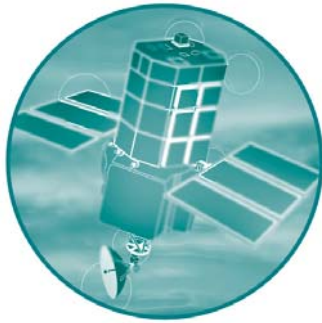# Defra/Environment Agency
Flood and coastal erosion risk management
R&D Programme

Performance-based Asset Management System (PAMS) – Phase 1 Scoping Study

Technical Report W5-070/TR

defra
Department for Environment
Food and Rural Affairs

ENVIRONMENT
AGENCY

Performance-based Asset Management System (PAMS) Phase 1 Scoping Study

R&D Technical Report W5-070/TR

Authors
HR Wallingford
In association with Posford Haskoning and RMC

Publishing organisation

Dissemination Status
Internal: Released Internally   External: Released to Public Domain

Statement of use
This document presents the findings of a scoping study into performance-based asset management systems for flood and coastal defence. It constitutes an R&D output from the Joint Defra / Environment Agency flood and coastal erosion risk management R&D Programme.   The findings will be taken into account in future development of a performance based asset management system.

Document History

Date	Revision	Prepared	Approved	Authorised	Notes
10/10/03	-	CGO/PBS			Incomplete draft circulated as part of Task 1 and 2 report to MB and ICM
21Jan04	0.1	CGO			Tasks into single interim report and restructured internally
21Jan04	0.2	CGO			Initial draft document including internal comments
28Jan04	0.3	CGO			Comments incorporated from JDS/PBS and added from ICM
02Feb04	1.0	CGO/PBS			Final editing of workshop draft addressing comments by ICM
04Feb04	1.1	CGO			Box titles amended in Figures 5.1 to 6.1
31Mar04	2.0	PBS/JDS	PBS		Edits based on Workshop discussion and subsequent discussions with Project Board. In particular amendments to Section 4 and 5. Report renamed.
06May04	3.0	PBS	PBS		Edits based on comments by ICM. In particular amendments to include Gnatt chart of future activities.
29 July 04	4.0	PBS	PBS		Edits to text and diagrams based on discussions with Jackie Banks and Tim Reeder
23 September 04	5.0	PBS	JDS	CRF	Final Report – various edits based on discusions with JDS and ICM

EXECUTIVE SUMMARY

This project scopes a Performance-based Asset Management System (PAMS) that will provide the Environment Agency with improved methods for deciding how to manage its flood defence assets. The overall aim is to manage flood risk as efficiently and effectively as possible by inspecting, maintaining, repairing and if necessary replacing flood defences in order to achieve the required performance and to reduce risk. As PAMS is developed it will progressively replace existing maintenance and improvement approaches with a more organised approach that utilises risk-based methods. PAMS will apply to all flood defence assets including embankments, walls, and rivers (conveyance), and tidal and sea defences. It will also apply to structures which have a primary flood defence function such as gates, sluices and pumps. It is expected that PAMS could be adapted to coast protection structures and other non-flood defence assets, although this scoping study deals only with flood defence assets.

A framework for the development and implementation of PAMS is presented in the figure below. Full operational implementation will take a significant time (perhaps 5-10 years). In the short term, however, it will be possible to provide a measured step forward in asset management through a small number of key improvements to present practice. These short term improvements will support both the development of PAMS in the longer term as well as improved present day decisions.
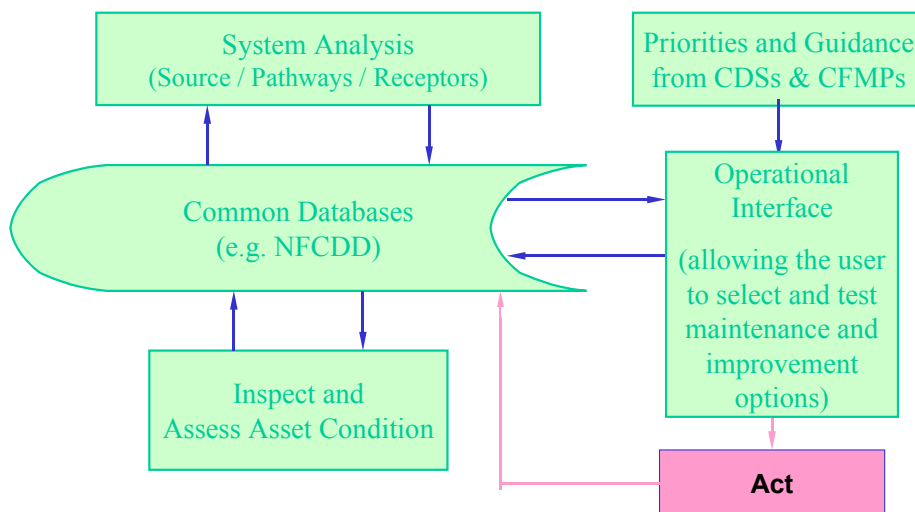
Overview of the proposed PAMS framework

In the short term, two primary improvements have been identified:

- Improved inspection and condition assessment of defences – that more explicitly recognises the relationship between the condition and the performance of an asset.

- Increased use of *hazard indexing* as a means of rapid, approximate field assessment of the criticality of an existing asset.

Achieving the take up and operation of these improvements will involve a revision of the Flood Defence Management Manual (FDMM) to smooth the transition from the

present approach to PAMS. In the longer term a combination of software, databases, activity procedures, work instructions and training will all be needed.

Once fully implemented the information delivered to the user is likely to consist of both map and section information (see figures below). These data will highlight those assets that contribute most to risk and the components of an asset that contribute most to its fragility. This information will then form the basis of decisions to either structurally intervene or gather further data.
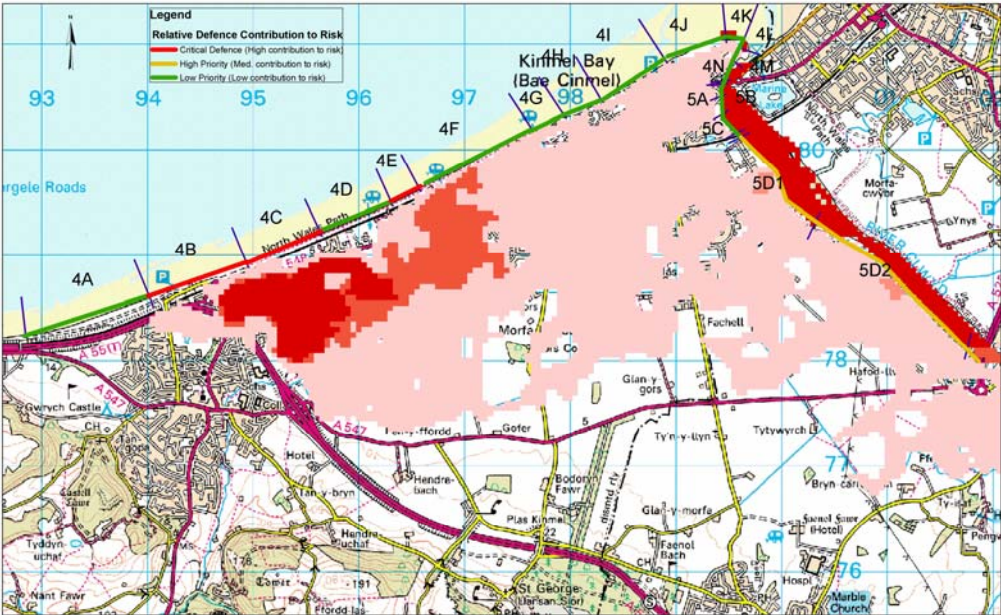
An example of mapped output showing critical linear defences
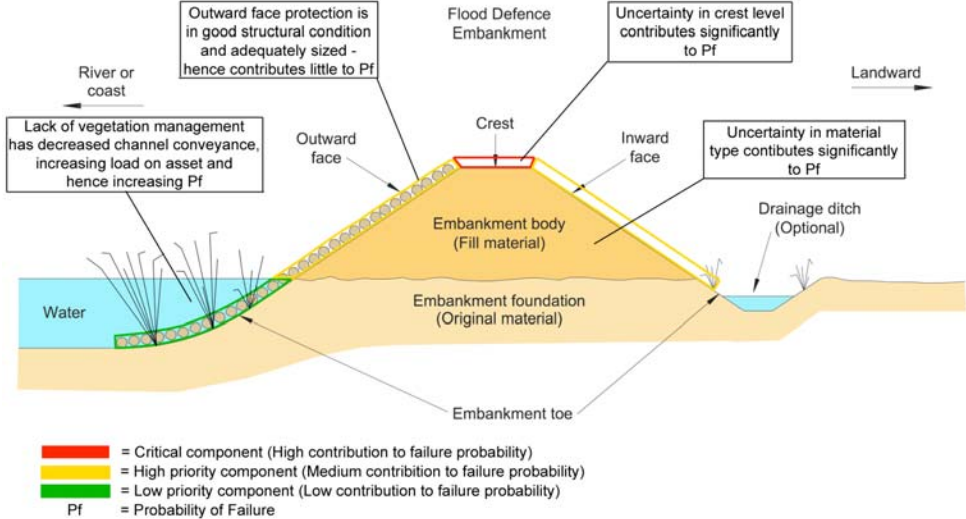
An example of the output showing critical elements of an asset

The implementation of PAMS will demand a number of research and development activities together with field trials and piloting.   To be successful these activities will need to be integrated within the broader scope of parallel activities inside and outside of the Agency.

CONTENTS

Figures

Boxes

Appendix

1. INTRODUCTION

Relative to existing methods associated with the appraisal of new flood defence schemes, current approaches to justifying maintenance needs are crude. In particular, the Environment Agency's Flood Defence Management Manual (FDMM) is no longer consistent with the Agency's focus on managing flood risk, as opposed to providing flood defence. Both the FDMM and the FDMS provide only limited guidance on which assets offer a critical contribution to flood and coastal erosion risk reduction and how best to manage them. These shortcomings are widely recognised within the Agency.

1.1 Project aims and objectives

This project aims to establish a Performance-based Asset Management System (PAMS) that enables flood and coastal defence managers to assess the performance of, and management requirements for, existing flood defence assets. These may involve maintenance, adoption / replacement or removal. In the longer term, the project also seeks to provide a means of identifying the preferred management intervention to achieve a particular performance outcome or expenditure profile.

The project objectives as set out in the project specification are as follows:

Overall objective
"To take a measured step forward in developing a performance-based approach to identifying and prioritising the work needed to manage existing flood defences. Existing methods of appraisal of new flood defence schemes are based on an assessment of the costs and benefits of a management intervention. Current approaches to justifying maintenance needs are – in relative terms – crude.

This project addresses Phase 1 of a major programme to develop a decision support system for flood defence asset management. Phase 1 is a detailed scoping phase supplemented by case examples. The results will provide the basis for a strategy to develop and implement a new approach to asset management and operations. This strategy will be implemented with support from further phases of the R&D programme."

Specific objectives
"The specific objectives of the project are:
- *To demonstrate the practicality and utility of such a decision support system for asset management (including risk-based prioritisation and justification of interventions) through text based argument illustrated by case examples.*
- *To produce a plan for the development and implementation of a transitional system as part of the next major revision of the Agency's Flood Defence Management Manual (FDMM) and Management System (FDMS) that will support the longer term development of a software supported performance based asset management system.*
- *To identify similar appropriate approaches for the management of coastal protection assets."*

In addition to the above, the project aims to support the philosophy of improved asset management set in the Environment Agency's Strategy for Flood Risk Management,

including whole life cycle appraisal (to secure the greatest return on investment) as well as maintenance, renewal, and replacement options with the goal of optimising the performance and effectiveness of the assets.   Therefore, although PAMS is focused on performance of flood defence assets and related flood risk reduction it will form a part of the broader asset management strategy of the Agency to support its overall approach to water and flood risk management.

1.2   Project programme

The development of PAMS has been organised in three phases:

- Phase 1 (the subject of this report) is a scoping study and aims to review possible approaches and highlight a number of options. The option review will be aided by case examples.

- Phase 2 will take forward the most promising options and develop a detailed methodological approach, tested through pilot study. It will also outline a plan for implementation within the Agency including training, documentation, software interfaces, etc (first system design likely to be completed by 2006).

- Phase 3 will see the implementation of the new approach along with supporting manuals, work instructions, training and software.

Note: Phases 2 and 3 will overlap.

1.3   Project links

This project supports the business objectives of the Flood Defence Operations Management Group and derives from needs identified in its O&M Concerted Action and a range of R&D projects for a better link between asset co-ordination and operational performance. The development of PAMS will need to be closely linked to a number of on-going and future developments, as summarised in Figure 1.1.   These include:

Completed (near completed) projects
- Reducing the Risks of Embankment Failure under Extreme Conditions (HR Wallingford, 2003a).
- Hydraulic Performance of Bridges and Other Structures, Including Effects of Blockages, at High Flows (Jeremy Benn & Associates, 2003).
- Risk, Performance and Uncertainty in Flood and Coastal Defence – A review (Environment Agency, 2002).
- Reducing Uncertainty in River Flood Conveyance (HR Wallingford, 2003b).
- RASP (Risk Assessment of flood and coastal defence for Strategic Planning) – a research project investigating tiered assessment methods that include the influence of defences on flood risk (Environment Agency, 2004).
- NFCDD (National Flood and Coastal Defence Database) – Phase 3 is to be delivered September 2004.

Ongoing / starting projects

- NaFRA 2004 supported by RASP High Level Method *plus* – will provide basic flood probability and impact data for England and Wales using the RASP HLM *plus* under development at HR Wallingford.

- MDSF 2 (the development of the Modelling Decision Support Framework) – this will take on broad comments from the recent review of MDSF and will include RASP methodologies.

- Performance and reliability of flood and coastal defence structures (HR Wallingford) – this project is taking a more detailed look at the concepts of defence fragility – i.e. the relationship between load and failure – developed in the RASP research project. This will provide a sound basis for future improvements in understanding of the reliability of all flood defence assets.

- Thames 2100 supported PhD (supervised by HR Wallingford and Bristol University) to investigate the theoretical aspects of linking time dependent deterioration processes within the RASP type risk analysis methods. This will be linked to a case study within the Thames – probably the Dartford Creek to Gravesend area.

- EPSRC led Flood Risk Management Research Consortium and in particular, Research Priority Area 4 – Infrastructure involving research into condition assessment and time dependent deterioration.

- FLOOD*site* – A major EC research consortium led by HR Wallingford to investigate a wide spectrum of issues including defence performance.

Quarters (from April 2004)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	04				05				06				07				08			

1) Improvements in NFCDD - ongoing

2) RASP (Risk Assessment of flood and coastal defence for Strategic Planning) - Research

3) NaFRA supported by RASP High Level Method plus and subsequent improvements

4) MDSF 2 (the development of the Modelling Decision Support Framework)

5) Performance and reliability of flood and coastal defence structures (Phase 1 and 2)

6) Thames 2100 - PhD resarch on defence deteriortaion

7) EPSRC led Flood Risk Management Research Consortium

8) FLOODsite – A major EC research consortium

Improvements expected to be deliverables from the above projects

- Framework for strategic risk analysis
- Updated national risk information from NaFRA
- Improved insights into defence fragility - fixed assets
- A regional strategy planning tool supported by RASP HL/IL methods
- Improved insight into defence fragility - natural systems
- Fundamental insights into defence deterioration
- Improved understanding - failure modes/deterioration/ uncertainty*

Improved data on asset location/geometry/condition through NFCDD

* notes that both the EPSRC FRMRC and Floodsite provide a wide range of outputs - only those of relevance to PAMS shown here.

Figure 1.1 A programme of likely deliverables for selected on-going projects relevant to the development of PAMS

1.4   Outline of the report

This report follows the production of the three earlier interim reports covering Task 1 (A review of user needs and requirements), Task 2 (A review of existing approaches to asset management both within and outside of flood management) and Task 3 (Develop options for performance based asset management). The key points from these reports are summarised and extended to include recommendations for the way forward within this Technical Report. For completeness the interim reports are held as part of the Project Record (Environment Agency, 2004).

Following this introductory chapter, the report is structured as follows:

- Section 2 provides a general background to the PAMS project.

- Section 3 provides an overview of the role of PAMS within the broader framework of flood risk management and its interactions with other ongoing developments and activities.

- Section 4 presents a summary of user needs.

- Section 5 presents some lessons learnt from past experience and other industries.

- Section 6 presents the conceptual framework for the development of PAMS.

- Section 7 presents the translation of the conceptual framework into an operational framework.

- Section 8 presents the recommendations for the development of PAMS, including the research and development and suggested pilot sites.

- Section 9 presents some conclusions.

- Section 10 provides a list of references.

- Section 11 provides a biblography.

- Appendix 1 explores a series of options to support a measured step forward towards the longer term operational framework set out in Section 5.

2. BACKGROUND TO PAMS PROJECT

Flood defence managers need an asset management system that allows the assessment of risks associated with a flood defence system and provides a means of identifying the optimum programme of management interventions to achieve a particular outcome (i.e. some desirable reduction in flood risk). PAMS will apply to all flood defence assets including embankments, walls, and rivers (conveyance), and tidal and sea defences. It will also apply to structures which have a primary flood defence function such as gates, sluices and pumps. It is expected that PAMS will also be able to be adapted to coast protection structures but these are not explicitly covered by the current proposed project. It is expected that lessons learned from PAMS will benefit other Agency asset management functions such as navigation and water resources.

