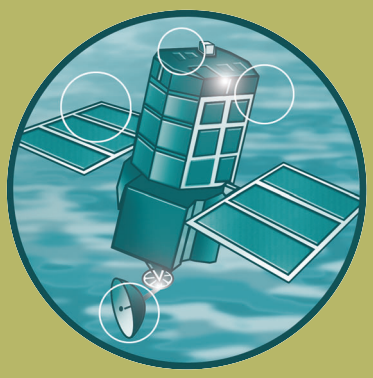
Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Reducing the Risk of Embankment Failure Under Extreme Conditions

A Framework for Action

R&D Technical Report FD2411/TR2



Environment Agency

defra
Department for Environment Food and Rural Affairs

Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

Reducing the Risk of Embankment Failure Under Extreme Conditions

Framework for Action

R&D Technical Report FD2411/TR2

November 2003

Statement of use
This Framework for Action (R&D Technical Report FD2411/TR2) recommends twelve areas for action either as research projects under the Defra / EA Joint Flood and Coastal Defence R&D Programme or as initiatives under the Environment Agency's Flood Defence operations. All the proposals outlined in this document have the broad objective of improved management (and hence performance) of flood embankments.

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

Keywords: Flood embankments (or levees), research , flood risk management, risk assessment, embankment performance, good practice, geotechnics

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Published by the Department for Environment, Food and Rural Affairs (November 2007). Printed on material that contains a minimum of 100% recycled fibre for uncoated paper and 75% recycled fibre for coated paper.

PB No. 12171

Acknowledgements

The authors wish to record the contributions of the following individuals, and in particular their collective effort in drawing together the different strands of scientific knowledge, research results, good practice and site-specific experience that were found.

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Context of this report

Project FD2411 on “Reducing the risk of embankment failure in extreme conditions” was carried out for the purposes stated in Section 1.1. This Framework for Action was completed in November 2003 and has been used to assist identifying subsequent research projects and operational initiatives. This version has had minor edits in 2007 in line with the publication of its companion Report 1 – Good practice guide. The latter was edited to link into the performance and risk based approach to asset management (which the review espoused) that had recently been implemented by the Environment Agency for Flood Risk Management.

The objectives and basic details of the proposals have not been changed from the final draft version which has been in use since November 2003, and was reported to the Defra Flood and Coastal Management Conference in July 2004.

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1. INTRODUCTION

There are some 7500 km of coastal and flood embankment in England and Wales. Effective performance of these embankments is critical to provide sustainable Flood or Coastal Defence, including the management of extreme flood events.

Ensuring that flood embankments in England and Wales are designed and maintained to achieve optimum performance requires that the design and management of these embankments is considered within a comprehensive framework. This report is one of two documents that provide an overview and guidance towards achieving this approach.

***Report 1**:* Provides an overview of the embankment management cycle along with a review of good practice for embankments.

Report 2: Addresses needs and proposes actions for future flood risk management of flood embankments (this document).

1.1 Aims and objectives

The need for improved guidance on the design and management of embankments across coastal and fluvial areas has been established through Defra and Agency Concerted Actions and is supported through experience gained in recent UK flood events.

The design and management of flood and coastal defence embankments needs to draw on several disciplines including hydraulics, geotechnics, survey inspection techniques, modelling and data analysis, and risk management. During the past decade there have been a range of developments, research projects and initiatives from which Operating Authorities can learn and develop improved methods to enhance performance.

The aim of Report 1 is to present an overview of embankment performance issues and guidance on good practice for dealing with all aspects of embankment design, operation and management. The report does not offer a detailed reference document on specific methods and practice, but rather a good practice index through which practitioners may identify realistically achievable improvements, and move towards ensuring that consistent standards and approach are achieved.

To achieve consistent standards, and to simultaneously raise these standards to provide maximum performance from our flood embankments, will require a range of initiatives in addition to the adoption of good practice, as presented within Report 1.

This report (Report 2) presents recommendations for actions and initiatives affecting many aspects of embankment performance. These recommendations have been developed through an extensive programme of consultation across a wide sector of the flood defence industry. Where possible, the recommendations have been prioritised to assist Defra and the Environment Agency in planning and prioritising their actions.

1.2 Users of this report

This report presents a vision of how the performance of flood embankments may be enhanced and developed in the future. The content provides an overview of issues leading to recommendations for action. It is therefore intended for use by Defra / EA flood risk managers in planning and prioritising actions.

1.3 Structure of this report

A summary of the recommended actions is presented in Chapter 2. Prioritisation of these actions is detailed in Chapter 3.

Supporting material may be found in the Appendices. Specifically:

Appendix 1 Specifications for the recommended initiatives
Appendix 2 The study approach.

2. RECOMMENDED ACTIONS AND INITIATIVES

2.1 Introduction

This Section presents an overview of the recommended actions and initiatives including a brief summary of objectives and justification for the various initiatives. This is followed in Section 3 by a review of potential costs, need, urgency etc. leading to a prioritised list of initiatives. A tabular summary and Gantt chart showing links between initiatives and their suggested timing is also provided.

2.2 Overview of recommended initiatives

Figure 2.1 shows a sketch of an embankment indicating the various features or functions of flood embankments that are recommended for action within this document. A total of 12 actions are recommended. Some of these entail significant long-term research programmes whilst others entail considerably less work to achieve gains in embankment performance.

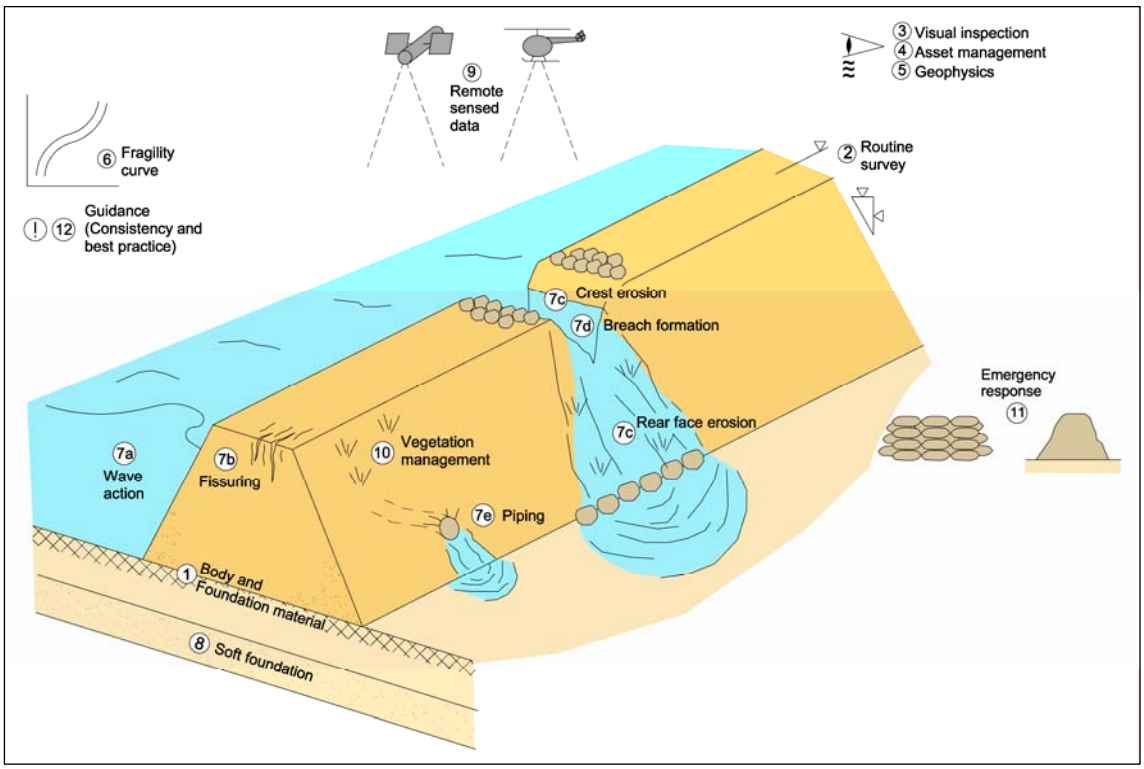

Figure 2.1 Proposed initiatives relating to embankment features or functions

2.3 Summary of recommended initiatives

The following sections provide a summary of each of the twelve recommended initiatives. Information has been presented to highlight the initiative objective, justification and likely deliverable items. More detailed information on each recommendation may be found in Appendix 1.

2.3.1 Establishing flood embankment body and foundation material

Objective:
To establish the nature of embankment body and foundation material nationwide through a programme of data review, sampling, analysis and data collection. Subsequently, to analyse the correlation between soil type, local geology and historic failure of flood embankments.

Justification:
In order to predict embankment behaviour, or to understand the nature of specific embankment problems, it is crucial to know the composition of embankment material and the founding strata. Whilst some information is likely to exist where specific site investigations have been undertaken, this information is not collected and held routinely for all flood embankments.

Indicative Methodology:

- Stage I: Review the link between embankment performance and foundation / embankment body soil properties. Identify which key material properties that are required in order to achieve significant value in determining embankment performance. Consider how such properties might be established (field collection and analysis) and in particular the cost in relation to the value that the data offers. As part of this analysis, consider how local geology / surface deposits might correlate with embankment performance. Determine the most cost effective approach that will support flood future risk management tools, including the integration of existing and / or more detailed site investigation information and the value that this offers. Develop an outline methodology demonstrating how the data collected will integrate with and / or enhance flood risk management tools.
- Stage II: Define the process for collecting information taking into consideration existing Agency practice and procedures.
- Stage III: Ensure development of appropriate fields / methods for storage of information within the NFCDD. Also develop an appropriate mechanism for the long term storage and easy access to more detailed site investigation data that is generated when specific works are undertaken on flood embankments. Where feasible, this system should also integrate with the wider data storage system for embankment soil properties.
- Stage IV: Develop a methodology for implementing field data collection nation-wide. This will require consideration of issues including:
    - Sampling frequency (sub-division of embankment lengths and section)
    - Current work practice (integration of collection into programme of work to minimise costs)
    - Steps required to initiate and integrate into standard practice
- Stage V: Implement data collection and analysis

Deliverables:

- Optimised methodology defining soil parameters for collection, method for collection and method for analysis supporting wider flood risk management tools including correlation between soil type, geology and embankment failure
- Implementation of programme for data collection and analysis, feeding into routing Agency practice

See Section A1.1 of Appendix 1 for a more detailed description of this proposed action.

2.3.2 Routine monitoring of flood embankment crest levels

Objective:
Ultimate aim is to implement a programme of routine surveying and assessment of flood embankment crest levels. In order to establish this routine it will first be necessary to confirm the risk associated with embankment crest variation and secondly to establish the best technique / approach.

Justification:
Embankment performance is fundamentally linked to embankment crest level. Without the ability to compare actual level against design level, or to ensure that a consistent level is maintained, performance cannot be assured. Crest levels are not routinely surveyed across the Agency at present.

