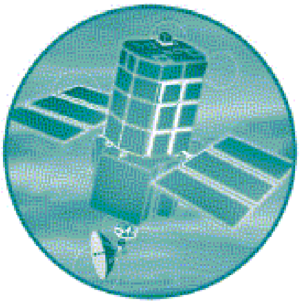
Defra/Environment Agency
Flood and Coastal Defence R & D Programme



Interim Report on Failure on-demand of Flood Defence Scheme Components

Phase 1 Data Gathering and Pilot Database Development

R&D Technical Report W5-031/TR

defra
Department for Environment
Food and Rural Affairs

ENVIRONMENT AGENCY

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

Interim Report on Failure on-demand of Flood Defence Scheme Components

Phase 1 Data Gathering and Pilot Database Development

R&D Technical Report W5-031/TR

Authors: Z A Gralewski, S G Oldfield - RM Consultants Limited
R Dawson, J Pulsford - Peter Brett Associates

Publishing Organisation
Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol BS32 4UD

Tel: 01454 624400
Fax: 01454 624409
www.environment-agency.gov.uk

ISBN 1 844 32127 4

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

Statement of Use
This document has been produced for the purposes of reporting the interim findings for the project and for the purposes of discussion of the programme of work for the next phase.

Keywords
Flood defence, Reliability, Failure, Flood Risk, Culvert, Gate, Lock, Outfall, Pumping Station, Screen, Barrier, Weir, Spillway

Foreword
The authors of this report gratefully acknowledge the support of the Environment Agency during the course of the work and more specifically the assistance of all Environment Agency Staff and others who contributed by supplying the data used in developing the Pilot database.

Contractor Details
Steve Oldfield, RM Consultants Ltd, Suite 7, Hitching Court,
Abingdon Business Park, Abingdon, Oxfordshire OX14 1RA, United Kingdom
Tel: +44 (0) 1235 555755 Fax: +44 (0) 1235 525143

Defra / Environment Agency Project Manager
Ian Meadowcroft, Environmental Policy - Risk and Forecasting Team,
Environment Agency, Kings Meadow House, Kings Meadow Road, Reading RG1 8DQ
Tel: 0118 953 5247 Fax: 0118 953 5265

Further copies of this report can be obtained from the Environment Agency's National Customer Contact Centre by emailing enquiries@environment-agency.gov.uk or by telephoning 08708 506506.

EXECUTIVE SUMMARY

The project aims to support an integrated approach to flood risk management by analysing the failure of flood defence scheme components to improve the understanding of how these contribute to overall flood risk. The first phase of this project has been concerned with establishing data on the failure of flood defence scheme components. This information has been used to develop a pilot database system from which to derive estimates of the likelihood of a given component failing, whether this be in a situation of continuous or intermittent use. This work is proceeding in parallel with, and complementary to, R & D on the performance and reliability of static 'linear' flood defence structures such as embankments.

The R & D will lead to improvements in the way flood defence components are represented in flood risk assessments such as of Flood Defence Systems for Strategic Planning (RASP) and the Modelling and Decision Support Framework (MDSF). It will also support the management of the asset base, through the new Performance Based Asset Management System (PAMS) programme.

Preliminary results from the database have been generated but to date this has been based on a relatively small data set. The derived expectations of flood defence scheme component failure have been calculated by averaging across the relevant entries in the data. However these are higher than would be anticipated as they currently do not account for similar components that are also in operation but have not failed.

A principal challenge in conducting the project has been the collection of sufficient data. From the process as it has been completed so far it is estimated that of the flood defence scheme component failure incidences over the past ten years, between 12 % and 15 % have been identified and included in the analysis. In extending the work this indicates that there is the possibility of increasing the size of the data set by at least six times. In addition by employing methods to 'add value' to the data there is potential to produce effective and reasonable predictions of the risk associated with a given component.

From the work carried out under phase 1 of the project it has been possible to draw a number of conclusions that affect this and future projects:

- Documentation of information relating to the failure of non-linear flood defence system components has tended to be inconsistent and lacking in both the Environment Agency and elsewhere.
- A further source of inconsistency within the data may be the sources from which it has been collected. In particular use of the knowledge of field staff who were asked to recall failure incidents invariably has meant that more recent examples have been remembered and described more easily than those that occurred a greater length of time ago.
- Rather than being concentrated in a small number of sources, relevant information is distributed amongst different stakeholder groups. Over the current work it has not been possible to make contact with representatives from all of these groups.
- Various instances of component design failure have been uncovered which tends to suggest the need for more robust design 'best practice' guidance.

