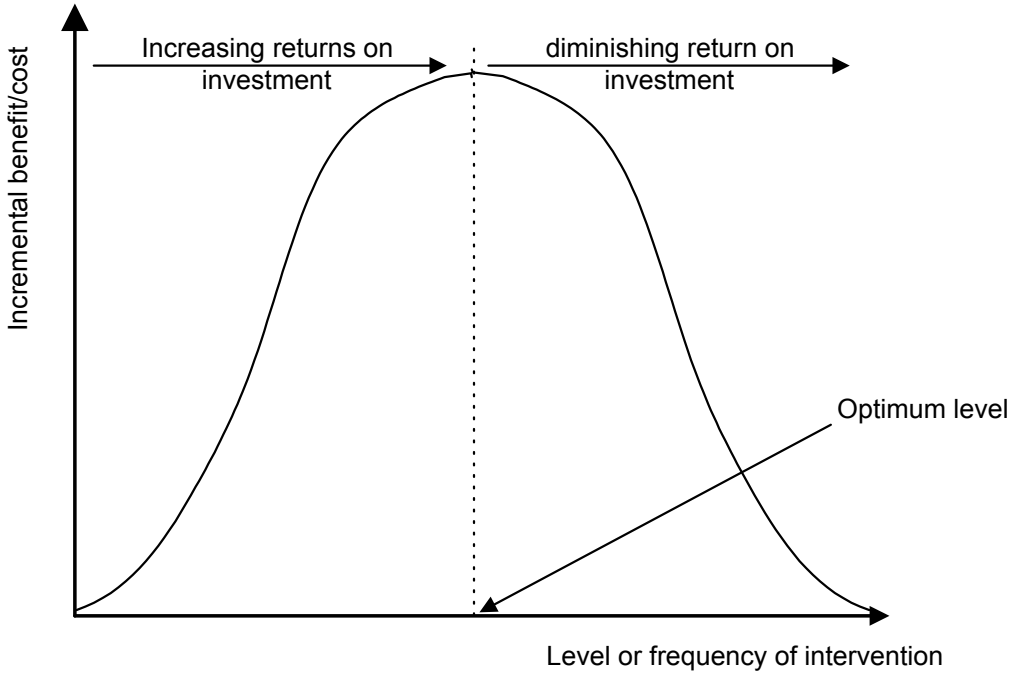

Figure 2.7 Optimisation of Investment

2.3.7 Prioritise and Programme Works

The output of the appraisal process is a number of required management interventions within a number of assets and systems. Due to the finite resources available for maintenance works prioritisation of the works will need to be carried out, based on their relative urgency. The urgency will depend on the relative risks of not carrying out the works, to the performance of the overall system.

Once the required works are prioritised in the terms of risk, they will then need to be fitted into a programme of works, typically an annual programme which forms part of a longer term programme incorporating works which are less urgent or required on less frequent basis. The timing of works during the year will also need to consider the seasonal effects such as summer vegetation, tidal working or seasonal risk. This seasonal pattern may also affect the engineering feasibility and environmental impacts of the works, as well as risk of exposure of a defence. The programme will normally need to be detailed enough for effective planning but flexible enough to incorporate operational emergencies.

2.3.8 Implementation

This is the delivery and management of the programme of works to ensure realisation of the performance objectives. This stage involves the design/specification, procurement and execution of the works. It would usually cover engineering techniques, health and safety, and environmental management among other issues with the emphasis on using available best practice to ensure technical efficiency, value for money, safe working methods, sustainability and environmental acceptability.

2.3.9 Performance Review

The performance monitoring and review is an important process whereby the expected outcomes from carrying out management interventions are checked against expectation. This process will be used to calibrate the whole performance assessment process and enable improved knowledge of the effect of management intervention on performance to be fed back into the decision making and evaluation processes.

2.3.10 Data Management

The success of the framework in providing a logical process for O&M management is highly dependent on the use of information within each of the stages and the management of information across stages. The information should be easily inputted and retrieved from the system in a manner appropriate for various tiers of uses from policy to delivery.

For a simple asset, a system that shows the flow of information, and how that is managed would suffice. At a reach, catchment or local scale, however, more detailed procedures linking the inputs and outputs of each stage would be required. Some automation of some of the processes or use of computer as aids would be required for effective management at this scale.

The fundamental rule in data management is that data input is only sustainable when there is a clear advantage to those inputting the information. The overall management framework, from policy to performance delivery, relies to a high degree on information obtained during routine management of O&M. The function of data, however, at different tiers is radically different in scale, timescale and discrimination.

The use of GIS, supported by databases and tools that connect performance to damage over a range of loading conditions provide an opportunity for meaningful transferral of consistent information between the tiers.

3 REVIEW OF CURRENT PRACTICE

A detailed review of current practice was carried out as part of the concerted action research and presented at a Workshop on 23rd September 2001 (Environment Agency, 2001). A summary of the outcome is presented below within the context of the framework set out in Section 2. Wherever good practice is identified within or outside the flood defence industry, this was particularly highlighted. Due to the scale of importance, some issues of particular relevance to one or a group of Operating Authorities have been highlighted.

3.1 Summary Review

The issues, which stand out from the consultation and review, are outlined below:

- A wider culture change is required to enable effective whole life management, from construction of new works through to O&M, major upgrades and refurbishment/replacement at the end of its useful life.
- Good practice abounds but is not widely communicated and applied.
- Absence of generic basis and systems for recording information across activities and tiers of management is restricting the ability to obtain information required to make decisions based on benefits of O&M intervention.

3.1.1 Whole-life Management:

Organisational set-up especially in the larger operating authorities segregate policy, strategy and delivery as well as capital and revenue aspects of flood and Coastal Defence, without clear management links or lines of responsibilities between the tiers. In addition to this, the difficulty in obtaining grant-aid for maintenance work as compared to new works, improvement or replacement schemes has produced a culture of damage response and budget led O&M management. As a result, some operating authorities have elected to maximise opportunities for capital works instead of working towards optimum management of the whole life cycle of their systems. Effective links between these tiers is critical for the optimum management of flood and coastal defences over their life and across the whole range of expected loadings (including management of extreme events).

A framework is required in order to achieve effective whole life management within a range of organisational structures which do not necessarily assist the cause. The framework development concentrates on managing the processes within the whole life chain and allowing effective information transfer within it. An example of transfer of information between new works or major improvement and O&M is shown in *Figure 3.1*.

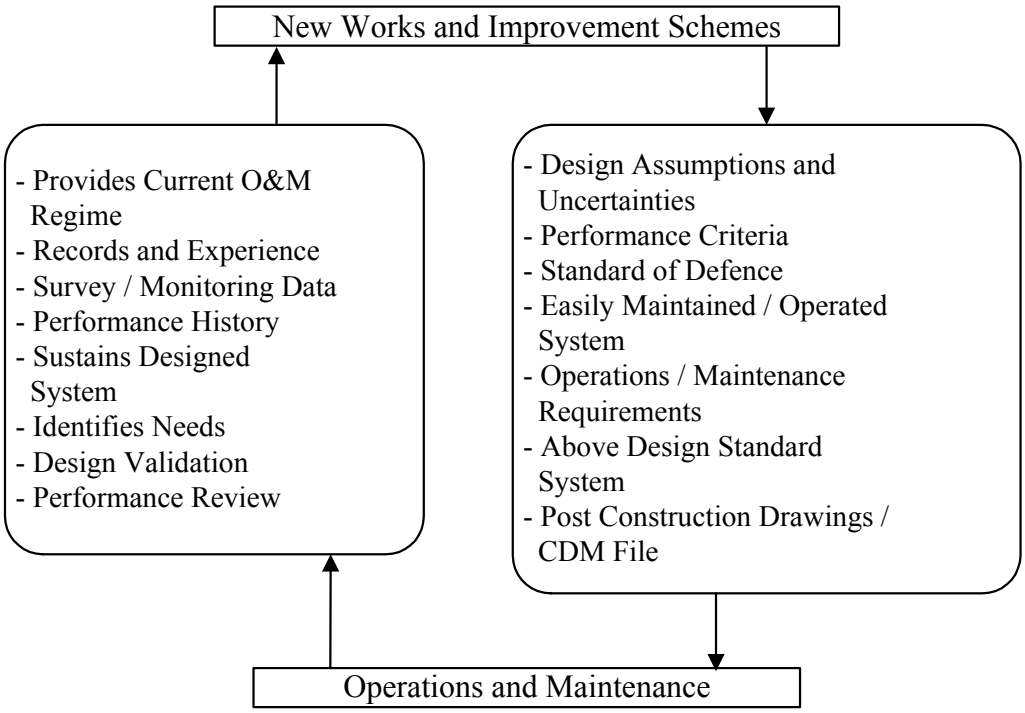

Figure 3.1 Interlinks between Improvement / New Works and O & M

3.1.2 Application of good practice

Reviews and consultations showed that O&M engineers, due to their closeness to the sharp end of delivery, are very innovative and have through experience and improved knowledge from elsewhere developed good techniques for maintenance and operational management. There is however a large degree of variation in the application of the good practice within and among operating authorities. This wide variation shows that there are considerable benefits to be gained from collation and dissemination of good practice to raise the standard of practices within the industry in general.

3.1.3 Information management:

Despite an annual spend of about £90 million per annum within O&M attempts at obtaining detailed whole life costs, deterioration rates, benefits of work, features and similar performance related information have been hindered in some areas by a lack of consistent terminology and comparable data. This coupled with lack of information on links within systems make it difficult to build up strategic or policy level information from local delivery records. The development of the National Flood and Coastal Defence Database (NFCDD) is seen as key to achieving improved information management, as existing and new systems will rely on it for information. It therefore needs to address this consistency issue with the use of generic activities that can be tiered though up to policy level information and which data management tools from operating authorities can relate to. There will

be, however, a need to ensure also that the NFCDD is designed around a need to accommodate synopsis of information from a range of data management systems designed around broader and different sector management requirements. It will also be essential to recognise that a number of IDBs and local authorities are progressing ideas of individual management databases and GIS systems. NFCDD will need to consider the issue of data transfer from such systems and vice versa. The pilot testing of NFCDD is ongoing and should provide an opportunity to review the data transfer, compatibility to relevant systems and ease of use.

In addition to the three issues above, which stood out from the review process, it was clear that there were some particular high knowledge uncertainties within some processes, which were very critical in terms of flood risk management. Particular issues from the review of the current state of the O&M business is presented in the following sub-sections.

3.2 Policy and Performance Objectives

3.2.1 Policy Objective

Government's policy as it concerns flood and coastal defence is set out in Defra's strategy for flood and coastal defence in England and Wales. This can be summarised as follows:

- To reduce the risk to people and the developed and natural environment from flooding and coastal erosion; and
- To provide flood and coastal defence protection which is sustainable in terms of engineering, economic, environmental and social considerations.

One of the key issues, which emerged from the consultation and review process, was that while there was a good understanding of the overall policy on flood defence there was however, a clear difficulty in applying the policy at operational and delivery level. This was particularly highlighted on the issue of "Do Nothing Policy" (now referred to as "no active intervention") from Shoreline Management Plans (SMPs), in effect being ignored at a local maintenance level due to lack of communication, inability, or of lack of guidance on implementation.

A review of the flood defence industry and the construction or process related industries in general identified that good practice in the effective delivery of policy required a clear knowledge and management of the processes cycle from policy to delivery. Within this particular attention needs to be given to the processes within as well as the inter-relationships between the processes. Such process cycles need to be captured in a single and clear framework, the management of which will ensure effective tiering of a consistent chain of thought through the process life cycle. Another key element of the framework is the development of a two-way process of

information transfer, where strategic and delivery issues, results and constraints inform policy direction, as suggested by *Figure 2.5.*

The outline of a process-based framework has been developed (*Figure 2.4*) with the above good practice in mind.

This hierarchical process is beginning to be established from the higher tiers through the development of Catchment Flood Management Plans (CFMP) and (SMP). These are establishing strategic approaches to managing defence systems and producing direction for decision making at a Catchment or Coastal cell scale. The CFMP processes have recently been developed and undergone pilot testing. They are now being reviewed with the view to catchment scale plans across the country. A modelling and decision support framework (MDSF) system has been developed to provide assistance in assembling and managing catchment data, guidance on flood water level prediction, calculation of flood extent, and flood depth, and their associated economic damage and social impacts. The SMP process has been around for longer. A two-way process across the tiers is being encourages through the reviews undertaken as part of the ongoing second generation of SMPs, although not yet emerging as a clear system of upward dissemination.