Indicative Methodology:

- Stage I: Establish the benefit and extent of more detailed data collection. In order to define the most appropriate extent of data collection, it is first necessary to establish the value that the data will offer. Specifically, assessing the flood risk and sensitivity of calculation associated with variation in crest freeboard and lower than design crest levels. This will aid definition of the most appropriate risk related accuracy and resolution of survey data that should be collected. Consideration should also be given to the cost benefit of extending data collection to include the entire embankment profile rather than simply the crest level. The approach adopted here will be strongly influenced by potential techniques for remote sensing data (Action 9), data requirements for stability and / or performance analysis (Action 1) and systems available for long term storage and analysis (MDSF, NFCDD etc.).
- Stage II: Develop a programme for integrating the survey work and analysis into regional routine practice to determine problem areas. Demonstrate how data collection and analysis will contribute towards improved flood risk management. The programme should also allow for the long term storage and integration of existing survey data into the management approach. Interfacing with the NFCDD will be an important aspect of this work.
- Stage III: Implement routine data collection and analysis in regional flood risk management.

Deliverables:

- Assessment of the impact that varying degrees of data collection will have on assessing flood risk related to variation in embankment crest level and freeboard allowance. Development of an approach for data collection and analysis that offers maximum value for cost of data collection and analysis.

- Identification of long term Agency approach for topographic data collection, data storage and analysis, linking where possible to existing practice and procedures
- Implementation of crest level and embankment monitoring programme.

See Section A1.2 of Appendix 1 for a more detailed description of this proposed action.

2.3.3 Performance-based Asset Management System (PAMS)

Objective:
To take a measured step forward in developing a performance-based approach for identifying and prioritising works needed to manage existing flood defences. In doing so, to build a system that integrates with the risk based approach being adopted across all areas of flood management.

Justification:
Relative to existing methods of appraisal for new flood defence schemes, current approaches to justifying maintenance needs are less refined. The PAMS project will provide an asset management system that enables flood and coastal defence managers to assess the performance of and maintenance requirements for flood defence assets. Furthermore, the project will provide a means of identifying the optimum management intervention to achieve a particular outcome.

Indicative Methodology:
- Phase 1 to be a scoping study supplemented by case examples
- Phase 2 to further develop the resulting methodologies
- Phase 3 to provide supporting manuals and software.

Deliverables:
- In the medium term, improvements to the current asset management system consistent with the Environment Agency's interim approaches replacing the Flood Defence Management Manual (FDMM) and Management System (FDMS)
- In the long term, full operational delivery of a software-supported, performance based asset management system (to include training, documentation, software interface, etc.)

See Section A1.3 of Appendix 1 for a more detailed description of this proposed action.

2.3.4 Improved condition assessment through visual inspections

Objective:
To improve the effectiveness of Environment Agency visual inspections and to increase the efficiency with which potential problem sites are identified and acted upon

Justification:
The visual inspection of embankments is undertaken by a variety of Agency staff, whose knowledge and experience varies. Implementing a national programme of training and providing guidance / expert system to support action where problem sites are identified will improve the standard to which embankments are maintained and operated.

Indicative Methodology:

- Stage I: To develop a short training course that introduces issues from basic concepts through to inspection and interpretation of data. The Good Practice Guide on management of flood embankments may be used as an index to aid development of the course structure. A review of existing embankment dam safety courses may also help in developing content. A review of current practice and courses in the Agency regions should also be undertaken prior to development of the course to ensure that this maximises use of and builds upon existing knowledge
- Stage II: Implement training course on a national basis; establish as part of routine training
- Review regional systems for acting on inspection data and develop steps to ensure that appropriate action is taken based upon such data. Note: This action may be undertaken via the PAMS project under Action 3 or alternatively in close liaison with Action 3.

Deliverables:

- Review and development of a training module to increase understanding of flood embankments and hence the effectiveness of visual inspections
- Training of Agency staff to ensure consistent and high standards of visual interpretation
- Appropriate systems in place to ensure that embankments at risk are identified and acted upon within an appropriate time frame (Action 3 – PAMS?).

See Section A1.4 of Appendix 1 for a more detailed description of this proposed action.

2.3.5 Non-intrusive flood embankment integrity assessment

Objective:

To develop system(s) for assessing flood embankment integrity that are more effective than visual observation, but less complex, quicker and more economic than 'tradition' site investigations.

Justification:

Visual inspections provide no direct information on the internal nature of a flood embankment. 'Traditional' site investigations typically require a range of time-consuming techniques that provide varying degrees of information over limited lengths of embankment. A technique that permits the economic, rapid assessment of long lengths of embankment would significantly enhance our ability to ensure consistent embankment performance.

Indicative Methodology:

- Stage I: Review existing methods for visual inspection, geotechnical investigation and use of geophysical techniques. This review should including assessment of work currently underway in ongoing research projects such as the IMPACT project, the Dam Safety Interest Group (DSIG) project (Canada), the EPSRC flood risk management consortium etc. Processes, parameters and methods for collection should relate closely to work undertaken under Actions 1, 3 and 9. Develop a theoretical approach for inspection, building upon existing practice but using new techniques wherever practicable. Assess the cost benefit of implementing such an approach through determining the cost of implementing data collection and

assessment against the added value that the information offers in determining embankment performance and hence supporting flood risk management.

- Stage II: [Assuming Stage I offers a practical solution and a positive benefit]. Undertake trial application of the proposed procedures on selected site(s). Assess performance of the approach and review the added value offered by the methodology.
- Stage III: [Assuming Stage II confirms value of the approach]. Introduce new practices into the existing Agency programme for inspection and monitoring. This may require development of a supporting training programme. Integration will also need to mesh with activities under Actions 1, 3 and 9 to ensure maximum value is gained.

Deliverables:

- A review of non-intrusive systems for assessing embankment integrity. Development of a recommended approach appropriate for use within the Agency and offering maximum value on investment that is appropriate for the rapid and economic assessment of long lengths of embankment.
- Trial application and development of assessment system
- Integration of assessment system within Agency practice. Training of Agency staff as appropriate.

See Section A1.5 for a more detailed description of this proposed action.

2.3.6 Developing Fragility Curves to represent flood embankment performance

Objective:
To establish performance relationships (between load and failure) for flood embankments, taking into consideration key factors such as material type, surface protection, embankment condition, time varying properties etc.

Justification:
Risk based management systems (such as RASP) are based upon the use of fragility curves which represent the performance of flood defence structures. These curves require development and validation to ensure that the management system operates effectively.

Additional gain may be made through integration of time varying features such as embankment age, condition, residual life and short term conditions leading to response during an event such as preceding weather conditions, maintenance etc.

Indicative Methodology:

- Stage I: Establish performance relationships (between load and failure) taking into consideration key factors such as material type, surface protection, embankment condition etc. This will require identification and prioritisation of factors affecting performance, and subsequent assessment of performance processes in relation to these specific factors.
- Stage II: Further develop the reliability of fragility curves by including an assessment of temporal effects. Temporal effects may apply to the factors identified in Stage I, but may also be relevant to other factors.

Deliverables:

- Development and justification of basic fragility curve representation of flood embankments
- Further development of fragility curve representation of flood embankments to include time dependency variables.

See Section A1.6 for a more detailed description of this proposed action.

2.3.7 Understanding and predicting flood embankment failure

Five process areas have been identified in order to support a full understanding of flood embankment failure. Agreed to promote these under EC FLOOD*site* project. These are:

a) Initiation through wave action
b) Initiation through fissuring and cracking
c) Initial stages through erosion of crest and inward face
d) Breach formation through overtopping / overflowing
e) Breach formation through seepage / leakage / piping

Each of these areas requires specific research to be undertaken.

a) Initiation through wave action

Objective:
To develop / refine methods to predict the onset and development of erosion to the front face of flood embankments.

Justification:
Breach initiation in exposed coastal or open water areas can be prompted through wave induced erosion of the exposed face. Wave action can also accelerate internal erosion and instability through raised pore pressures. Research into basic processes leading to guidance on this aspect of initiation will permit improved embankment management and design in these areas.

Indicative Methodology:
The research into fundamental processes is likely to entail a combination of laboratory modelling, numerical analysis and, where possible, validation using field test sites.

Deliverables:

- Methods to predict the onset of erosion to the front face
- Guidance for managing assets to avoid the onset of erosion.

See Section A1.7a for a more detailed description of this proposed action.

b) Initiation through fissuring and cracking

Objective:
To establish the mechanisms leading to fissuring and cracking, their effect on embankment stability / failure and cost effective solutions for flood embankment management.

Justification:
Fissuring and cracking of embankments appears to be a commonly occurring problem, for which there is limited guidance on how to determine the severity of the problem and the need / best approach for repair. Failure to act can result in embankment failure although the time scale for progression to failure is far from clear. However, overreacting will result in unnecessary expense. Guidance is required to help asset managers make appropriate decisions to optimise flood embankment performance.

Indicative Methodology:
- Stage I: Literature review; establish current state of knowledge
- Stage II: Assessment of cause and nature of fissuring; analysis of growth patterns (likely to entail a combination of field and laboratory work)
- Stage III: Analysis to demonstrate link between extent of fissuring and threat to embankment performance; understanding of the transition from fine fissuring through to block failure, instability and / or pipe formation and failure
- Stage IV: Development of fragility curve representation of fissuring effects on embankment performance
- Stage V: Development of guidance to optimise mitigation and management, including an assessment of the cost benefit for implementing various measures.

Deliverables:
- Improved knowledge and understanding leading to guidance on i) indicators of fissuring; ii) Implications for embankment performance; iii) options for mitigation and management.

See Section A1.7b for a more detailed description of this proposed action.

c) Initial stages through erosion of crest and inward face due to overtopping / overflowing

Objective:
To establish the onset of flood embankment erosion during overtopping for a range of flows and surface conditions.

Justification:
In order to determine the risk posed to a flood embankment during overtopping, it is necessary to understand how the embankment will respond under a range of flow conditions and for a range of surface coverings and conditions.

Indicative Methodology:
- Stage I: Review / collation of existing material (including work undertaken overseas, particularly by USDA in US
- Stage II: Develop and implement a programme of field / laboratory testing on a range of key materials and conditions (taking into consideration existing and future Agency procedures for condition grading, protection design etc.). [The extent of this programme of work should first be justified by considering key embankment types, conditions etc. to ensure maximum value for research]
- Stage III: Interpret field / laboratory data to design curves and fragility curves for embankments

Deliverables:

- Design guidance detailing flood embankment performance under varying flow, surface and embankment conditions and materials
- Fragility curves representing flood embankment performance for varying overflow and embankment condition and types

See Section A1.7c for a more detailed description of this proposed action.

d) Breach formation through overtopping / overflowing

Objective:
To understand and predict the breach formation process through various (typical) types of flood embankment.

Justification:
In the event of an embankment breach, the flood risk manager needs to be able to estimate the rate at which growth might occur and hence the likely flood flows. This affects prediction of potential inundation, safe emergency access, options for breach closure etc. Breach formation rate varies according to flood embankment type, condition and hydraulic loading.

Indicative Methodology:

- Review state of art position (following completion of IMPACT project in Nov. 2004) in relation to emergency planning and risk management tool requirements
- Probable development of predictive tools through lab / field testing of failure of real embankment sections for a range of material types, material conditions, age etc.