The flood and coastal defence manager needs an asset management system that enables him/her to assess the risks associated with a flood defence system, and provides a means of identifying a preferred programme of management interventions to achieve a particular outcome – some desirable reduction in flood risk. In attempting to construct a decision support system to aid this management a number of difficulties arise, for example:

- The complexity of the flood defence system (e.g. a river reach / estuary / or coast) with a number of different components, all of which contribute to the state of the system and the way it performs in a storm event.
- Difficulties in achieving a meaningful assessment of the condition of existing assets through monitoring or inspection.
- The potential complexity of the relationship between the condition of individual assets and the overall system performance (or reliability) in response to the "loading".
- Difficulties in assessing the improvement in performance (or reliability) that will result from a given management intervention(s) – which could range from routine maintenance (e.g. grass cutting or weed clearance) to a major remodelling of individual assets (e.g. the heightening of a waterfront wall).

In overcoming these difficulties it will need to be recognised that:

- Current asset data is not wholly appropriate for performance / risk-based asset management; any future system will need to be capable of highlighting these deficiencies and the impact/value of improved data collection.
- Whole life asset management will need to be more closely integrated with maintenance and replacement/improvement decision-making, reflecting asset deterioration and replacement/renewal costs.
- Risk assessment will need to consist of a multi-criteria analysis that includes social / environmental as well as economic risks and takes account of the performance of the whole defence system that acts to reduce flood or erosion risk.
- Maintenance and improvement options will need to be better linked to changed asset performance and associated performance of the defence system and hence risk reduction.
- The preferred management approach will need to be selected from a wide range of different maintenance/improvement interventions within the context of achieving policies set out in higher level plans.

Recently, significant advances have been achieved in understanding the concepts underpinning a risk-based approach to flood management, for example the Defra / Environment Agency R&D Report, FD2302/TR1, entitled *Risk, Performance and uncertainty in Flood and Coastal Defence – A Review* (HR Wallingford, 2002). This has built on the Government's standard "Source / Pathways or Barrier / Receptor" approach to risk management (see Figure 2.1). FD2302/TR1 established the concept of a tiered approach to risk-based decision-making with an interactive suite of tools, models and data addressing the national, catchment / coastal cell, and local (i.e. asset management and river reach) levels. This concept is now well established and accepted and has been widely used in National Flood Risk Assessment, National Appraisals of Defence Needs and Costs and most notably and publicly in the Foresight Flooding project. Within this context of tiered flood risk management, PAMS is now focussed on developing an improved approach to managing fluvial and coastal defences at the local level and not, for example, addressing catchment wide issues such as the management of rural run-off.
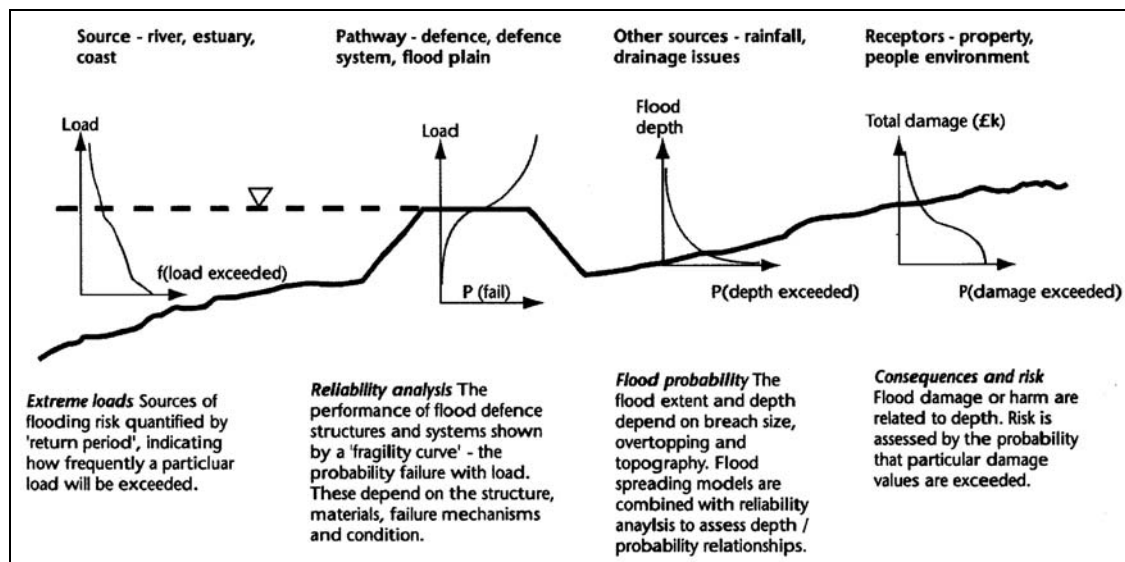
Figure 2.1 Source / Pathway or Barrier / Receptor / Consequence model for flood risk

3. PAMS IN CONTEXT

In support of a common approach to risk and risk management across all of its flood management functions, the Environment Agency is currently developing a series of tools to support specific decisions in each of its main business functions (see Figure 3.1). PAMS is a key element of this overall framework.

In recognition of this overall framework, PAMS will take its policy lead from higher level tools (CFMP/SMP and Coastal Defence Strategies) and then aim to ensure that assets are managed to meet specific policies or measures for each location as set out in these regional management plans. Where these policies include management or improvement of assets on their current alignment (or similar) PAMS will ensure that these are implemented (in the best way) to ensure the overall policies (as encoded in SMP / CFMP) are met in the most efficient and effective manner. It will also be important that the added-value provided by PAMS through detailed site specific analysis is able to be fed back to the higher level tools to inform future decisions.

It is recognised that a system such as PAMS is needed to bring these approaches together and aid the specific decisions made by asset managers. In developing PAMS the user requirements can be conveniently grouped under three headings:

1. Strategic queries – referring to specific, but high level, queries in support of managing asset groups.

2. Tactical queries – referring to specific, detailed level, queries in support of determining interventions associated with individual assets.

3. Operational system requirements – referring to the way in which the system is accessed and used.

General user queries

- What is the risk in this area (national/ regional/ local)?

- What is the contribution of a given defence to risk?

Note: User queries based on most recent/reliable data held in NFCDD - thereby integrating a mosaic of results

NFCDD (plus other associated databases

Exports
Imports

Integrated decision specific tools (run by decision-makers)

NaFRA	**CFMP/SMP (MDSF)**	**PAMS**	**Regulation**	**Flood Event Management**
National performance evaluation	Regional policy planning	Maintenance and Improvements	Regulation advice	Flood warning & forecasting

Decision specific guidance / procedures

For example appropriate policies for CFMP's or best practice ameliorative solutions to maintenance issues

Non-decision specific integration methodologies & frameworks
Common language, system analysis methodologies, intelligent option searching techniques, uncertainty propagation / handling

Common understanding of system components.

1. Receptors
Benefits and harm to people, property and environment.

2. Pathways.
Hydraulic behaviour (e.g. run-off, conveyance, groundwater, urban drainage, floodplain behaviour)
Morphological behaviour (e.g. foreshore change, channel change)
Infrastructure performance (e.g. reliability, failure modes, deterioration)

3. Sources (fluvial, coastal, groundwater, pluvial)
Forecasting, extreme statistics and temporal / spatial dependencies.

System responses.

Innovative responses to reduce risk (i.e enhance receptor or pathway performance, e.g. resilient buildings)

Common Data
Includes *Source-Pathway(Barrier)-Receptor* terms and new approaches to gathering added value data (visual/remote and *insitu* measurements).

Figure 3.1 Integrated risk management – Tools, concepts and data

4. SUMMARY OF USER NEEDS

The first stage of PAMS included a comprehensive review of users and requirements through a process of consultations, meetings and workshops. The key findings from this process are summarised below. Full details can be found in the Project Record (Environment Agency 2004). (Note: These research results have had a major influence on the direction recommended for PAMS and the required activities to implement PAMS as an operational tool.)

For PAMS to be successful it must both be accessible through a user-friendly interface and provide the user with outputs that help him/her to make a range of management decisions. Typical strategic and more tactical queries that could be answered by PAMS are shown in Boxes 4.1 and 4.2. An overview of the requirements of the operational system are provided in Box 4.3.

Box 4.1   Strategic user queries

The primary strategic queries to be supported by PAMS are likely to include:

1.   Form and frequency of inspection
Significant expenditure within the Agency is associated with inspection. The frequency of asset inspection, currently carried out at 6 month, 1 year or 3 year intervals according to a crude assessment of risk, should continue to be risk-based but more explicitly take account of:
- The probability of an asset overtopping, breaching or otherwise falling below some functionality threshold
- The consequences of that "failure" in terms of flood risk
- The cost of changed inspection frequencies
- How both the probability and consequence may change in time due to deterioration, climate and social change.

PAMS will provide all of these. The data gathered through inspection must then be capable of being accessed by other users at National and Regional levels. The NFCDD provides the ideal conduit for this information flow. The methodologies developed to analyse flooding systems as part of RASP will support this process and ensure consistency of approach with higher level planning. Note: significant improvements in our knowledge of both the failure processes and deterioration of an asset, together with an ability to analyse its response through time, will need to be developed in support of PAMS over the medium term.

2.   Prioritisation / optimisation of spending on operations, maintenance, and improvements
Action to improve asset performance accounts for a considerable portion of Agency expenditure. Therefore, a clear driver for the development of PAMS is to support the optimum flood risk reduction through the prioritisation of replacement/improvement and maintenance spending. To do this PAMS will need to provide information on the following:

- What contribution does a given asset within a defence system make to flood risk and flood risk reduction?
- Can a minimum standard of performance be identified for a given asset? If so, what would be the minimum programme of expenditure for maintenance and improvement works reflecting these minimum standards of performance (e.g. associated with statutory levels of protection or habitat issues)?
- What are the whole life costs associated with a given intervention?
- How can the value of investment in terms of risk reduction be maximised?

Box 4.1   Strategic user queries (continued)

In supporting these decisions, PAMS will need to move away from compartmentalised thinking about replacement/improvement and maintenance costs of different kinds of assets in order to deliver the Government's policy of focussing on whole life costs. This broader view will be underpinned by the move to block grant.

It is also necessary to understand how and in what terms the minimum standards of performance should be set and "best value" defined. Although a detailed debate will be required as part of the next phases of the PAMS development, it is clear that it will be necessary to replace the current approach of House Equivalents and the minimum and lower/upper target Flood Scores in FDMM. It is worth noting that there is no suggestion that PAG3 methods for replacement/improvement investment appraisal should be replaced in any future development of PAMS.

Box 4.2   Tactical user queries

It has been recognised that asset management occurs at a number of levels (Environment Agency, 2004) ranging from national, regional, local, asset (geographical, geometry and structural). PAMS is focused at the latter levels in this hierarchy:

- *Local Level*
  What do the assets within the local system of flood defence assets comprise?
  How is flood probability distributed within the floodplain?
  How are the receptors distributed within the floodplain and how vulnerable are they?
  How is flood risk distributed across the floodplain?
  Which assets contribute most to risk and risk reduction?

- *Geographical Level*
  Where are the assets located?
  Are they moving (i.e. eroding)?

- *Geometrical (linear asset)*
  What is the probability of failure (structural or non-structural) of a given asset under load?
  What is its expected annual probability of failure (structural or non-structural)?
  What is its Standard of Protection (SoP) ?
  What is its contribution to risk and how might this change in time?
  What aspect of the geometry underpins the protection it affords against flooding (including crest level, front slope, toe level)?
  Will these change in time (and, if so, at what rate)?

- *Structural (linear asset)*
  What is the structural condition of the asset, including both its overall condition and the condition of its individual elements?
  In what ways can the structure fail (i.e. what are its failure modes) and which are most likely?
  How is the condition of an asset and its elements likely to change with time due to deterioration?

(Note: The condition of an asset is currently assessed using the Condition Grade approach as set out in FDMM. However, a key requirement of any future PAMS will be to provide an improved procedure for condition assessment which explicitly links condition assessment to performance in a more objective and process-based way. This will need to be linked back into

Box 4.2   Tactical user queries (continued)

the concept of defence fragility (HR Wallingford, 2002, 2003c and 2004) to ensure the value-added information on asset condition and performance collected and analysed at a local level is capable of use by others involved in flood risk management.)

- *"Point" assets*
  A separate group of assets, are point assets. These include pumps, sluice gates etc. Key questions here include:
  What is the capacity (e.g. of a system of pumps)?
  How reliable is that capacity under load?
  What is its contribution to flood risk?
  What is its contribution to flood risk reduction?
  How will it change with time?

Box 4.3   Operational IT System Requirements

The key functional requirements of the IT system are as follows:

- *An open software system architecture* – The IT system must be capable of being updated without the fundamental framework having to be revised. It must also integrate seamlessly and in real time with NFCDD and other relevant databases.

- *Facilitate preservation of corporate knowledge* – As the behaviour of assets and optimisation of resources is a dynamic, iterative process, a learning process will therefore be an integral attribute of PAMS.

- *Enable improved use of inspection/condition assessment data* – The need to provide an improved asset characterisation and condition inspection methodology is a primary goal. The existing FDMM provides a condition grading approach which is not clearly related to performance. Amongst other things, this approach must reflect the known weaknesses of the current condition grading methodology and replace it with an approach based on more objective condition indexing that relates directly to expected asset performance.

- *Provide a consistent and robust approach to decision support* – The need for an improved approach to investment prioritisation that avoids false distinctions between different types of replacement/improvement and maintenance activities. The approach will also need to utilise information from higher level plans. Therefore the ability to receive multiple data from CFMPs/SMPs as well as future national appraisal will be crucial.

5. LEARNING FROM PAST EXPERIENCE AND OTHER INDUSTRIES

Through review of existing approaches within the Environment Agency as well as methodologies adopted in other industries and countries a number of conclusions have been drawn. These are summarised below.

5.1 Lessons learnt from the introduction of FDMM / FDMS

The lessons learnt from the introduction of FDMM/FDMS are as follows:

- FDMM is basically founded on a risk-based approach since it bases prioritisation and maintenance decisions on some combination of likelihood and consequence, but the measures used for both of these aspects of risk can (and should) be significantly improved
- The reliance on House Equivalent (HE) values is no longer required for the majority of receptor types given the data now available
- The appraisal method needs to include social and environmental issues, probably within the context of a multi-criteria approach
- FDMM largely excludes a calculation of benefits arising from a true "Do Nothing" baseline. Thus, the effect of embankment breaching or deterioration is not considered
- Continuing the detailed appraisal of arterial drainage schemes is questionable. The whole approach to agricultural benefits is too complex and needs to be simplified
- Audit is difficult
- Collection of Standards of Service data is expensive and represents a 'moment in time' evaluation with regular updating prohibitively expensive.
- The concept of a Target Standard of Service is useful, as it represents a key performance indicator. However, its should be more explicitly related to risk and definitions would need to be revised (if maintained at all as a term in PAMS)
- Adequate training is a vital component of achieving consistency within the application of the FDMM – this will be equally true for any future approach.

5.2 Lessons to be learnt from other industries

Existing approaches to both condition assessment and prioritisation within other industries and countries have been reviewed and lessons drawn. This review has been wide ranging including:

- Approaches in the Netherlands to assessing flood defences
- Condition indexing methods used by the US Army Corps of Engineers (USACE)
- Cause-Consequence models used within Network Rail and London Underground
- The reliance on standardised procedures within the Aviation Industry
- The probabilistic risk assessment and supporting data used within the Waste Disposal Industry
- Quantified Risk Assessment used within the Offshore and Hazardous Industries
- Failure mode element and criticality analysis – FMECA – based concepts used with the UK Dams industry

- The Computerised Maintenance Management Systems (CMMS) adopted by many of the Utility industries
- The risk-based wastewater management processes used by the Water industry
- The computerised asset management systems, involving tiered inspections supported by routine remote sensed data collection used by British Waterways.

Although the needs and requirements of specific industries can vary widely it has been possible to draw a number of lessons from their experiences. These key lessons are summarised below.

5.2.1 Condition assessment / inspection

- A number of industries attempt to ensure consistency of inspections. The approaches adopted include:
  − Use of standardised measurement and observation over time. These standard measurements and observations are then used to generate a condition index that is directly linked to the measurements and observations (for example the approach in the US and the Soil Slope Hazard Index).
  − The provision of best practice sheets, which contain clear descriptions of the aspects that should be considered and typical examples of defects, to support a systematic and consistent visual inspection.
  − Clear definitions of different condition ratings, such as 'good' or 'poor' where used.
  − British Waterways give useful insights into the way inspections might be carried out. They identify different kinds of inspection to be carried out by different types of individual and the competency requirements for each type of inspection.

- The dams industry offers useful insights into examining the *causes* and *indicators of structural failure.* Here a criticality score (based on the consequence of structural failure of a given structural element on the overall structure, likelihood of element failure and uncertainty) is used both for comparisons between reservoirs (in terms of their likelihood of structural failure) and for assessing the criticality of individual asset elements. It also enables simple sensitivity analyses to be undertaken to investigate the contribution from individual failure modes to the 'likelihood of structural failure' and hence prioritise remedial works on the basis of reduced structural failure probability – not *risk* per se.