CONTENTS

Executive Summary		**ii**
List of Tables		**iiv**
List of Figures		**iiv**
Definitions		**v**
1.	**Introduction**	**1**
1.1	Background and Objectives	1
2.	**Current Project Status**	**3**
2.1	Achievements against the Project Programme	3
3.	**Data Gathering**	**11**
3.1	Data Elicitation Meetings	11
3.2	Other Contacts and Sources of Information	12
4.	**Database Development**	**17**
4.1	User Requirements	17
4.2	Database Specification	18
4.3	Database Structure	19
4.4	Typical Data Manipulations – Continuously Operating Components	29
4.5	Typical Data Manipulations – Intermittent and Emergency Operation	30
4.6	Use of Failure Probability in Risk Calculations	30
4.7	Adjustments for Incomplete Data	30
5.	**Preliminary Results**	**32**
5.1	Failure Rate Prediction	32
5.2	Lessons Learnt	35
5.3	Summary	36
6.	**Proposals for Phase 2**	**38**
6.1	Issues Requiring Further Consideration	38
6.2	Revised Programme for Phase 2	40
7.	**References**	**42**

APPENDICES

A. Brochure
B. Questionnaire
C. Preliminary Assessment of Typical User Needs
D. Database Specification
E. Tasks for Phase Two

LIST OF TABLES

Table 2-1: Data Gathering Meetings 4
Table 2-2: Taxonomy 7
Table 3-1: Additional Contacts 13
Table 5-1: Preliminary Failure Data for Selected Flood Component Systems 32

LIST OF FIGURES

Figure 2-1: Schematic of Phase 1 Programme of Work 3
Figure 2-2: Map of EA Regions Covered by Data Gathering to Date 6
Figure 3-1: Time of Occurrence for Identified Failures 11
Figure 4-1: Distributed Data Gathering Architecture 18
Figure 4-2: Key Elements of Database System 20
Figure 4-3: Pilot Database User Interface 23
Figure 4-4: Example of Standardised Data Entry Report Form 24
Figure 4-5: Data Flow Diagram for Failure Probability – Continuous Operation 25
Figure 4-6: Data Flow Diagram for Failure on-demand – Intermittent and Emergency Operation 26
Figure 4-7: Data Flow Diagram for Hidden Failures and Intrinsic Failure Rate 27
Figure 4-8: Data Flow Diagrams for Supporting Functions 28
Figure 5-1: Breakdown of Reasons for Failures 33
Figure 5-2: Breakdown of Causes of Failure for Gates 34
Figure 5-3: Breakdown of Causes of Failure for Pumping Stations 34
Figure D-7-1: Translation of Questionnaire Responses to Database Elements D3
Figure D-7-2: Schematic of Database Architecture D4
Figure D-7-3: Data Flow Diagram for Failure Probability – Continuous Operation D5
Figure D-7-4: Data Flow Diagram for Failure on-demand – Intermittent and Emergency Operation D6
Figure D-7-5: Data Flow Diagram for Hidden Failures and Intrinsic Failure Rate D7
Figure D-7-6: Data Flow Diagrams for Supporting Functions D8

DEFINITIONS

Many definitions connected with risk, uncertainty and performance are given in R & D Report FD2302/TR1 (Defra / Environment Agency 2002). The following definitions apply in the context of the work reported here:

Failure on-demand: An event in which a system or component fails to perform its intended function for whatever reason, including but not limited to: Incidents which overwhelm its design capacity, failures of systems or components in continuous or intermittent use.

Failure Rate: The annual rate at which systems or components in continuous operation fail. If there is a strong time dependent effect on this failure rate then the period over which the failure rates or probabilities are estimated is important and should be taken into account in the interpretation and use of failure data.

Probability of failure on-demand (Intermittent Use): The probability that a system or component, (when in intermittent use), will fail while in operation on an annual averaged basis.

Probability of failure on-demand (Emergency Use): The probability that an emergency system fails to operate when called upon in an emergency.

1. INTRODUCTION

This report gives an overview of the first phase of study concerned with the identification of failure data and the development of a pilot database system for generating generic estimates of failure rate or failure on-demand of flood defence scheme components (characterised by the Probability of Failure on-demand).

1.1 Background and Objectives

In order to support an integrated approach to the assessment and management of flood risk the Environment Agency (EA) wish to gather, collate and analyse 'on-demand' failure of flood defence scheme components (discrete items such as gates, weirs, screens etc. Linear flood defence systems such as banks, walls and barriers were excluded from this project). These data are to be used to derive generic failure rates for flood components, taking account of the fact that some components may also have a navigation and flood warning function.