Deliverables:

- Improved understanding and predictive model(s) for use in flood risk assessment and emergency planning

See Section A1.7d for a more detailed description of this proposed action.

e) Breach formation through seepage / leakage / piping

Objective:
To understand and predict the pipe formation process through various (typical) types of flood embankment.

Justification:
Unless stopped, pipe formation will lead to breach formation through an embankment. Current knowledge of the pipe formation process is limited and predictive modelling capability very poor. Flood risk managers need to be able to assess the risk posed by seepage or pipe flow through an embankment (whether developed from fissuring, seepage through permeable layers or animal burrowing)

Indicative Methodology:

- Stage I: Update on current state of knowledge (via Birmingham University)
- Stage II: Assessment of cause and nature of pipe formation; analysis of growth patterns (likely to entail a combination of field and laboratory work)
- Stage III: Analysis to demonstrate link between extent of piping and threat to embankment performance; analysis to understand the interaction between seepage, fissuring and pipe formation; development of fragility curve representation of embankment performance
- Stage IV: Development of guidance to optimise mitigation and management

Deliverables:

- Improved understanding and predictive model(s) for use in flood risk assessment and emergency planning
- Fragility curves representing embankment performance
- Guidance on mitigation and management measures

See Section A1.7e for a more detailed description of this proposed action.

2.3.8 Flood embankment construction on organic and soft clay foundations

Objective:

To provide guidance for the design and construction of new flood embankments or the raising of existing flood embankments built on foundations of soft or organic soils [addressing the issue of predicting and / or avoiding long term embankment settlement]

Justification:

By their very nature, many flood embankments are constructed in areas that are frequently underlain by significant thickness' of alluvial soils including soft clays, organic clays and peats. Such materials provide poor foundations with low shear strengths and a tendency for continuing long-term settlement. Whilst many geotechnical reports and papers have been written about the construction of embankments on soft soils, no concise document is available in the UK for the design of flood embankments, particularly in the way in which similar design guides are available for road and rail embankments. A single and targeted design guide is needed to ensure that all new flood embankments are designed and constructed to minimum acceptable standards. This should include methods for prediction of long term settlement and how to design for settlement in embankment construction.

In recent years the use of lightweight materials is being further investigated as an approach to reduce loading upon poor foundations. Guidance on this alternative approach should also be included.

Indicative Methodology:

- Establish a project team comprising industry and academics to ensure that theory and practice are combined in producing guidance. A steering group of key end users would help ensure value.
- Produce a practical guidance document based upon addressing the issues from two directions:
  - Review existing techniques for geotechnical analysis; assess and produce guidance

– Review current innovations in use of recycled lightweight materials; assess and produce guidance

Deliverables:
- Guidance for the design and construction of new flood embankments or the raising of existing flood embankments built on foundations of soft or organic soils (including innovative approaches using lightweight materials).

See Section A1.8 for a more detailed description of this proposed action.

2.3.9 Use of remote sensed data for surveying flood embankments

Objective:
To review and develop the most appropriate system for rapid, reliable and economic collection of survey data appropriate for the assessment of flood embankment geometry (and hence time varying condition).

Justification:
It is a fundamental requirement for the Agency to know what the crest levels and side slopes of their embankments are. Regular monitoring of embankment geometry provides a mechanism for early warning of potential stability problems. The huge lengths of embankment mean that it is not economically viable to survey all of these embankments by traditional techniques. LIDAR / FLIMAP offer a potential approach, however data accuracy (±100-150mm) is still not sufficient for assessment of embankment performance. Satellite data offers an alternative approach. The most viable long-term approach requires identification and development to ensure cost effective data collection of appropriate accuracy and resolution.

Collection of topographic data underpins many aspects of flood risk management. Establishing a reliable and economic method for collection of such data is a priority task.

Indicative Methodology:
- Review current state of remote systems and data management in relation to other Agency initiatives regarding data collection and management
- Identify preferred long-term strategy for topographic data collection (i.e. use of remote sensed data etc.)
- Identify required developments in sensing techniques; implement R&D work as appropriate
- Develop system for data collection and extraction to fit within existing Agency systems and link to appropriate initiatives (such as RASP, MDSF, PAMS, NFCDD etc)
- Implement procedures nationally.

Deliverables:
- Review, comparison and evaluation of current and future data collection techniques; identification of a long term strategy for Defra / EA consistent with use throughout the organisation (i.e. flood defence, asset management etc.).

- Development of preferred approach / technique into a working system for Agency use [this may entail funding specific research initiatives to improve system accuracy, resolution etc.]

See Section A1.9 for a more detailed description of this proposed action.

2.3.10 Research and guidance on vegetation management on flood embankments

Objective:
To research vegetation behaviour and develop concise guidance on the use and management of vegetation on flood embankments

Justification:
The type and condition of vegetation on an embankment affects the way in which the embankment is used, the soil moisture content, cracking / fissuring and resistance to surface erosion. Vegetation can have both a positive and adverse effect on embankment performance. Current guidance on choice and management of vegetation is limited. Maintenance procedures vary from Agency region to region resulting in inconsistent embankment performance.

Indicative Methodology:
- Phase I – Currently underway – investigation into maintenance / management processes through field trial experiments
- Phase II:
  - Review of different types and uses of vegetation suitable for embankment protection (multi purpose – surface protection, access limitation etc)
  - Field trials into effectiveness of types for function
- Guidance document on selection and use of vegetation (including guidance on how agricultural practice may affect vegetation and embankment condition)

Deliverables:
- Phase I – Investigation into vegetation management processes; guidance on management impact on vegetation performance
- Phase II – Investigation into vegetation performance; guidance upon the selection and use of vegetation on embankments.

See Section A1.10 for a more detailed description of this proposed action.

2.3.11 Emergency response – best practice for flood embankments

Objective:
To disseminate good practice for emergency response management for flood embankments

Justification:
The Autumn 2000 floods tested the Environment Agency emergency response system to the limits. Valuable lessons were learnt during these floods. North East Region has drawn on this experience and implemented a programme of changes in procedure and response. Similar approaches may have been taken elsewhere. To ensure consistent

good practice, review and dissemination of best practice between Agency regions should be undertaken.

Indicative Methodology:

- Establish core project team drawn from Agency areas worst hit by flooding during the past decade
- Review procedures, practice and solutions that have evolved from experience in different regions during various flood events; undertake wider industry consultation
- Consolidate findings and develop guidance on good practice for emergency management; disseminate via a guidance document and workshop. Scope of guidance to cover all aspects of emergency response ranging from staffing during events through to emergency repair of structures.

Deliverables:

- Good practice guidance drawn from regional Agency experience; dissemination workshop

See Section A1.11 for a more detailed description of this proposed action.

2.3.12 Flood embankment management manual

Objective:

To provide a definitive manual for the whole life design, maintenance and management of flood embankments (including guidance on site investigation). Subsequently to provide a mechanism for the rapid integration and dissemination of new knowledge and practice relating to embankments.

Justification:

Existing guidance is variable in detail and scattered (as demonstrated through this project review). During consultation, requests for better guidance and design office methodology were noted from a range of consultees covering a wide range of different issues. Some of these needs can be addressed by directing towards existing best practice (the Good Practice Guide), others require collation and writing of new guidance.

Indicative Methodology:

- Develop project team and steering group drawing from range of consultants, practitioners and researchers. Ensure an appropriate mix of water, geotechnical, O&M, design and construction professionals are involved. Confirm target audience, function and scope of guidance.
- Draw together good practice material and develop industry standards for all aspects of flood embankments making use of:
    - existing Environment Agency policy and procedures across all regions
    - Highways Agency, Network Rail, British Waterways
    - International experience, particularly from US and Netherlands
- Produce guidance document (both paper and electronic format) which may be used as an industry standard for all Agency works relating to flood embankments.

Deliverables:

- Wide ranging professional document providing definitive source of information for all Agency related embankment works. (Electronic version online allows for easy updating as additional knowledge / research is undertaken).

See Section A1.12 for a more detailed description of this proposed action.

3. PRIORITISATION OF RECOMMENDED ACTIONS AND INITIATIVES

Prioritisation of the various recommendations requires consideration of a number of factors including:

- Perceived technical / operational urgency
- Interdependence upon other recommended actions or projects
- Likely source of funding.

Table 3.1 presents a summary of all of the recommended actions. A short review and prioritisation of actions is also presented in Section 3.1 below.

In Table 3.1 actions are categorised according to:

Description:

Type of Initiative:

QW 'Quick Win' Initiative (either by action or opportunity; minimal risk to provide gain)
Int Intermediate - Initiative will take longer than QW but gains will result from implementation
L Longer term research (risk entailed to reach objectives).

Nature of Initiative:

Field Fieldwork
Res Research
BP Best Practice / Guidance Documents
Train Training
Data Investigations / data collection
Proc Understanding physical processes
Tools Developing new tools or practice for management.

Priority of Initiative:

H / M / L High / medium / low
(Note that priority indicated here is based upon perceived need through industry consultation)

Table Notes:
[1] An initiative for developing Performance-based Asset Management has already been started.
[2] Establishing embankment body and foundation material type is a relatively simple task. However, initial work is required to confirm best approach and subsequent data collection requires a large amount of field work, hence high costs (£Ms).
[3] Routine monitoring of embankment crest levels can be incorporated into standard regional practice rather than undertaken as a separate initiative. However the true extent

of topographic data collection and most appropriate method must be established before integrating this into routine practice.

[4] Development of improved procedures for visual inspection should be possible at relatively low risk and with minimal cost / duration. However, development of investigation techniques through the use of geophysical techniques is inherently uncertain and of a longer duration.

[5] Recent studies have been undertaken by the Agency into the use of LIDAR and FLIMAP systems. It is perceived that with a relatively small improvement to data accuracy, the value to the Agency would be significant – hence QW listing. This does however entail some research and development work, which contains a risk.

Table 3.2 provides a Gantt Chart showing possible interaction and duration of the various initiatives. Initiatives 1-5 broadly relate to operational initiatives, 6-10 to research initiatives and 11-12 to dissemination activities. A few of the initiatives are dependent upon other actions, whilst the majority could start more or less immediately.

It should be noted that the duration and budgets allocated to the various recommendations are initial broad estimates.

3.1 Prioritising Actions

Table 3.1 provides a summary of 12 recommended actions, which becomes 16 actions if actions under Action 7 are treated separately. It should be recognised that this list has been created by already prioritising actions down from a much longer list. Items listed here are therefore all of a relatively high priority.

Consideration may be given to further prioritising these actions. Whilst in practice other factors such as parallel national or international research programmes and projects will influence the order in which work may be undertaken, the following points should be noted:

Priority Actions

Actions 1, 2, 3, 9 and 12 are identified as priority actions.

Actions 1 & 2: Flood embankment material and geometry

These actions are fundamental requirements to allow a future risk based approach to understanding of how embankments will perform. The practical extent and value of this work should be established as soon as possible by initial scoping studies.

Action 3: Performance-based Asset Management System

This action has already been initiated.