- In the case of the offshore industry, and flood defence management in the Netherlands and in the UK, several levels of inspection are practised. Decisions to move to a more detailed level of inspection and/or to adjust the inspection intervals are linked to the condition of the asset and not performance/risk.

- The approach to waste management within the water industry suggests that a tiered approach to the assignment of indicators is particularly useful where data availability is highly variable and sparse. It therefore may provide a useful concept within the hierarchical framework envisaged for the Agency; although the details will no doubt be different.

- A wide variety of methods for condition grading and condition indexing are found across other industries and countries. The Condition Indexing system of the US Army Corps of Engineers is of particular interest as it probably represents the most advanced thinking in this area although contacts with USACE suggest users are already looking for significant change in the system. Where such systems are available, both inspection frequency and the urgency of potential interventions are linked to asset condition (not *risk*). In the Netherlands, asset inspection frequency is determined through a combination of condition grading information, with pre-set regular inspection frequencies, and the nature of emerging defects – not *risk*.

  (Note: In the Netherlands a clear safety assessment interval is applied. Although methods to support risk-based inspections are under development in the Netherlands these do not exist at present and *inspection interval*s and *risk assessment intervals* should not be confused. Inspection intervals may have a degree of pre-set definition whereas observed or anticipated change to the flood or erosion system will be the driver to initiate a new risk assessment.)

- Overall, it is generally recognised that a move towards risk-based inspection is desirable and that to achieve this it is first necessary to explicitly link performance/risk assessment and condition assessment/inspection. This issue is receiving attention in the offshore, nuclear and petroleum and refining industries as well as flood and coastal defence. A common theme across these industries is that whilst it may be desirable to adopted a risk-based approach to all decisions, it is not practicable to adopt this approach in support of localised/short-term inspection and maintenance strategy. Instead, the complexity of the decision making process must be appropriate and proportionate to the decision and therefore PAMS must make provision for decisions to be made on the basis of the inspection results alone, for example in support of limited further investigations or small-scale interventions. It remains unclear, however, as to which decisions would appropriately remain outside of more detailed quantified risk-based approach and which would appropriately be based on "best practice" guidance.

5.2.2   Performance assessment

- Cost-benefit analysis seems to be widely used as a prioritisation tool; including the sister industries of rail and highways. In the industries where a risk-based cost-benefit analysis forms the basis of the decision-making process, a common hierarchy exits. First a strategic level decision is made to prioritise among a system of assets. Such strategic level decisions correspond with the RASP High Level and Intermediate Level methodologies to be enshrined within the MDSF in support of CFMPs/SMPs and National FRA studies (Environment Agency, 2002). These high level studies then inform more local / detailed level analysis in setting short/medium term investment plans/policies.

- At the most detailed level various approaches exist outside of flood and coastal defence. The offshore industry divides the detailed risk assessment into three levels: a qualitative, a mixed qualitative-quantitative and a fully quantitative risk assessment. Within the context of PAMS, there may be utility in exploring the qualitative and mixed risk assessment approaches to update the inspection cycle on a small scale (outside of the formal risk assessment).

5.2.3   Data management

- The use of field devices which make the data entry and checking easier (e.g. Project Checkmate) and facilitate direct transfer to the mother databases (e.g. NFCDD) provide significant opportunities for PAMS.

- Computerised asset databases similar to the NFCDD form a key part of the asset management of waterways and rail systems. These include detailed observations of individual assets and their constituent parts, recorded on a large asset planning inventory. Interestingly, dimensional checks may be relegated to assets thought to be particularly critical; although there seems to be a presumption that the baseline dimensional information is already known (which is often not the case in the flood and coastal defence industry).

- Management and organisation of data within geo-referenced and temporally referenced databases is a key feature of all industries with proactive and targeted asset management.

### 5.2.4   The need for training and trialing

- The aviation, nuclear and offshore industries are perhaps furthest removed from asset management of flood defence systems, but can still offer useful insights in the way they stress the training and involvement of workers in developing safe working practices. Because of the highly technical nature of their work, approaches tend to be strongly rule-based but are trialed extensively with practitioners. Flood defence should not be afraid of introducing some rule-based components to its management systems so long as they are properly trialed first. Training and trialing alone will not eliminate inconsistency in inspection results.

5.2.5   Sophisticated models are often required to answer detailed questions consistently

- Standard generic cause-consequence models of "Base-events" or accident types are maintained in the rail industry and in the waste industry. They are used as underpinning data to more sophisticated tools for assessing the change in risk, for example a new working practice. This supports the idea of having a relatively sophisticated approach to reliability and performance analysis that is based on well defined and understood datasets of the sources, pathways and receptors of risk in order to reliably prioritise interventions. In the Netherlands, for example, understanding of the condition and geometry of linear assets together with agreed source parameters (e.g. wave and water level conditions) underpin a much broader analysis of risk and hence risk reduction decisions that can be achieved by particular asset interventions.

6. PAMS - THE CONCEPTUAL FRAMEWORK

The process of flood risk management can be considered in four generic stages as repeated in Figure 6.1 below.
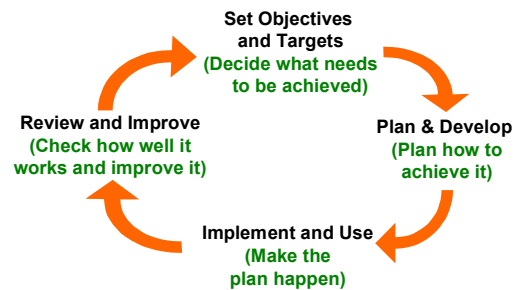
Figure 6.1 Processes in the Environment Agency's 4-stage management system

As part of the O&M Concerted Action these generic stages have been converted into a management cycle specifically related to the management of assets within the Operations function of the Agency. This 'logical framework for O&M' as set out in Figure 6.2 uses multi-criteria methods, risk assessment, performance evaluation, cost models, deterioration models, inspection / monitoring methods, and whole life approaches.
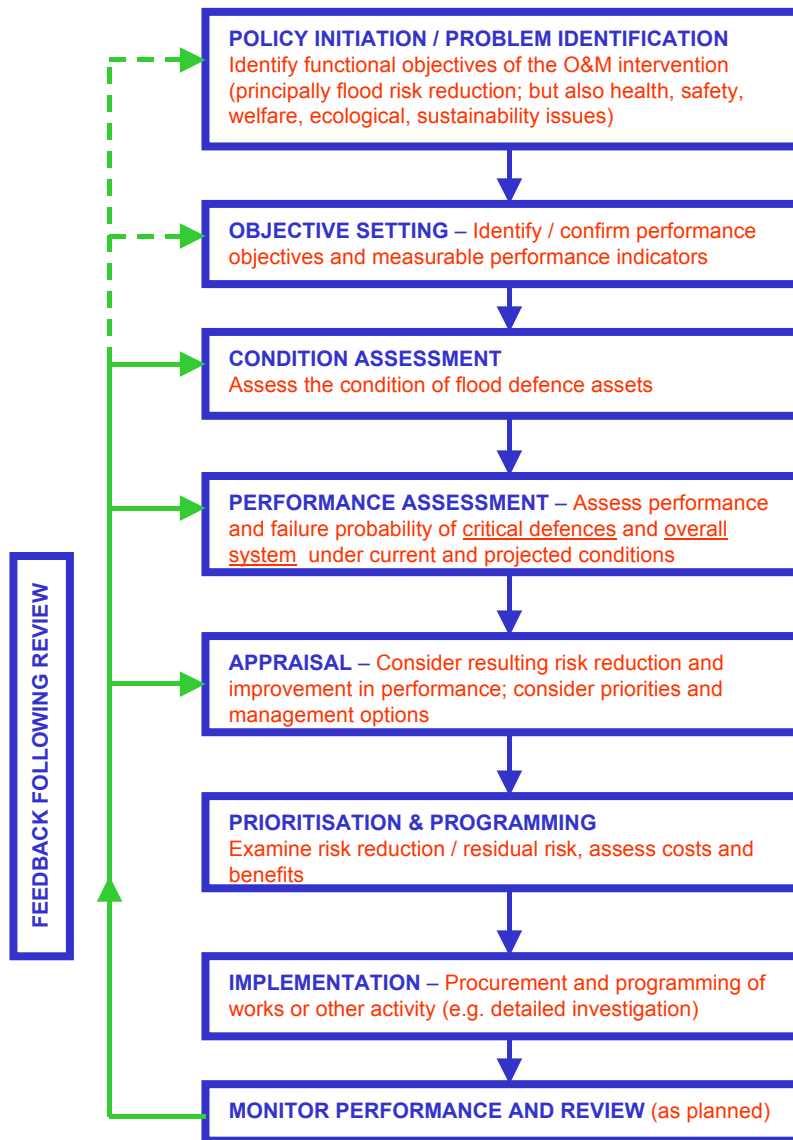
Figure 6.2 The Environment Agency's Logical Framework for O&M Activities from O&M Concerted Action (Posford Haskoning, 2002)

In terms of an operational system, these conceptual process frameworks may be considered in terms of four primary modules as shown in Figure 6.3. This shows the gathering of asset data, the transfer of this information through to system analysis tools via a common database and the subsequent use of this information in the decision process which in turn takes its lead from higher level plans.
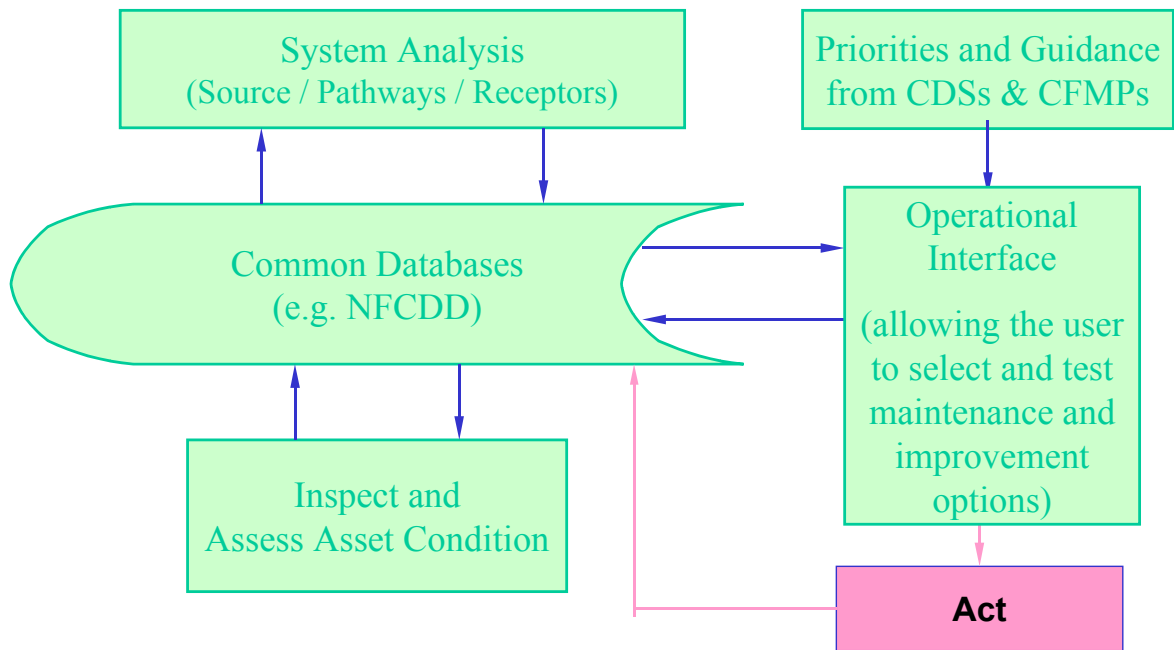
Figure 6.3 Potential structure of PAMS

The five key elements of PAMS shown in Figure 6.3 cover the following issues:

- **Inspection and condition assessment methodologies** – To improve asset management decisions it will be important that PAMS includes an improved approach to condition assessment. This module of PAMS refers to the process by which data is collected and asset condition is assessed. It will also include recommendations on minimum information requirements, for example the features of an asset that should be collected as a matter of routine (crest level for example) and which should only be gathered if the collection costs can be justified in risk reduction terms.

- **System analysis (Performance assessment)** – To understand flood risk and the effectiveness of any intervention the decision maker must first have an understanding of how risk is generated and how it can be influenced (reduced). The general concepts of system analysis are currently being addressed outside of PAMS through projects such as RASP (Environment Agency, 2003) and the review of risk methods within flood and coastal defence (Environment Agency, 2002). However, PAMS will need to develop these methods to cover the issues relevant to asset managers. The systems analysis module of PAMS will involve the integration of *source*, *pathway* and *receptor* terms together with information on how these drivers of risk are modified through management intervention and/or asset deterioration as well as climate or social change (i.e. *performance assessment and appraisal* in Figure 6.2). Therefore this module will include the analysis undertaken to provide an understanding of the performance of an asset (in its present, deteriorated or improved state) and the defence system in the context of risk and risk reduction.

The typical sources, pathways and receptors to be included within the context of PAMS are outlined below:

Sources
Both extremes and time series loading – to develop the full PAMS approach time series loading will become increasingly important to capture deterioration processes and other time dependent issues such as whole life costing.

Pathways
1) *Hydraulic behaviour* - Rivers flow/levels, shoreline tides/waves & inundation.
2) *Morphological behaviour* - Changes in foreshore and river morphology.
3) *Infrastructure performance* - The performance of linear defences, pumps and gates on existing alignment supporting CFMP/SMP and CDS policies

Receptors
Multi-criteria analysis: amenity, economics, health, safety and ecology

Interventions
These will include interventions targeted to improve the performance of assets (e.g. weed cutting / toe strengthening/ structural improvement/ raising) within the context of high level strategic objectives.

- ***Decision approaches and option selection techniques*** – As with the system analysis a number of generic issues are currently being addressed – or are planned - outside of PAMS. However, significant effort will be required to develop the specific decision approaches within PAMS to reflect the interface with higher level plans and the broad spectrum of criteria to be considered in selecting the preferred maintenance or operational intervention. This module of PAMS will therefore cover the process of the decision-making and option selection (i.e. *Problem Identification, Objective Setting, Prioritisation and Programming, Implementation and Feedback/Review* in Figure 6.2).

- ***Common databases and data and information management*** – Allowing data to be stored and accessed for re-use will be a key feature of PAMS. Maximising the use and re-use of data will inform any of the modules outlined above. In particular, PAMS will specify the asset data to be recorded; including format, mandatory and optional parameters, histories, uncertainties etc and appropriate fields developed within NFCDD and the use of related databases on flood plain assets.

7. PAMS – AN OPERATIONAL FRAMEWORK

To realise PAMS within an operational business process the series of core modules outlined in previous chapters will need to be developed over the coming few years, namely:

- Inspection and condition assessment.
- System analysis (including sources / pathways and receptors).
- Decision approaches and option selection.

Technical advances in these areas will need to be supported by data and information management processes and IT infrastructure, some of which exists and some of which will need to be developed.

A more detailed description of the conceptual framework shown in Figure 6.3 is provided in Figure 7.1. Figure 7.1 illustrates the cyclic process of revising the inspection/condition assessment (updating data in the NFCDD) through analysis (e.g. flood inundation and economics) and decision making to the eventual user interface. As such, the process shown in Figure 7.1 can be described as a continuous cycle of inspection and assessment populating ever-improving common databases. These data are then used within a structured analysis enabling decisions to be made followed by action.

The preferred intervention may involve structural improvement of an asset or perhaps simply a decision to improve data quality (thereby reducing uncertainty and either confirming or reducing the potential risk attributable to a given asset). Once enacted these actions change the information held within the common database and the hence the risks. These changes are reflected within the analysis and new intervention priorities emerge. (In reading this figure the blue arrows indicate the primary flow of information through the system, whilst the red arrows highlight processes that must be reproduced for each option considered in an intervention to assess the associated benefits).