The context of the project is set by the Review of Risk, Uncertainty and Performance in Flood and Coastal Defence (Defra / Environment Agency 2002). That project sets out the definitions, framework and tools for risk assessment and management. A key concept is the *Source-Pathway-Receptor* model for risk. The *source* is generally some environmental loading such as rainfall, river or tide levels. The *pathway* represents defences, defence systems and flood inundation characteristics. *Receptors* are the people, properties and environmental assets that we seek to protect. This model forms a useful basis for environmental risk assessment and modelling (DETR / Environment Agency, IEH 2000) including risk from flooding and erosion (Defra/Environment Agency, 2002 and ICE, 2001).

The present project is a key to understanding risk and reliability associated with certain components of the flood defence system. Failure of linear flood defence systems is being studied in separate projects including studies into embankment breaching mechanisms and has, in general, been more closely studied in the past.

Many of the elements of the risk framework mentioned above are being incorporated into a set of tools within the R & D project on Risk Assessment of Flood Defence Systems for Strategic Planning, or RASP, see www.rasp-project.net [HR Wallingford, 2002]. The RASP methodology accounts for failure probability for, potentially, many elements of a flood defence system and the present project is aimed, in part, at providing a basis for estimating failure probabilities for scheme components. In turn this will improve the assessment of risk and enhance the Agency's capacity to manage risk in an integrated way.

Note that the present project is largely concerned with historical data and experience of component performance. Other projects in the Agency's R & D programme are dealing with hydraulic performance of certain classes of structure such as afflux at bridges and other structures (Project W5A-061).

The intention is that this information would be of use to various stakeholders in flood management, by supporting, for example:

- maintenance planning
- 'what-if ' assessments and decision-making related to flood emergencies
- capital project management and option studies
- guidance on the selection and design of appropriate components and the promotion of best practice
- guidance for policy development on preferred generic solutions and the promotion of high level aims such as resilience to climate change.

The current project is split into two phases. This report relates to the first of these phases which is concerned with data gathering; the development of a taxonomy, and pilot database system to demonstrate the feasibility of such a system. The second phase will seek to analyse the gathered information in more detail, add functionality to the database system and 'adding value to' information generated from the database.

The database is to be developed for use by

- strategic planners;
- operations and maintenance staff; and
- designers.

Its outputs would be used as essential inputs to the assessment of flood risk, by providing estimates of component failure rates. They would be used in establishing appropriate levels of maintenance and inspection for flood defence scheme components and help in developing best practice design guidelines. The operation experience encapsulated in the database could also help in giving more reliable flood warning and forecasting advice.

This report gives an overview of the work performed, and revises the original proposals for the second phase, based on the findings from work performed to date.

2. CURRENT PROJECT STATUS

The tasks performed to date and how they inter-relate is illustrated in the Schematic given in Figure 2-1. An overview of the work performed under each of these tasks is given below.