The hierarchy of policy/strategy/solution is the whole basis of CFMP and SMP process, and from it should flow the future balance of O&M and improvement schemes. Tools to assist strategic planning are being developed within the Risk Assessment for Flood and Coastal Defence for Strategic Planning (RASP) project. These tools would provide flexible risk assessment methodologies to support decisions such as strategic prioritisation of flood and coastal defence investment, targeting flood warning and emergency preparedness, prioritisation or justification of maintenance and optimisation of scheme design. The strategic outputs from these processes should therefore be the starting point for O&M intervention and to ensure a two-way process. O&M information needs to feed back through to inform the updating of strategic decisions. This management hierarchy is illustrated in *Figure 3.2.*

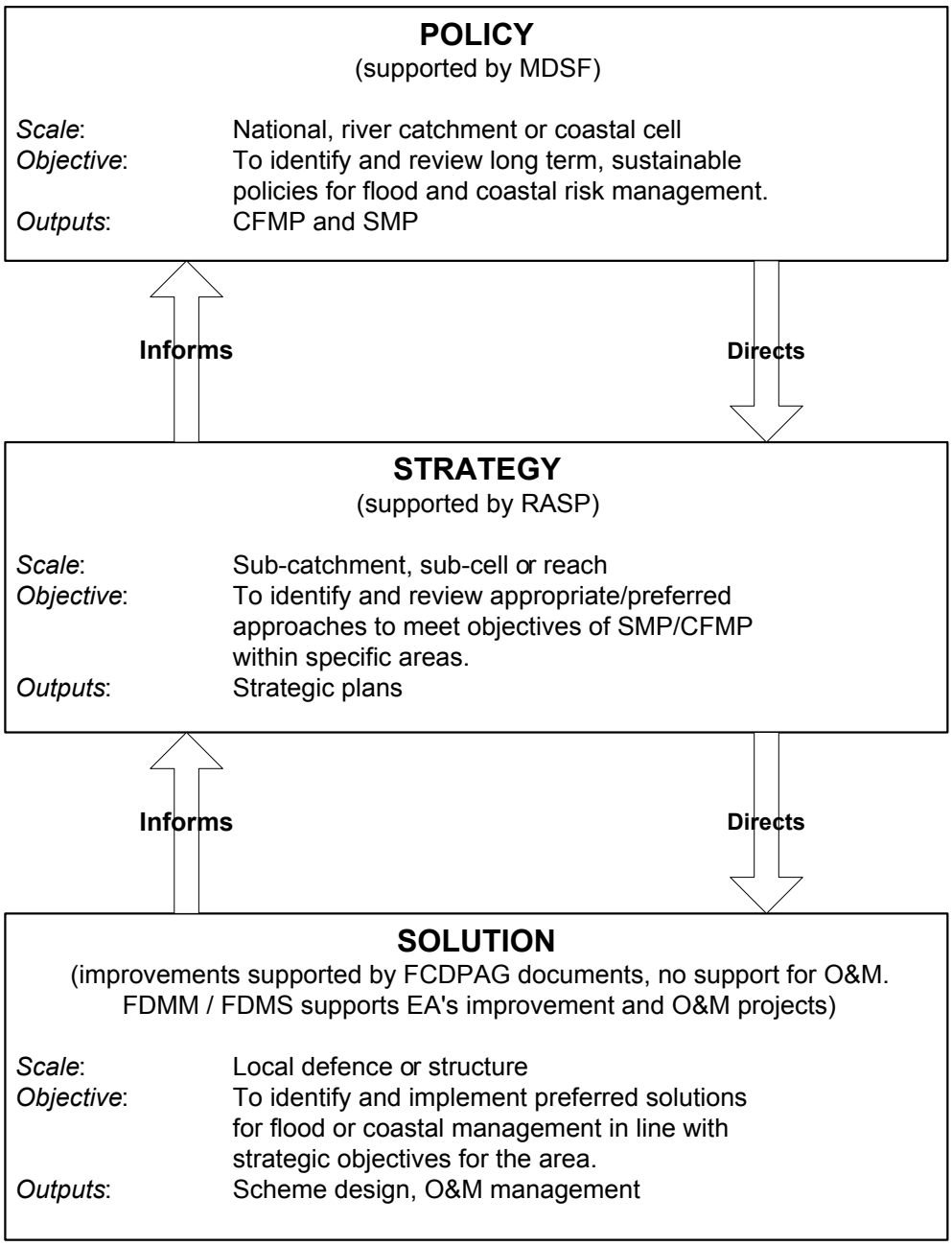

Figure 3.2 Flood and Coastal Defence Management Hierarchy

Recent development within operating authorities show renewed focus on management of whole process cycles. An example of this is the Environment Agency's Management Systems (AMS). The AMS is a new process-based framework that allows the Environment Agency to set out procedures for consistency in good practice, and provide a framework for its continuous improvement. The development of this process would require

the identification and collation of best practice in all activities within the O&M Processes.

3.2.2 Performance Objective

Performance can be defined as the creation or achievement of something that can be valued against some stated initial aim or objective (Defra, 2002).

A review of current practices show that performance-based management which involves the development of clear and measurable performance objectives is not carried out consistently within the business as compared to other parts of flood and coastal defence such as improvement works or flood warning. Where an area being maintained has been subject to an improvement scheme in the past, it is usually managed in an attempt to maintain the standard of the scheme. It was noted that the level of intervention to maintain the required standard is seldom communicated to the O&M team following the improvement scheme. Where there is no previous scheme or strategic study, there is no clear framework or guidance within which performance standards are set. In a majority of cases some apparent standard of management has been developed over time, usually without any obvious basis. These methods are unsustainable in the light of environmental pressures, changing levels of public perception and most importantly the need to optimise management intervention in terms of flood risk, value for money and other performance indicators, which are inherent in the policy objective.

Within flood and coastal defence improvement works, the suite of Flood and Coastal Defence Project Appraisal Guidance documents (FCDPAG) provide guidance for the appraisal of improvement schemes. FCDPAG3 (MAFF, 1999b) has within it indicative standards of protection, which relates a range of annual probability of failures to the land use and hence potential consequence of flooding. These same standards have been reflected in the Environment Agency's Flood Defence Management Manual (FDMM). While this is not provided as entitlement to protection, its adoption within O&M and minor improvement schemes do improve the consistency between performance objective setting across flood and coastal defence. It provides for the management of all systems irrespective of whether they have been subject to previous improvement or new works in the past. These indicative standards are related to house equivalents and can amount to over simplification and it presently ignores the human aspects of flood damage. In terms of coast protection, performance objectives are more situation-specific in terms of serviceability requirements and often irreversible once a section of coast is eroded it is lost.

An accepted good practice is for performance indicators, which can be measured and are related to the overall policy objective to be developed. These indicators will then be monitored over time and through periodic performance reviews following an estimation of present performance levels.

Performance objectives need to be understood and set in a hierarchical way, which recognises the various tiers (policy, strategy and delivery) and the interaction between them. There is a requirement for the objectives to be cascaded through the tiers to avoid conflicts. FCDPAG6, which is currently being developed, will provide national guidance on performance evaluation.

3.3 Condition Assessment

A review of practices within the operating authorities showed that all performed formal or informal condition assessments for their flood and coastal defence assets. These range from having special asset inspection teams, to carrying out inspection as part of routine operations and maintenance activities. The predominant form of asset inspection is by visual methods. The present procedures such as the FDMM (Environment Agency, 1997), aided by the National Sea and River Defence Surveys Condition Assessment Manual (Environment Agency, 1999), assist in the visual assessments and derivation of condition grades ranging from one through to five. Where one indicating very good condition and five indicating very poor condition.

An independent audit into the EA's visual condition assessment concluded that while the assessment methods were applied with reasonable consistency across the EA's eight regions, key differences existed in what constituted an asset and in the reporting methods. It also showed that little information on the design, construction and history was used within the assessment. The condition assessment processes generally concentrate on visual inspection, which is of limited use for some types of assets, without reference to other forms of monitoring and testing which may be necessary to obtain reliable assessments. The relationship between the assessed asset condition and their performance is unclear. This is as a result of non-application of loading/response/damage models within the assessment process. This link is crucial in order to relate assessed condition to performance. In some cases visual condition assessments are being interpreted to infer performance assessment despite their being no clear link between the assessed condition, performance objectives and risk of failure. Most of the more formal systems include an assessment of residual life. The basis for the residual life assessments was often unclear.

Good practice within flood and coastal defence as well as similar industries such as rail, water, dam and highways suggest the use of suitably experienced personnel for the condition assessments. In the dam industry for example, professionals carrying out various levels of inspections and supervision are empanelled and their suitability periodically re-assessed.

A good assessment process involves three key stages:

- background information gathering and determination/review of frequency of inspection
- asset inspection

- condition assessment (which may include further testing).

This process is outlined in *Figure 3.3*.

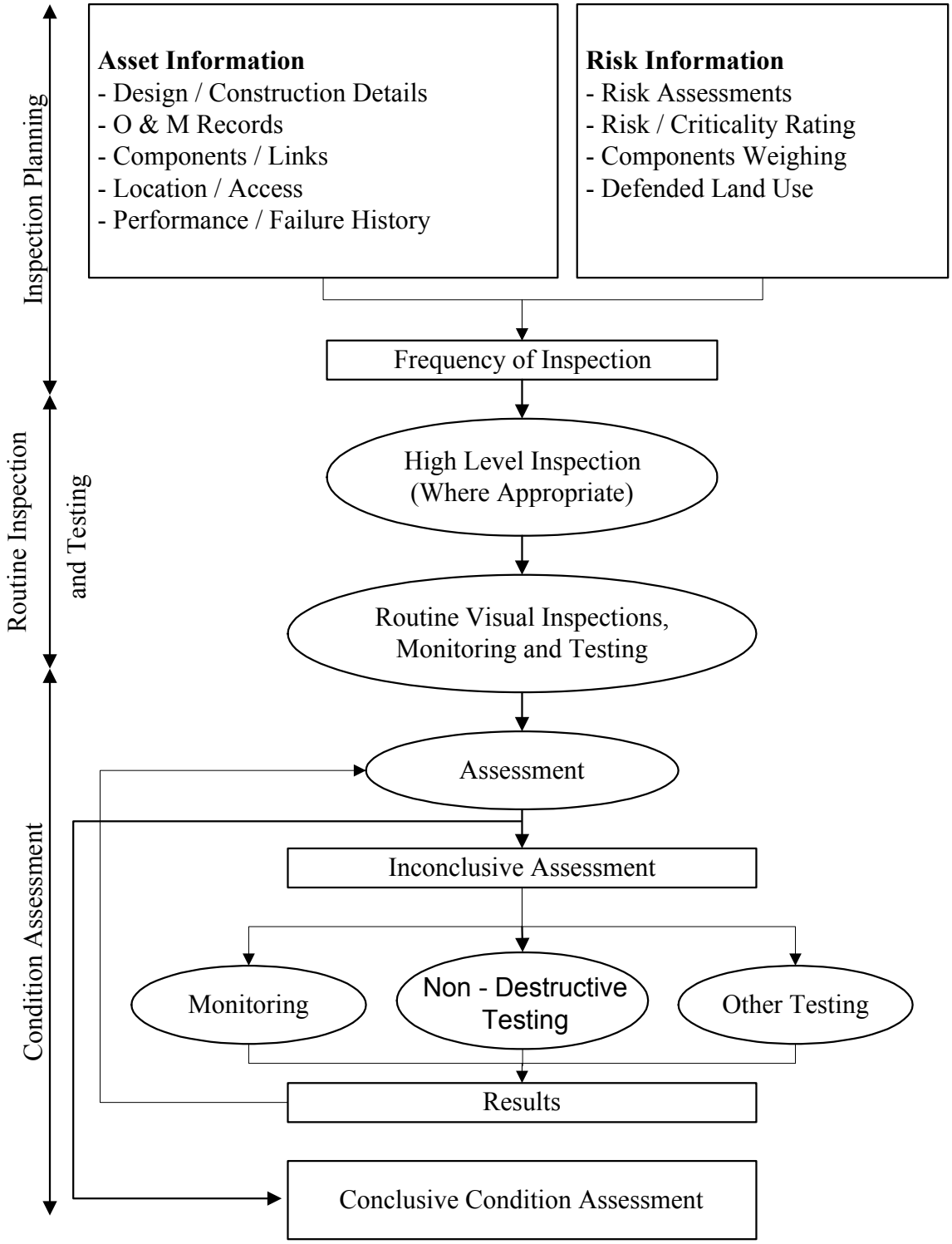

Figure 3.3 - Condition Assessment Process

3.3.1 Inspection Planning

Background Information: Background information about the assets such as their design and construction, their interaction with other assets and their system, information on how they deteriorate with time, their history and past inspection records guides the inspection and helps to provide realistic assessments. The front-end cost of documenting such information should not prevent the process as experience shows it to be of immense value, and once documented with the right systems, updating is very easy. Where actual information such as year or method of construction or improvement information is not available, the best available information, such as decade of construction or use of construction techniques to estimate period of construction, often suffices. The important issue is the collation of best available information to ensure all assessments are carried out using a common basis.