The operational framework shown in Figure 7.1 also incorporates early feedback to the inspector on asset performance and its criticality in terms of risk. This simplified system provides the asset manager with a ready reference against which the results of the more rigorous analysis can be compared. Where appropriate, it is envisaged that the asset manager will be able to act upon these rapid calculations to support emergency remedial measures. Whereas less immediate actions will be guided by the priorities identified through the more rigorous PAMS analysis.
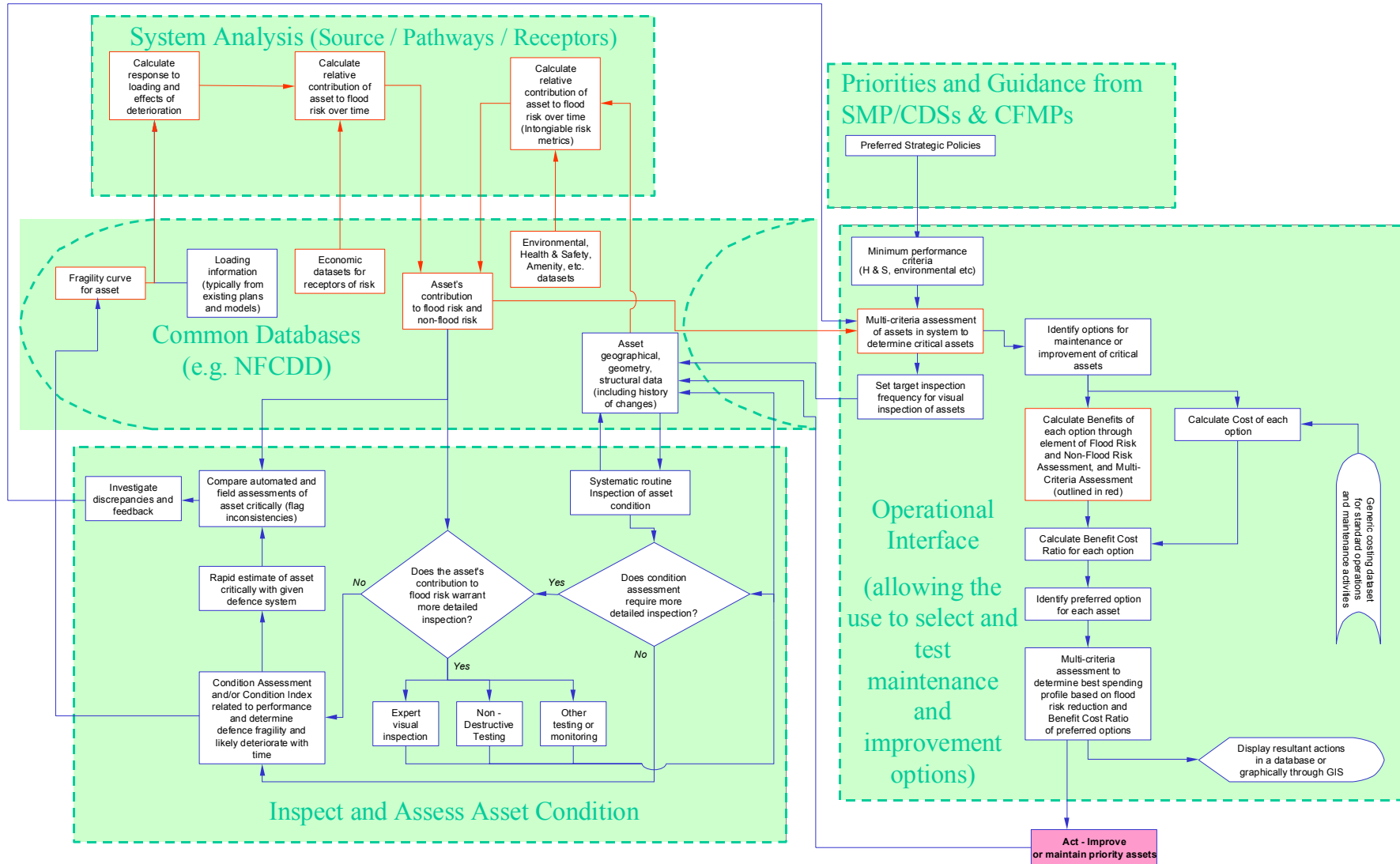
Figure 7.1 PAMS – An operational framework

7.1 PAMS – How the results might look

PAMS is likely to be a combination of software, databases, activity procedures and work instructions. The information delivered to the user is likely to consist of both map and section information. These will highlight those assets that contribute most to risk and the components of an asset that contribute most to its fragility – perhaps expressed as a contribution to an annual failure probability as suggested in the draft PAG 6. An example of the information that could be provided in terms of the asset components is shown in Figure 7.2. An example of the mapped output that PAMS could provide is shown in Figure 7.3. As can be seen, once the analysis is complete the user is presented with detailed information on the relative importance of given defences as well as the most important failure modes and uncertainties associated with each asset. This base information will then form the basis of decisions to either structurally intervene or gather further data.
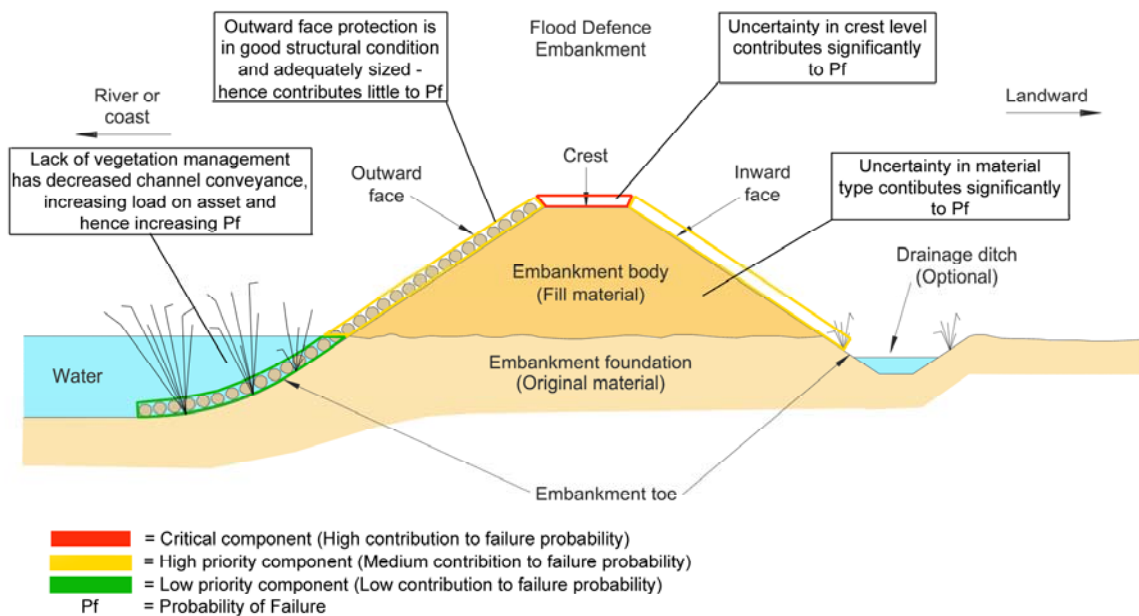
Figure 7.2 PAMS – Example of output showing critical components in a defence cross section

Figure 7.3 PAMS – An example of mapped output showing critical linear defences
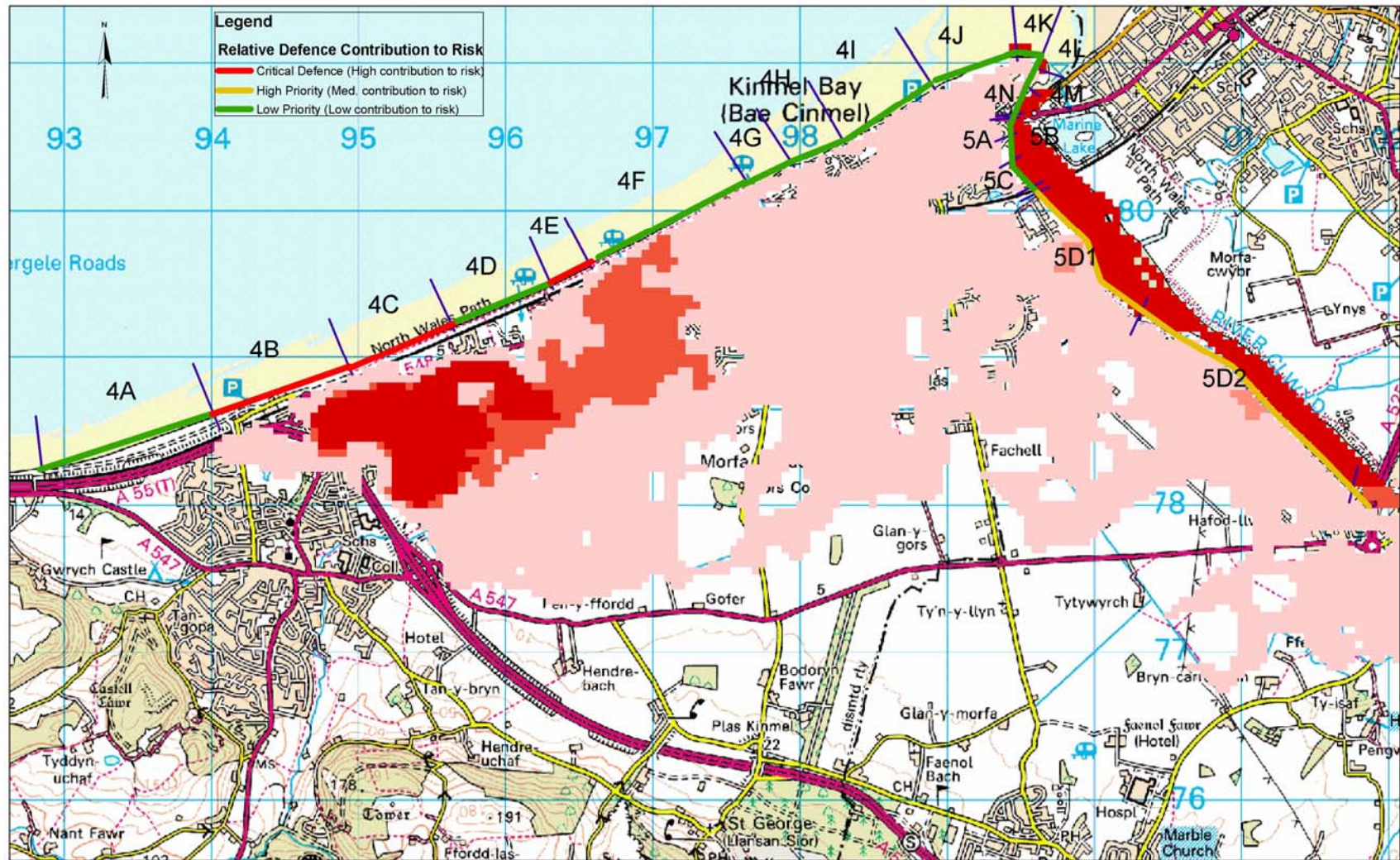
7.2   PAMS – How the procedures might change

Once developed, PAMS will not only modify the information provided to the users but will also demand new approaches to the way in which information is gathered and stored.   This will necessarily involve the development of new guidance including activity procedures and work instructions. Allied with these changes, will be a need to improve competencies within the Environment Agency, recognising that the inspection of different structures will demand different competencies. Training will need to form a key element of achieving this in practice.

For example, within the existing Environment Agency AMS, activity procedures provide guidance to inspectors on their responsibilities, their specific tasks and the steps that should be taken. An example of how the existing activity procedure relating *to "Inspect flood defence systems"* might change is provided in Table 7.1.

Although the example in Table 7.1 does not attempt to provide a fully revised procedure it does highlight a number of key changes that will be required to deliver a fully operational PAMS for the longer term. These are discussed in the following sections.

Table 7.1 Possible form of (revised) flood defence activity procedure "Inspect flood defence system"[1]

Who	Task	Steps	References/links
[2]	Establish the flooding system	Establish flooding system to be considered. Understand the implications of existing flood risk with regard to the policy objective of reducing risk to people, property and the environment.	Coastal Defence Strategies. Catchment Flood Management Plans. Flood Defence Strategies. Water Level Management Plans. Maintenance and Operational work plans. Works programmes LEAPs.
[2]	Ensure inspectors have appropriate competencies	Ensure that anyone who will inspect assets (staff, contractors, EWF etc) are suitably trained through attendance at approved course and through demonstration of competence.	Develop a clear description of competencies levels for different asset types and environmental conditions.
[2]	Prepare risk-based programme of inspection	Prepare risk-based programme to inspect reach and assets (utilise results held in NFCDD on asset risk contribution).	Work Instruction for 'Assessing the risk-based frequency of flood defence asset inspections' (as part of Decision Support and Option Selection for maintenance and improvements module of PAMS).

---

[1] This is part of the flood defence operations process to reduce known flood risk by maintaining assets and watercourses. It covers work carried out to identify inspect and assess the condition of assets within the flood defence system.
[2] The Area Operations Team Leader is presently responsible for the entire Activity Procedure "Inspect Flood Defence System."

R&D TECHNICAL REPORT W5-070/TR

Table 7.1 Possible form of (revised) flood defence activity procedure "Inspect flood defence system" (continued)

Who	Task	Steps	References/links
_2	Routinely survey and inspect assets	Remotely sensed surveys of asset geography and/or geometry and comparison with design /previously recorded information Site-based visual assessment and recording of reach and asset condition.	Work Instructions for 'Flood defence asset condition reporting' and 'Flood defence crest level and asset geometry status reporting.' Provide results of survey and engineering assessments into NFCDD.
_2	Decide on further more detailed inspection	Utilise the revised condition assessment and risk information provided by PAMS to decide whether asset structural condition and/or change in geometry warrants more detailed inspection.	
_2	If required, survey and assess assets & reaches in more detail	Organise and carry out more detailed surveys or engineering assessments utilising guidance on failure modes and fragility provided by PAMS. The additional surveys may involve expert appraisal, detailed crest level survey, physical sampling and testing, non-destructive testing etc. Prepare and review reports on reach and asset condition.	Result of surveys and engineering assessments recorded in NFCDD for use across the Agency Business Functions.
_2	Assess current contribution of asset to food risk reduction	Assess defence fragility and likely deterioration with time Utilise Hazard Indexing techniques to provide a rapid estimate of asset criticality as part of overall defence system. Compare Hazard Index with automated value obtained from PAMS and held in NFCDD. Investigate discrepancies and repeat investigation and assessment process as required.	NFCDD Review existing analysis from higher level plans. Apply detailed analysis procedures (supported by RASP) for assessing contribution to flood risk if required.
_2	Modify maintenance & improvement programmes	Use results of assessment and appraisal used to identify intervention needs for inclusion in maintenance and improvement programmes – see revised 'Identification of Need' (procedure 84_02).	Maintain Flood Defence System Activity Procedure (84_02). Improvements Process – Identification of Need and Pre-feasibility activity Procedure.
_2	Identify need for urgent work/action	Any need for urgent work, e.g. very poor assets or potential enforcement action, to be assessed and action taken as appropriate.	
_2	Review risk-based programme	Review risk-based inspection programme to identify any need to re-programme or re-prioritise inspections.	

7.2.1 Activity procedure task – "Ensure inspectors have appropriate competencies"

As part of PAMS it is envisaged that condition indexing will be used to characterise asset condition. In terms of inspections and the skills required to inspect an asset there is a need to move away from a 'one size fits all' approach to the assessment of the value of the condition index. This will in turn be reflected by the need for different **competencies** to be developed for the assessment of each major group of asset types, including:

- hard defence structures
- embankments and slopes
- impacts of changes to channel beds and foreshores on structures
- channel conveyance and requirements for dredging and aquatic plant management
- culverts
- screens etc
- pumps and other M&E assets.

The new Competencies may need to be supported by:

- **Standardised scoring approaches** for the condition of each asset type by informed non-experts, based on a framework developed by specialists in each of the asset types new **Guidance** associated with the above

An example of how these new requirements might be phrased is shown in Box 7.1.

7.2.2 Activity procedure task – "Routinely survey and inspect assets"

A number of revisions will be required in the nature of data collected to underpin the development of PAMS. For example:

1. 'Flood Defence Asset Condition Reporting' – revised Work Instruction

This existing Work Instruction will need revising to take account of such matters as:

- The need to include asset geometry in the condition assessment process
- Any revised Condition Indexing System that may be implemented as part of PAMS
- The process for deciding the level of expertise required to carry out the initial inspection and whether external experts need to be brought in to assist.

2. Flood defence crest level and asset geometry status reporting – new Work Instruction

This new Work Instruction is needed to reflect the fact that regular reassessment of crest elevation is needed to make a proper assessment of the Standard of Service actually being offered by the defence asset. (For coastal structures, cross-sectional geometry is required as well, because wave overtopping is influenced by the shape of the structure presented to the wave and not just by the crest elevation. Cross sectional geometry may also be an important indicator of embankment structural condition).

<div style="border: 1px solid black; padding: 10px;">

Box 7.1   Example requirements for new competency for the *"Routine inspection of embankments"*

Be able to identify the principle modes of failure of an embankment.

1. Understand the kinds of tell-tale signs that might be observed to suggest distress or incipient failure of an embankment. These might include:
   * Loss of vegetation
   * Crest erosion
   * Presence of fissures and cracks
   * Effect of burrowing animals
   * Uneven crest elevation
   * Uneven slope profile (e.g. toe bulging)
   * Seepage or signs of dampness

2. Be able to complete an Embankment Condition Indexing form and arrive at an overall index for the embankment.

3. Assess the most likely processes by which the embankment will deteriorate in the future and the likely time for deterioration to reach a critical condition requiring intervention. (Guidance on these critical conditions will be provided.)

4. As part of 3 above, understand the impact, now and in the future, of foreshore or river bed changes on embankment stability, such as toe scour. Refer to new Competency for "Understanding the impact of changes to channel beds and foreshores on structural condition."

</div>

The work instruction will need to reflect the fact that surveying of crest elevations (and cross sections where appropriate) should become part of the routine activity of the Agency, probably carried out by remote sensing in most cases. The procedure will need to have embedded within it a requirement to compare with an original or baseline survey, the existence of which must become mandatory.

The Work Instruction may need to be supported by a new **Competency** and associated **Guidance**.

3. 'Assessing the risk-based frequency of flood defence asset inspections' – revised Work Instruction

This existing Work Instruction will need revising to take account of the revised approach embedded within PAMS for assessing the likelihood and impact of failure. This will make use of a combination of:

* the best database information on contribution of the defence or defence system to flood risk reduction available within NFCDD, as derived from national/regional/local flood risk assessments, and
* the estimates of asset criticality derived from the latest inspection or appraisal information obtained by the Area Operations Team.