Action 9: Use of remote sensed data for surveying flood embankments

The collection of topographic data underpins a number of areas fundamental for flood risk management as a whole, as well as for embankments specifically.

Action 12: Flood embankment management manual

The need for a guidance manual setting standards for a wide range of embankment issues has been identified. Many issues that were raised during consultation would be addressed by having a single definitive source of information. By undertaking an initial

structuring study, and developing the guide in a modular fashion, this action offers a 'quick win' opportunity and an approach whereby guidance may be provided in a prioritised fashion, and updated as knowledge and procedures progress.

Quick Wins

Actions 4 and 11 are identified as quick win opportunities.

Action 4: Improved condition assessment through visual inspections

Dissemination of existing knowledge through training offers a rapid and economic means for improving the overall level of risk management of embankments.

Action 11: Emergency response – best practice for flood embankments

Collation of existing best practice from Agency regions, followed by national dissemination ensures consistent, high standards nationwide. A relatively quick and economic means for improving flood risk management.

Supporting other Initiatives

Actions 6 & 9 support other Agency initiatives.

Action 6: Development of fragility curves to represent flood embankment performance

Risk management tools being developed (such as RASP) require the performance of flood defences to be represented through fragility curves. For the other initiatives to succeed, it is therefore important that these supporting actions are undertaken. Work on general fragility curve representation has been initiated. However, it should be recognised that representing all aspects of embankment performance in this way is a complex task and likely to require considerable research effort.

Action 9: Use of remote sensed data for surveying flood embankments

Recommended above as a priority action.

Other Actions

The remaining actions (5, 7, 8 and 10) comprise areas of research where our understanding of embankment performance limits the extent to which we can manage flood risk.

These have been divided into delayed starts (pending completion of existing project work) and 'others'.

Delayed Starts

Action 5: Non-intrusive flood embankment integrity assessment

Work under the EC FP5 IMPACT project is currently making an initial investigation of these issues. This project concludes in Dec 04. Any action on this topic should build upon this work.

Action 7d: Breach formation

Considerable work is being undertaken under the EC FP5 IMPACT project to investigate breach formation processes. This will conclude in Dec 04. Required actions should then be reviewed.

3.1.1 Action 10: Guidance on vegetation management on flood embankments

Initial work investigating the effects of vegetation management has been initiated. Work relating to choice and performance of different vegetation type should build upon this initial initiative.

Others

Action 7a: Breach initiation through wave action
Research required. With an emphasis on prevention of breach formation, understanding initiating mechanisms is important for determining likely location and timing of potential formation.

Action 7b: Breach initiation through fissuring and cracking
Some research initiated (Mark Dyer, Durham University using the Thorngumbald managed retreat site). Whilst this will provide an initial investigation of the issues, a more detailed research programme is likely to be required to make significant advances in this area.

Action 7c: Breach initiation through crest and inward face erosion
Research required. With an emphasis on prevention of breach formation, understanding initiating mechanisms is important for determining likely location and timing of potential formation.

Action 7e: Breach formation through seepage and piping
Some research initiated (Gurmel Ghataora, Birmingham University using the Thorngumbald managed retreat site). Whilst this will provide an initial investigation of the issues, a more detailed research programme is likely to be required to make significant advances in this area.

Action 8: Flood embankment construction on organic and soft clay foundations
Research and guidance required. Guidance could feed into (priority) Action 12.

Table 3.1 Summary of Recommended Actions and Initiatives

No.	Initiative	Description			Indicative Funding				Related initiative	Deliverables	Priority
		Type	Nature	Priority	Budget (£1000)	Duration (Years)	Defra / Agency	EPSRC			
1	Establishing flood embankment body and foundation material	Int	Field Data	H	50-100 + High[2]	1 + ongoing	λ		Action 2	Recorded details of flood embankment body and foundation type Correlation between soil and geology	λ
2	Routine monitoring of flood embankment crest levels	QW	Field Data	H	100 + High[3]	1 + ongoing	λ		Action 1, 9	Assessment of sensitivity of flood risk to variation in crest level; Selection of optimum approach; Routine recording and analysis of crest levels (and historic variation)	λ
3	Performance-based Asset Management System	L[1]	Res Tools	H	250	3	λ		PAMS Action 5	A transitional asset management system A software-supported, performance based asset management system	λ Started
4	Improved condition assessment through visual inspections	QW	Train Tools	H	100	1-2		λ		Agency staff training Agency procedures	
5	Non-intrusive flood embankment integrity assessment	Int[4]	Res BP Proc	H	150	1-2		λ	IMPACT Action 3	Economic and rapid technique for integrity assessment appropriate for long lengths of flood embankment	
6	Developing fragility curves to represent flood embankment performance	L	Res Proc	H	100 – 500	2-6	λ	λ	Risk & Performance	Fragility curves covering different flood embankment types, condition etc.	Initiated
7	Understanding and predicting flood embankment failure:								EC FLOOD*site* initiative		
7a	Breach initiation through wave action	L	Res BP Proc	H	100 - 200	2-3		λ		Methods to predict the onset of erosion	
7b	Breach initiation through fissuring and cracking	L	Res Proc	H	100 - 200	2-3		λ	Thorngumbald (Durham Univ)	Knowledge and understanding relating to processes, embankment inspection and embankment failure	Initiated

Table 3.1 Summary of Recommended Actions and Initiatives (continued)

No.	Initiative	Description			Indicative Funding				Related initiative	Deliverables	Priority
		Type	Nature	Priority	Budget (£1000)	Duration (Yrs)	Defra / Agency	EPSRC			
7c	Initial stages through erosion of crest and inward face due to overtopping / overflowing	L	Res Proc	H	100 - 200	2-3		λ		Performance curves for various flow and surface conditions	
7d	Breach formation through overtopping / overflowing	L	Res Proc	H	100 - 200	2-3			IMPACT	Knowledge and understanding supporting predictive breach model	
7e	Breach formation through seepage / leakage / piping	L	Res Proc	H	100 - 200	2-3		λ	Thorngumbald (Birmingham Univ.)	Knowledge and understanding supporting predictive pipe / breach model	Initiated
8	Flood mbankment construction on organic and soft clay foundations	Int	Res BP	H	100	1-2	λ	λ	Tyres	Guidance on options / innovative approaches	
9	Use of remote sensed data for surveying flood embankments	L / QW[5]	Res Tools Data	H	100 - 200	1-2		λ		Review of current and future options Development of preferred system to appropriate accuracy and resolution	λ
10	Research and guidance on vegetation management on flood embankments	Int	Res BP	H	100	1-3	λ		Vegetation management	Guidance on vegetation management Guidance on vegetation selection	Started
11	Emergency response – Best practice for flood embankments	QW	BP	M	50 – 75	1	λ			Good practice guidance drawn from regional Agency experience	[λ]
12	Flood embankment management manual	Int	BP	H	200 - 300	2	λ			Wide ranging embankments management manual setting consistent standards for all aspects of EA flood embankment asset management work [online document for easy updating / expansion]	[λ]

Table 3.2 Gantt Chart showing recommended actions and initiatives

	Recommended Initiative			2004 Year 1	2005 Year 2	2006 Year 3	2007 Year 4	2008 Year 5
1	Establishing flood embankment body and foundation material	*Planning*	Operational Initiatives					
		Field collection						?
		Correlation						
2	Routine monitoring of flood embankment crest levels			ST. I	ST II			?
3	Performance-based Asset Management System							
4	Improved condition assessment through visual inspections	*Training*						
		Procedures						
5	Non-intrusive flood embankment integrity assessment	*Geophysics*						
6	Developing fragility curves for flood embankment performance	*Basic curves*	Research Initiatives					
		Temporal var.						
7	Understanding and predicting flood embankment failure:							
	a) Initiation through wave action							
	b) Initiation through fissuring and cracking							
	c) Initial stages through erosion of crest and inward face							
	d) Breach formation through overtopping / overflowing							
	e) Breach formation through seepage / leakage / piping							
8	Flood embankment construction on organic & soft clay foundations							
9	Use of remote sensed data for flood embankment surveying							
10	Guidance on vegetation management on flood embankments	*Management*						
		Type						
11	Emergency response – best practice for flood embankments		Dissemination					
12	Flood embankment management manual							

APPENDICES

Appendix 1

Specifications for recommended actions and initiatives

The following tables present more detailed specifications for each of the recommendations for future actions by Defra./Environment Agency (as summarised in Chapter 2). These recommendations are based upon the issues raised during consultation, and the problems identified and recognised when reviewing the current management approach, level of understanding and needs to support ongoing initiatives.

A1.1 Establishing flood embankment body and foundation material

1
Action: **Establishing flood embankment body and foundation material**
Objectives: Development and implementation of a national programme of data collection to identify flood embankment body and foundation material. Specifically to: • Investigate and establish the best value approach for collecting data to support the assessment of embankment performance. • Establish a practical framework for field investigation / sampling • Implement field survey work • Ensure integration of data into NFCDD and subsequently Agency assessment and management procedures
Justification: Current records do not detail embankment construction material or foundation material. Whilst some information is likely to exist where specific site investigations have been undertaken, this information is not routinely stored for all embankments. In order to investigate embankment problems, knowledge of embankment material is a fundamental requirement. With knowledge of flood embankment material, correlation between performance issues and construction material may be undertaken.
Indicative Methodology: • Stage I: Review the link between embankment performance and foundation / embankment body soil properties. Identify which key material properties that are required in order to achieve significant value in determining embankment performance. Consider how such properties might be established (field collection and analysis) and in particular the cost in relation to the value that the data offers. As part of this analysis, consider how local geology / surface deposits might correlate with embankment performance. Determine the most cost effective approach that will support flood future risk management tools, including the integration of existing and / or more detailed site investigation information and the value that this offers. Develop an outline methodology demonstrating how the data collected will integrate with and / or enhance flood risk management tools. • Stage II: Define the process for collecting information taking into consideration existing Agency practice and procedures. • Stage III: Ensure development of appropriate fields / methods for storage of information within the NFCDD. Also develop an appropriate mechanism for the long term storage and easy access to more detailed site investigation data that is generated when specific works are undertaken on flood embankments. Where feasible, this system should also integrate with the wider data storage system for embankment soil properties. • Stage IV: Develop a methodology for implementing field data collection nation-wide. This will require consideration of issues including: - Sampling frequency (sub-division of embankment lengths and section) - Current work practice (integration of collection into programme of work to minimise costs)

- Steps required to initiate and integrate into standard practice
- Stage V: Implement data collection and analysis

Deliverables:

- Optimised methodology defining soil parameters for collection, method for collection and method for analysis supporting wider flood risk management tools including correlation between soil type, geology and embankment failure
- Implementation of programme for data collection and analysis, feeding into routing Agency practice

Issues:

- Development of this programme of work might link with Action 2: Collation of crest levels / embankment geometry
- Identifying the most appropriate sampling frequency requires careful consideration. Factors affecting this choice will include:
  - variations in local surface and embankment material
  - variations in embankment geometry / loading
  - existing database identification of defence lengths
  - assessment of optimum spacing for embankment sampling to ensure representative of entire section

Related initiatives / opportunities:

- Work investigating the relationship between data sampling spacing and assessment of embankment performance is / has been undertaken by Delft Geotechnics
- Initial work undertaken in the Agency NE and NW regions to develop simple risk based approaches to assessing embankment performance based upon limited soil data should be reviewed. Current work in NE Region analyses performance using soil type and stratification. However, no validation of the approach through, for example, comparison of predictions against observations, has yet been done.
- Links to proposed breach formation work – specifically correlation between surface geology maps and breach formation. If both field and local geology data is collected then analysis should be undertaken to determine the extent of correlation between historic failure / problems, local geology and embankment material type. This may provide a simple system for prioritising potential problem embankments. Work under the EC IMPACT project 'touches' on this topic

Priority: **H**	Budget Costs: Stages I-IV £50-100K Stage V £Ms	Probable duration: Stages I-IV 1 yr Stage V Ongoing prog.
Type/Nature: Data collection and analysis		

A1.2 Routine monitoring of flood embankment crest levels

2

Action:

Routine monitoring of flood embankment crest levels

Objectives:

To implement a programme of routine surveying and assessment of flood embankment crest levels in order to monitor actual standard of protection. In order to establish this routine it will first be necessary to confirm the risk associated with embankment crest variation and secondly to establish the best technique / approach.