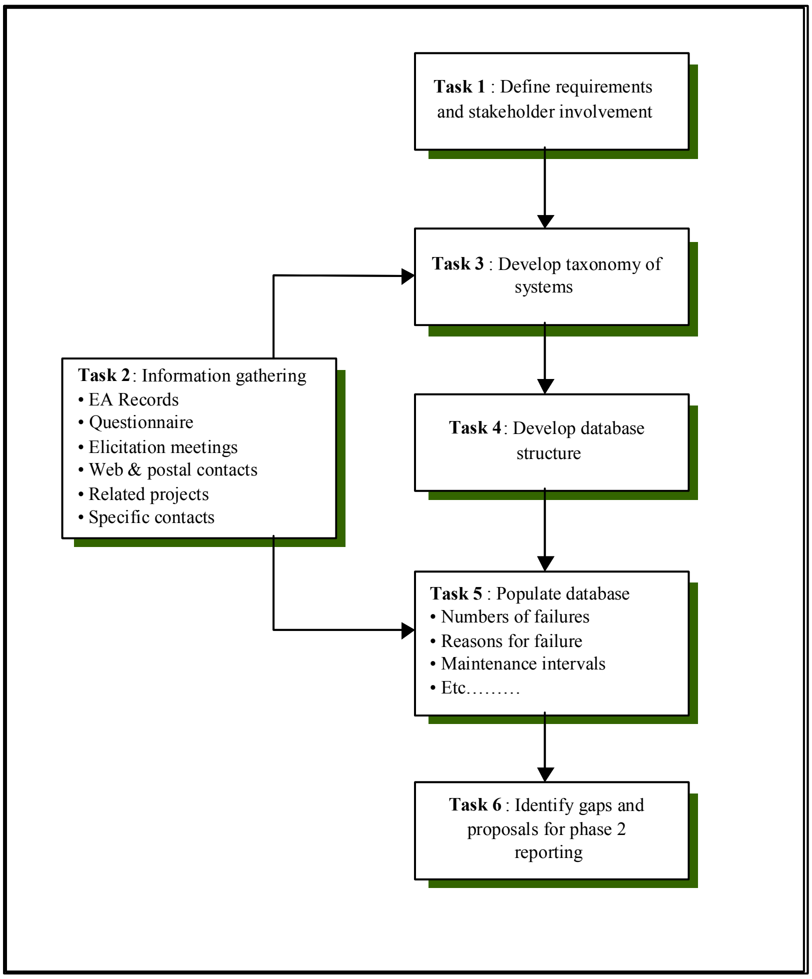


Figure 2-1: Schematic of Phase 1 Programme of Work

2.1 Achievements against the Project Programme

Task 1. Define requirements and stakeholder involvement

This task involved agreeing a common understanding of the overall scope of the pilot system to be developed, the types of information to be gathered and the potential sources of this information.

A publicity brochure (see Appendix A) was produced for promoting the aims of the project. The brochure was posted on the Internet to reach as wide an audience as possible and used to encourage additional input of data to the project.

Task 2. Information gathering

Central to the information gathering on this project was the development of a questionnaire. This questionnaire was piloted at the first information gathering meeting with Environment Agency (EA) staff. It was subsequently revised and used as the main means of collecting information on flood defence component failures. A copy of the questionnaire is given in Appendix B to this report.

To date five information gathering meetings have been held with various field operations staff from the EA Regions, (see Table 2-1). These meetings were used to facilitate the completion of questionnaires on failure incidents known to the participants. The questionnaire has been distributed to other key EA personnel who were unable to attend the meetings, and to 29 contacts within local authorities. A facility for downloading the questionnaire from an Internet web-site was also provided in an attempt to gain further responses.

Table 2-1: Data Gathering Meetings

Meeting	EA Region	Participants	
1	Southern Region – Kent area	Richard Francis Mike Taylor Paul Deane	Trevor Carman Ken Frampton
2	Southern Region – Sussex Area	Andrew Jackson Tony Turnbull	David Bonner Paul Deane
3	Thames Region – North East Area	Brian Izzard Mel Jones	Darsha Gill Bill Morgan
4	Midlands Region – Upper Severn	Roy Stokes Phil Foxley	Ian Morris Anthony Crowther
5	Midlands Region – Central M&E	Fred Tucker	Colin Barker
6	North East – Dales and Ridings	Mark Tinnion Nigel Bulmer	Mark Fuller Steve Gerrard

It is estimated that, to date, approximately 50 % of the Environment Agency Regions offices that could be covered have been. Of these, it is estimated that between one quarter and one third of the relevant incidents that have occurred over the last 10 years have been captured. This suggests that between 12 % and 15 % coverage of the data within the EA has been achieved. A map indicating the EA Regions covered by the data gathering performed to date is given in Figure 2-2.

To date a total of 54 completed questionnaires have been received from contacts within the Environment Agency. Seven of these have been received very recently, have yet to be entered into the database, and are therefore not included in the preliminary results presented herein. Currently only four responses have been obtained from postal contacts, and only one of these gave useful but non-specific information. It is likely that more time and follow-up phone calls will be necessary to obtain useful responses from postal contacts.

Further details of data sources investigated and data gathering carried out are given in Section 3 below.