It is envisaged that this will involve some kind of alternative to the simplified Inspection Frequency Matrix currently in this Work Instruction. It may be appropriate to widen the range of inspection frequency intervals from the current values which lie between 6 and 36 months.

There may also need to be reference to the need to consider additional inspections after extreme events.

The revised Work Instruction may need to be supported by a new **Competency** and associated **Guidance**.

8. RECOMMENDATIONS FOR DEVELOPMENT OF PAMS

8.1   Overview

PAMS will need to capitalise not only on the R&D work under the Defra/Environment Agency joint R&D programme but also through the EPSRC Flood Risk Management Research Consortium, the EC Flood*site* programmes, and project-based initiatives such as those associated with the Thames Estuary 2100 strategy study. PAMS will need to integrate these developments and provide a complete framework for asset management decision-making given higher level policies. A significant programme of research and development will therefore be required through the next phases of PAMS that is complementary to these initiatives and draws upon best practice from other fields (or other countries).

To realise PAMS as an operational business process a series of core techniques and tools will need to be developed over the coming few years covering the areas of:

- *Inspection and condition assessment.* Data on asset condition will be used to provide information the performance of an asset, compared with its with its required function. There is need to move forward from the present system of condition assessment while building on that approach.

  The key research and development needs in this area are outlined in Box 8.1.

- *System Analysis.* Analysis of the flooding system will be required in order to assess the effect of flood defences on that risk. Risk assessment frameworks are now well established and it is proposed that PAMS will draw heavily on the Risk Assessment of flood defences for Strategic Planning (RASP) project. This has developed risk assessment method which accounts for the source, pathways and receptors of flooding, and will be an ideal for relating the condition and performance of an individual defence or reach, to the overall risk.

  The key research and development needs in this area are outlined in Box 8.2.

- *Decision approaches and option selection techniques for asset management interventions.* This will cover the process of decision making, and option selection. It will include priorities and guidance from CFMPs and Coastal Defence Strategies (CDSs), constraints such as resources and logistics, and uncertainties.

  The key research and development needs in this area are outlined in Box 8.3.

- *System IT architecture and common databases.* PAMS will draw on national databases such as NFCDD, including national GIS layers. It will also feed back information to NFCDD, improving the quality of information on flood risk. Within the Scoping Study, anticipated requirements have been highlighted to the NFCDD development team.

  The key research and development needs in this area are outlined in Box 8.4.

- ***Case study and piloting.*** It is essential that PAMS is a practical decision-making tool. Development will be based on a number of case studies in order to ensure that the methods are appropriate and useful - this will also have the benefit of raising awareness of a group of end users.

The key research and development needs in this area are outlined in Box 8.5.

These technical advances will in turn need to be supported by effective data and information management and IT infrastructure (see Box 8.6); some of which exists and some which will need to be developed. All activities will need to be co-ordinated, particularly with respect to development of the National Flood Risk Assessment methodologies supported by RASP HLM+ as well as regional planning tools such as MDSF supported by the RASP ILM/HLMs.

An example of the how PAMS could operate as a technical process is provided in Figure 8.1. This shows how improved information on loading could be used to support improved understanding of defence fragility in time and hence the likelihood of flood inundation that in turn would support broader multi-criteria based decisions.
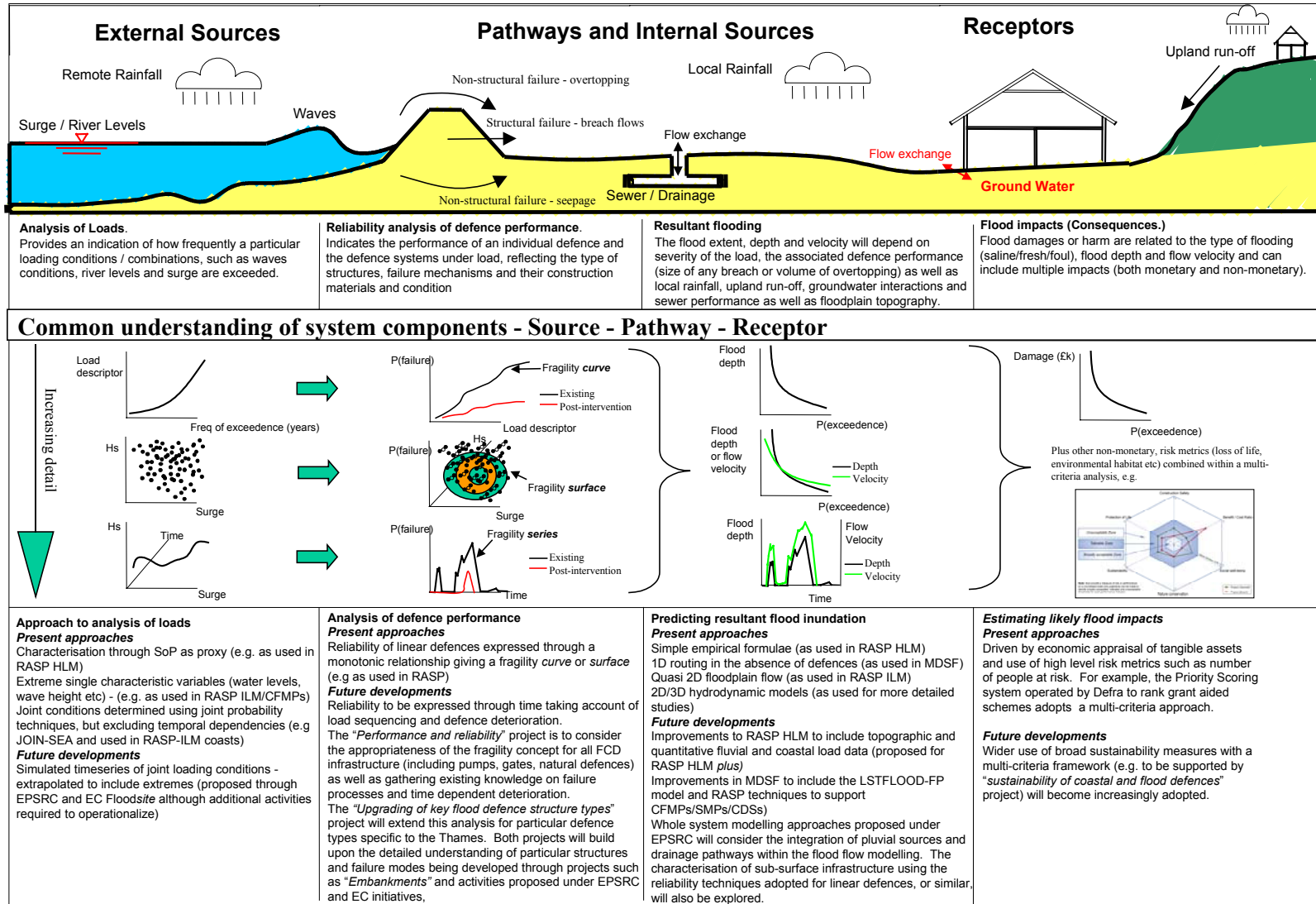
Figure 8.1 A possible S-P-R model including time dependent deterioration and multi-criteria analysis

Box 8.1   Inspection and condition assessment

Asset managers and inspectors provide the base information on assets for use by other Agency and Local Authority management functions. This is a vital role and requires asset managers to be aware of the information needs of others. As such, inspection and condition assessment methodologies are recognised as central to PAMS.

Unreliable assessment, or poorly focused assessment, directly undermines a wide range of flood management decisions. While it should be recognised that a level of uncertainty will always remain regarding the condition and performance of an asset there is a minimum level of reliability and coverage below which robust decision-making becomes untenable. It is the role of PAMS to set these minimum standards that recognise the needs of not only operation and maintenance, but also the needs of CFMPs/SMPs, flood warning officers, regulation activities and others.

It is vital that the process of asset inspection and condition assessment yields a real understanding of the likely performance of an individual defence, and associated defence systems, under load and how this may change in the future. This understanding needs to reflect the type of structure, its failure mechanisms and exposure to loading, construction materials as well as their present condition and likely future deterioration. In the future development of PAMS, these issues will need to be addressed as outlined below.

1) Better understanding of asset location and geometry
At present, the method for carrying out inspection is principally based on walkover surveys with limited quantitative survey of basic location and geometry. As observed in all other industries where asset management forms a significant element of their investment profile, basic information on location and geometry are routinely gathered without explicit justification. Advances in remotely sensed data such as FliMAP, LiDAR, SAR and other techniques are now available to enable such basic data to be gathered and routinely updated. Through PAMS a specification of this basic data should be established and is likely to include, as a minimum, crest level, profile etc.

Recommendation: To develop a hierarchy of data requirements for all asset types. At the highest, perhaps mandatory level, this will need to be restricted to key attributes and will need to include methods of collection and recording.

Timescale: Short term

2) Understanding asset condition and linking condition assessment to performance

If an assessment of condition is to be utilised within a performance assessment it must be couched in performance terms. The present approach of characterising condition through the five grade system fails to link the assessment of condition with performance and relies heavily on the expertise of the inspectors. Improvements in knowledge (for example regarding structural and geotechnical failure modes) and technological advancements (for example in intrusive and non-intrusive inspection) will increasingly provide support to the assessment of asset condition. These improvements need to go hand-in-hand with research into improved methodologies for visual condition assessment and the characterisation of condition (e.g. condition indexing). This combination of improved knowledge, technology and inspection methodologies will enable improved objectivity and consistency in determining asset condition.

Recommendation: Continue to update guidance to users on asset inspection through the publication of a best practice and revisited work instructions.

Timescale: Short term

Note: A number of research projects have already been identified in support of the above. For example, a key advance in describing the likely performance of a defence under load has been made through the RASP project that expresses performance through a fragility curve or surface (Environment Agency, 2004). At present, however, it is unclear whether the concept of a fragility curve translates to other asset types beyond linear defences. The "Performance and reliability" project recently commissioned under the REUU TAG is set to consider the appropriateness of the fragility concept for all FCD infrastructure

R&D TECHNICAL REPORT W5-070/TR

Box 8.1   Inspection and condition assessment (continued)

(including pumps, gates, natural defences) as well as gathering existing knowledge on failure processes and time dependent deterioration. More specific research is proposed under the EPSRC Flood Risk Management Research Consortium. Here, the specific issues surrounding geotechnical failure of embankments will be extended. Under the *"Upgrading of key flood defence structure types"* project it is proposed to apply these concepts to defence types specific to the Thames; notably embankments and vertical walls. However, further work will be required to translate existing and further research into specific guidance to accompany PAMS.

3) Understanding and characterising the change in asset condition and performance through time

The ability to express the performance of an asset through time, taking account of the sequencing of loading and asset deterioration will be a key component in support of risk-based programming of maintenance and inspection activities. To support this analysis it will be important that information is gathered and recorded as to the likely future deterioration of assets. This will include both time dependent (e.g. corrosion of sheet piling) and load dependent (e.g. river bed lowering) deterioration models.

Recommendation: Provide a generic approach to the characterisation of deterioration processes and summarise existing knowledge on deterioration processes for all asset types.

*Timescale: S*hort term – then ongoing

Note: This should be done in conjunction with, and build upon, an existing project titled *"Performance and reliability of flood and coastal defences"* and is partially supported through the project work planned under the Flood Risk Management Research Consortium together with doctoral research supported directly by the Thames 2100 project in asset deterioration being undertaken by HR Wallingford/Bristol University titled "*Extension of time dependent reliability-based analysis, applied to Thames Estuary flood defences"*

4) Linking surface and sub-surface infrastructure

In the longer term it is likely that flood and urban drainage will be managed in an integrated fashion (already recognised in the Consultation Draft Defra Strategy on Flood and Coastal Defence). To facilitate this longer term goal it will be important that both surface and sub-surface infrastructure are characterised using similar techniques. An initial exploration of the present differences that exist between the approaches adopted in flood and urban drainage is proposed through the FRMRC Flood Risk Management Research Consortium, but this will need considerable future work.

Recommendation: A scoping study to explore the issues and difficulties in developing a unified approach to the analysis and management of flood defence infrastructure; including surface and sub-surface infrastructure would establish the opportunities and difficulties in more forward towards a fully integrated management approach.

Timescale: short term research leading to improvement in the longer term

Note: This is partially supported through work planned under the ESPRC Flood Risk Management Research Consortium although significant research and development will be required to achieve a practical and operational system.

Box 8.2   System analysis

The term "system analysis" within PAMS provides an understanding of the performance of an asset (in its present, deteriorated or improved state) and the defence system in the context of risk and risk reduction. It involves the integration of *source*, *pathway* and *receptor* terms and how risks change due to management intervention and deterioration as well as climate or social change. It also seeks to articulate uncertainties to enable the informed judgement as to the robust of different options for intervention. All of these issues are discussed below in the context of a PAMS.

- Sources – Predicting system loads
- Pathway response
- Receptors
- System interventions

Sources – Predicting system loads
An indication of how frequently a particular loading condition / combination (such as wave conditions, river levels and surge) may be exceeded is a pre-requisite to informed asset management. A range of approaches are currently used within Agency decision-support tools and by their consultants. These include:

- *Simplest "proxy" methods* - Utilise Standard of Protection as proxy for loading (e.g. as used in RASP HLM).

- *Marginal extremes* - Extreme single characteristic variables (water levels, wave height etc.) - (e.g. as used in higher level and intermediate level RASP methods).

  Note: Within the context of PAMS, it is likely that this approach would provide sufficient detail where decisions are more *routine*. Such an approach would make direct use of the simple extremes and measurements calculated through the CDS/CFMP process.

- *Joint extremes (excluding temporal dependencies)* – Joint conditions determined using joint probability techniques, but excluding temporal dependencies are used routinely in more detailed studies such as Coastal Defence Strategies (for example JOIN-SEA). These methods be readily incorporated into risk-based analysis as demonstrated within the RASP-ILM coastal case study.

- *Continuous simulations including temporal dependencies* – Continuous simulation of loading would support the direct simulation of future system performance and the dynamic inclusion of asset, climate and demographic change. Before its practical use, however, significant research will be required. Therefore, in the longer term its potential is significant, in particular enabling temporal influences on defence deterioration to be resolved (e.g. morphology change).

In reviewing the utility of the above methods in the context of PAMS it is important to note that asset management fundamentally relies on how assets change in time. Therefore an ability to reflect the likely sequencing of future loading conditions, not only extreme single events, but extreme combinations of events will be a key input to PAMS in the longer term. Therefore it is recommended that research is undertaken to develop practical tools for providing time series loading either through detailed continuous simulation techniques and/or extended joint probability techniques. A key feature of this research will be to ensure the methodologies are practicable in the context of PAMS.

Recommendation: Initiate an R&D project to develop practical tools for providing time series loading either through detailed continuous simulation techniques and/or extended joint probability techniques.

Timescale: Short to medium term

Box 8.2   System analysis (continued)

Pathway response
As a systems analysis tool PAMS will need to resolve issues of defence performance (structural and non-structural failure – including morphology responses) and the resultant inundation. Significant work on both of these issues remains on-going and it will be important that PAMs does not repeat this analysis but builds upon it to meet the specific needs of the asset manager. The key issues for PAMS are discussed below.

Pathway response – Understanding individual failure modes and component deterioration
Many failure modes remain poorly understood and less is known about how components deteriorate through time and under load. To support more routine use of reliability analysis within PAMS (and high level analysis methods) and reduce the associated uncertainties in the results, significant on-going research will be needed to inform our knowledge about defences and our ability to model individual and multiple failure modes. A number of completed and on-going studies have identified key gaps in knowledge. These should be marshalled in a single forward programme for the development of underpinning knowledge of the processes of asset failure.

Recommendation: To continue programmes of research to understanding and model individual failure modes.

Timescales:

Short-term – Develop a prioritised programme of underpinning research into individual defence failure modes ranging from geotechnical failure, overtopping and surface erosion. This will be supported by the review of failure modes and knowledge gaps being developed throughout the Defra/Environment Agency funded project "Performance and reliability of flood defences". Phase 1 of this project is currently on-going.

Ongoing – a prioritised programme of research should be developed as part of the Performance and reliability project and then progressively implemented.   These projects will be partially supported through work planned under the ESPRC Flood Risk Management Research Consortium to investigate some specific aspects of geotechnical failure as well as the proposed Defra funded projects into toe scour. Related activities are also proposed under the EC funded Flood*site* project into surface erosion under wave action.

Pathway response – Analysis of defence performance
It is vital for the asset manager to understand the performance of an individual defence, and associated defence systems, under load and how likely it is to fail. A key advance in describing the likely performance of a defence under load has already been made through the RASP project that expresses performance through a *fragility curve.*

To enable information behaviour of the system in time to be included in PAMS significant research will be required. In particular, efficient techniques for utilising continuous simulation of loading sequences within the defence reliability analysis will need to be developed. This will then enable differential deterioration of different components, and the associated change in the likelihood of failure, to be captured and hence managed.

Recommendation: To develop and test a practical methodology for assessing defence performance, including the effects of deterioration and intervention.

Timescale: Short to medium term

Note: This will be partially supported through work under the ESPRC Flood Risk Management Research Consortium through research lead by HR Wallingford and the on-going a PhD studentship funded through the Thames 2100 supervised jointly by HR Wallingford and Bristol University.