Justification:

In order to assess flood risk, it is essential to know both the potential flood levels and the level of defence offered by embankments. Routine surveying of embankment crest levels is not currently undertaken consistently across the Agency Regions.

- With routine data collection and analysis, embankment problems may be identified and monitored before more serious conditions develop.
- Historic records of embankment deformation / settlement provide valuable information against which to gauge the seriousness of problems, should they occur.

Indicative Methodology:

- Stage I: Establish the benefit and extent of more detailed data collection. In order to define the most appropriate extent of data collection, it is first necessary to establish the value that the data will offer. Specifically, assessing the flood risk and sensitivity of calculation associated with variation in crest freeboard and lower than design crest levels. This will aid definition of the most appropriate risk related accuracy and resolution of survey data that should be collected. Consideration should also be given to the cost benefit of extending data collection to include the entire embankment profile rather than simply the crest level. The approach adopted here will be strongly influenced by potential techniques for remote sensing data (Action 9), data requirements for stability and / or performance analysis (Action 1) and systems available for long term storage and analysis (MDSF, NFCDD etc.).
- Stage II: Develop a programme for integrating the survey work and analysis into regional routine practice to determine problem areas. Demonstrate how data collection and analysis will contribute towards improved flood risk management. The programme should also allow for the long term storage and integration of existing survey data into the management approach. Interfacing with the NFCDD will be an important aspect of this work.
- Stage III: Implement routine data collection and analysis in regional flood risk management.

Deliverables:

- Assessment of the impact that varying degrees of data collection will have on assessing flood risk related to variation in embankment crest level and freeboard allowance. Development of an approach for data collection and analysis that offers maximum value for cost of data collection and analysis.
- Identification of long term Agency approach for topographic data collection, data storage and analysis, linking where possible to existing practice and procedures
- Implementation of crest level and embankment monitoring programme.

Issues:

Fundamental issues to consider include:

- When assessing the value offered by data collection, consideration will need to be given to current variation in crest levels / freeboard in relation to embankment locations and flood risk. For example, does embankment crest level variation differ between defences protecting urban areas in comparison to rural? Does potential variation relate to the level of protection?
- How much data should be collected? (e.g. crest, embankment profile, embankment and floodplain etc.)
- Required accuracy and resolution of data? [Are remote sensing techniques sufficiently accurate? What data do you extract from remote sensed data sets?]
- How will the data be analysed? How will this support existing and new flood risk management procedures? Guidance is required on frequency of analysis and method / detail of analysis
- How will seasonal variations affect data collection (e.g. vegetation)

Related initiatives / opportunities:

- Delft Geotechnics are currently undertaking an investigation into survey spacing for long term monitoring of embankments
- Further refinement of LIDAR / FLIMAP is required to provide cost effective data collection, at an appropriate resolution and accuracy. There appears to be differences of opinion as to the current accuracy of LIDAR data. However, it is perceived that the current accuracy (i.e. ±100-150mm) is not sufficient for assessing variations in embankment crest level and subsequent flood risk.

Priority: **H**	Budget Cost: Stage I: £50K; Stage II: £50K; Stage III: Variable	Probable duration: Stages I& II: 1yr Stage III: routine
Type/Nature: Data collection / inspection procedures		

A1.3 Performance-based asset management system

3
Action: **Establishing a Performance-based Asset Management System (PAMS)**
Objectives: To take a measured step forward in developing a performance-based approach for identifying and prioritising works needed to manage existing flood defences. In doing so, to build a system that integrates with the risk based approach being adopted across all areas of flood management. The work will build on the Environment Agency's Flood Defence Management Manual (FDMM) and Management System (FDMS) in developing a transitional system and, in the long term, a software-supported, performance based asset management system (to include training, documentation, software interface, etc.) must be developed.
Justification: Relative to existing methods of appraisal for new flood defence schemes, current approaches to justifying maintenance needs are more crude, as identified by the recently completed report on Operations and Maintenance Concerted Action. The PAMS project will provide an asset management system that enables flood and coastal defence managers to assess the performance of and maintenance requirements for flood defence assets. Furthermore, the project will provide a means of identifying and optimising management intervention to achieve a particular outcome.
Indicative Methodology: • Phase 1 to be a scoping study supplemented by case examples • Phase 2 to further develop the resulting methodologies • Phase 3 to provide supporting manuals and software.
Deliverables: • In the medium term, improvements to the current asset management system consistent with the Environment Agency's interim approaches replacing the Flood Defence Management Manual (FDMM) and Management System (FDMS) • In the long term, full operational delivery of a software-supported, performance based asset management system (to include training, documentation, software interface, etc.)
Issues: • Current data is not wholly appropriate for performance / risk-based asset management, and the demonstration project will highlight weaknesses and identify future needs / benefits; • Whole life asset management will need closer integration of maintenance and capital decision-making, as well as good representation of asset life and performance; • Risk assessment will need to include social / environmental as well as economic risks; • Value management will need to assess the implications of improved cost / performance data so as to enable best asset management options;

- Maintenance options will need to consider the links between maintenance and performance; and
- Management approaches will need to recognise a range of different maintenance interventions.

Related initiatives / opportunities:

- O&M (Operations and Maintenance) Concerted Action (Posford Haskoning);
- Risk, Uncertainty and Performance Review - SR587 (HR Wallingford);
- Performance Concerted Action (HR Wallingford);
- CMAM (Condition Monitoring and Asset Management) (University of Bristol);
- NFCDD (National Flood and Coastal Defence Database);
- RASP (Risk Assessment of flood and coastal defence for Strategic Planning);
- MDSF (Modelling Decision Support Framework);
- Reducing Uncertainty in River Flood Conveyance (HR Wallingford);
- Reducing the Risks of Embankment Failure under Extreme Conditions (HR Wallingford);
- Hydraulic Performance of Bridges and Other Structures, Including Effects of Blockages, at High Flows (Jeremy Benn & Associates); and
- Failure rates 'on demand' of Flood Defence components (RMC / Peter Brett Associates).

Priority: **H**	Budget Cost: £250K	Probable duration: 3 years
Type/Nature: Management		

A1.4 Improved condition assessment through visual inspections

4

Action:

Improved condition assessment through visual inspections

Objectives:

- To increase the effectiveness of visual inspection through provision of training to ensure consistent standards across Environment Agency regions
- To increase the efficiency through which problems are identified and further investigated

Justification:

Two issues require investigation:

Firstly, embankment inspections are undertaken by a variety of Agency staff. The knowledge of inspection staff varies. By providing national training to raise awareness of embankment features and performance indicators, the efficiency of the inspection process may be improved and the reliability of data stored within NFCDD increased.

Secondly, having collated field observations it is important that an effective system is in place for recognising and acting upon the information collected. An appropriate 'expert system' is required to support wider data collection and observation.

Indicative Methodology:

- Stage I: To develop a short training course that introduces issues from basic concepts through to inspection and interpretation of data. The Embankments Report 1 may be used as an index to aid development of the course structure. A review of existing embankment dam safety courses may also help in developing content. A review of current practice and courses in the Agency regions should also be undertaken prior to development of the course to ensure that this maximises use of and builds upon existing knowledge
- Stage II: Implement training course on a national basis; establish as part of routine training
- Review regional systems for acting on inspection data and develop steps to ensure that appropriate action is taken based upon such data. Note: This action may be undertaken via the PAMS project under Action 3 or alternatively in close liaison with Action 3.

Deliverables:

- Review and development of a training module to increase understanding of flood embankments and hence the effectiveness of visual inspections
- Training of Agency staff to ensure consistent and high standards of visual interpretation
- Appropriate systems in place to ensure that embankments at risk are identified and acted upon within an appropriate time frame (Action 3 – PAMS?).

Issues:

- Ensure that the focus of any Agency specific training course meets the inspection staff needs. Course development should draw on and combine expert judgement in

hydraulics, soil mechanics, design and construction.

- A number of approaches have been developed within the last few years both in the UK and Internationally for infrastructure assessment. Of particular relevance is the Soil Slope Hazard Index that Network Rail has been developing. A similar approach should be developed within the Agency to improve prioritisation of more detailed investigation of embankments at risk. This relates strongly to Action 3, but does affect the way in which visual inspections should be undertaken and acted upon
- Where embankments form part of a reservoir (within the 1975 Reservoirs Act) different standards of inspection apply. Consideration should be given to the integration of information collected for these sites within any new system.

Related initiatives / opportunities:

- See existing Dams Industry training for Supervising Engineer qualification
- See Railtrack (Network Rail) initiative for Soil Slope Hazard Indexing
- See Action 3

Priority: **H**	Budget Cost: Stage I: £55K Stage II: £45K	Probable duration: 1.5 years
Type/Nature: Training		

A1.5 Non-intrusive flood embankment integrity assessment

5

Action:

Non-intrusive flood embankment integrity assessment

Objectives:

- To investigate the development / use of geophysical techniques for rapid assessment of long lengths of flood embankment
- To develop a system for assessing embankment integrity that is more effective than a visual inspection, but is quicker and cheaper than site specific investigations

Justification:

Visual inspection can only provide judgement on embankment internal condition based upon indicators that may (or may not) be observed. A simple technique that can be applied easily over long lengths of embankment would significantly improve knowledge on the condition of flood embankments and permit a more focussed asset management programme.

Indicative Methodology:

- Stage I: Review existing methods for visual inspection, geotechnical investigation and use of geophysical techniques. This review should including assessment of work currently underway in ongoing research projects such as the IMPACT project, the Dam Safety Interest Group (DSIG) project (Canada), the EPSRC flood risk management consortium etc. Processes, parameters and methods for collection should relate closely to work undertaken under Actions 1, 3 and 9. Develop a theoretical approach for inspection, building upon existing practice but using new techniques wherever practicable. Assess the cost benefit of implementing such an approach through determining the cost of implementing data collection and assessment against the added value that the information offers in determining embankment performance and hence supporting flood risk management.
- Stage II: [Assuming Stage I offers a practical solution and a positive benefit]. Undertake trial application of the proposed procedures on selected site(s). Assess performance of the approach and review the added value offered by the methodology.
- Stage III: [Assuming Stage II confirms value of the approach]. Introduce new practices into the existing Agency programme for inspection and monitoring. This may require development of a supporting training programme. Integration will also need to mesh with activities under Actions 1, 3 and 9 to ensure maximum value is gained.