Frequency of Inspections: Inspection frequencies need to be based on the risk of flood and coastal erosion at the system level. A number of operating authorities have developed generic frequencies for the inspection of various types of assets. While this considers the likelihood of their failure and how that could affect the system, the consequence of the failure depending on the nature of the protected area is seldom considered. Best practice requires all aspects of flood and coastal erosion risk to be considered to ensure optimum levels of inspection based on risk. At a simple level, the probability and consequence can be represented by low, medium or high and the relative risks analysed on this basis. The level at which this risk is considered, needs to be at a system, flood or coastal cell scale, with frequency based on both the relative effects of the individual assets on the performance of the system and the expected rate of deterioration of the asset. The inspection frequencies once set are then reviewed over time based on inspection results, or significant changes in loading or content of the protected area. The Environment Agency has recently developed a risk-based system for determining the frequency of inspection of their flood defence assets.

3.3.2 Asset Inspection

Accepted good practice for asset inspection involves a tiered process outlined below:

i) High level inspection using quick assessment tools such as remote sensing. This would allow relative movements and settlements and failures to be identified and can help target other more detailed assessments to areas most at need. This level of inspection is increasingly being used within the general construction industry. It is presently more suitable for long linear assets/systems. A review of the use of a helicopter mounted laser scanner and digital photography (Environment Agency, 2002a) confirmed its potential

as an asset management tool for linear assets. Further guidance is required on the required type and standard of outputs that would be required from such systems when used for flood and coastal defence inspection.

ii) Visual inspection. This would follow the high level inspection where appropriate or be the first stage in the process. This would involve on-site inspection of all visible parts of the asset, with critical non-visible parts inspected at pre-determined intervals based on risk, and in some cases non-accessible parts may require CCTV or robotic technology.

iii) Monitoring and further testing. This would be required for assets where a visual assessment is not sufficient to give reliable information on which to base an assessment of the asset and the risk of failure are sufficient to justify the expenditure. It could involve non-destructive or intrusive methods. A recent publication - 'Geophysics in engineering investigations' (CIRIA, 2002), provides good information on the application of non-destructive testing techniques. In addition to this a framework for use of non-destructive testing in flood and coastal defences has been developed following a review of use in similar industries (Environment Agency, 2002d).

This stage can be used as part of a routine assessment following a risk assessment of the asset or as a means of further investigating the condition of an asset. Critical assets in particular require a high level of confidence in their assessment relative to their risk. Where visual inspection cannot give an assessment with high confidence, then further testing should be developed as part of the routine condition assessment process. Further testing can also be used following a possible defect or concern highlighted by a visual inspection.

3.3.3 Condition Assessment.

This is the process of reviewing the results from the earlier tiers of inspection, and assessing the condition of the asset. Where the assessment result is inconclusive, further testing or monitoring would be required to produce a conclusive assessment.

The assessed condition needs to be reviewed in the light of performance information for the asset and the system, which it forms a part of, in order to carry out a performance assessment of the system. This link between condition assessment and performance is key to determining how a change in the condition of an asset affects its performance and that of the overall system.

3.4 Performance Assessment

A review of current asset management methods within flood and coastal defence showed that the link between the assessed condition of assets and systems and their performance is often blurred.

3.4.1 Performance Assessment Methodology

Current best practice as indicated in a recent review (Defra, 2002), highlights the importance of linking condition characterisation from the condition assessment process to performance levels.

Once this is done, performance assessment is then simply the review of the asset or system condition in the light of other performance determinants such as design standard, performance and failure history. The outputs from the performance assessment include the estimation of residual life, failure probability, factor of safety against failure and importantly whether the present performance meets the performance objective.

The performance assessment process is a hierarchical process whereby the performance of the assets is assessed following which the system performance is assessed from a consideration of the relationship between the performance of the individual assets and that of the system. This suggests a pre-understanding of this inter-dependence. It also introduces the concept of critical assets within the systems, which are the ones whose performance is most critical to the performance of the system. Current methods involve classifying the relative importance of each asset using a range of numbers (say 0 – 10, or low/medium/high at the very simple level).

A methodology to support hierarchical performance assessment from asset, sub-system and system through to overall policy has been developed within the Defra/EA/EPSRC R&D project "Condition Monitoring and Asset Management of Complex Infrastructure Systems, (CMAM)". This tool is a software-supported methodology for linking performance indicators to overall system performance. This good practice is currently being used within the development of RASP. It involves associating each defence asset to fragility curves that describes in probabilistic terms the defence response to loading. A fragility curve is a plot of conditional probabilities of failure of a defence over a range of loading as shown in *Figure 3.4*. By characterising the defence responses to loadings a probabilistic assessment of probability of flooding can be made. Flood extent and depth information is obtained from flood spreading tools and converted to damage data from available flood depth/damage tools. The flood risk is then calculated using the probability to flooding from loading/response data and consequence of flooding from the damage data.

The key aspects of the above methodology is that complex information can now been represented by simple functions such as fragility curves and that there is now the capacity to develop decision support tools in the face of

uncertain and incomplete information. This is made possible by the characterisation of uncertainty within the process and the hierarchical set-up of the tools being developed which allows varying levels of information to be fed onto the systems, but allows all levels of decision making to utilise the same consistent set of data. The more the available data, the less the band of uncertainty gets.

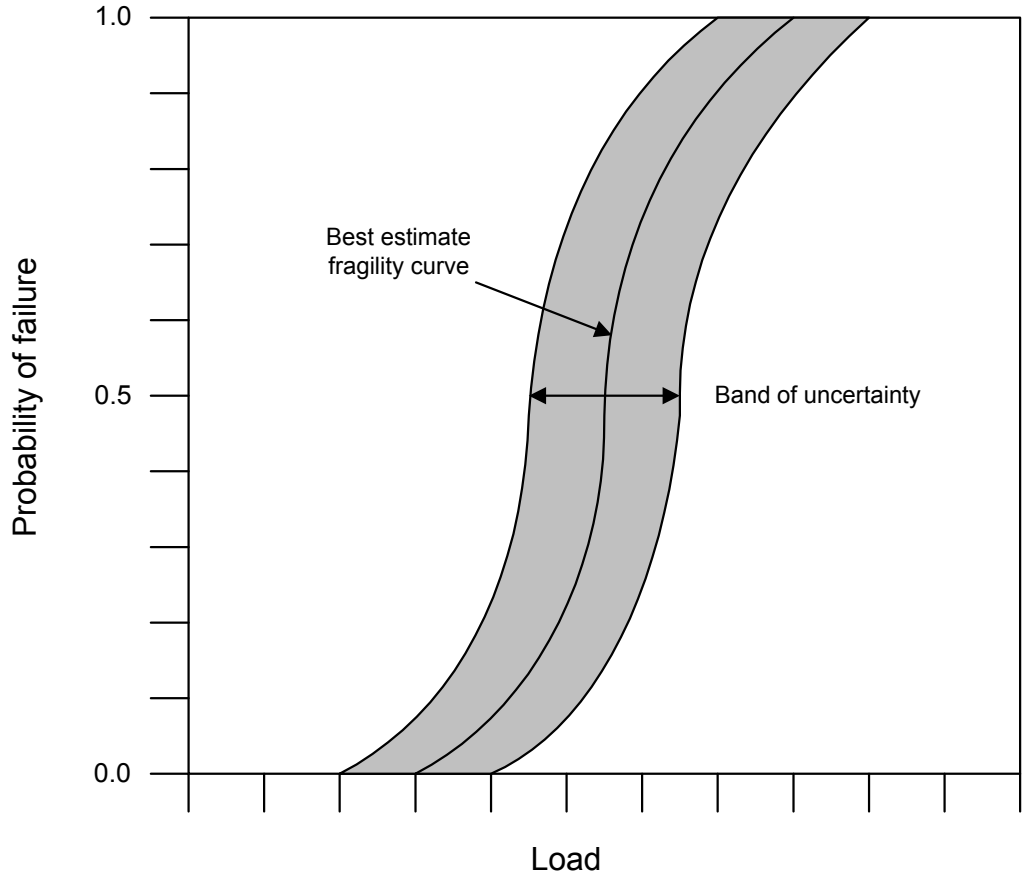

Figure 3.4 Typical Fragility Curve

Such approaches are seen as good practice as they are in line with the general move in the industry towards probabilistic approaches to flood and coastal management. The recent and ongoing works outlined above are targeted at strategic and higher levels. There is considerable benefit in tailoring these developments to O&M management and pilot testing them to improve confidence in their practicality.

3.4.2 Performance Assessment of Defence Assets

A review of the ability of performance assessments to be carried out from current (predominantly visual) condition assessments showed that there was a lot of knowledge about the performance of defence assets such as concrete, steel, brick and block walls. There was however insufficient knowledge about earth embankments and masonry (stone) walls in

particular and soft engineering works in general. Understanding of the performance of soft engineering coastal structures such as dunes, shingle beaches and soft cliffs often depend on the understanding of the coastal processes. The deficiency of knowledge on embankments is of particular concern as embankment is the most used form of flood defence. Recent condition assessments and failures show that the current methods may not be robust enough to assess the performance of earth embankments. An understanding of the effects of embankment composition state, cover, foundation and exposure on its ability to withstand loadings and its breach process when overwhelmed is required in order to assess its performance and the critical factors that affect it. This current situation has led to widely varying embankment monitoring and management methods within and across the Operating Authorities. With regards to soft engineering and newer technologies, field trials in their use are required within routine management and improvement works to further understand their behaviour, required whole life management and durability.

Assessing the performance of coastal defences is particularly difficult, as the data to calibrate performance following storm events is not easily comparable to the design data. This is due to the number of variables usually involved such as water levels, wave periods, wave height, beach movement (wave run-up), wave angle, wind direction, depression tracks and surge. The ability to measure these variables and the wave and water level they cause is limited by the limited tide gauges available along the coast. The improvement of performance monitoring ability is necessary in order to assess the performance of the systems, to understand their behaviour and to assess their requirements for effective whole life management.

The ability to characterise this varying complex information with simple diagrams should allow probabilistic characterisations to be made for this system, and all available information used within decision making. The more knowledge or data there becomes available, the less the uncertainty. The particular complex nature and mobility of coastal processes and soft defences are being specially considered in the ongoing research in the improved use of fragility curves (Performance and reliability of flood and coastal defence structures).

3.4.3 Performance Assessment of Structures

Structures are used within flood and coastal defence to control flows or other processes within, to or from a system. They include watercourse flow and level control structures such as sluices, outfalls, weirs and pumps, and sediment control structures such as groynes and breakwaters. Most flood defence structures require operational management over all ranges of flow conditions, including extreme conditions. The current practice is to have routine inspection and maintenance of the structures as recommended by manufacturers where such information is available and by generic frequencies based on experience from other structures. A good level of knowledge exists in what works are required to ensure the performance of

moving structures during normal usage (including civil, mechanical and electrical). Ensuring their reliability during major events after long periods of limited use is an area of uncertainty.

In particular for coastal structures, the severity of the conditions, access difficulties and cost makes robustness of structures and minimisation of maintenance a major factor. For beach control structures such as groynes or breakwaters, their performance (as opposed to condition) may best, or even only, be assessed in terms of their success in modifying coastal processes and sediment movement. This ties in with the system level assessment.