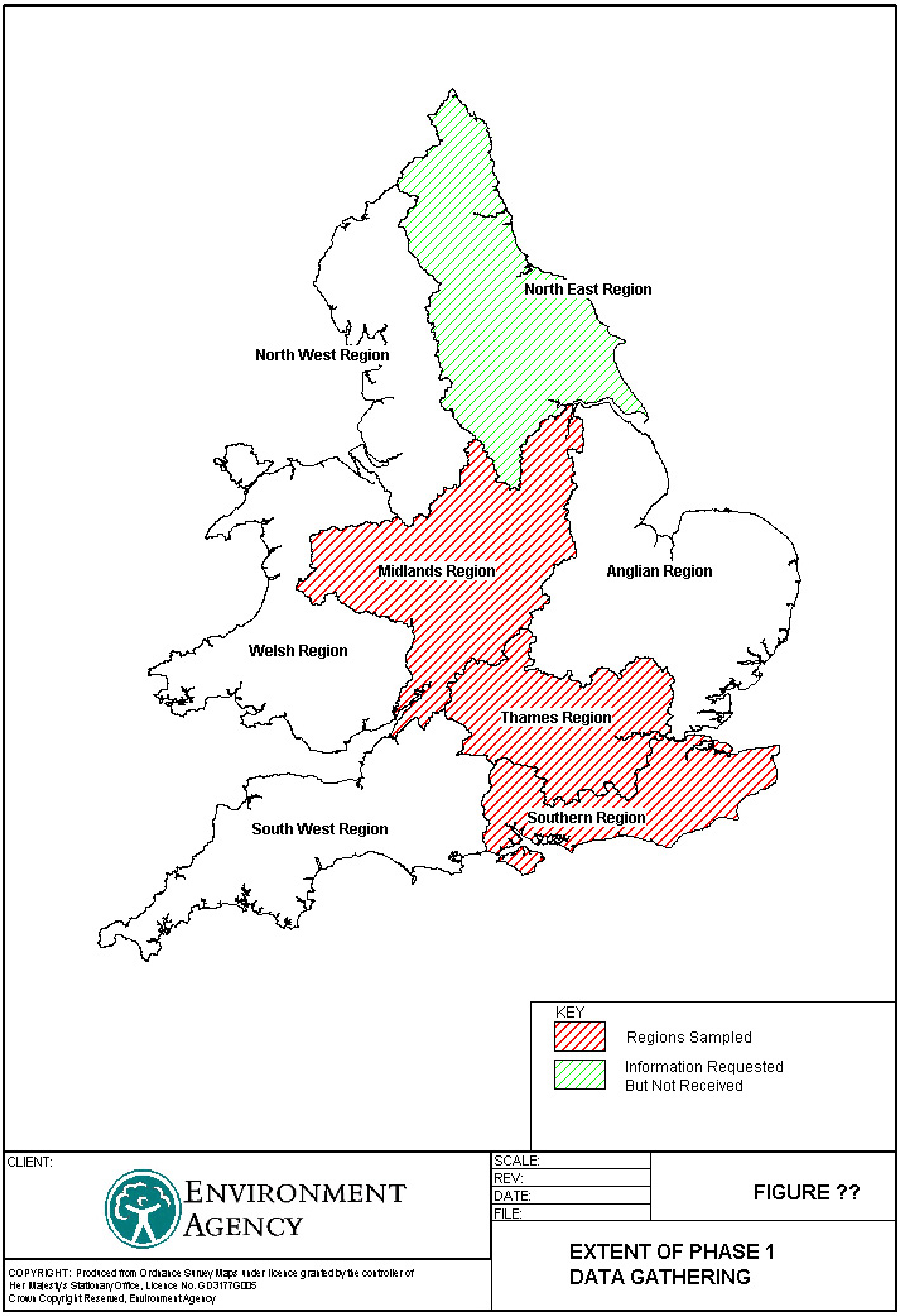


Figure 2-2: Map of EA Regions Covered by Data Gathering to Date

Task 3. Develop taxonomy of systems and components

This project is concerned with developing generic (rather than individual component) failure rates from evidence from the field. In order that generic rates may be estimated it is essential to categorise and group the information against recognisable, industry standard types of system (e.g. pumping station) and component (e.g. screen). This grouping of systems and components to form a standardised taxonomy is essential for effective retrieval and calculation of failure rates against each system and component type. This taxonomy has been developed to be compatible, as far as possible, with that used in the Flood Defence Management Manual (FDMM) [Dunderdale JAL and Morris J, 1998].

The taxonomy used in the present project is given in Table 2-2. This provides the structured breakdown of flood defence systems into industry standard components to be used for calculating failure rates or probabilities of failure on-demand as appropriate. Further descriptors may be used to further categorise the components according to their size, throughput, etc. Additional systems and components can be added as the need arises.

The figures given in brackets in Table 2-2 indicate the number of failure incidents that have been recorded in the database for each system and the corresponding system type and component or sub-component that failed.

Table 2-2: Taxonomy

System	System Type	Sub-system
Culvert (2)	Multiple (0)	Inlet (0)
	Single (0)	Screen (0)
	Combination (1)	Barrel (0)
	Not known (1)	Outlet (0)
		Not known (2)
Gate (24)	Tidal (0)	Fixings (1)
	Sluice (6)	Structures (2)
	Flap (8)	Seal (2)
	Radial (1)	Gate (2)
	Mitre (1)	Hydraulics (2)
	Penstock (3)	Motor (0)
	Vertical (3)	Gearbox (3)
	Coastal (1)	Actuator (1)
	Not known (1)	Operating mechanism (2)
		Sensor (1)
		Controls (3)
		Power supply (1)
		Locking mechanism (1)
		Electrical Earth (1)
		Hinge (2)
		Not known (0)