It is anticipated that these techniques will be developed with reference to the case study site within the Thames (Long/Medium Term Maintenance and Improvement Planning and the identification of key structure types as part of the TE 2100 project).

R&D TECHNICAL REPORT W5-070/TR

Box 8.2   System analysis (continued)

Pathway response - Morphological behaviour
Changes in morphology can have a significant influence on the performance of a defence asset; both in the short and long term. This is a particularly important issue for coastal defences that rely critically on the performance of the foreshore. At present little is done to routinely include morphological responses in asset management decisions.

Existing models / knowledge can already be used to provide insight into the volatility of a beach / river bed (for example, for coastal areas derived from the ABMS data). In the longer term, and where appropriate, PAMS will need to include time dependent variation in morphology within the defence reliability analysis. Initial steps towards this capability are being taken within the EPSRC Flood Risk Management Research Consortium, EC Flood*site* and Tyndall Projects. However, considerable further effort will be required before the techniques are sufficiently robust to include within an operational PAMS system.

Recommendation: Develop a hierarchical set of time dependent models to reflect changes in morphology within the context of potential impact on asset performance. These will need to range for the simple to more computational intensive. In the short term the focus should be towards simplified methods.

Timescale: Short to medium term – partially supported through work planned under the EPSRC Flood Risk Management Research Consortium, Flood*site* and ongoing work through the Tyndall centre.

Pathway response - Predicting resultant flood inundation
The flood extent, depth and velocity will depend on severity of the load, the associated defence performance (size of any breach or volume of overtopping) as well as local rainfall, upland run-off, groundwater interactions and sewer performance as well as floodplain topography. A range of approaches are currently used within Agency decision-support tools and by their consultants. These include:

- Simple empirical formulae (as used in RASP HLM)
- 1D routing in the absence of defences (as used in MDSF)
- Quasi 2D floodplain flow (such as LSTFLOOD, InfoWorks-RS)
- 2D/3D hydrodynamic models (as used for more detailed studies – TELEMAC-2D/3D etc.).

However, as an alternative to using such methods, at a screening level PAMS could simply draw upon results from existing initiatives such as National Flood Risk Assessments (using RASP HLMs and the Extreme Flood Outline Project) and completed CFMPs / SMPs and Strategies. In the future development of PAMS these approaches will need to be extended and reviewed. In particular:

- Improvements to RASP HLM used in support of the National Flood Risk Assessment 2002 have been developed to support the NaFRA 2004. The improvements enable topographic and quantitative fluvial and coastal load data to be included within the national analysis of flood risk. This revised approach provides considerable greater certainty in the local estimates of flood depth and flood extent in the event of a failure in the defence system.

- Improvements in the MDSF and its linkage with RASP are proposed. The proposal includes the inclusion of an inundation model within the RASP and MDSF techniques to support CFMPs/SMPs/CDSs. At present it is unclear which is the preferred inundation model – but on-going projects (in particular the Thames Embayment projects) will provide strong guidance as to the suitability of different approaches including LISFLOOD-FP, InfoWorks-RS, TU-FLOW and TELEMAC-2D.

- Whole system hydraulic modelling approaches proposed under EPSRC will consider the integration of pluvial sources and drainage pathways within the fluvial/coastal flood flow modelling. The nesting of modelling to enable the interaction of regional and local scale models (1D, 2D and 3D models) will also be explored. However, considerable effort will be required to operationalise these techniques and are likely to appropriate in the most complex of urban areas.

Box 8.2   System analysis (continued)

While it is recommended that PAMS, CFMPs and NaFRAs aspire to the same basic approach to system analysis (as outlined in RASP), flexibility will be required in the choice and application of specific models.

Recommendation: To develop the system analysis module of PAMS – based on the RASP High/Intermediate/Detailed levels – to include an inundation modelling capability. The approach implemented should be hierarchical including both simplified modelling (as included at the High Level of RASP) as well as a more detailed modelling capability taking its lead from the Thames Embayment project to provide an increasing detailed understanding of asset management priorities.

Timescale: Short to medium term – partially supported through work planned under the development of MDSF (under the BSM Theme), Thames Embayments, EPSRC Flood Risk Management Research Consortium and Flood*site*.

Receptors
Flood damages are related to the type of flooding (saline/fresh/foul), flood depth and flow velocity and can include multiple impacts (both monetary and non-monetary). At present the analysis of likely flood losses is driven by simplified economic appraisal of damages using the proxy of Housing Equivalent to support maintenance decisions. Improvement works use more rigorous economic appraisal as well as other high level risk metrics, such as number of people at risk, to inform the Priority Scoring system operated by Defra to rank grant aided schemes.

PAMS will rely on multi-criteria approaches and could make use of the evolving concept of Appraisal Summary Tables. In particular, it will be important that a PAMS draws a broad assessment of potential damages into the analysis, including:

- Economic damage
- Risks to people
- Environmental improvement / degradation (habitat / water quality / landscape etc)
- Maintenance of river flows
- Health and safety of asset users
- Recreational amenity
- Navigation.

Recommendation: To develop a PAMS-specific multi-criteria approach to establishing potential impact. In doing this PAMS will need to draw in the latest guidance on quantifying impacts. In the short term simple measures using data available from higher level plans will need to be developed as part of the measured step forward.

Timescale: Ongoing.

System interventions

Intelligent searching of possible interventions - In the context of PAMS, intervention is rightfully constrained by the policy options laid down in higher level plans (e.g. CFMPs/SMPs) including:

− Improved management of the rural landscape (e.g. managing run-off)
− Managing the urban fabric (e.g. improved integration of the sewer and fluvial/coastal infrastructure)
− Managing flood events (e.g. improved flood forecasting/warning, maintaining conveyance)
− Managing flood losses (e.g. improved receptor resilience, including raising of property thresholds and changed building construction)
− Engineering – including maintenance of existing infrastructure as well as large scale interventions)

Given an appropriate knowledge of the policies for a given catchment or coastal cell, PAMS will need to be capable of working within these to deliver the operation and maintenance activities in an optimal manner. Where significant / large scale interventions are proposed within the higher level plans, intervention that significantly alter the river or coastal system, these are considered to be outside of the scope of a PAMS and most appropriately dealt with as scheme specific studies.

R&D TECHNICAL REPORT W5-070/TR

Box 8.2   System analysis (continued)

As highlighted above, asset management provides an example of decision making within the context of multiple inter-related issues *par excellence*. To help make better decisions, PAMS needs to provide guidance on the performance of possible intervention measures and highlight a set of preferred interventions for standard situations. The combinatorial problem raised by PAMS will demand the development of need for new option searching/optimisation techniques to enable preferred management actions to be efficiently identified.

Recommendation: To develop methods that can help users search for and identify optimal interventions based on whole life benefit cost analysis. The information provided by the analysis should enable the asset manager to develop a prioritised list of activities and weight the merits of one approach against another across a wide range of intervention possibilities. Clearly this analysis will need to be supported by appropriate detail on the behaviour of different intervention options over time, including both costs and benefits (see below).

Timescale: Short to medium term

Guidance on the performance of interventions - Present methods provide only limited guidance here. For example, it will be important that PAMS is capable of distinguishing the relative merits of improving the crest protection, undertaking toe works, concrete patching or investing in data collection etc in order to reduce risk and associated uncertainty. In areas demanding significant investment these processes are likely to utilise detailed reliability models; elsewhere simplified procedures and guidance may be sufficient.

Recommendation: To develop best practice guidance on the performance of a range of interventions in terms of their whole life costs and functional characteristics.

Timescale: Short to medium term

Design guidance for interventions – There are a number of generic issues faced by asset managers when determining the design of an intervention. Although some guidance exists outlining standard design details (including preferred materials, standard deterioration curves etc) this is limited and often out of date. A limited number of design guidance notes, showing best practice material specifications and design details (e.g. supporting groyne repair, concrete repair) would provide a useful reference for the asset manager and could build on various guidance manuals that have been produced recently or are in preparation or are planned.

Recommendation: To develop up-to-date best practice guidance on interventions, including construction details, materials, deterioration processes, pitfalls and experience. This should be updated as new knowledge and experience is gained.

Timescale: Short to medium term

Box 8.3   Decision approaches and option selection techniques

To ensure ultimate success and uptake of PAMS the primary user interface within PAMS will need to cover the process of decision-making and option section. In particular it will need to include:

- Problem Identification
- Objective Setting, Appraisal
- Prioritisation and Programming
- Implementation
- Feedback/Review.

In supporting these activities PAMS will need to include the following capabilities:

- *Sensitivity analysis* – Sensitivity of risk and risk reduction to intervention options.

- *Multi-criteria techniques* - Multi-criteria techniques will need to take account of amenity, economics, health and safety, ecology and other issues, perhaps expressed within the context of a *figure of merit* or radar diagram or making use of Appraisal Summary Tables. The selection of the criteria used will need to be informed by on-going projects such as "*sustainability of coastal and flood defences*" as well as "*Intangibles benefits/impacts of flooding*" supported by Defra and the Agency).

- *Uncertainty propagation techniques* - Techniques to highlight the uncertainty in outcome associated with a given course of action, and the key issues contributing to this uncertainty, provide a useful insight to the decision-maker. Uncertainty propagation will therefore need to be a key feature of a PAMS and will enable informed choices between further data collection and engineering intervention to be made. However, to make use of this data effectively the option selection process could be aided by techniques for the intelligent searching of options.

- *Value of Information* – A key component of asset management is inspection and data collection. Methodologies to prioritise inspection strategies based on data value will be needed to inform data collection strategies.

- *Prioritisation techniques* - Prioritisation techniques to inform medium term planning that utilise the results of multi-criteria and uncertainty analysis.

- *Simplified criticality analysis* - An important element of PAMS will be to provide the inspecting engineer with ability to crosscheck and influence outputs from the full PAMS. Thus, simplified methods to establish defence criticality (e.g. hazard indexing) could provide structured hand calculations for cross-checking priorities established by more elaborate means and provide an effective method of testing sensitivities.

- *Expert judgement* – often it is difficult to identify a uniquely optimal approach and a number of solutions provide equal valid approaches. Final selection will always rely on expert preference. To support this process better methods are required to produce more consistency and robustness.

*Recommendation: T*o develop the decision support module within PAMS taking account of all of the above factors and issues.

Timescale: Short to medium term

Box 8.4   System architecture, IT support and common databases

Common databases
With respect to data management, asset managers and inspectors provide the base information for all other Agency functions. This is a vital role and requires asset managers to be aware of the information needs of others and highlights the critical need to maintain a common asset database. This is currently provided by NFCDD, supported by other cross-Agency data held by the Technology Group at Twerton, the importance of which is likely to increase as all Agency tools begin to draw upon them. However, to maximise the utility of a common database, the data provided must be reliable and relevant.

Recommendation: To maintain a close linkage between the development of PAMS and NFCDD as well as other national databases.

Timescale: Short terms – PAMS will need to feed requirements to NFCDD.

System IT architecture
Any future development must take account of the constraints and opportunities offered by IT / data management and modelling and the Agency's drive towards an open architecture system with common components.   While explicit research in this area is outside of the scope of PAMS project, any recommendations made must be informed by IT issues. These include issues such as management of inspection / monitoring information, as well as managing the flow of data that supports prioritisation. Furthermore, at a more basic level, the Environment Agency has well defined standards for software and data to which any operational development must adhere.

PAMS itself should be developed in an open architecture fashion utilising, where possible, components from other modelling and data management systems (e.g. MDSF, NaFRA). To future-proof PAMS it will also be important that the IT architecture is modular in nature enabling new modules to be easily included as knowledge and methods improve.

Recommendation: To develop in detail the open architecture framework within which PAMS will operate. This will be a significant task. The first task will be to include a logical map of the software elements of PAMS and its linkage and use of common resources such as NFCDD and analysis modules. It will also include the user interface, including data enter, modification and display.

Timescale: Ongoing

Box 8.5   Case studies and piloting

It will be important that PAMS is developed and proven on real situations. It is envisaged that the following areas will provide key pilot study areas to aid the development and prove the utility of PAMS:

Thames Estuary – Improved condition assessment and high level identification of key structures
As part of the Thames 2100 project the base information on assets will be improved. It is envisaged that a high level PAMS tool will be rapidly established to provide initial guidance on the location of critical assets to help prioritise inspections.   Following this initial step it is envisaged that the improved inspection and condition assessment methodologies to be developed in PAMS will be trailed in associated with the prioritised inspection of assets. This will ensure that the condition assessment methodologies developed within PAMS are of practical use and the data collected as part of the TE 2100 Project has maximum value within the context of asset management and risk reduction. The regional PAMS tool will then be updated based on the collected data and priorities reassessed. This information will then be passed upwards to the regional policy decision support tools to be developed as part of the TE 2100 and downwards to the detailed PAMS tool to be developed by the Maintenance and Improvement teams as part of their Long/Medium Term Plans (see below).

Contact: Tim Reeder (Thames 2100)

Thames Estuary – Long/Medium Term Maintenance and Improvement Planning
The Agency annually update their long term (<10 years) and medium term (<3 years) maintenance and improvement plans. It is understood that Thames, Southern and Anglian Regions will be developing unified plans within the context of the TE 2100 Strategy Envelope and that Southern Region provide the lead. This forum provides an excellent opportunity to link the research and development of PAMS to a detailed case study on the tidal Thames.   It is envisaged that the regional PAMS model developed in support of the TE 2100 above will be locally improved and extended to include the identification of preferred maintenance and improvement interventions (within the constraints of the TE 2100 Strategy Envelope).

Contact: Clive Older (lead maintenance and improvement planning) / Tim Reeder (TE 2100)

A lowland embanked fluvial system (Anglian Region) – The issues associated with maintaining a lowland river system are quite different from those facing managers in the Thames. Significant effort has been applied towards improved maintenance of a number of rivers in Anglian Region. Selection of a pilot study in this region will provide an excellent test in terms of aiding the management of a lowland embanked river. In particular this case study will focus upon the risk-based management of channel conveyance and embankment vegetation.

Contact: Dave Denness (Environment Agency)

An urban river system (Midlands Region) – The RASP ILM has recently been trialed through application at Burton-on-Trent. Management of river defence assets within an urban setting presents a contrast to the lowland fluvial system discussed above. Selection on this pilot study area will provide a focus on managing a mosaic of river primary and secondary defences.

Contact: Richard Coxhill (Environment Agency)

A coastal town (North Wales) – The RASP ILM has recently been trialed through application on the North Wales coast at Towyn. Management of coastal assets presents another set of problems to those in a river or estuary system. In particular, morphological changes can be significant and the joint loading conditions are important. It is recommended that the model already established for Towyn – including detailed defence data – is utilised in developing the PAMS methods and tools within the context of a coastal flooding system.

Contact: Geraint Edwards – Conwy District Council

8.2 Priority research and development recommendations

Based on the research and development needs outlined in Section 8.1 it is recommended that PAMS taken further through two phases. An outline for the activities under Phase 2 and 3 are summarised in the below. The strategic work packages have been developed running from October 2004 to March 2007. These are listed in the table below.

Table 8.1 Priority research and development recommendations for the advancement of PAMS

Phase	Title
2	**Development**
	Case study and pilot sites - data collection, field testing, collaborative work
	Provide 'quick win' (priority status) upgrading benefits. (Here it is envisaged that short term benefits will be delivered by using recent nationally derived risk data to identify high priority assets.)
	Develop, test and deliver inspection and condition assessment methods
	Develop, test and deliver hazard indexing methods
	System analysis tools
	Decision approaches and option selection techniques
3	**Implementation**
	Software systems and associated databases
	PAMS system development and delivery
	System architecture and data management
	Business process infrastructure
	Training courses etc
	Work instructions and activities

Clearly some elements of Phase 2 and 3 will need to run in parallel to ensure compatibility benefit the software systems and IT support and the PAMS technical methods. As such early and on-going effort will need to be devoted to the development of the IT system architecture and data management structures.

9. CONCLUSIONS

This report has scoped a Performance-based Asset Management System (PAMS) that will provide the Environment Agency with improved methods for deciding how to manage its flood defence assets. The overall aim is to manage flood risk as efficiently and effectively as possible by inspecting, maintaining, repairing and if necessary replacing flood defences in order to achieve the required performance and to reduce risk. As PAMS is developed it will progressively replace existing maintenance and improvement approaches with a more organised approach that utilises risk-based methods.

Before PAMS can be realised as an operational business process a series of core techniques and tools will need to be developed covering the areas of:

- Inspection and condition assessment
- System analysis (including sources / pathways and receptors)
- Decision approaches and option selection
- Common databases.

These technical advances will in turn need to be supported by data management and IT infrastructure; some of which exists and some which will need to be developed.

In the shorter term, however, it will be possible to provide a number of key aids to present day decisions and take significant steps towards a more performance-based approach to asset management. In particular opportunities exist for the early development of:

- Improved inspection and condition assessment of defences – more explicitly recognising the relationship between condition and performance.

- *Hazard indexing* methods as a means of rapid, approximate field assessment of the criticality of an existing asset.

- National planning tools, such as the RASP HLM+ used in support of NaFRA 2004, to provided information on asset management priorities and the contribution to risk of individual assets.

To ensure the take up and use of PAMS the technical methodologies will need to be supported by significant resources directed towards piloting, IT and the development of guidance. In particular it is recommended that:

- A small number of pilot sites are established with a principal focus on the Thames. At each pilot site it is envisaged that PAMS is used support the delivery of the medium term maintenance and improvement plans as well as basic data for use in higher level strategic plans.