3.4.4 Performance Assessment of Systems

Systems are usually made up of a number of assets. This could be a coastal cell/length or channel/flood plain reach. Two areas where major performance assessment issues were identified are in river/floodplain conveyance assessment and in coastal defence performance assessments.

A number of activities are carried out to improve the conveyance of river channels such as weed-cutting, dredging and obstruction clearance. The annual spend on these items are a significant part of the O&M budget, however it is normally unclear what the effect of these activities are on the channel conveyance. In order that interventions are based on effect on flood risk or other performance objective, the effect of these interventions need to be clearly linked to performance. This requires better assessments of the effect of vegetation, siltation and other types of channel deposits, on the conveyance of various types and sizes of channels, and the effect of options for intervention on them. Also these activities can have environmental impacts which the Operating Authorities aim to minimise. A targeted programme on flood conveyance is ongoing within the Defra/EA R&D, which includes the development and pilot testing of a conveyance estimation system.

Ability to manage coastal morphology at a system cell/sub-cell scale is inherently linked with our understanding of coastal processes and the long-term response of coastlines, with or without intervention. Current storm response models (with the exception of quite basic beach performance models) are limited in terms of identifying long term behaviour. System behaviour over a longer term may well depend on a series of events and quite possibly on threshold change or very specific loadings. Improvement in the scale of storm response models in terms spatially and temporarily, and long-term morphological processes are ongoing within the Processes Theme research. The development of a hierarchical performance system should however, still enable decisions on system management to be taken based on current knowledge on performance, with the band of uncertainty reducing over time as more knowledge becomes available. It should be noted however, that current practice on coast protection is moving away from rigid control. This of necessity may increase our uncertainty as to the precise behaviour of the coast.

3.5 Appraisal

A review of the current practice within the business showed that some appraisal of required levels and types of maintenance intervention occurs. The extent to which consideration of the adequacy of present levels of intervention is appraised has been limited by the knowledge base in quantifying performance. Also once some level of performance is determined, the lack of link between condition assessment and performance makes performance monitoring difficult hence limiting the ability to make decisions on whether the level of intervention is adequate or if changes are required.

Once a decision is made that a change in the level of intervention is required, there is good knowledge on identifying the best technical options. The inability to quantify the additional benefits derivable from the intervention, however, makes it difficult to justify works based on risk reduction. Where a step is required from one level of performance to the other (improvement), guidance within FCDPAG3 often suffices. Where maintenance intervention is required, the lack of published information on the rate of deterioration of various assets and the effect of that on their performance makes obtaining a baseline information for comparison of performance under a given level or range of maintenance standards difficult.

Some methods which describe good practice for determining the optimum levels of maintenance intervention have been developed within a 'quick-win' study carried out as part of this concerted action (Environment Agency, 2002b). This provides understanding of the important concepts involved in decision making.

In addition to identifying the benefits of an intervention, the costs associated with the whole life management of the asset or system is also required to determine the most cost-effective option. This includes consideration of one-off new build, improvement and replacement costs as well as maintenance and operational (routine and emergency) costs. Current practice shows that aggregated costs are usually easily obtainable at the catchment or coastal cell scale, but not at the asset scale. Where these are available, the non-standard methods of characterisation make them difficult to compare on a larger scale.

Best practice within the wider industry suggests the development of generic asset and system types and the recording of their whole life management costs within management database or system. This should provide the basis for improved whole life costing and assessment. A methodology for considering whole-life costs in port, coastal and fluvial engineering is now available (HR Wallingford, 2002). This confirms the importance of whole life costing and assessments in making appropriate investments at the macro scale (between improvement and maintenance, and between replacement

and extension of the life of an asset), and at the micro scale (making decisions between asset management options).

Having considered the whole life costs and benefits of each option for intervention, a benefit/cost analysis is carried out to compare each option ensuring the cost and benefit information use to the same base. Accepted common bases include Net Present Values (NPV) or average annual values (AAV). While economical optimisation is usually the most important objective, the appraisal needs to be in line with the stated performance objectives, which could also include health and safety, legal obligations, environmental and sustainability objectives. Some of these may be overriding in some cases.

Operating authorities currently carry out detailed appraisals for improvement schemes but less carry them out for general maintenance works. The Environment Agency's FDMM provides a framework for appraising non-capital schemes. While some of the methodologies are based on good practice, the work required for each appraisal process does not make it user-friendly especially for smaller projects. Absence of a link with GIS limits its application in terms of flood spreading and damage modelling. The assessments within it are also not clearly linked to performance. The integration and part-automation of a number of the data and processes required would be needed to ensure more modest efforts are required for it or any other future methodologies. These could include information on flood risk (mapping and damage information), effect of intervention on flood damage, effect of do-nothing and historical costs tiered through asset, river-reach/coastal-subcell and catchment/coastal-cell.

Ongoing developments within CFMP and RASP are already automating the entire processes of loading, response, inundation and damage. Similar system for O&M work should provide more useful and user-friendly system for the appraisal of flood and coastal defence interventions. Lessons from the application of FDMM/FDMS to date show that at an O&M scale, ability to represent complex data by simple methods and availability of systems that are user-friendly, but allow robust appraisals of options for intervention are required.

3.6 Prioritisation and Programming

The output of the appraisal process is a number of management interventions, which need to be prioritised and developed into a programme of works. As compared to particular improvement schemes, prioritisation of O&M work is complicated by elements of work, which are mandatory, by nature such as health and safety or legal requirements. The current practice among most organisations is to prioritise works based on their apparent urgency within any budgetary constraints from the source of funding.

Best practice suggests that prioritisation should be based on a comparison of the relative risks, reduction obtainable by carrying out the works. Issues

such as current performance level and rate of deterioration under expected loadings are critical to such considerations. Environment Agency's FDMM provides a process which considers present level of service as compared to target standards and the land use. While this uses information on the present state, no effect of deterioration has been considered which could lead to wrong assessments for assets with significantly different deterioration profiles, or those at various stages of deterioration within their life cycle. While this may be acceptable with current knowledge on deterioration of assets, improved knowledge in the area should improve ability to prioritise. Good practice involves providing priority ranking for works (such as 1, 2, 3, 4, 5) accompanied by describing the level of urgency. Another method would be to have periods during which work must be carried out to maintain the required level of performance (such as <3 months, 3-6 months, 6-12 months, <2 years, 2-5 years and >5 years).

Once a prioritised set of works are available this needs to be collated into a programme of works. Most operating authorities prepare annual programmes of work, which are updated throughout the year. These programmes are based on priorities and other constraints such as budgets, timing to fit engineering, environmental and other constraints.

Best practice requires the development of broad programmes over the largest estimated time for required works and more detailed annual programmes. The use of flexible electronic packages where adequate links are provided within activities which affect each other is crucial to the management of ad-hoc operational and emergency events In these events provision can be made within the programme but probability of occurrence and timings can never be pre-determined. Generally knowledge base and application in this area is good.

3.7 Implementation

The implementation includes the management and delivery of the programme of works for the flood and coastal defence area. This includes the design, procurement and execution of the planned work and the operational management of the systems during events above their design standard to manage the remaining flood risk.

Once the required work is decided and programmed, techniques for carrying out engineering works are generally well developed as compared to other processes within the framework. The Penning Rowsell Report (MAFF, 1999a) confirmed that previous research and development work had concentrated on this area and other areas should be allowed to catch up, to enable effective performance management of the whole life of our systems. Particular attention is however paid here to specific activities due to the amount of money spent on them, or where significant issues were highlighted during the consultation and review stages.

3.7.1 Dredging and Obstruction Removal

Dredging is a major spend for most operating authorities. It is also the activity that provides most waste products. Whole bulk disposal is becoming expensive and unsustainable. Most operating authorities carry out dredging works during the winter season to balance workloads and minimise environmental damage. Best practice in the assessment of the amount of dredging required is by conventional surveying for small channels over short lengths and boat mounted ultrasonic bed level survey tools for longer sections where the depth of water permits its use. The use of laser based techniques have so far proved inappropriate, due to the inability to assess levels below water.

Techniques are available that provide some guidance on which sections of the watercourse is more critical to conveyance and those that are less. Further knowledge is required in this area to more confidently decide when silt or other channel deposits pose a threat to channel conveyance and how efficient dredging can ensure optimisation of conveyance and environmental enhancements while working with the natural morphological processes as much as possible. Good dredging practice documented with two CIRIA documents, "Inland Dredging - guidance on good practice" (CIRIA, 1997) and "Guidance on Disposal of Dredged Material to land" (CIRIA, 1996b).

Best practice, which provides maximum cost-effectiveness and minimum environmental impact, requires the maximisation of re-use of the dredged material within the site, re-use of remainder at appropriate locations and minimisation of any disposal to landfills. Dredging techniques vary from land based to water-based excavation and suction dredgers. There is generally good knowledge by practitioners on available techniques and their appropriateness.

Removal of obstruction to channels and structures is a key activity carried out to avoid constrictions within the systems which can cause blockage or reduce conveyance or obstruct the operation of moving parts of structures. Obstruction within channels is more common in urban watercourses, a lot of which are non-main rivers. Disposal of removed materials is an increasing problem as re-cycling is seldom possible due to the content and state of the deposits.

Another major form of blockage occurs from trees and branches growing within conveyance paths or those, which have fallen into or across channels. They form obstructions by themselves and also act as skeletons for floating debris to latch onto and create a larger mass of blockage. Such obstructions are managed by stopping the unwanted vegetation from growing or cutting them back away from the flow path. The challenge is ensuring an environmentally friendly management without compromising conveyance standards.

Obstruction at structures tends to be at constrictions especially where weed screens are present and within structures themselves (such as small culverts).

Good practice in the management of blockage requires the estimation of the debris load, proper consideration of the need and design of screens and adequate consideration of blockage removal methodology and technique. These could involve automatic mechanical means such as weed-screen cleaners depending on the risk of blockage. Good practice in the consideration and management of blockage from weed-screen is documented in Environment Agency's guidance document, (Design and Operations of Trash Screens – Interim Guidance Notes, NRA 1995). This guidance is currently being updated with the 'Trash Screens - Design and Operations Manual' (Environment Agency, 2003).

3.7.2 Salt Marsh and Beach Management

There is a general move among practitioners to provide softer management for soft cliffs and beaches, working more with the morphological processes. In addition to obvious recreation and amenity advantages, high beach levels adjacent to coastal protection and sea defences provide wave attenuation and increase the stability of the defences.

Techniques for maintaining beach levels include construction, lowering and raising of groynes, beach recycling and dredging. The success of these methods requires a good knowledge of the processes along the length of coast concerned. One of the critical issues with beach management is ensuring structures such as groynes are adequately maintained to be able to carry out their designed purpose.

Techniques for groyne repairs whether timber or rock are well understood, however, even though cost and access difficulties often make their robust design for minimum maintenance the most cost-effective option. Considerable experience has been obtained on beach management, and is provided within the Beach Management Manual (CIRIA R153, 1996).

While beach management is a relatively well developed technique, salt marsh tends to be undertaken at a more strategic scale and local maintenance techniques such as warping or creek closure are still developing. Many of these draw upon traditional experience. The processes surrounding salt marsh regeneration are not well understood. While environmental legislation has limited the number of new sea defences where material is sourced from the seaside, the regeneration of old borrow pits is still a concern. These issues are being addressed within the processes theme.

Salt marsh management is however, a growing area of comprehensive research at the strategic level. Ongoing research ranges from examination

of estuary morphology, re-suspension, sediment movement and monitoring of coastal re-alignment schemes, to the evaluation of wave attenuation by marshes and the influence of invertebrates in the development of salt marsh. These recent and ongoing studies are producing new knowledge that needs to be applied. An update of the existing guidance produced by the National Rivers Authority "A guide to the understanding and management of Saltmarshes - R&D Note 324 (NRA, 1994a)", is required to establish and disseminate current best practice. This update needs to incorporate both engineering functionalities, and overall habitat management guidance regarding effect of marsh levels.

3.7.3 Dune and Coastal Cliff Management

The management of an eroding coastline or cliff needs to dovetail behind a more strategic assessment at SMP or lower strategic scales. At this stage, the development of the preferred strategic direction would have considered the local protection of the cliff, with respect to the sediments which erosion protection would prevent from contributing to the dynamic stability of the rest of the coastline.