System	System Type	Sub-system
Lock (0)	Manual (0)	Structure (0)
	Mechanised (0)	Gate (0)
	Not known (0)	Hinge (0)
		Paddle (0)
		Bypass (0)
		Seals (0)
		Not known (0)
Outfall (2)	Tidal (1)	Structure (0)
	Non-tidal (0)	Bypass (1)
	Not known (1)	Operating mechanism (1)
		Not known (0)
Pumping Station (22)	Axial	Structures (0)
	Submersible	Inlet (0)
	Archimedean	Screens/filters (1)
	Not known (22)	Pump (10)
		Pipe work (0)
		Valves (0)
		Motor (1)
		Outlet (1)
		Hydraulics (1)
		Mountings (0)
		Controls (6)
		Sensor (2)
		Power supply (0)
		Earth (0)
		Not known (0)
Screen (4)	Manual (0)	Structure (0)
	Automatic (1)	Screen (0)
	Trash (3)	Sensor (1)
	Not known (0)	Operating mechanism (1)
		Controls (0)
		Motor (0)
		Gearbox (1)
		Power supply (0)
		Not known (1)
Barrier (3) Barrier (Continued)	Stop boards (2)	Structure (1)
	Fixed Barrier (0)	Controls (1)
	Not known (1)	Bypass (1)
		Not known
Weir (0)	Fixed (0)	Structure (0)
	Radial (0)	Gates (0)
	Flap (0)	Hydraulics (0)

System	System Type	Sub-system
	Not known (0)	Lifting cables or chains (0)
		Motor (0)
		Gearbox (0)
		Actuator (0)
		Controls (0)
		Power supply (0)
		Not known (0)
Spillway (1)	Non-siphonic (0)	Inlet (1)
	Siphonic (1)	Structure (0)
	Not known (0)	Not known (0)
Flood warning (4)	Auto voice messaging (1)	Signal (1)
	Groundwater (2)	Power supply (1)
	Not known (1)	Sensor (1)
		Not known

Task 4. Develop database structure

The objective has been to develop a simple, transparent database system that will be easy to develop and maintain, and useful to various stakeholder groups with the minimum of training. An outline of the typical usage envisaged for the database was provided by the EA and is reproduced in Appendix C. These details and knowledge of the data availability, gained from the initial data gathering, were used to develop a brief outline specification for the database. The outline specification is given in Appendix D and is Section 4 of this report.

Task 5. Populate Database

The information gathered from the questionnaires was first entered electronically verbatim into an MS Excel™ spreadsheet. This raw information was then translated on the standardised taxonomy, terminology and units system. To ensure traceability of the information flow, both the original and the translated information are maintained within one large spreadsheet allowing crosschecks to be made on the origins of individual data items.

The information translated in this way was then imported into an MS Access™ database. It is not intended that spreadsheet intermediary stage be maintained beyond the life of the current project. However it is considered an essential precursor to provide traceability of information flow until a stable database system is achieved.

Once completed it is intended that new incident data could be entered directly into the database. Prior to finalising the pilot system it may be necessary to attempt a process of substantiation of the data entries for the purposes of Quality Assurance and to eliminate any inconsistencies in the data.

Selected initial results from the data provided so far are given in Section 5 to this report, with more details given in Appendix E.

Task 6. Identify gaps and proposals for phase 2

As stated above the numbers of failure incidents recorded for each of the systems and components in the taxonomy are indicated in brackets against each entry in Table 2-2. It can be seen that there are some notable gaps. These gaps in the data could be because failures in these systems and components have yet to be discovered; are not generally recorded as failures; these systems or components are successfully maintained in continuous working order, or they are particularly reliable and so rarely fail.

The notable gaps in the data gathered to date are failures of locks and weirs. There is a reasonable spread of failure information for each of the other system components, but in general only one or two instances of each.

The lack of failure information on locks is likely to be, at least partially, due to the fact that they are a well established "low technology" component and in regular use. They have an important navigation function, often continuously manned and hence any problems that could lead to a failure are likely to be corrected before they become an issue.

The lack of information on weirs may result from some questionnaire respondents classifying some 'movable' weirs as gates. It should, however, be possible to re-classify 'gate' entries, which are designed specifically to raise water levels as weirs. It is proposed that this reclassification should be done as part of data checking and substantiation in the next phase of work.

Data gathering is very time consuming, and hence for the purposes of development of a pilot system it was limited at this stage. The present system is, therefore, built on the limited data that could be obtained relatively easily via the questionnaire and data gathering meetings involving EA field staff. It is anticipated that further data could be obtained using current methods given sufficient time and effort.

Other sources of information identified on this project, such as works orders, could be pursued. Direct elicitation of subject failure estimates for each component type could also be undertaken. Proposals for additional data gathering are discussed further in Section 6 of this report.

3. DATA GATHERING

It was quickly found that there is very little if any formal recording of component or system failures within the EA, and therefore the data elicitation meetings would be the main source of information. However, other potential sources of information were investigated as described below.