Deliverables:

- A review of non-intrusive systems for assessing embankment integrity. Development of a recommended approach appropriate for use within the Agency and offering maximum value on investment that is appropriate for the rapid and economic assessment of long lengths of embankment.
- Trial application and development of assessment system
- Integration of assessment system within Agency practice. Training of Agency staff as appropriate.

Issues:

- Knowledge and use of geophysical techniques seems dispersed and not routinely applied within the flood defence industry
- Specific geophysical techniques to identify / locate voids and fissures need to be tested (conditions where sea water may leave salt deposits in the voids perhaps offer special case)
- Whilst non-intrusive systems may be helpful at identifying problem areas within an embankment (for example, the presence of voids) they will (probably) not directly allow an assessment of embankment integrity to be made. To assess integrity, an engineering model of the embankment needs to be generated and calculations performed to determine the margin against failure. This process needs to be integrated into any methodology produced.

Related initiatives / opportunities:

- The IMPACT project is currently undertaking research in this area (WP6 – see www.impact-project.net) This research may provide initial results on applicability of systems. Scope and programme currently under development. Initial fieldwork assessment of systems will be in Czech Republic and Austria. This provides an opportunity for the Agency to benefit from EC research and potentially expand research trials to include UK sites. Austrian partner also investigating use of infrared and earth observation data. (EO data plus automated analysis to provide assessment of earth cover and hence more intelligent analysis of infrared data). Research programme completes in Dec 04. It is recommended that work builds upon findings from this project.
- The Dam Safety Interest Group (DSIG – Canada) has recently completed a review of geophysical techniques in relation to embankment dam integrity. Whilst the focus here is on longer term assessment techniques, much information will be valid and should be reviewed.
- Work under the EPSRC flood risk management consortium will cover some issues related to this action.

Priority: **H**	Budget Cost: Stage I: £50K Stage II: £75K Stage III: £30K	Probable duration: 1-2 years
Type/Nature: Science (supporting asset management)		

A1.6 Developing fragility curves to represent flood embankment performance

6

Action:

Developing fragility curves to represent flood embankment performance

Objectives:

Risk based management systems (such as RASP) require a performance relationship (between load and failure) to be established. Such a fragility curve relates to a wide range of factors. For example, embankment material type, surface protection, condition etc.

Stage I:

Each of these factors requires investigation for their contribution to overall embankment performance to be established (i.e. initial generation of basic fragility curves).

Stage II:

Extend analysis of the fragility curves by considering time variation. Four specific objectives are:

- How does the Fragility Curve vary with time (i.e. what is the effect of ageing upon performance of the flood embankment. How do we predict residual life of defences?)
- How does a recent time series of events effect performance of an embankment? (i.e. If we have 3 months of dry summer, followed by 2 weeks of torrential rain or high waves, how does this affect the way in which the embankment performs?)
- Identify the influence of salt water on wetting / drying and deterioration processes
- How do predicted Climate Change effects integrate with the time varying predictions?

Justification:

The reliability of the RASP methodology is dependent upon the reliability of fragility curves used to represent various defence structures. These curves need to be validated if the RASP system is to be adopted.

A key aspect of asset management is the prediction of embankment condition / residual life. This is currently undertaken through combined visual inspection / judgement. Developing the supporting science beneath time varying embankment performance will improve the reliability performance estimation and hence efficiency of asset management

The development of a risk based approach to asset management is a significant step forward from current management practice. Developing a system based upon an observed series of events (weather, maintenance, use during preceding months) permits an even more efficient level of asset management – but requires the supporting science to be established first.

Indicative Methodology:

- Stage I: Establish performance relationships (between load and failure) taking into consideration key factors such as material type, surface protection, embankment condition etc. This will require identification and prioritisation of factors affecting performance, and subsequent assessment of performance processes in relation to these specific factors.

- Stage II: Further develop the reliability of fragility curves by including an assessment of temporal effects. Temporal effects may apply to the factors identified in Stage I, but may also be relevant to other factors.

Deliverables:

- Development and justification of basic fragility curve representation of embankments
- Further development of fragility curve representation of embankments to include time dependency variables

Issues:

- An initial review of contributing factors is required before more specific performance factors are investigated. The initial review will likely spawn a number of more detailed research initiatives.
- This research requires combined geotechnical and hydraulic expertise. Initial review could be undertaken within 'industry'. Subsequent specific research areas within academia (EPSRC)
- It is currently unclear as to the extent or reliability to which time variation in fragility curves may be established. Current state of the art is beginning to consider the science behind fragility curves. Progress in this area will need to be assessed before considering the time varying dimension

Related initiatives / opportunities:

- Work area overlaps with IMPACT and RASP projects and should be undertaken in close liaison
- Scientific research within the EPSRC programme is likely to contribute to the underlying science. Outputs should be steered towards supporting fragility curve development.
- Work under the proposed EC FP6 FLOODsite project is likely to address some of these issues or associated topics. This research project programme should be reviewed when undertaking initial work on this topic.

Priority: **H**	Budget Cost: £100-500K	Probable duration: 2-6 years
Type: Science (supporting management tools)		

A1.7 Understanding and predicting flood embankment failure

A1.7a Breach initiation through wave action

7a

Action:

Understanding and predicting flood embankment failure:

Breach initiation through wave action

Objectives:

Research to advance understanding of the nature and impact of wave overtopping to support development of fragility curves for embankment performance.

Specifically:

- Improved understanding of overtopping and related failure processes, particularly on impact pressures, wave-by-wave and peak discharges, overtopping flow depths and velocities
- Factors influencing initiation of the erosion process by overtopping and related loadings must be identified to give acceptable limits
- Linked studies should identify how wave processes on the front face, coupled with overtopping, modify key geotechnical resistances or loadings
- To develop / refine methods to predict the onset and development of erosion to the front face of embankments
- Develop / refine information on wave induced pressures on and within embankment faces as input to research on piping, sliding and other geotechnical failures.

Justification:

There is a need to understand and quantify failure mechanisms induced by waves – combining geotechnics and fluid mechanics in order to predict (for example) the onset of local erosion, and its progress (or otherwise) into breaching, how many and where breaches will occur. All current management processes rely upon Benefit Cost analyses which in turn depend upon failure assumptions. There is little guidance to support current failure assumptions, so the reliability of scheme justifications may vary considerably.

Uncertainties in the onset, frequency and severity of erosion-induced breaching of embankments are rated by major consultants as the single main contribution to uncertainties in the analysis of flooding risk, particularly in tidal / coastal locations. Present analysis methods use very crude rules supported by few validation data. Research is proposed elsewhere into geotechnical failures of embankments, but many of those failures will be initiated or accelerated by pulsating or impulsive wave pressures.

Indicative Methodology:

The research into fundamental processes is likely to entail a combination of laboratory modelling, numerical analysis and, where possible, validation using field test sites.

Deliverables:

- Methods to predict the onset of erosion to the front face
- Guidance for managing assets to avoid the onset of erosion (e.g. careful

management of vegetation, use of geotextiles etc.)

- Development of fragility curves (or modification to existing curves) representing behaviour under wave action

Issues:

- The dynamic nature of wave action can induce conditions within the embankment that differ from more steady state overtopping
- Research should be undertaken in conjunction with other initiatives within the 'Understanding and Predicting Embankment Failure' cluster to ensure continuity of work. Additional issues include:

a) Field data is needed on geotechnical conditions of embankments, and how those conditions vary both seasonally and in response to environmental loadings (particularly to drought, rain or spray, plant or animal effects);

b) Levels of variability of (a) the material properties above, (b) the main hydro-dynamic loadings, and (c) initiation of the failure process must be quantified to assist the development of appropriate risk modelling;

- Guidance must be synthesised over two timescales. Present data / methods must be assembled, tested and clarified to refine present "best practice". Fundamental research as outlined above will be needed to generate significant advances in gaps or areas of weakness.
- Wave attack, even relatively small waves in sheltered areas, can rapidly erode unprotected embankment materials by direct effects. Wave driven pressures can accelerate internal erosion by piping or suffusion. There has however been no significant research projects (papers or reports) in the UK on wave impact processes on embankment slopes, although un-analysed data might be extracted from archives of previous research.
- Analysis of wave driven pore water pressure variation within an embankment should also include assessment of likely effects caused by rapid draw down or recession of flood water

Related initiatives / opportunities:

- Data on wave impact pressures on various embankment slopes are held at HRW (and possibly in Germany), but are not in accessible / analysed forms. Modest joint effort would be sufficient to generate input data on external wave pressures to research on piping, sliding and other geotechnical failures.
- Current (2002/03) Defra / EA research at HR Wallingford is enhancing information on mean and wave-by-wave overtopping volumes on example embankment slopes using physical and numerical models. Interrogation and further analysis of this data should be focussed on parameters driven by understanding of erosion processes.
- Research work proposed under the EC FP6 FLOODsite project relates to this topic. This project is likely to commence Spring 2004 and run for a period of 5 years.

Priority: **H**	Budget Cost: £100-200K	Probable duration: 2-3 years
Type/Nature: Science (supporting design, analysis and risk / asset assessment)		

A1.7b Breach initiation through fissuring and cracking

7b

Action:

Understanding and predicting flood embankment failure:

Breach initiation through fissuring and cracking

Objectives:

- To establish the mechanisms leading to fissuring and cracking, their effect on embankment stability and failure [in particular the transition between fissuring and failure] and cost effective solutions for embankment management [prevention and cure]
- To support development of fragility curves representing embankment performance under varying fissure-load conditions

Justification:

Fissuring and cracking of embankments appears to be a commonly occurring problem, for which there is limited guidance on how to determine the severity of the problem and the need / best approach for repair. Failure to act can result in embankment failure although the time scale for progression to failure is far from clear. However, overreacting will result in unnecessary expense. Guidance is required to help asset managers make appropriate decisions to optimise embankment performance.

Indicative Methodology:

- Stage I: Literature review; establish current state of knowledge
- Stage II: Assessment of cause and nature of fissuring; analysis of growth patterns (likely to entail a combination of field and laboratory work)
- Stage III: Analysis to demonstrate link between extent of fissuring and threat to embankment performance; understanding of the transition from fine fissuring through to block failure, instability and / or pipe formation and failure
- Stage IV: Development of fragility curve representation of fissuring effects on embankment performance
- Stage V: Development of guidance to optimise mitigation and management, including an assessment of the cost benefit for implementing various measures.