Current cliff management activities carried out by operating authorities are generally to slow down erosion, remove or stabilise unsafe overhangs and reprofile soft cliff faces to improve stability. Following a recently completed soft cliffs research project funded by Defra, a book has been published by Thomas Telford, "Investigation and Management of Soft Rock Cliffs" (E.M Lee et al., 2002) now provides current best practice in soft cliff management. Defra is currently producing its own publication (due Autumn 2002) from the same research focused on providing guidelines to coastal managers (rather than detailed advice to engineers). Opportunities should be taken to trial the techniques within the O&M programme. Cliff and general coastal monitoring needs to be improved. Improved use of remote sensing should assist in this regard due to access difficulty and scale.

Dune management varies in scale from major profiling, where aeolian erosion has occurred, or re-nourishment, where there are problems with supply, to local replanting and sand fencing. The techniques are generally well developed, although more frequently, in the past, as habitat management rather than coastal defence. Good practice is being developed for monitoring along the East Anglian Coast (Sea Defence Management Strategy) integrating both local and strategic level need and information from a variety of sources.

3.7.4 Vegetation Management

Vegetation management is carried out to maintain channel conveyance, to provide effective cover to earth embankments and to allow safe inspection of assets and other uses of the assets. An underlying objective, which all operating authorities carry out within vegetation management, is

maximising habitat creations and management within the flood and coastal defence functional objectives.

The techniques for aquatic and bank vegetation maintenance are well developed. The consultation process identified a major problem with maintaining adequate standards of engineering functional performance and environmental performance. This has led to a wide variety of management methods, timings and frequencies of management within and across Operating Authorities.

The effective management of flood and coastal vegetation management needs to be based primarily on functional performance. This relies on knowledge about the required functionality of any system and the effect of any intervention on it. The principal function of a flood or coastal defence structure or flood conveyance system is to provide a particular level of performance over its whole range of loading conditions. The flood and coastal defence O&M functions is to ensure this performance is maintained. Within the management strategies to ensure functionality the optimum environmental effect should be achieved. This optimum effect relies on a clear definition of environmental objectives and benefits for the system or locality and the indicators of environmental performance for a proper consideration of the decision on management intervention.

To improve knowledge in the effect of interventions on performance, field trials of different management techniques are required to investigate the engineering and environmental effects of various forms of intervention. This will also help trial new products such as drought tolerant or low maintenance grass. The Environment Agency Regions and Areas have developed a number of options for vegetation and channel maintenance. These contain a lot of good practice for options for management. There will be a lot of benefit in pulling them together into a national document to promote a consistent standard and framework for management based on flood risk reduction. There is a plethora of environmental guidance on vegetation management. These includes "Nature Conservation and the management of drainage channels" (Newbold et al., 1993).

The control of invasive weed (such as Japanese knotweed, Himalayan balsam and hogweed) within aquatic and bank vegetation is a major issue which has legal implications if not controlled or if improper control leads to further spreading. The weeds out-compete the more desirable vegetation during the summer and die off in the winter leaving banks unprotected. A study into biological control of weed "Scoping study into the biological control of aquatic and riparian weeds in the UK" (Environment Agency, 1996) confirmed the significant cost effectiveness of biological control over chemical or mechanical means. Further research and trials are required in this area.

3.7.5 Operational Management

A key part of O&M is the operational management of the systems and processes during normal and extreme events. Current practice shows inadequate links between design, maintenance and operation of normal and extreme events. Information on how extreme loadings will affect defence systems and its effective management is often an after- thought. Good practice demands the consideration of responses and their management at a system scale over the expected range of loading. The issues surrounding the extreme event management and associated costs should be part of the considerations during the appraisal and design stages.

Effective risk management involves the management of all risks within a system, ensuring the protection offered and the investment on them is commensurate with the risk of loss or damage to the people and property protected. This would involve the whole system along an entire coastal cell, or a river catchment, from source to sea. Such risk based management is apparent in other developed countries such as flood management in the Netherlands, where good information exists on the flood extents, and the defended areas are managed in terms of the risk of damage to life and properties within their 53 hydraulically unconnected defence rings.

UK's ability to follow such good practice will rely on better use of GIS information to establish flood compartments/rings, extents and expected loss and damage to people, natural and build environment at a catchment and national scale. Whole life operational management of flood events will then be based on flood risk reduction. This is of particular concern for operational management of extreme events, where controlled over-topping of pre-planned artificial breaches into lower value areas could be considered. Such operational management relies upon good knowledge of flood cell boundaries, extent of flood spreading and potential loss/damage.

In terms of coastal protection similar issues will apply when considering the effect of coastal protection at a local site on the whole cell or sub-cell. These however, depend more on the coastal processes and loading/response of the coastal structures/defences. Issues such as health and safety risk assessments and management are important and knowledge and practices within operating authorities are generally in line with good practice. Extreme events are by their nature rare, less predictable and occur following little notice. Good practice suggests the need for adequate planning, resourcing training and readiness. Operational management in itself is a management planning and response process, but relies on information about estimation of loadings, expected response of the defences and systems and a knowledge of the resources and techniques to manage the event.

Earth embankments provide a special case due to their non-homogeneity and current low knowledge base on their behaviour, the formation and propagation of its breach under extreme conditions. A recent publication, "Temporary and Demountable flood protection - Interim guidance on use"

(Environment Agency R & D Publication 130, 2002c), provides guidance on choosing and management of temporary and demountable flood protection systems. This provides a means of increasing the probability of flooding for short periods of time without the long-term aesthetic impacts. The use of this document needs to be backed with training and testing of available systems to confirm their performance and limitations.

Current practice during extreme events is to utilise real-time monitoring if available to produce an up to date information on loadings. This is normally backed with on-site monitoring. There is a need for increased use of real time forecasting for flood and coastal extreme event management. These issues are being addressed within the flood forecasting and warning theme. At a strategic scale severe coastal events can normally be tracked along the East coast, however the conditions on the west coast tend to vary to a greater extent with wind and wave direction making prediction confidence levels low. At a local defence scale, the complexities of wind, wave, surge and depression tracks can create a highly variable water depths in relatively short distances and as such cannot be accounted for by the present low level of coastal tide level monitoring points.

The improvement of knowledge in the response of defences to extreme conditions will require proper documentation of the loadings, response and operational management techniques during such rare events.

While these events are rare along specific reaches, they are less rare at a national or international scale. There is a need for the collation of available data on response of defences to extreme loadings and the formation and propagation of breaches. To improve the availability and usefulness of future data, there is a need for the development of a national procedure for incident recording by bringing together best practice within the industry. This procedure must recognise the relative magnitudes and record requirements of the range of events. An Environment Agency document "Emergency Sealing of Beaches (NRA, 1994b) provides a good approach for the planning, execution, monitoring and post-event reviews of beach repairs.

3.7.6 Resource Management

The larger operating authorities employ operational staff who carry out majority of their O&M work while smaller authorities contract out routine and/or emergency resourcing or have contracts for obtaining extra staff during extreme flood scenarios. The Environment Agency carries out most if its O&M activities via their Emergency Work Force (EWF). An Environment Agency Report, "Flood Emergency manpower response" (NRA, 1993) confirmed the huge benefits of retaining an in-house emergency workforce and the importance of O&M work to their skills development. Another study "Viability of emergency plant and vehicles" (NRA, 1992) confirmed that the economic justification of the Authority's ownership of its emergency plant would require their use in maintenance

and some capital schemes. A database of plant, vehicles and equipment was developed as part of this study. This or any similar database on plant could not be identified during consultation. An up to date record of plant and resources is crucial to the assessment of resource capability for future emergencies. An Environment Agency national team is presently reviewing the EWF and its management.

A review of existing practice showed that the methods of procurement of services where these are not available in-house varied depending on the policy requirements of each organisation. Good practice procurement methods are available within the industry. It is good practice to know the limitations of the use of in-house resources and have plans in place, preferably contracts, ensuring availability of adequate resource at short notice, for more extreme events. The new framework agreement with contractors opens an additional opportunity to the Environmental Agency for development of longer-term resource for emergencies greater than the current 1 in 10 years event which the Agency EWF is resourced for. The record of plants and other resources available in an emergency should be extended to include those obtainable from the framework contractors at reasonable notice. A review of resource requirement for national extreme events is currently ongoing within the Environment Agency.

3.8 Performance Review and Data Management

3.8.1 Performance Review

The success of the framework described in Section 2 relies on appropriate collation of performance information, the review of effect of intervention on achieving policy and delivering objectives, and the feedback of that information back up to inform policy and other process associated with its achievement. In other words it is a process of learning and feedback. Some particular information required by Defra is outlined in Defra's high level targets (MAFF, 1999c).

Until recently performance measurement and review was not carried out within flood and coastal defence in a consistent manner. More recently the Defra targets and the renewed desire to obtain a national picture of flood and coastal defence has led to the consideration of consistent methods of measuring, and recording performance at the delivery level and cascading that upwards through the strategic and policy tiers. The review of performance depends on the ability to characterise performance of assets and systems at the delivery level and measure the change in performance as a result of management interventions. Good practice in performance review suggests the setting of clear performance indicators, which cascade through and are clearly linked from policy to delivery. The performance indicators should be measurable and relate to the state of the defence systems. The success of this process relies on good data management through the framework chain, which enables performance information at all levels to be obtained from a consistent set of data. FCDPAG6 currently being

developed will provide future guidance on best practice in performance review.

3.8.2 Data Management

The transfer of information within and between processes within the framework is critical to its overall success. The data requirement can be summarised as follows:

- data on damage (consequence of flooding, erosion, or overtopping)
- data on loadings on the defence systems
- data on standard and state of defence systems and their components
- data on performance of defence systems over a range of loading conditions
- data on effect of interventions on system performance

A review of data management and storage within flood operating authorities showed that a number of systems are used to store and manage information on separate processes within O&M with no apparent ease of linking the outputs for overall data management and performance-based decision making. Common systems in use for information storage and management include Flood Defence Management System (FDMS), Data Update Capture System (DUCS), Flood Plain Information System (FPI) and SANDS.

There is a need for a system that is able to store all types of performance information from flood plain data to defence performance data, where tiered decisions and outputs are based on the same sets of data. Such a system needs to be supported by tools linking the floodplain information to damage, state of assets to expected performance under various loadings. While such systems should be based on the recording of generic performance indicators linked to performance objectives, at the delivery stage they need to be adaptable for use or easily compatible to other systems. This is necessary to allow operating authorities to record the level of information they require for their local management as long as these are linked to the overall generic performance indicators for consistent information management up the tiers. Systems developed with setting of performance objectives, identification and measurement of performance indicators for all range of interventions in mind is required for a successful performance-based asset management system.

The NFCDD being developed needs to be a warehouse capable of storing all performance information including information on loading, condition of assets and systems and flood plain/defended area information. Databases required to input and retrieve information from NFCDD also need to be able to supply similar information in compatible formats.

Various sectors of the Environment Agency are demonstrating the benefits of a step change that can be achieved by the use of databases to support decision-making. This work is presently confined to the higher tiers; strategy and CFMP development. These developments are advancing

knowledge in the use of decision-support tools to better assist with performance-based management. There is a clear benefit in developing such a system to assist in making consistent decisions based on reduction of flood risk and other performance improvement through the tiers of management. Such a system will aid risk-based decisions within O&M using incomplete or deficient information by considering the uncertainties over the range of loading/response/damage processes. This recognises that information on which managers have to base decisions on are usually incomplete and while the uncertainties can be reduced with time, they will never be removed and hence have to be managed. The development of any system should include proper pilot testing and end-user input. Ease of use and compatibility rated highly during consultation with O&M managers.

The way improved decision making would fit into the current risk information management framework, is shown in *Figure 3.5*.