- An early revision of the Flood Defence Management Manual (FDMM) that reflects the revised approaches to condition assessment and asset inspection.

- In the longer term, the development of a software-supported, performance based asset management system (to include training, documentation, software interface, etc.).

In support of these goals a series of research and development activities have been outlined together with suggested opportunities for field trials and piloting. These recommendations will need to integrated within the broader scope of parallel activities inside and outside of the Agency, including the TE 2100 project, Flood Risk Management Consortium and the EC Flood*site* projects.

10. REFERENCES

DEFRA/EA, 2003a. Reducing Uncertainty in River Flood Conveyance, Interim Report 2: Review of Methods for Estimating Conveyance, Project W5A- 057, *HR Wallingford Ltd*., United Kingdom.

Environment Agency (2002). National Flood Risk Assessment. HR Wallingford Report EX 4722.

Environment Agency (2002). Risk, performance and uncertainty in flood and coastal defence – A review. Defra / EA R&D Report No FD2302/TR1. HR Wallingford Report SR587, January 2002.

Environment Agency (2003). RASP –Risk assessment for flood and coastal defence for strategic planning. Report No. W5B-030/TR1. HR Wallingford Report No. SR 603

Environment Agency (2004). PAMS – Project record (including a review of needs and requirements and performance-based asset management in other industries.) W5-070/PR

HR Wallingford (2002) Risk, performance and uncertainty in flood and coastal defence – A review. Defra / EA R&D Report No FD2302/TR1. HR Wallingford Report SR587, January 2002.

HR Wallingford (2003a). Reducing the risk of embankment failure under extreme conditions, Defra / Environment Agency Flood and Coastal Defence R&D Programme.

HR Wallingford (2003c) Risk assessment for Flood and Coastal Defence for Strategic Planning – High Level Methodology – Technical Report. Report No. W5B-030/TR1.

HR Wallingford (2004) Risk assessment for Flood and Coastal Defence for Strategic Planning – A summary – Technical Report. Report No. W5B-030/TR2.

Posford Haskoning (2002). Operations and maintenance concerted action. EA R&D Technical Report W5A-059/TR/3.

11. BIBLIOGRAPHY

CIRIA (2000). Maximising the Use and Exchange of Coastal Data: A guide to best practice. Publication C541.

CIRIA (2001). Infrastructure embankments: condition appraisal and remedial treatment. Report C550, Construction Industry Research and Information Association, London.

CIRIA (2003). Infrastructure embankments – condition appraisal and remedial treatment. Perry J., Pedley M., and Reid M. Publication C592 RP657, Construction Industry Research and Information Association, London.

Cullen, N. (1989). Risk assessment of earth dam reservoirs DOE Report 0002-SW/3, Water Research Centre, Swindon.

Defra (2002/3). Catchment Flood Management Plans: Guidelines.

Defra (2002). Shoreline Management Plans: A guide for coastal defence authorities.

Defra/Environment Agency (2002). Improving the implementation and adoption of flood and coastal defence R&D results. Technical report W5G(00)01.

Dawson, R.J. & Hall, J.W. (2001). Improved condition characterisation of coastal defences. Coastlines, Structures & Breakwaters 2001 Conference, Institution of Civil Engineers, London.

Dyer, B. & Millard, K. (2002). A Generic Framework for Value Management of Environmental Data in the context of ICZM, Journal of Ocean and Coastal Management, 45, pp59-75, Elsevier.

Environment Agency (1996). Condition Assessment Manual.

Environment Agency (2000). Review and development of the risk decision box for flood warning. Environment Agency Report No.20.

Ewan Associates and Mott MacDonald (2001). Development of enhanced serviceability indicators for sewerage assets, Ofwat and Environment Agency Report, October.

Holland, G. and Andrews, M.E. (1998). The inspection and risk assessment of slopes associated with the UK canal network. Geohazards in engineering geology (J G Maund and M Eddleston, eds). University of Coventry, 10–14 September 1995. Geological Society Engineering Geology Special Publication 15, pp 155–166. Geological Society, London.

HR Wallingford (1997). A procedure for planning irrigation scheme rehabilitation. G. Cornish and J. Skutsch, TDR Project R5832, Report OD/TN 84, February.

HR Wallingford (1998). Aids to maintenance, incorporating guidelines for monitoring system condition. G. Cornish, TDR Project R6260, Report OD/TN 94, June.

HR Wallingford (2003b). Reducing the Risk of Embankment Failure Under Extreme Conditions, Report 1: Good Practice Review. Defra / Environment Agency Flood and Coastal Defence R&D Programme, November.

McKay, D.T., Rens, K., L., Greimann, L.F. and Stecker, J.H. (1999). Condition Index assessment for US Army Corps of Engineers Civil Works. Journal of Infrastructure Systems, June 1999, Vol 5, Issue 2, p52-60.

MAFF (2000). A Review of Shoreline Management Plans 1996-1999 Report produced for MAFF by a consortium led by the Universities of Newcastle and Portsmouth.

MAFF (2000a). Flood and Coastal Defence Project Appraisal Guidance: Approaches to Risk FCDPAG4.

MAFF (2001). Flood and Coastal Defence Project Appraisal Guidance: Overview (including general guidance) FCDPAG1.

MAFF (2001). Flood and Coastal Defence Project Appraisal Guidance: Strategic Planning and Appraisal FCDPAG2.

MAFF (2001). Flood and Coastal Defence Project Appraisal Guidance: Environmental Appraisal FCDPAG5.

MAFF (1999). Flood and Coastal Defence High Level Targets, November 1999.

MAFF (1999a). Flood and Coastal Defence Project Appraisal Guidance: Economic appraisal FCDPAG3.

MAFF (1995). Post Project Evaluation of flood and coastal defence schemes – procedural guidelines Revision B, Nov 1995, MAFF, London.

Modarres et al (1999). Reliability engineering and risk analysis: a practical guide, Marcel.

Moffat, A.I.B. (1988). Embankment dams and concepts of reservoir hazard analysis. In: Proc. Conf. Reservoir Renovation 88, Paper 6.4. BNCOLD, London.

Posford Haskoning (2002a). Investigation of 'Fli-map' system for flood defence asset monitoring, Environment Agency R&D Technical Report W5A-059/TR/1, July.

Posford Haskoning (2002b). Use of non-destructive testing within flood and coastal defence, Environment Agency R&D Technical Report W5A-059/TR/2, December.

RPA (2003). Evaluating a Multi Criteria Analysis (MCA) methodology for application to flood management and coastal defence appraisal: Phase 1 Report – Seminar conclusions and preliminary methodology. Defra/EA Flood and Coastal Defence R&D Programme. FD2014: Draft Phase 1 Report, July.

Sarkaria, G.S. (1973). Safety appraisal of old dams: an updated perspective. In: Inspection, Maintenance and Rehabilitation of Old Dams, pp 40-417 American Society of Civil Engineers.

Sayers, P., Hall, J., Dawson, R., Rosu, C., Chatterton, J. and Deakin, R. (2002). Risk assessment of flood and coastal defences for strategic planning (RASP) – a High Level Methodology. Defra Conference for Coastal and River Engineers, September 2002.

Thompson, G. and Clark, P.B. (1994). Rapid hazard ranking for large dams. In: Reservoir Safety and the Environment. Proceedings of the 8th British Dam Society Conference, pp 306-15. Thomas Telford, London.

APPENDIX

Appendix 1

PAMS – A measured step forward – options for development

From the preceding discussion, two core issues have been identified as amenable to improvement in the short term as part of the measured step towards a fully PAMS. These include:

- inspection and condition assessment
- hazard indexing.

The options to support a measured step forward under these headings in the short term are discussed below.

A.1 A measured step forward for inspection and condition assessment

Asset inspection needs to be considered within a framework focussed on the assessment of the state or condition of the asset. Posford Haskoning (2002b) developed such a framework during the Operations and Maintenance Concerted Action R&D, and a similar framework has been incorporated into PAMS as shown in Figure A.1.

Highlighted by red circles in the figure, the four principal stages in this analysis are:

- inspection planning (IP)
- routine inspection and testing (RIT)
- detailed inspection and testing (DIT)
- condition assessment (CA).

A review of each of the stages within the framework and some options for improving the individual processes and delivering the overall framework are discussed below.
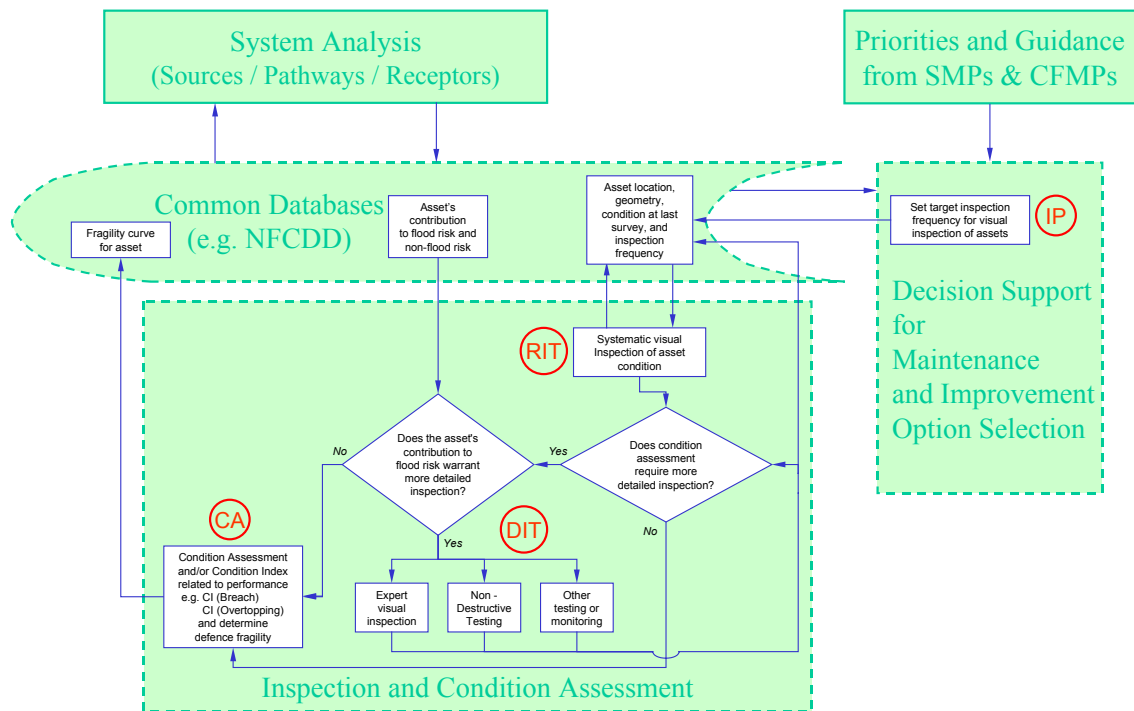
Figure A.1   PAMS framework for asset inspection focussed on condition assessment (extracted, with annotation, from Figure 6.2)

A1.1   Inspection planning (IP)

Information about assets such as the design concepts and standards, construction and expected performance is key to setting a benchmark for performance. The performance/failure history provides information on the deterioration profile under the corresponding levels of maintenance. This information is not always available. It is hoped that with the development of NFCDD, extra effort would be made to identify and record all available information about the defence infrastructure and the protected area. The Environment Agency regions carry out annual maintenance programmes through their emergency workforce and external contractors. As a result of preparing these programmes and supervising the works, data/knowledge is generated about these works. Obtaining such records is, however, usually difficult. Incorporation or linking of these to NFCDD would improve access to the maintenance history of the assets. It is expected that NFCDD development would pick these issues up, being important to the effectiveness of PAMS.

The frequency of inspection needs to be based on the current risk of failure and how that is expected to change over time. The Environment Agency's current inspection frequency matrix is risk based. It can be improved by further development of the likelihood to include, for example, known structural characteristics, asset criticality, rate of deterioration, and standard of protection and impact to be linked to affected flood cells and their contents. While this can be the basis for setting original inspection frequencies, as repeated assessments are carried out, the results (rate of deterioration) should feed back to amend the inspection frequencies as necessary.

The EA's inspection frequency matrix may be further improved for the assessment of flood risk, allowing for feedback of assessment and analysis results (e.g. rate of

deterioration) to amend the inspection frequencies. This tool needs to maximise the use of outputs from such projects as performance and reliability (dealing with structural characteristics, asset criticality, and rate of deterioration), as well as flood plain information and damage potential from tools such as detailed level RASP and information on flood cell boundaries.

A1.2   Routine inspection and testing (RIT)

This involves the physical presence of an inspector at a structure or defence to obtain a snapshot of the state of that asset by carrying out a walkover survey and noting physical defects and other indicators of condition within the easily accessible parts of the structure. The inspectors within the Environment Agency are currently trained to assess assets consistently to FDMM. The Agency's condition assessment manual is used as a guide for deciding on asset condition based on the visual inspection.

The manpower required to carry out visual inspections as desirable is often not available. The use of remote sensing as appropriate can reduce the need or frequency of visual inspections. The inspections need to record information that is related to the known performance/failure indicators. In order to achieve this, a study to map out the failure processes/trees for typical flood defence structures is required. This will enable indicators of deterioration/failure to be identified which are directly linked to potential defects. This way the inspection information can pick up defects which are linked to some mode of failure and hence performance. This simplifies the route from asset inspection to condition and performance assessment.

The current Agency condition assessment manual and FDMM assume that an assessment would always be possible following a visual inspection and does not allow for further investigation when the uncertainty in an assessment is too high. A further study to map defects to a range of potential methods for further investigation is also required as a useful source of information when the extents of the defects in affecting asset condition is not clear. The decision to carry out further investigation should, however, be made by a competent person depending on the flood risk. In the absence of further investigation, a conservative assessment would be required.

A1.3   Detailed inspection and testing (DIT)

Previous research projects conducted for Defra and the Environment Agency have identified the potential application of more detailed inspection and monitoring methods (e.g. beyond visual), to include:

- investigation of 'Fli-map' system for flood defence asset monitoring (Posford Haskoning 2002a)
- use of non-destructive testing within flood and coastal defence (Posford Haskoning 2002c)
- characterisation of embankments to better understand performance (HR Wallingford in preparation).

These methods include such approaches as aerial surveys (establishing the asset geometry and changes therein over time), radiography (to locate areas of variable compaction or voids), and resistivity (to detect stratification and conductivity of earth

embankments and sub-soil). Although the cost associated with some of the above techniques is prohibitive for routine use others can be applied rapidly across long lengths of defences. The main drawback is the lack of information regarding the reliability of the techniques and the interpretation of the results. However, the performance of such techniques will be a key issue if insight into the internal condition of flood defence assets and quantitative measurements is to form a routine element of a future PAMS system.

A.2 Possible options for improved inspection in the short term

As discussed in the main report, the development and delivery of the framework in Figure 3.1 is key to obtaining credible and consistent information about the state of the assets. Options for delivering this are discussed below, illustrated for clarity using bullet point processes and diagrams, accompanied by any relevant notes. For simplicity, the term 'non-expert inspector' is used to refer to a relatively inexperienced asset inspector, with minimal training, while 'expert inspector' indicates those with significant experience and/or training (i.e. with a higher level of competency in structural and geotechnical behaviour of assets). Input from the two levels of inspectors is indicated in the diagrams by 'NE' or 'E' of non-expert and expert inspector, respectively.