Deliverables:

- Improved knowledge and understanding leading to guidance on:
  - i) indicators of fissuring;
  - ii) Implications for embankment performance; fragility curves
  - iii) options for mitigation and management; cost benefit of measures

Issues:

- An earlier Agency study investigated fissuring, and provides recommendations on methods for prevention or remedial measures. It does not, however, investigate the mechanisms of fissuring / cracking and relate the extent of cracking to risk of embankment failure. This link is essential to help asset managers choose the most appropriate course of action.
- Understanding how an embankment performs under load with and without fissuring requires a combination of soil mechanics and hydraulics expertise. It is

recommended that work in this area is undertaken by a team combining both of these skills (at minimum)

- Failure of an embankment through fissuring is likely to integrate a number of failure mechanisms and processes. Understanding behaviour of the embankment will likely require a wider consideration of issues than simply crack formation
- The interaction of cracks and fissures with seepage flow, either from overtopping, rainfall or flow through the bank, requires particular attention. Time will be an important parameter for consideration. Guidance on the speed with which action is required in the event of a dangerous combination of fissuring and loading is needed.

Related initiatives / opportunities:

- Research into fissure growth is currently being undertaken at Durham University (Mark Dyer) using embankments at the Thorngumbald Managed Retreat scheme to provide field data.

Priority: **H**	Budget Cost: £100-200 Stage I: ~£25K Stage II: ~£50K Stage III: ~£25K Stage IV: ~£25K Stage V: ~£25K	Probable duration: 2 yrs
Type/Nature: Science (supporting asset management)		

A1.7c Initiation through erosion of crest and inward face due to overtopping / overflowing

7c

Action:

Understanding and predicting flood embankment failure:

Initiation through erosion of crest and inward face due to overtopping / overflowing

Objectives:

- To establish the onset of erosion during overtopping for a range of flows, surface materials and conditions

Justification:

Current capabilities for predicting the onset of erosion and breach formation are limited to extremely crude predictions, with better tools to simulate breach progression currently being developed. In order to determine the risk posed to an embankment during overflowing, it is necessary to understand how the embankment will respond under a range of flow conditions and for a range of surface coverings and conditions. Understanding the conditions that lead to initiation of surface erosion (for a range of flow and embankment conditions) is essential to prevent progression towards breaching.

Indicative Methodology:

- Stage I: Review / collation of existing material (including work undertaken overseas, particularly by USDA in US)
- Stage II: Develop and implement a programme of field / laboratory testing on a range of key materials and conditions (taking into consideration existing and future Agency procedures for condition grading, protection design etc.). [The extent of this programme of work should first be justified by considering key embankment types, conditions etc. to ensure maximum value for research]
- Stage III: Interpret field / lab data to design curves and fragility curves for embankments

Deliverables:

- Design guidance detailing embankment performance under varying flow, surface and embankment conditions and materials
- Fragility curves representing embankment performance for varying overflow and embankment condition and types

Issues:

- Current research is investigating basic breach formation processes. Current ability to predict formation given breach initiation is limited – accuracy perhaps ±50% on peak discharge and considerably worse on timing. There is a need to build up understanding from basic processes. Current research will improve accuracy of predicting the formation process (extent as yet unclear), but will only initiate work on breach location and timing.
- Existing guidance on erosion protection offered by different materials is fairly limited and requires expansion and interpretation to support the fragility curve representation of embankment performance.

- The extent of research undertaken under Stage II needs to be considered carefully. The number of permutations required to develop information covering all embankment types, protection materials, condition grades etc. is potentially very large and would prove costly and time consuming. An initial review should identify all parameters and then refine the test programme so as to achieve maximum value from the research – also taking into consideration the need to feed results into other Defra / Agency initiatives such as RASP and PAMS.

Related initiatives / opportunities:

- Breach formation process are being investigated under the EC FP5 IMPACT project. However, work focuses only on steady, fluvial, conditions and undertaking as well as undertaking some initial work on breach location
- Future work under the EC FP6 FLOODsite project (2004-2009) will be of relevance to this topic.
- Long term research work into surface erosion and the performance of vegetation continues in the US at the USDA-ARS centre at Stillwater.
- Work is currently being undertaken by Posford Haskoning (for Defra / EA) on the maintenance of vegetation in relation to embankment condition. This will also be relevant.

Priority: **H**	Budget Cost: £100-200 Stage I: £25K Stage II: £100K+ Stage III: £50K	Probable duration: 2-3 years
Type/Nature: Science → Guidance		

A1.7d Breach formation through overtopping / overflowing

7d

Action:

Understanding and predicting flood embankment failure:

Breach formation through overtopping / overflowing

Objectives:

- To improve prediction of the embankment breach formation processes (time development, geometry and flood flows)
- To provide tools in support of flood risk management planning [i.e. what if breach occurs scenarios]

Justification:

In the event of an embankment breach, the flood risk manager needs to be able to estimate the rate at which growth might occur and hence the likely flood flows. This affects prediction of potential inundation, safe emergency access, options for breach closure etc. Breach formation rate varies according to embankment type, condition and hydraulic loading. Current abilities are limited.

Indicative Methodology:

- Review state of art position (following completion of the IMPACT project in Nov. 2004) in relation to emergency planning and risk management tool requirements.
- Probable development of predictive tools through lab / field testing of failure of real embankment sections for a range of material types, material conditions, age etc.

Deliverables:

- Improved understanding and predictive model(s) for use in flood risk assessment and emergency planning

Issues:

- Current research is investigating basic breach formation processes. Current ability to predict formation given breach initiation is limited – accuracy perhaps ±50% on peak discharge and considerably worse on timing.
- For effective flood risk management, any modelling tools will need to be integrated into dynamic flow models to permit advance planning of 'what if' scenarios and quicker than real time simulation for emergency application

Related initiatives / opportunities:

- IMPACT project investigating breach formation process (but only under steady, fluvial, conditions) and undertaking some initial work on breach location
- Rijkswaterstaat currently funding research into techniques for closure of embankment breach
- Work under the EC FP6 FLOODsite project will be relevant to this topic.

Priority: **H**	Budget Cost: £100-200K	Probable duration: 2-3 years
Type/Nature:	Science (supporting design, analysis and risk / asset assessment)	

A1.7e Breach formation through seepage / leakage / piping

7e

Action:

Understanding and predicting flood embankment failure:

Breach formation through seepage / leakage / piping

Objectives:

- To establish the mechanisms leading to pipe formation, their effect on embankment stability / failure and cost effective solutions for embankment management
- To support development of fragility curves representing embankment performance under pipe formation and load conditions

Justification:

Pipe formation can result from a number of embankment conditions where a seepage route develops. This may initiate through fissuring, structure interfaces, animal activity or simply hydraulic load and material condition / quality. There is limited guidance on how to determine the severity of the problem and the need / best approach for repair. Time development of a pipe is notoriously difficult to judge. Failure to act can result in embankment failure whilst overreacting will result in unnecessary expense. Guidance is required to help asset managers make appropriate decisions.

Indicative Methodology:

- Stage I: Update on current state of knowledge (via Birmingham University)
- Stage II: Assessment of cause and nature of pipe formation; analysis of growth patterns (likely to entail a combination of field and laboratory work)
- Stage III: Analysis to demonstrate link between extent of piping and threat to embankment performance; analysis to understand the interaction between seepage, fissuring and pipe formation; development of fragility curve representation of embankment performance
- Stage IV: Development of guidance to optimise mitigation and management

Deliverables:

- Improved understanding and predictive model(s) for use in flood risk assessment and emergency planning
- Fragility curves representing embankment performance
- Guidance on mitigation and management measures

Issues:

- Understanding how pipe formation progresses requires a combination of hydraulics and soil mechanics expertise. Current knowledge is limited. Our ability to predict the formation process is poor and our ability to predict the rate of pipe growth even worse. Both issues require resolution if genuine guidance is to be given to asset managers for action in the event of a pipe
- Scaling of sediments makes small scale laboratory tests of pipe formation difficult. Use should be made of field sites wherever possible to validate work.

Related initiatives / opportunities:

- Current area of research at Birmingham University (Dr Gurmel Ghatoara). Work is

being undertaken to analyse pipe formation using samples from the Thorngumbald Managed Retreat scheme		
Priority: **H**	Budget Cost: £100-200	Probable duration: 2-3 years
Type/Nature: Science (supporting asset management)		

A1.8 Flood embankment construction on organic and soft clay foundations

8

Action:

Flood embankment construction on organic and soft clay foundations

Objectives:

- To provide guidance for the design and construction of new flood embankments or the raising of existing flood embankments built on foundations of soft or organic soils [addressing the issue of predicting and / or avoiding long term embankment settlement]

Justification:

By their very nature, many flood embankments are constructed in areas that are frequently underlain by significant thickness' of alluvial soils including soft clays, organic clays and peats. Such materials provide poor foundations with low shear strengths and a tendency for continuing long-term settlement. Whilst many geotechnical reports and papers have been written about the construction of embankments on soft soils, no concise document is available in the UK for the design of flood embankments, particularly in the way in which similar design guides are available for road and rail embankments. A single and targeted design guide is needed to ensure that all new flood embankments are designed and constructed to minimum acceptable standards. This should include methods for prediction of long term settlement and how to design for settlement in embankment construction.

In recent years the use of lightweight materials is being further investigated as an approach to reduce loading upon poor foundations. Guidance on this alternative approach should also be included.

Indicative Methodology:

- Establish a team comprising industry and academics to ensure that theory and practice are combined in producing guidance
- Produce a practical guidance document based upon addressing the issues from two directions:
  - Review of existing techniques for geotechnical analysis; assess and produce practical guidance
  - Review current innovations in use of recycled lightweight materials; assess and produce practical guidance

Deliverables:

- Guidance for the design and construction of new flood embankments or the raising of existing flood embankments built on foundations of soft or organic soils (including innovative approaches using lightweight materials).

Issues:

- Academic capabilities in geotechnical analysis have developed considerably during the last few decades. This knowledge is not always being practised within industry. Technology transfer is required, and this should be achieved through this guidance material.
- Where scientific knowledge is limited, options to bypass the issue include the

innovative design of embankments to reduce foundation loading. Guidance on these techniques should be disseminated through the Embankments Manual (Action 10). Current approaches include the integration of polystyrene and recycled tyres into the embankment body. Case study development of these techniques is to be encouraged in parallel with scientific research into poor foundation material behaviour.		
Related initiatives / opportunities: • Use of recycled tyres (DETR – Jonathan Simm) • Considerable expertise / data stored at BRE from analyses undertaken on the Thames during 1970s		
Priority: **H**	Budget Cost: £100K	Probable duration: 1-2 years
Type/Nature: Innovative guidance		

A1.9 Use of remote sensed data for flood embankment surveying

9

Action:

Use of remote sensed data for flood embankment surveying

Objectives:

- To review and develop the most appropriate system for rapid, reliable and economic collection of survey data appropriate for the assessment of flood embankment geometry (and hence time varying condition).
- To develop data management / manipulation systems to allow easy use of survey data by Agency staff

Justification:

It is a fundamental requirement for the Agency to know what the crest levels and side slopes of their embankments are. Regular monitoring of embankment geometry provides a mechanism for early warning of potential stability problems. Without knowledge of embankment crest and geometry it is not possible to proactively manage embankments to minimise flood risk.