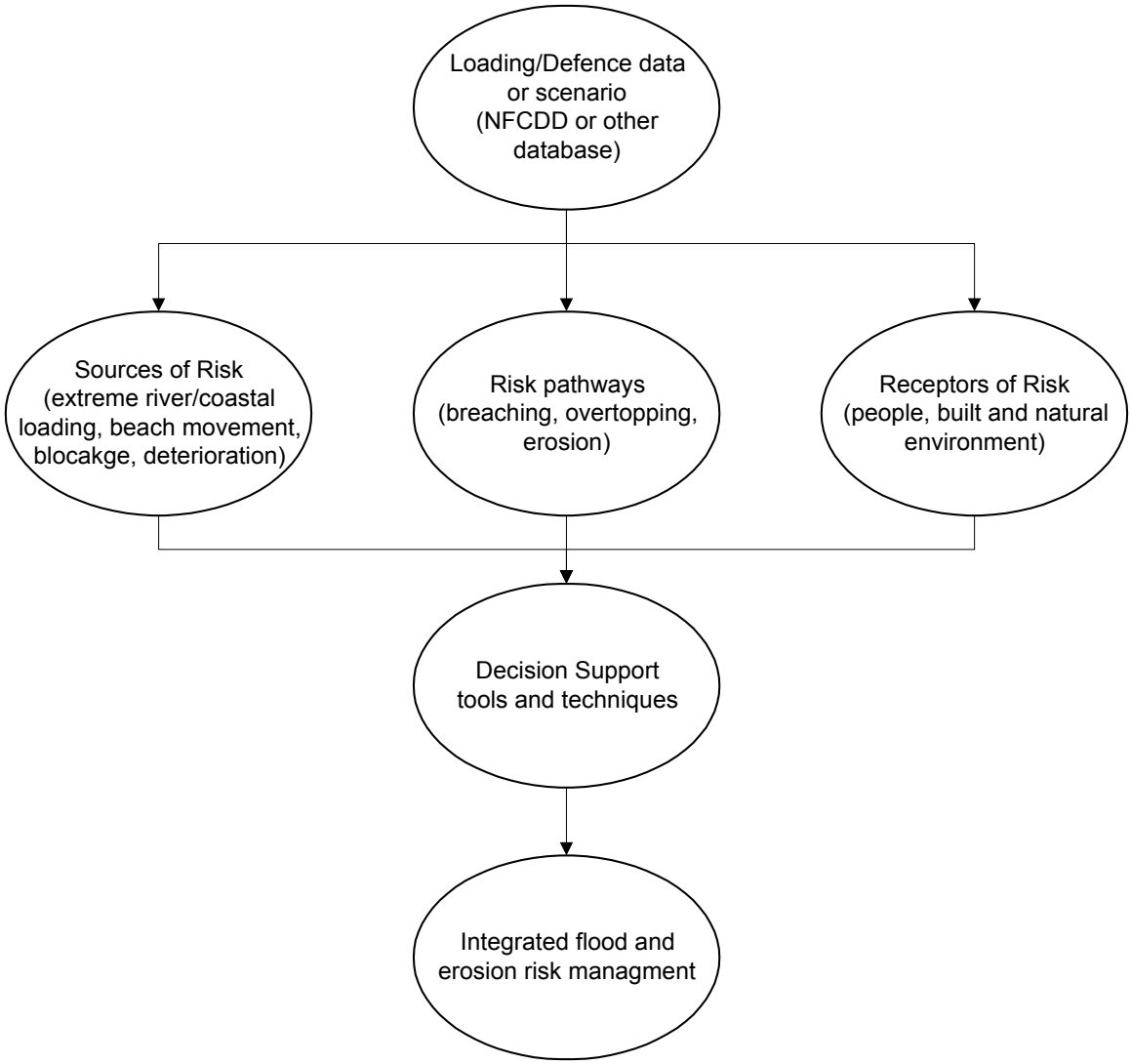

Figure 3.5 Provision of Decision Support within Integrated Flood and Erosion Risk Management

4. PRIORITY AREAS FOR ADVANCEMENT

This section presents the proposed future priority areas for advancement of the improved delivery of O&M services to the business. It is based on the need to develop the framework presented in Section 2 in the light of the review presented in Section 3.

"Advancement" necessarily covers a spectrum of activities aimed at making the business more effective. These range from major R&D projects carried out to deliver a step change in the business process, through lesser R&D projects that give an incremental improvement to some aspect of O&M, to the routine task of continuous improvement carried out by the business itself.

4.1 Approach to future O&M Development

4.1.1 Development of the performance-based management framework

The key elements of the O&M decision-making framework that need developing are condition assessment, performance assessment, appraisal and the prioritisation of options (Figure 2.4 refers). Since this aspect of O&M is relatively poorly developed and, for the Agency, must fit into the tiered approach to flood risk management (Figure 3.2 and Annex A), this aspect of future O&M development should be planned and delivered as a step change.

While several individual projects have taken place (particularly over the last few years on characterising risk and performance and developing concepts for their application to higher tiers of decision making), little work has been done on implementing a performance-based approach to O&M management. These prototype methodologies need to be piloted on actual flood management systems in order to set and monitor performance objectives, and the changes in performance of defence systems caused by different options for management intervention. This will achieve the overall objective of carrying out and prioritising intervention (including optimising the balance between O&M and improvement works) based on its effect in reducing flood and erosion risk or other performance objective.

A similar performance-based approach must also be piloted on improvement works so that a consistent process is developed for both aspects of flood or coastal erosion management. For decisions on management interventions to be based on reduction of flood risk or other performance improvement, analysis of benefits and costs over the whole life (or some appraisal period) is required. Estimation of the benefits of a management intervention requires realistic assessment of the deterioration profiles and reliability of the asset or systems (with and without intervention) and easy-to-use flood probability and "damage / probability" assessment models. This generic approach is described in Annex A.

The development and proper linkage of the above elements are a pre-requisite to the development of what we have termed a performance-based asset management system (PAMS – see Figure A.2 for its position within the proposed integrated system of data management and modelling tools).

Estimation of costs over an appraisal period requires reasonable estimates of the relative costs of intervention over the period concerned.

4.1.2 Development of specific tools and techniques

Alongside putting the performance-based management framework into place, major benefits can be gained in the short term from lifting the whole of the O&M business to a higher level of competence by maximising the use of existing knowledge and practices currently available to the business. This includes:

- transfer of knowledge into the O&M business from other sectors,
- collation of known good practice from within the O&M business, and
- application of knowledge from past research.

In all cases, this would be followed by wide dissemination into the O&M business. Priority would be given to issues where there is a big gap or variation between potential best practice and current practice.

In many cases, at the local level, many O&M techniques and practices were found to be well developed and at a high level of maturity. Experience has been captured and past investigations have addressed that aspect of the business. However there will be benefits from developing and rationalising these nationally.

If possible, the process of drawing together and disseminating existing knowledge and practice is best addressed within the O&M business as continuous improvement (through avenues such as the Environment Agency's AMS). It is suggested that R&D funds are used to assist the development of the most critical and highly beneficial ones – e.g. those that provide a step change in capability, for example with the improved approach to the management of embankments.

4.1.3 Pilot and demonstration projects

Areas where the knowledge, tools and techniques are reasonably developed would benefit from the use of pilot or demonstration projects in the form of site trials to achieve best delivery to users. Opportunities should be taken to trial new methods as part of ongoing or planned maintenance and improvement works, or in collaboration with other projects to obtain maximum value. Where this is not possible, maximising the use of sites, which have been developed for monitoring, would increase cost-effectiveness. Fundamental research would be required where the basic underlying science is not well established.

4.1.4 Priorities and approach for programme development

Priority should be given to those issues from which greatest incremental benefits (i.e. returns per £ of development funding) will be obtained. These are (i) developing the first step in performance-based management, and (ii) optimising the application of current knowledge and practices. Alongside these, R&D funds should be applied to developing new knowledge, tools or techniques in issues showing either of the following:

- High combination of (a) risk and (b) knowledge uncertainty
- Significant expected response to R&D investment

The establishment of (i) and (ii) above will provide huge benefits and allow performance-based management to develop within the business. Management intervention will then be based on realistic assessment of effect on performance (principally flood and erosion risk reduction). This in effect is a step forward into PAMS, and a commitment to updating existing management systems such as the Agency's FDMM/FDMS into performance-based systems. This approach is summarised in Figure 4.1 and forms the basis for the prioritised research areas outlined in Section 4.3.

The improved understanding of the effect of intervention on the performance of defences and the flood or coastal management system will then guide the prioritisation of future research. The ultimate goal is to develop a management system and best practice techniques for carrying out all O&M processes which could be available together (or in a limited or cross-reference form). These are illustrated in the overall system of data management and modelling tools in Figure A.2.

In summary, maximum benefit can be achieved in terms of O&M by bringing together knowledge from recent and ongoing projects and from current best practice and making them widely available for use within O&M nationally. This will gradually move the whole of the O&M business to a position of current best practice.

4.2 Ongoing R&D programme

The O&M Concerted Action was carried out alongside, and has influenced, other relevant ongoing R&D projects, concerted actions and scoping studies within the Joint Defra/Environment Agency R&D Programme. These are summarised in this section.

A clear consensus has emerged over the past 12 months across the six Themes of the Joint R&D Programme that a tiered decision-making framework must be developed for flood risk management. This view has been strongly influenced by the parallel R&D projects in the Risk and Broad-scale Modelling Themes where work on the RASP and MDSF projects has been done to deliver decision-making tools for Flood Defence practitioners (see below). It was also confirmed by points raised at the O&M Concerted Action workshop held in September 2001. The tiered framework will draw together a number of ongoing projects. Those relevant to O&M are summarised in Section 4.2.1 under the heading "performance-based management framework". (Note that the start and end dates are shown).

Other O&M issues that were already ongoing, or which have been identified as being of high benefit from the initial review and discussions with end users, have been progressed in parallel with the development of the Concerted Action. Those that were better progressed within other themes and subject areas were passed onto the appropriate teams. In some cases, opportunities have been taken for early starts and collaboration with other funders to address issues of common concern. These other O&M issues are summarised in Section 4.2.2 under the heading "self-contained projects on specific tools and techniques".

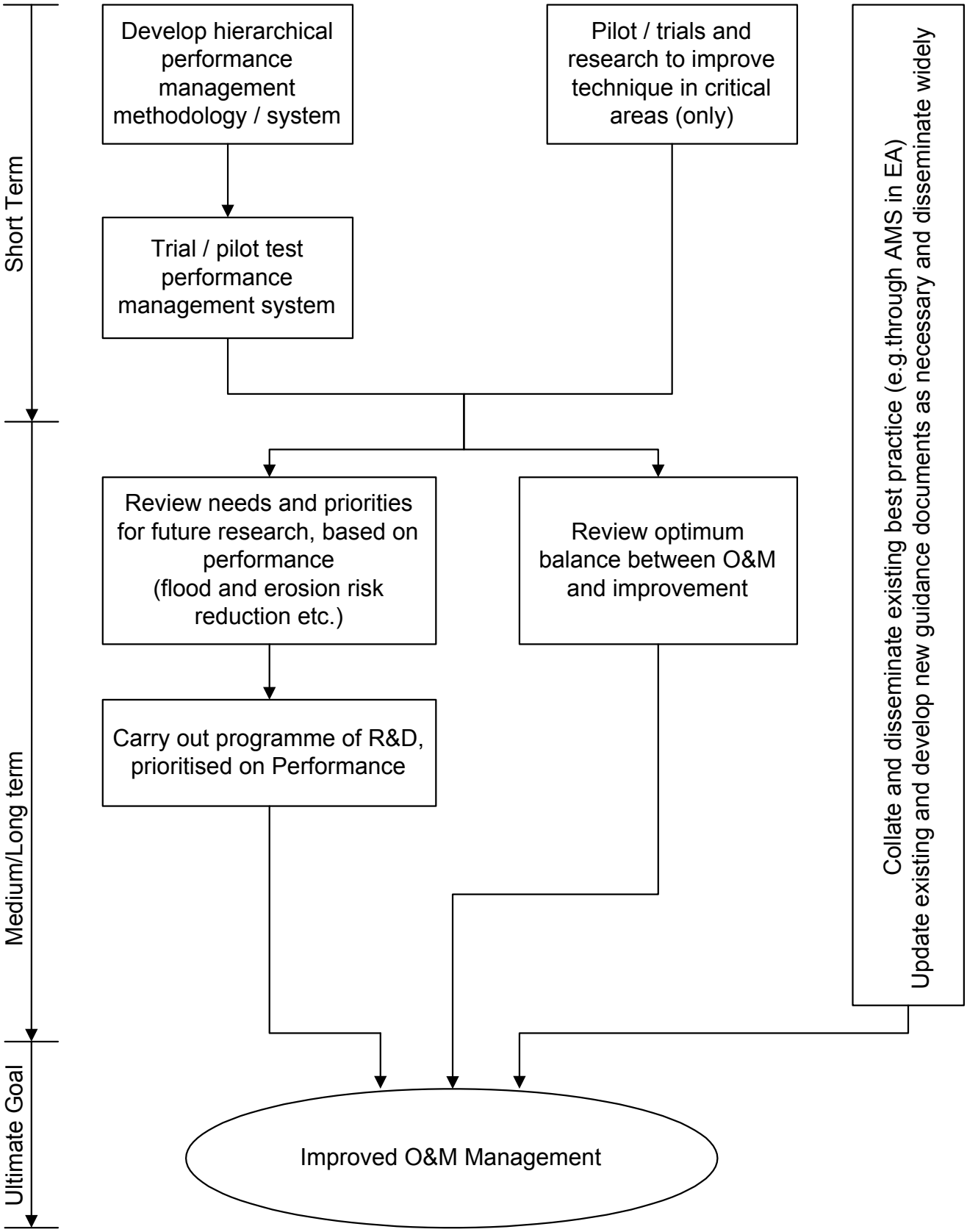

Figure 4.1 Approach to future R&D Development

4.2.1 Performance-based management framework

- **Condition Monitoring and Asset Management of Complex Infrastructure Systems (CMAM)** (W5A(99)03, ENG Theme - University of Bristol, ending early 03) – Providing new ways to characterise condition and performance of individual flood and coastal defence structures and the overall system, particularly given uncertain or incomplete data.