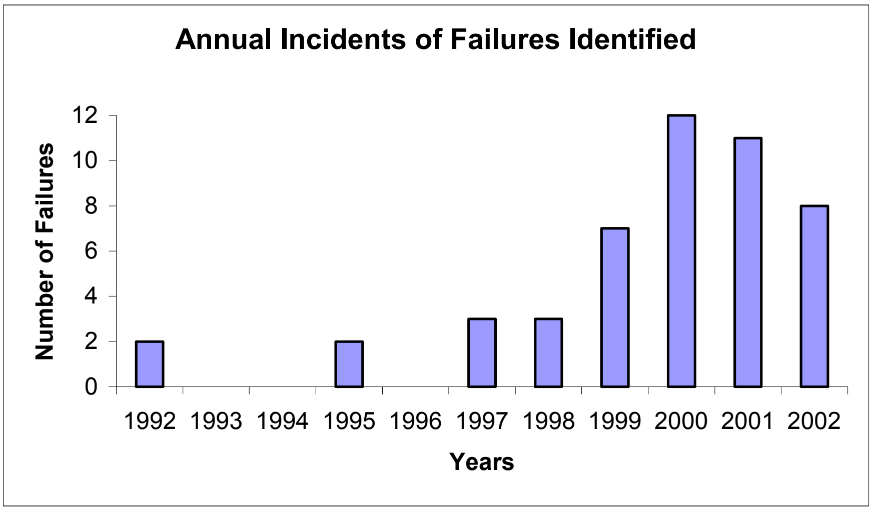
3.1 Data Elicitation Meetings

Five group meetings with EA Regional operations staff were organised, see Table 2-1 above, and some additional individual contacts were made with individuals who were known to have relevant information.

Data elicitation meetings involved between 3 and 5 EA staff and at least one member of the project team who acted as facilitator. The facilitator used the questionnaire to structure the session, prompting the participants to answer each question in turn. This was found to be reasonably effective in capturing identifiable and memorable incidents, but less effective in capturing the less memorable minor incidents for which there may be many.

Figure 3-1 gives a breakdown of the recorded failures against the year that they occurred. It can be seen that there is a trend of increasing failures. There are several possible reasons for this including:

- Relying on memory tends to reveal the most recent failures, and incidents that happened more than ten years ago are often lost.
- The actual frequency of failures may be increasing.
- The detection of failures may be improving.
- The number of floods may be increasing, loading and 'testing' components more often.



Note that in the figure above, year 2002 only has data up to March of that year

Figure 3-1: Time of Occurrence for Identified Failures

In the absence of written or electronic records it is more difficult to capture minor incidents, particularly those that happened more than a few years ago. Some considerable effort was, therefore, expended in trying to trace other sources of information.

3.2 Other Contacts and Sources of Information

Various potential data sources have been explored with a view to augmenting the information gathered via the questionnaires. These are listed below, with a brief comment as to their potential as a future source of information.

- **Secondary contacts** - A number of stakeholder groups have been identified as possible sources of failure information, in addition to those involved in the data gathering meetings, see Table 3-1. Currently, no specific information has been obtained, but further telephone or personal contact may give some useful information.
- **Published documents** - An electronic search of the EA reference database revealed a few possibly useful reports of interest, but none of direct relevance to the current project. It is proposed that the short listed documents should be followed up through EA library services in the next phase of work.
- **Related projects** - A number of projects, some sponsored by the EA, have been identified which may provide information on specific aspects or components, see Table 3-1.
- **Site diaries or logs** - A number of respondents who completed questionnaires indicated that some incidents are recorded in site diaries or logs. However, site records of failures are rarely kept and those that do may be difficult to acquire.
- **Drainage Board meeting minutes** - It is suggested that this may be a useful source of non-specific supporting information. However, copies of minutes are not regularly filed and hence are difficult to trace.
- **Maintenance works orders and inspection sheets** - Records of maintenance orders and inspection sheets would be useful, but are difficult to trace. They are not routinely stored. One region maintains an electronic database, which was reviewed and revealed only non-specific information. It is understood that others use Planet G5 maintenance Planning/Recording software, and Midlands region is known to maintain a paper record of works orders.
- **National Incident Reporting System** - It was concluded that this source was adequately covered by the internal knowledge of EA staff already involved in the project, since they would be aware of any substantive incidents raised.