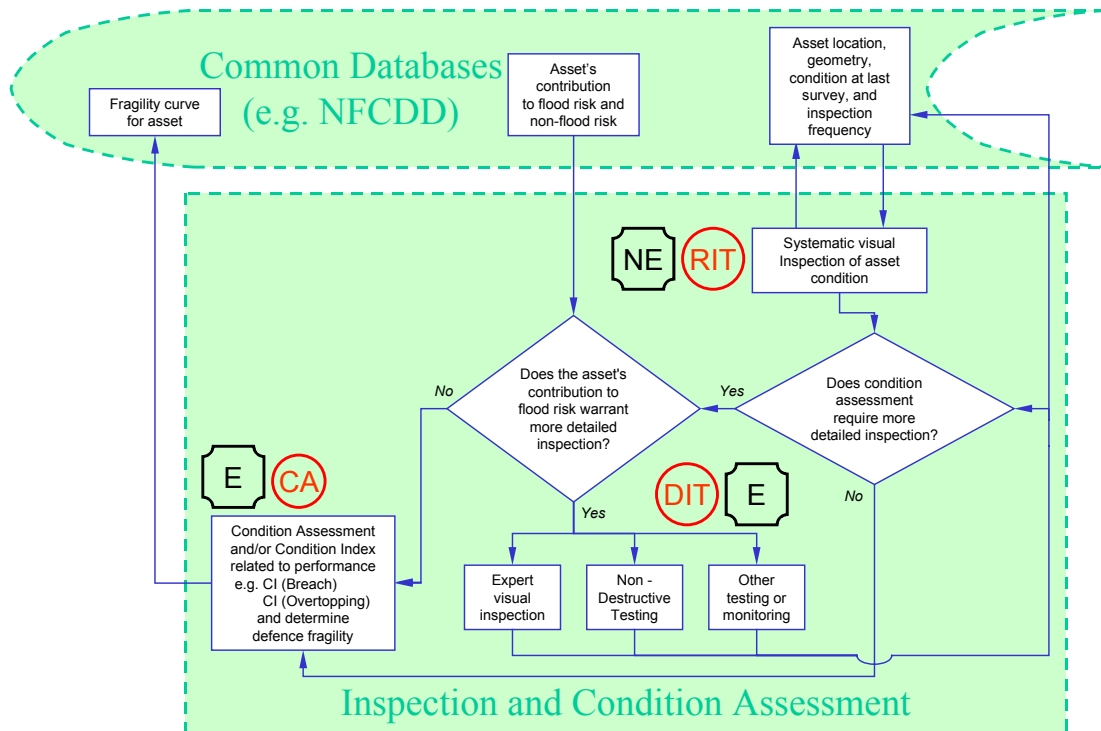## A2.1 Improved inspection - Expert inspection and condition assessment (Option A)
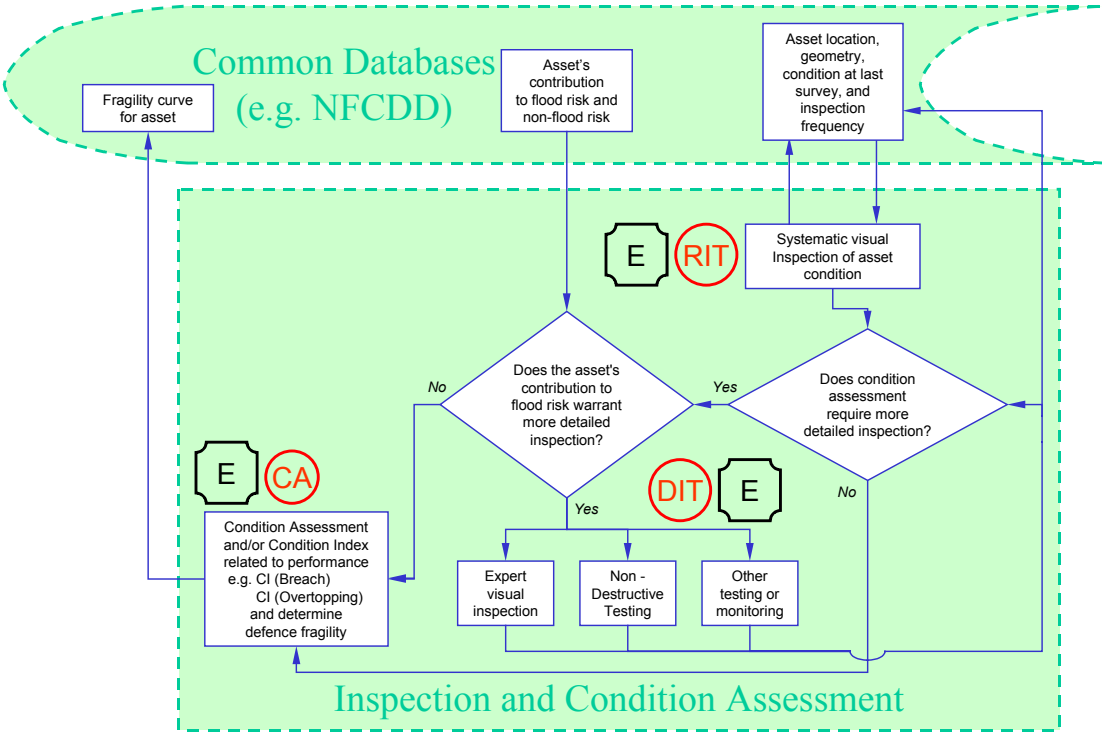
Figure A.2   PAMS Option A for inspections – Expert inspection and condition assessment

- Expert inspectors carry out routine inspections.
- Expert inspectors make condition assessments.

- Expert inspectors decide on the need for further inspection/testing/monitoring.

At present there are a limited number of staff with the required level of expertise for this option. Given the large number of experts required, this would require a high level investment in training for existing staff. Furthermore, it may be highly difficult to recruit staff of sufficient numbers of adequate calibre given resources in the flood defence industry.

A2.2 Improved inspection - Non-expert inspection with expert condition assessment (Option B)
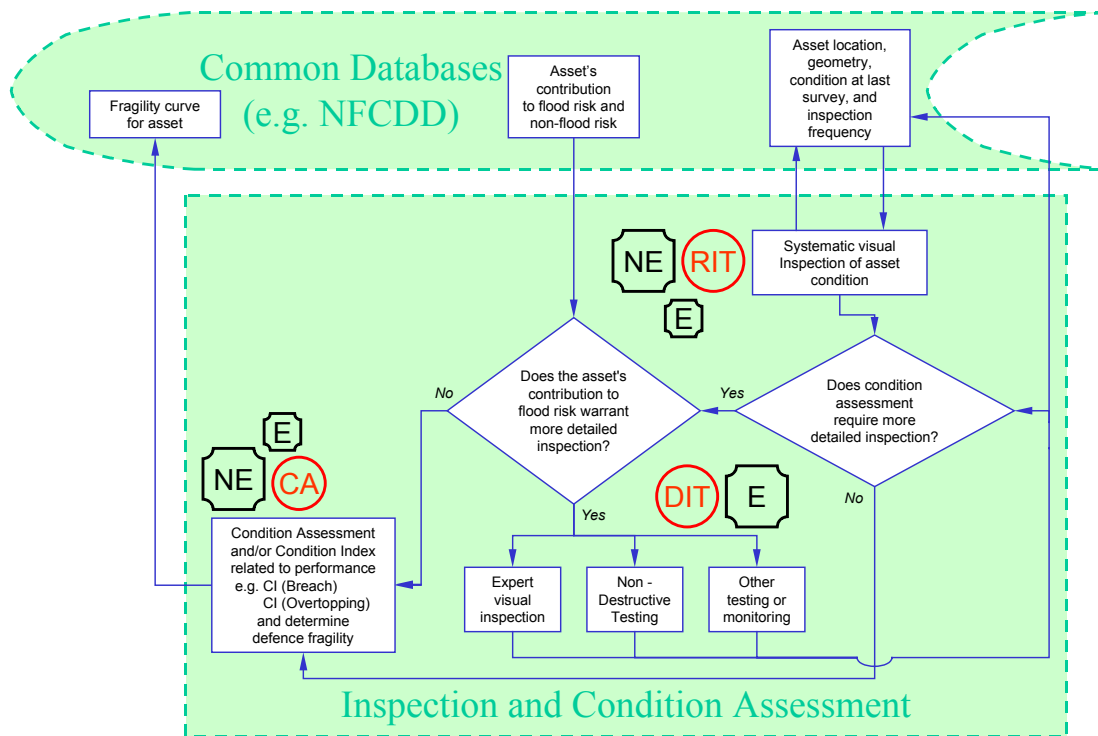

Figure A.3   PAMS Option B for inspections – Non-expert inspection with expert condition assessment

- Non-expert inspectors carry out routine inspections.
- Expert inspectors make condition assessments based on their records.
- Expert inspectors decide on the need for further inspection/testing/monitoring.

This will require training of asset inspectors on what to look out for and what to record. However, more experienced and qualified personnel (who can make a decision on asset condition or need for further works based on the interpretation of the recorded data) are also involved.

A2.3 Improved inspection - Non-expert inspection and condition assessment with periodic expert inspection and condition assessment (Option C)
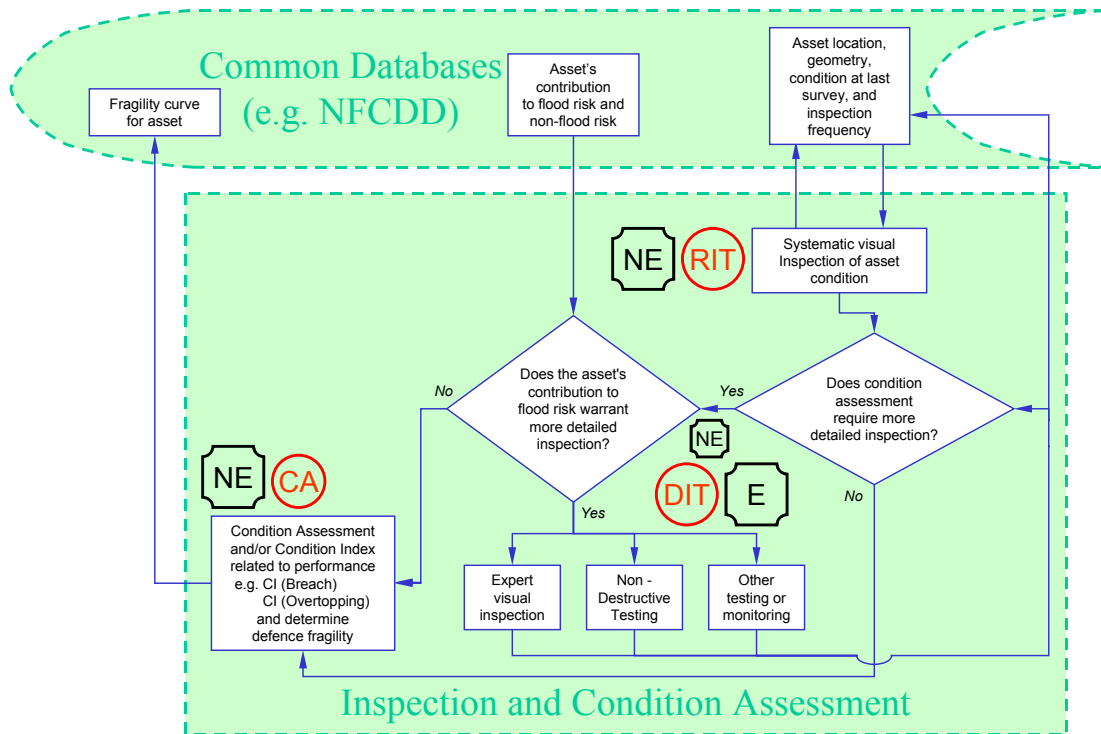

Figure A.4 PAMS Option C for inspections – Non-expert inspection and condition assessment with periodic expert inspection and condition assessment

- Non-expert inspectors carry out routine inspections.
- Non-expert inspectors make condition assessments.
- Expert inspectors carry out periodic inspections (e.g. every 5 to 20 years) jointly with non-expert inspectors.
- Expert inspectors make periodic condition assessments jointly with non-expert inspectors.
- Expert inspectors decide on the need for further inspection/testing/monitoring.

The periodic inspections (with more expert judgement) will guide requirements and particular areas to target on routine assessments.

A2.4 Improved inspection - Non-expert inspection and condition assessment with expert input (Option D)

Figure A.5   PAMS Option D for inspections – Non-expert inspection and condition assessment with expert input

- Non-expert inspectors carry out routine inspections.
- Non-expert inspectors make condition assessments.
- Non-expert inspectors make suggestions about the need for further inspection/testing/monitoring.
- Expert inspectors approve or disapprove further inspection/testing/monitoring.

This will require training of the asset inspectors to a relatively high level (with supporting tools and decision support).   However, involvement of more competent professionals is also provided.

A2.5 Preferred option improved inspection

Of the asset inspection options discussed above, the option preferred at present is Option C (Non-expert inspection and condition assessment with periodic expert inspection and condition assessment). The overall inspection methodology described for Option C is similar to that currently applied by British Waterways, with relatively cursory routine inspections (by less experienced inspectors) and more detailed periodic inspections (by more senior inspectors). While this option presents a more complex process to manage, it is as a consequence more adaptable, with the potential for varying inspection frequencies of both routine and periodic inspections. Furthermore, if non-expert inspectors accompany expert inspectors during the less frequent periodic inspections and condition assessments, these evolutions may form part of a continuing

education and training process. Thus, this option will aid in preserving corporate knowledge, i.e. helping to transfer knowledge and skills from expert inspectors to the non-experts.

A.3 Options to support improved condition assessment (condition indexing)

A3.1 Condition assessment - Basic Condition Index (Option A)

Development of a Condition Index for assets will require a process similar to that used by the US Army Corps of Engineers, who relied heavily upon expert input to produce procedures specific to each flood and coastal defence asset type. However, it may be possible to simplify the approach, resulting in a less detailed method that may be more easily applied. Similar to the USACE index, the system would produce scores from 0 (very poor/failed) to 100 (excellent/new).

While such a basic Condition Index would require less resource to develop, it should be recognised that the level of detail would result in a less precise assessment. One possible approach would be to adapt the current method from FDMM and the Condition Assessment Manual. Thus, in addition to supplying pictures and text descriptions of asset condition, checklists with simple queries could be provided to prompt the inspector (e.g. 'Are cracks wider than 2mm present in the concrete?' or 'Is the embankment crest even and level?'). Based on responses to the various queries, a suggested Condition Index would be generated.

A3.2 Condition assessment – Process-based Condition Index (Option B)

In contrast, further research and development may be conducted to introduce more process-based methods of estimating asset condition, potentially similar to methods developed by Network Rail for assessing the stability of rail embankments. Based on data from both routine inspections and detailed investigations, such methods could be used to augment the basic method of Option A, with the more basic procedures maintained for lower risk assets and assets for which process-based calculations have not yet been developed.

A3.3 Preferred option condition assessment

With regard to condition assessment, it is expected that the most appropriate approach in the short term (3-5 years) would be to adopt a somewhat basic Condition Index (Option A). However, with further research into the physical processes involved in structural and non-structural failure of all types of flood defence assets, process-based methods may be developed, and such techniques may then be phased in to augment the Condition Index with physical calculations (Option B). Development of such process-based techniques could be expected to rely upon continuing research into the reliability of flood defence structures (to include progress in developing concept of fragility curves proposed by the RASP project).

A.4 PAMS – Possible options to support rapid identification of critical assets (Hazard Indexing)

An important element of PAMS will be to provide the inspecting engineer with ability to crosscheck and influence outputs from the full PAMS. Thus, simplified methods to establish defence criticality (e.g. hazard indexing) could provide structured hand calculations for cross-checking priorities established by more elaborate means.

PAMS could incorporate a hazard indexing methodology based on multiple parameters identified as contributing to risk. Such a method could draw upon developments in the RASP research project to identify key parameters. Critical parameters utilised in such a calculation could include:

- Estimated flood risk within the flooding system – estimated from national flood risk assessments.
- Defence Standard of Protection (SoP) – although definitions will require alternation to reflect a more objective description.
- Defence condition, whether expressed as condition grade or condition index.
- Distance from the defence to receptors at risk (as estimated during an inspection or from geographical reference).
- Elevation difference between defence crest and the receptors (as estimated during an inspection or from geographical reference).
- An index of receptors (population and property), based on national datasets, inspection or analyses, for example:
  - no. of people within the flooding system
  - estimated expected annual damages (property and agriculture) – taken from national or more local studies
  - vulnerability of social groups in the area at risk
  - infrastructure at risk (e.g. transport, power, water supply)
  - other land use (e.g. environmental, recreational).
- Factors to account for:
  - different types of defences (to include both linear defences and structures)
  - flood plain slope and cross-section from the defence to the receptor
  - type of vegetation along the river bank and potential effects on flow
  - presence of structures in the river that may be restricting flow.

(Note: Guidance on selection of appropriate values for these last two parameters may be taken from the Conveyance Estimation System and Afflux Estimation System, in production by related Defra/EA funded R&D projects ('Reducing Uncertainty in River Flood Conveyance' and 'Estimating afflux at bridges and structures').)

A4.1 Hazard indexing – Based on separate consideration of probability of structural failure and consequence (Option A)

A hazard indexing methodology similar to many of those developed for reservoir safety in the late 20th century could be adopted, whereby multiple parameters are identified as contributing to the probability of structural failure. A single equation is developed to calculate a result. A separate calculation is then undertaken to assess likely consequences in the event of failure using simplified procedures. The output may be in the form of a consequence index scaled on a 0-100 for example to indicate the level of hazard without suggesting erroneous accuracy in output (e.g. estimated annual damage). Consideration of the two terms would then provide an indication of the critical of an asset.

A4.2 Hazard indexing – Based on combined probability and consequence terms (Option B)

Using similar underlying parameters as Option A, the parameters are used to calculate two distinct terms related to probability of failure and consequence of failure, which are then multiplied to provide the Hazard Index. Thus, such information as Condition Index, Standard of Protection, vegetation type, etc. would be used to calculated a probability-related term; and number of properties, vulnerability of social groups, infrastructure at risk, etc. would form the basis of the consequence-related term. Similarly to Option A, the index could focus on a scaled output (e.g. 0-100) to indicate the level of hazard without suggesting erroneous accuracy in output (e.g. estimated annual damage).

The Hazard Index would then take the form given below:

Hazard Index = (Probability of Failure) x (Consequence of Failure),

where:

Probability of Failure would be a function of condition, crest height, conveyance, afflux, etc.

and

Consequence of Failure would be a function of number and type of properties, social vulnerability, infrastructure, environment, etc.

A4.3 Preferred option for Hazard Indexing

At present, the preferred option for Hazard Indexing is Option B above. It is, however, noteworthy that no direct comparison will be possible between a rigorous probability/reliability-based flood risk analysis and any such Hazard Indexing method – but rather an indicative comparison. Nonetheless, Hazard Indexing will be a simple and rapid means of assessing risk which may act as a practical means of auditing output from more complex approaches and supporting rapid decision-making where necessary (e.g. programming emergency works during a flood event).