- **Concerted Action on Performance Evaluation** (FD 2315, Risk Theme - HR Wallingford, ending mid 03) – Providing insight and guidance on performance review, evaluation and management. A key output of the Concerted Action will be the draft Defra FCDPAG6 on Performance Evaluation.

- **Risk Assessment of Flood and Coastal Defence Systems for Strategic Planning, (RASP)** (W5B(01)02, Risk Theme - HR Wallingford/University of Bristol, ending mid 04) – Developing the basic strategic approach to assessing risk associated with defence systems. Successive tiered levels will provide (a) a national assessment of risk with local information which may be used for identifying high priority defences, and (b) approaches for more detailed, strategic and site specific risk assessments which can fit into a decision-making approach.

- **Modelling and Decision Support Framework (MDSF)** (EA development project, BSM Theme - Consortium led by HR Wallingford, completing mid 03) – Providing customised GIS and techniques for calculating flood extents and depths, economic damages and social impacts. Finished for new catchment flood management plans, and under development for next generation of shoreline management plans.

- **Performance and Reliability of Flood and Coastal Defences** (W5B(01)06, Risk Theme project - out to tender end 02/03). Further development of the concepts of asset fragility curves and deterioration for assessing structural reliability taking into account the performance under a range of loads from flood and coastal events.

4.2.2 Self-contained projects on specific tools and techniques

- **National Flood and Coastal Defence Database** (EA development project - Science Systems) Developing national database to store and present information on flood and coastal defence risks and assets. Supported by and available to all Operating Authorities.

- **Reducing uncertainty in river flood conveyance** (W5A(01)01, ENG Theme - HR Wallingford, ending early 04) – Providing improved methods for assessing channel conveyance and consequent flood water level – particularly relevant to assessing the effects of alternative channel vegetation management and dredging regimes.

- **Reducing the risks of embankment failure under extreme conditions** (FD 2411, ENG Theme - HR Wallingford, ending mid 03) – Best practice review providing improved understanding of embankment management. Includes development of a risk-based framework for their design, inspection and

maintenance relating to potential mechanisms and consequences of failure, and identification of key further R&D.

- **Centre for Aquatic Plant Management user-led programme** (W5G(01)02, ENG Theme - CAPM / IACR, subject to 3-yearly review) – Programme of research into management of aquatic vegetation and production of best practice guidance – strong focus on control of aquatic plants to maintain flood capacity of channel

- **"Quick-win" issues followed up under O&M Concerted Action** (Posford Haskoning, ending early 03) – The following quick-wins were carried out:

  (i) The investigation of "FLIMAP" (A proprietary remote sensing system, mounted on a helicopter, which produces simultaneous video and laser-scanner data) for flood defence asset monitoring. R&D Report W5A-059/TR1.

  (ii) Engineering inspection techniques for flood defences using non-destructive techniques – A review of it's use in other industries and a framework for its application. R&D Report W5A-059/TR2.

  (iii) Development of models for reviewing flood defence maintenance requirements (Environment Agency, 2002).

- **Low cost rock structures for beach control and coast protection** (FD2409, ENG Theme - HR Wallingford, ending early 03) – To produce practical guidance for coastal performance of low cost rock structures.

- **Post event appraisal – Phase 1** (FD 2012, Policy Theme – Bullen Consultants, ending end 02) – To consult on the information and systems necessary for good post-event performance evaluation of flooding or coastal erosion.

- **Concerted Action on strategic approach to data and information** (FD 2314, Risk Theme – WS Atkins, scoping phase complete) – To identify data and information needs and sources for coastal and flood defence, and to develop R&D in monitoring, data management and application of new techniques.

- **Failure on-demand of flood defence scheme components** (W5B(01)03C, Risk Theme - RMC / Peter Brett, ending end 02) – To advise on the best management approach for considering the reliability of components such as gates, culverts and flap valves, and reducing the risks and uncertainty of component failure.

- **Impact of maintenance operations and capital works on river sediments and habitats** (FD1920, Processes Theme – Consortium led by HR Wallingford, ending mid 04). To identify and then support specific issues and potential physical trials and demonstration leading to improved river management. Open to influence from O&M Concerted Action and related end-users

- **Effects of coastal realignment / management** – (R&D projects in Processes Theme – ongoing) Monitoring at coastal and sea defences setback / natural defence

sites at Tollesbury, Freiston and Porlock to inform the management of coastal re-alignment and management.

- **Operational trials** – Several EA Regions, IDBs and Coastal Authorities are planning and undertaking trials of various approaches and methods of maintenance. Some (e.g. Anglian Region embankment vegetation management) have the potential to be developed as national pilot or demonstration projects. (See Section 4.3)

In addition to the above, there are several R&D projects in the Engineering Theme that have a strong operational component. The key projects are:

(a) In process of publication - River restoration manual and web-based tool (with RRC), and 'Manual for design and operation of trash screens'.

(b) Ongoing R&D - Sand dune processes and management for flood and coastal defence; Soft cliffs - prediction of recession rates and erosion control techniques; Hydraulic performance of bridges and other structures at high flows; Weirs - best practice guidance; Coastal and marine environmental site guide; Sustainable re-use of tyres in river and coastal engineering.

4.3 Proposed Priority Areas

In line with the approach outlined in Section 4.1 (and illustrated by Figure 4.1), and having considered the significant number of ongoing R&D projects listed in Section 4.2, a key conclusion of the O&M Concerted Action is that relatively little further R&D should be started up in the short term. The focus should be on the piloting, demonstration and delivery into practice of what has already been started – particularly the items that have been identified under the Concerted Action.

The ongoing work within the existing programme should continue but with greater transparency for the end-user. For the Environment Agency, progress on O&M related R&D projects should be reported regularly to the Operations Business Group. (This should become progressively easier with the new programme management software). As any phase or scoping study comes to an end, any further work must be identified and the outputs or required work from ongoing scoping studies should be supported.

The following areas of research and development are proposed in the short term (over the next five years). They are numbered in terms of their priority, with the first one having the highest priority.

(i) Development of a performance-based asset management system (PAMS)

O&M managers need decision-support frameworks that enable the assessment of the risks associated with the system and the identification of an optimum programme of management interventions to achieve desirable reduction in flood or erosion risk or other performance improvement. Current approaches are unable to provide risk-based applications that can assess the performance of structures and associated damage avoided due to interventions under a range of loading conditions. O&M interventions

must be capable of assessment on the same basis as improvement works. For the Agency, the system must fit into the overall framework for flood risk management.

Major benefits will be gained from drawing together all the existing R&D and other knowledge discussed in Sections 4.1.1 and 4.2.1. The key project ("**Establishing a performance-based asset management system, PAMS - Phase 1**") will be negotiated with a research consortium. In developing the approach outlined in Annex A into practical applications, PAMS will provide a measured step forward from current less structured approaches and a basis for delivering the new decision-support framework.

On completion of Phase 1, the prototype system would be pilot tested and developed with practitioners in a number of catchments or coastal units (e.g. lowland rural river reaches with significant vegetation management in the channel and on the embankments). This must demonstrate to practitioners the expected improvement of PAMS over current methods (e.g. FDMM/FDMS).

A further project on "**Performance and Reliability of Flood and Coastal Defences**" is needed to develop the concepts of asset fragility curves and deterioration for assessing structural reliability taking into account the performance under a range of loads from flood and coastal events.

Both of the above projects will be funded through the Risk Theme and are able to start in early 03. They cover process development and link into the overall development of RASP and PAG6 that are also being addressed under the Risk Theme. The prototype PAMS will then be able to link into specific projects on the performance of different asset types (e.g. vegetated / dredged channel; grassed embankment; sheet-piled wall; etc).

(ii) Development of good practice in self-contained areas

As explained in Section 4.1.2, significant benefits will accrue from the development, collation and dissemination of national guidance documents on good practice in specific areas of O&M. This will allow modest efforts to make a significant change in management practice and hence improved performance by using currently available information and techniques together with the results of targeted research. Key areas for R&D projects in the Engineering Theme are highlighted below:

(a) **Development of nationally consistent approach for conveyance management** (ongoing - 2004) The flood defence manager carries out a number of maintenance interventions including aquatic plant control and dredging to ensure adequate conveyance through waterways and resilience to overtopping. The ongoing R&D project (W5A(01)01) will develop a computer based conveyance estimator based on current best knowledge. To maximise the usefulness of this tool within O&M, it is proposed to deliver alongside this a nationally agreed set of options for channel management (i.e. with differing degrees of vegetation clearance in different seasons). These would enable the effects of any management regime on flood conveyance to be assessed for a range of watercourse types and sizes, thus enabling decisions on maintenance options to be based on the effects on performance. It will also help in considering the

effect of environmentally favourable options on the flood levels in the system, acting as a decision support tool for maximising environmental impacts while maintaining required engineering performance.

(b) **Collation of best practice techniques for managing extreme events** (2004 - 2006) Extreme flood and coastal events are by their definition rare and are often accompanied by dark and wintry conditions. The way that events are managed (including loading and defence monitoring, temporary protection, failure management and repair techniques, associated health and safety and the recording of the whole incident to enable post event assessment) is inconsistent. It does not provide the opportunity for maximising lessons learnt and disseminating good practices and techniques. Great benefits can be derived from collating good practices and developing a consistent method of reporting to improve future information and knowledge in this area. This project will build on the Policy / Engineering Theme Project on "**Sustainability in flood and coastal management**" scheduled to start in early 2003. The extent of R&D – as distinct from continuous improvement within the O&M business will be scoped within this project.

(c) **Updating of the Saltmarsh Management Manual:** (2003 – 2004) The current Saltmarsh Management Manual was produced in the early 1990s. Saltmarshes provide natural attenuation of wave attack at the foreshore and to estuarial defences, as well as being of environmental importance. There has been an active research and local studies in this area over the resent years, the results of which are not widely available to practitioners. There will be significant benefits in updating the currently available manual. This development should be done in conjunction with the Estuary Research Programme.

(d) Management / upgrading of key flood defence structure types: (2003 – 2007) Collation of experience and research to improve tools and techniques for (a) assessing the state of the nationally representative types of defence structures and their rate of deterioration over their whole life, (b) characterising structure load / response, (c) deciding whether to replace or upgrade, and (d) designing the upgraded structure for new loading. Key structures types include sheet-piled walls, masonry gravity walls, and flood embankments (with low foundation strength). This project will be developed first in conjunction with the Thames Strategy Project. Optimisation of the management / replacement strategy to take account of risks, costs and rates of decay. Will be informed by the types of risk-based maintenance strategy that have been introduced in other industries and for the key defences in the Netherlands (e.g. Eastern Schelt storm surge barrier).