Survey work is currently normally undertaken by hand. However, the huge lengths of embankment mean that it is not economically viable to survey all of these embankments by traditional techniques. LIDAR / FLIMAP offer a potential approach, however data accuracy (±100-150mm) is still not sufficient for assessment of embankment performance. Satellite data offers an alternative approach. The most viable long-term approach requires identification and development to ensure cost effective data collection of appropriate accuracy and resolution.

Collection of topographic data underpins many aspects of flood risk management. Establishing a reliable and economic method for collection of such data is a priority task.

Indicative Methodology:

- Review current state of remote systems and data management in relation to other Agency initiatives regarding data collection and management.
- Identify preferred long-term strategy for topographic data collection (i.e. use of remote sensed data etc.). Review current and proposed practice by other organisations undertaking large scale asset management.
- Identify required developments in sensing techniques (e.g. LIDAR, FLIMAP. Satellite data); implement R&D work as appropriate
- Develop system for data collection and extraction to fit within existing Agency systems and link to appropriate initiatives (such as RASP, MDSF, PAMS, NFCDD etc)
- Implement procedures nationally

Deliverables:

- Review, comparison and evaluation of current and future data collection techniques; identification of a long term strategy for Defra / EA consistent with use throughout the organisation (i.e. flood defence, asset management etc.).
- Development of preferred approach / technique into a working system for Agency

use [this may entail funding specific research initiatives to improve system accuracy, resolution etc.]

Issues:

- LIDAR and FLIMAP both provide a technique for surveying large areas of land relatively quickly. However, the accuracy of these techniques (±100-150mm) is still not sufficient for use in assessing embankment crest level and geometry.
- The current systems produce huge amounts of topographic data. The size and detail of data can be difficult to handle. Interpretation software is required to allow easy extraction of key features – such as embankment cross sections, crest heights etc. The methods / algorithms needed here will share considerable commonality with methods to interpret ditches, streams and related drainage channels from the mass of flood plain levels.
- The effectiveness of various remote systems is influenced by seasonal variations, such as vegetation, flood water levels etc. These factors must be taken into consideration to ensure that the chosen approach is effective, or that clear guidance is given as to when data should or should not be collected.
- The collection of topographic data underpins nearly all areas of flood risk management. Consequently development of effective and economic methods for collection is of high priority.

Related initiatives / opportunities:

- An Agency review of LIDAR and FLIMAP was undertaken. This work now needs to be extended into scientific development of the systems to improve accuracy. New intelligent data decimation techniques are required to extract key embankment / drain features.
- Other asset management organisations such as British Waterways, Highways Agency, Network Rail etc. are all facing similar challenges. A review of other approaches should be taken to ensure that the approach adopted by Defra / EA builds upon existing knowledge and experience.

Priority: **H**	Budget Cost: £100-200K	Probable duration: 1-2 yrs
Type/Nature:	Science (supporting data collection for asset management)	

A1.10 Guidance on vegetation management on flood embankments

10

Action:

Guidance on vegetation management on flood embankments

Objectives:

- To research vegetation behaviour and to develop concise guidance on the use and management of vegetation on flood embankments

Justification:

The type and condition of vegetation on an embankment affects the way in which the embankment is used, the soil moisture content, cracking / fissuring and resistance to surface erosion. Vegetation can have both a positive and adverse effect on embankment performance.

Current guidance on choice and management of vegetation is limited. Maintenance procedures vary from Agency region to region resulting in inconsistent embankment performance.

Indicative Methodology:

- Phase I – Currently underway – investigation into maintenance / management processes through field trial experiments
- Phase II:
  - Review of different types and uses of vegetation suitable for embankment protection (multi purpose – surface protection, access limitation etc)
  - Field trials into effectiveness of types for function
  - Guidance document on selection and use of vegetation (including guidance on how agricultural practice may affect vegetation and embankment condition)

Deliverables:

- Phase I – Investigation into vegetation management processes; guidance on management impact on vegetation performance
- Phase II – Investigation into vegetation performance; guidance upon the selection and use of vegetation on embankments

Issues:

There are a range of aspects to consider. These include:

- Effect of vegetation type on surface protection, moisture content, animal use, recreational use
- Effect of maintenance on vegetation condition
- Design guidance

This work links with research under Action 7c

Related initiatives / opportunities:

- The Agency has recently instigated a long-term programme of test control / monitoring to investigate the effects of varying maintenance procedure on grass

quality. This existing initiative meets part of the topic requirement, but not all. Further research on effect of vegetation type is required. • Long term research into the performance of grass protection on flood embankments continues at the USDA-ARS centre in Stillwater.		
Priority: **H**	Budget Cost: £100K	Probable duration: 1-3 years
Type/Nature: Science (supports asset management)		

A1.11 Emergency response – best practice for flood embankments

11

Action:

Emergency response – best practice for flood embankments

Objectives:

- To collate and disseminate good practice for emergency response management for flood embankments in extreme conditions

Justification:

The Autumn 2000 floods tested the Agency emergency response system to the limits. Valuable lessons were learnt during these floods. NE region has drawn on this experience and implemented a programme of changes in procedure and response. Similar approaches have been taken elsewhere. To ensure consistent good practice, review and dissemination of best practice between Agency regions should be undertaken.

Indicative Methodology:

- Establish core project team drawn from Agency areas worst hit by flooding during the past decade
- Review procedures, practice and solutions that have evolved from experience in different regions during various flood events; undertake wider industry consultation
- Consolidate findings and develop guidance on good practice for emergency management; disseminate via a guidance document and workshop. Scope of guidance to cover all aspects of emergency response ranging from staffing during events through to emergency repair of structures.

Deliverables:

- Good practice guidance drawn from regional Agency experience; dissemination workshop

Issues:

- Different regions have already developed individual guidance / modifications to their procedures based upon flood event experience. Best practice should be collated, reviewed and prioritised before dissemination. (e.g. best practice = sandbag material availability / location, availability / size of standby pumps, speed of contractor response etc.).
- Specific guidance is needed on optimum repair procedures for coastal tidal breaches where tidally driven flooding limits access for repair.
- Initial indications suggest that a number of Agency regional initiatives are underway which partially cover this topic (e.g. emergency response project (NE region)). These need to be reviewed and best practice drawn from existing knowledge.

Related initiatives / opportunities:

Priority: **M**	Budget Cost: £50-75K	Probable duration: 1 year
Type/Nature: Training / dissemination		

A1.12 Flood embankment management manual

12

Action:

Flood embankment management manual

Objectives:

- To provide a definitive manual for the whole life design, maintenance and management of flood embankments (including guidance on site investigation)
- To provide a mechanism for the rapid integration and dissemination of new knowledge and practice as existing and future initiatives are completed

Justification:

Existing guidance on flood embankments is variable in detail and scattered (as demonstrated through this project review). During consultation, requests for better guidance were noted from a range of consultees covering a wide range of different issues. Some of these needs can be addressed by directing towards existing best practice (see Report 1), others require collation and writing of new or additional guidance.

There are also a range of issues relating to embankments that are currently being researched by a variety of organisations (e.g. Rijkswaterstaat and US Army Corps of Engineers) .

In this situation, the most appropriate course of action is for the Environment Agency to liaise with other leading national management organisations and to integrate current knowledge and best practice with research findings / recommendations into a guidance manual. A single, definitive guide would make dissemination and wider uptake of consistent standards and approach easier and more effective.

Issues that might be addressed in this way include:

- Monitoring of embankments
- Geophysical investigation of embankments
- Innovative ways for raising embankments (limited space)
- Use of recycled tyres in embankment construction / raising etc.
- Legislation affecting the design, construction and maintenance of embankments

Many more might be included to form a definitive reference document.

Indicative Methodology:

- Develop a project team and steering group drawing from a range of consultants, practitioners and researchers. Ensure an appropriate mix of hydraulic, geotechnical, O&M, design and construction professionals are involved. [Confirm final target audience, function and scope of guidance from the outset].
- Draw together good practice material and develop industry standards for all aspects of flood embankments making use of:
    - existing Agency policy and procedures across all regions
    - existing asset management organisations specifications and guidance, such as the Highways Agency, Network Rail, British Waterways etc.
    - existing international experience (e.g. Rijkswaterstaat, USACE, USBR etc.)

- Produce a living guidance document (both paper and electronic format) which may be used as an industry standard for all works relating to flood embankments.

Deliverables:

- Wide ranging guidance document providing a definitive source of information for all Agency related flood embankment works. (Electronic version online allows for easy updating as additional knowledge / research is undertaken)

Issues:

- A balance must be struck between reproducing existing documents and reproducing this good practice reference guide. Material provided under Report 1 of this project may be used as a starting point for development of the guide.
- A staged and modular approach to development may be envisaged. By using this (Report 1) good practice reference document as an initial working document, and by structuring this document for access online, then guidance may be added progressively without the need for repeated publication and dissemination of a 'final' report. In this way, the guide would always be a 'live' document and may be updated as knowledge and expertise advances in the many areas relating to flood embankments. If this approach is adopted, an initial stage would be required to first clarify requirements / end users, develop the online structure and immediately expand some areas of text.
- If a web based approach to a guidance document is adopted, then updating of current best practice can be a deliverable written into each project relating to embankments that Defra / Agency initiates in the future.

Related initiatives / opportunities:

- Interest in developing a 'Flood embankments manual' has been expressed within CIRIA. A CIRIA team could be a mechanism for undertaking the initial structuring and web based development, with end product access via both CIRIA and Agency websites.

Priority: **H**	Budget Cost: £200-300K	Probable duration: 2 years
Type/Nature: Guidance		

Appendix 2

The study approach

A brief overview of the structure and approach taken when undertaking this project is presented below. Subsequent Chapters of this report relate to the various tasks detailed in Section 2.1 and presented in Figure 2.1 (main text).

A2.1 Project tasks

The following broad tasks were identified as necessary to achieve the project aims and objectives:

- a review of current knowledge and practice
- identification of industry needs and opportunities
- definition of a structure for future design and management of embankments, including appropriate further research.

In more detail, the scope of the project included:

- confirmation of issues affecting embankment integrity
- review of (or access to existing information on) current "good practice"
- review of relevant information in the science, engineering or technology base
- overview of relevant on-going Defra, Agency and other, particularly European, R&D projects
- discussion/correspondence with practitioners and researchers to envision how practice in this area might reasonably advance in future years
- confirmation of specific issues driving potential future embankment-related R&D or other related activities
- identification of potential future outputs and benefits, leading to a list of priority projects
- production of guidance on current best practice.

A workshop for the presentation, discussion and dissemination of project findings and issues was also held.

A2.2 Project team / programme

The project was primarily undertaken by HR Wallingford in conjunction with Posford Haskoning to provide core expertise relating embankment hydraulics and geotechnics. Additional expertise and guidance was also sought from a number of independent consultants who reviewed and guided production of project documents. The project team is listed in the front pages.

The programme of work was also meshed with the EC IMPACT project, through which R&D focussed on embankment performance at failure is being undertaken, and from which the work programme for Project FD2411 also benefited from knowledge and practice of many European and International partners. More information on IMPACT may be found at www.impact-project.net

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