(e) Development of framework for use of remote and non-destructive methods for flood and coastal defence condition assessment (2003 – 2006) Quick wins carried out as part of the concerted action development confirmed the potential benefits for improved use of remote sensing and non-destructive testing methods within a framework of improved asset condition assessment. Their use requires to be targeted to the best potential areas of benefit and the information requirements from the systems identified in order to maximise their potential benefits. There is great benefit in developing the requirements and framework

for their use, as this will enable better assessment of the conditions of the defence assets protecting over £200 billion of national resources protected or defended by flood and coastal defences.

(iii) Consideration of identified difficulties in applying flood and coastal defence policy at the delivery level: (2003) The review and consultation processes carried out as part of this study identified inconsistencies between policy decisions and the practices at the sharp end of Operating Authorities. While such issues should reduce with the recommended performance-based framework, the need remains to examine the root causes of this problem. This will ensure effective cascading and application of policy at the delivery level and feedback of delivery issues up through to the policy level. As the whole issue of hierarchical performance management is dependent on the success of information transfer through the tiers, there could be significant benefit in addressing this issue. To be considered within Policy Theme, possibly initially using one of its call-down contracts.

(iv) Field trials and pilot testing of new techniques: (ongoing) Support the O&M business in the use of demonstration studies and pilot projects to test out new techniques and develop further understanding on effect of different options for intervention. To be driven by the O&M business and to provide specific R&D support to trials that are principally funded through operational budgets. A specific allocation of funds will be allocated to support the embankment grass management trials being promoted by Anglian Region (starting in 02/03). Further items must be identified through the ongoing Processes R&D project FD1920 ("Impact of maintenance operations and capital works on river sediments and habitats").

4.4 Delivery and Management of Proposed Research

4.4.1 Business Case

The flood and coastal defences within England and Wales offer protection to an estimated 5 million people and over £200 billion of national assets from loss and damage due to flooding and coastal erosion.

The O&M business as the guardians of the flood and coastal defences, provide ongoing management intervention to ensure the defences continue to provide the desired levels of performance. The Concerted Action has showed that significant benefits could be gained by embarking on a targeted programme of R&D. The benefits are obtained from:

- wider application of good practice, which is currently poorly disseminated, providing improvements in the performance and the cost-effectiveness of maintenance works
- utilising knowledge and research results that will provide tools which are not currently available – including the performance-based framework – which will enable maintenance activity to be targeted in areas of greatest risk reduction
- new techniques for management of specific assets, notably enabling asset life to be extended and the costs of asset replacement to be deferred.

4.4.2 Investment Requirement

Delivery of the new research programme would require approximately £2million over the period 2003-2007, of which £1.5million is already budgeted for. As a result, additional R&D funding of about £500,000 would be required over the next four years to deliver the proposed new framework and the specific R&D projects on development of good practice. Further details are provided in Annex B. A review of further requirements would be carried out at the end of this period. This new investment is in addition to that required by the O&M business in the general collation of best practice and trialling of emerging good practices as part of its continuous improvement.

However, the cost is spread by (a) the applicability of some aspects to improvement works, and (b) the support to be provided for work on Areas (ii) (d) and (e) above by the Thames Strategy Project and the EPSRC-led Flooding Consortium. Both major programmes recognise the importance of the proposed programme.

Recent analysis showed that for every pound spent by the Environment Agency on constructing a flood defence asset, only 38p is spent on maintaining it over its design life. Only about 2% of this is spent on R&D – an extremely small amount. Practitioners agree that R&D on Flood and Coastal Defence O&M activity has been neglected in the past. This Concerted Action has not sought to carry out a full cost justification of the proposed research, but rather to identify a programme that is achievable and provides value for money.

4.4.3 R&D management

The development of the framework and its delivery through the improvement of performance management and techniques within O&M would require a commitment from the end user to engage with the R&D, and also effective management for the successful completion and implementation of the R&D.

ANNEX A

Generic Approach to Assessing the Effect of Management Intervention in the Defence System

A.1 Generic risk management framework

Flood risk has two components – the **probability** of a particular event and the **consequence**. A generic framework for flood risk management is being progressively developed and implemented at national, catchment / shoreline unit, and scheme / structure levels. The development of future approaches to O&M management in the Environment Agency needs to interface with this, and with the development initiatives and / or R&D on risk, strategic planning, modelling, performance and decision support tools. The framework can be applied to all flood and erosion management activities and will enable management interventions and activities to be targeted at areas of greatest risk or risk reduction. Decision support tools are being developed which measure the impact of the intervention on risk. Wherever appropriate, a systems approach is being adopted. Each business area (i.e. O&M) must understand how its activities affect flood management performance.

The Defra / Environment Agency R&D Technical Report on "Risk, Performance and Uncertainty in Flood and Coastal Defence – A Review" provides a baseline review of issues and approaches concerned (This is available on the Flood Management R&D web-site under the Risk Theme – see www.environment-agency.gov.uk/floodresearch). The Environment Agency has utilised the Government's standard "Source / Pathways or Barrier / Receptor" approach to risk management.

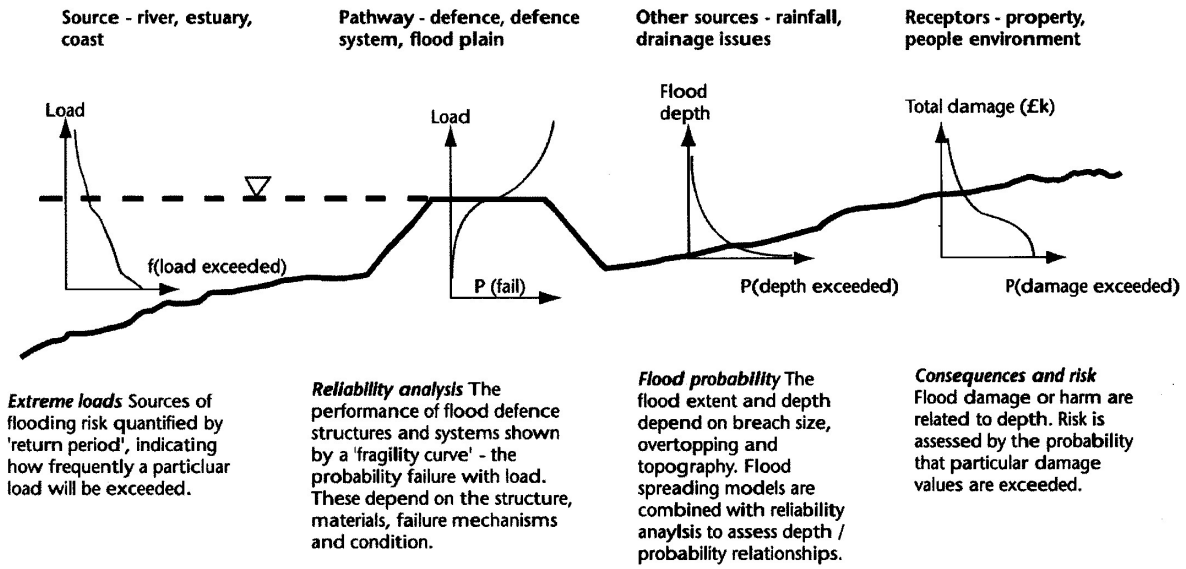

Figure A.1 Assessment of "damage / probability" function

Flood loading (source – shown as a probability distribution) acts on pathway (e.g. flood embankment) to generate a flood probability. This in turn generates a "damage / probability" curve.

The area under the "damage / probability" curve represents the average annual damage at the receptor due to flooding. Any management intervention in the flood management system will

change the performance of the system. This will affect one or more of the graphs – e.g. vegetation clearance in the flood channel will reduce the flood water level and hence the load for a given return period, or embankment strengthening will modify the fragility curve. Thus a new "damage / probability" curve is generated. The benefit derived from the management intervention is the difference in areas under the "pre" and "post" intervention curves.

A.2 Generic modelling framework for decision-making in flood management

Future flood risk management requires the development of an integrated decision-making system comprising models, data management tools and good practice guidance (Figure A.2). These must support a consistent, but wide, range of decisions from O&M on the individual structure and/or river reach, through strategic planning at the catchment or coastal cell level, up to the national level. These tools will utilise consistent data (see r.h.s. of Figure 2.4). Aspects associated with O&M management are shown at the bottom of Figure A.2.

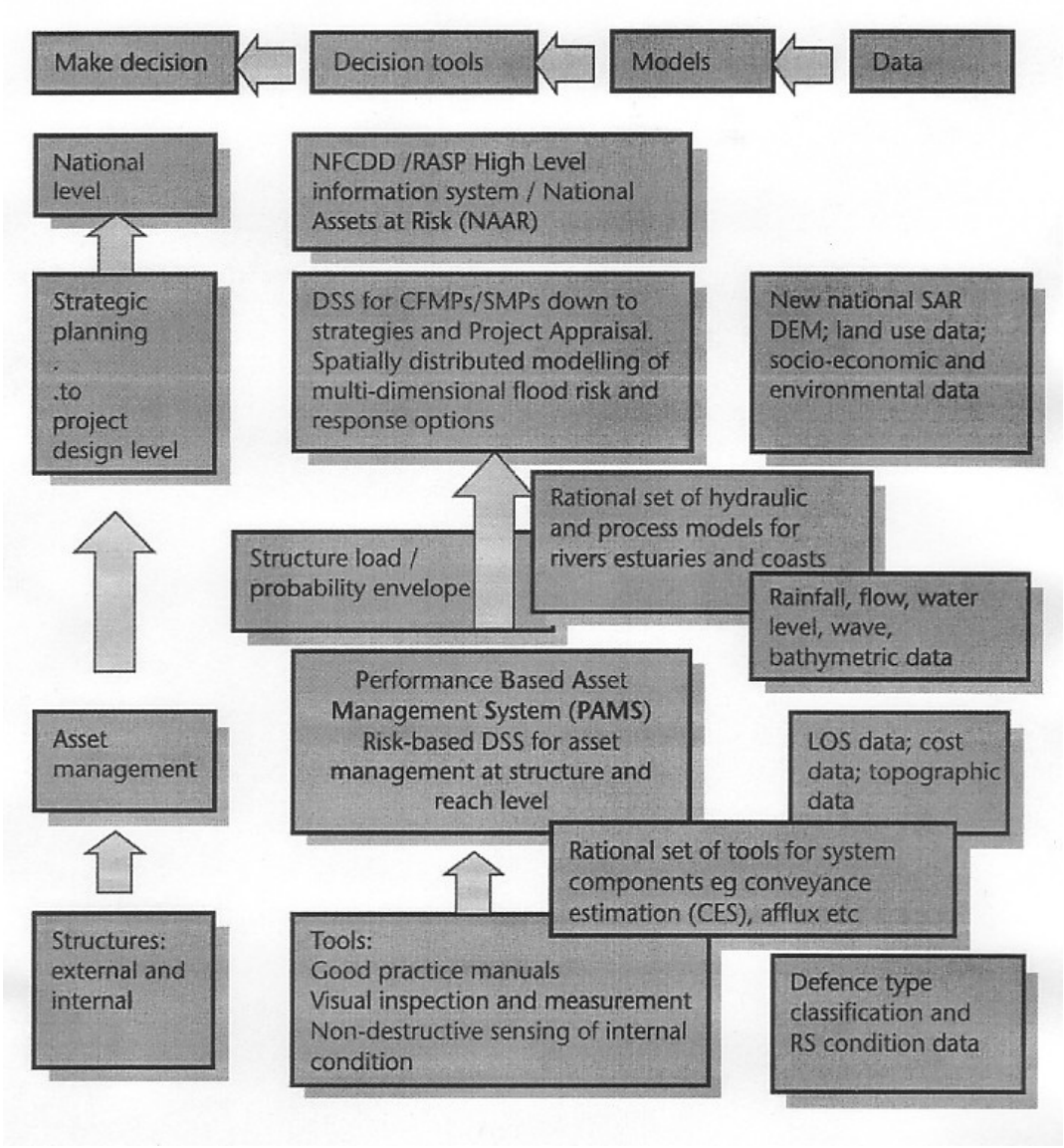

Figure A.2 Proposed decision-making system of modelling and data management tools and guidance. As indicated by Joint Defra / EA R&D Programme for EPSRC-led Flooding Consortium, November 2002

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