Table 3-1: Additional Contacts

Contact	Contributions
Specific EA contacts	Contact has been made with Andrew Graham and David Read, who have specific expertise that may supplement the data gathering in the second phase of the project.
Local authorities	Four replies have been received out of 29 requests for information. Three indicated that they were not responsible for flood defence components. The fourth stated verbally that they had some screens but that these were maintained sufficiently often for them to have only ever caused very minor flooding. No specific incidents were reported.
Hampshire	A list of further contacts has been provided by the EA. Those that have not already been contacted could be followed up in the next phase of work.
Southern Region	A list of further contacts has been provided by the EA. Those that have not already been contacted could be followed up in the next phase of work.
East and West Sussex	A list of further contacts has been provided by the EA. Those that have not already been contacted could be followed up in the next phase of work.
Water Companies	A list of company addresses has been compiled, and could be followed up in the next phase of work. Without specific contact names the response is likely to be poor.
British Waterways	A list of contacts has been drawn up and these could be followed up in Phase 2.
Jim Hall – Bristol University	Main contact for the Condition Monitoring and Asset Management (CMAM) project and a leading researcher in risks in engineering systems. Contact made, discussions to be arranged.
Paul Sayers – HR Wallingford Ltd	Main contact for the Risk, Uncertainty and Performance Review, and for the RASP project. Discussed synergies with these projects. Some background material from RASP provided, see also comments below.
Project web-page	No contacts have been made to date from the project details posted on the web, but the page has only been active for a few weeks.

Related Projects

The following projects have been reviewed to identify the links with the current project:

Risk Performance and Uncertainty in Flood and Coastal Defence – A Review

This project defines the concepts and definitions underlying risk and performance-based decision-making, and sets out a framework for introducing risk-based approaches in flood and coastal defence, including R & D needs. As such it is a key reference that sets the context within which failure data might be used. [Defra / Environment Agency, 2002].

RASP – Risk Assessment for Flood Defence Systems for Strategic Planning

The RASP project [HR Wallingford, 2002] is primarily concerned with the development of methodologies to assess risk to human life and the environment. The main aim is to develop and demonstrate methods for assessing risks associated with defence systems. At present there is little guidance available on assessing risks to large floodplain areas that depend on numerous, perhaps extensive and diverse, systems of defences such as embankments, walls and movable structures. Technical issues here include how critical or important a particular defence element is to a floodplain area, and what is the degree of dependence between failures of different elements.

The project is organised into three 'tiers' of analysis, recognising the need for an appropriate level of detail, consistent with the data available and the decision to be made. The 'High Level Method' focuses on the national picture for prioritisation and appraisal of policy. It is developing the method that will be used to update the appraisal of "National Assets at Risk" - NAAR project. More detailed analysis methods are to be developed to use more site-specific data to give more accurate assessments of risk at a local scale.

The RASP project uses fragility curves to represent the reliability of the flood defence structures. These are considered to be well suited to cases where the likelihood of failure is dominated by the 'load' on a defence (e.g. water level or wave height). That is to say this method assumes that there is a single dominant mode or mechanism (load) for failure of flood defence structures, but recognises that there are other factors which result in variability about the mean estimated time of failure against load.

In contrast, failures of system components are generally characterised as random events with associated probability distributions covering all modes (or mechanisms) of failure. Both methods attempt to quantify the likelihood of failure, or time between failures and thus are essentially compatible.

The failure on-demand database reported here will allow the user to filter the data against various factors including age, environment, component size, type etc. In this sense the user has control over which underlying failure data should be included in calculating estimates of failure rates. Ultimately the database system would have a provision for giving an indication of the level of confidence in the failure rate prediction, based on the number of data points and the quality of the data actually used.

CMAM – Condition Monitoring and Asset Management

This is a research project that has pioneered a hierarchical approach to system performance. This enables a range of data and information to be 'added in' to the analysis at a range of levels of detail. The results are one of the main foundations for the next step into performance-based asset management, and for the detailed tier of RASP (see above).

Risk and Reservoirs Project

This CIRIA project [Hughes, A, 2000] was concerned with risk assessment from the over-topping of dams. It considered amongst other things the importance of components in contributing to risk. It is also of generic interest here as an example of how failure data might be used. The Agency is currently reviewing the use of this methodology for application to flood retention reservoirs, and for the treatment of discrete components within dam structures that may contribute to the likelihood of failure. Here there is a particular synergy with the current project, because of the potential significance of the effects of failures of 'components' (e.g. spill-ways) of the dam.

The Thames Weirs Strategy Project

A Halcrows' project [Halcrow, 2001] that studied the risks associated with each of the weirs on the Thames. An initial contact with a representative from this study suggests that the project did not involve gathering quantitative information on failures. However, non-specific information on weirs may help fill the present gap in weir failure data.

Weirs Best Practice

This project, being undertaken jointly by Mott MacDonald and The University of Hertfordshire, seeks to prepare a best practice guide on weirs in rivers on behalf of the Environment Agency. The guide will cover the full lifecycle of weirs from design through construction, operation and maintenance to decommissioning at the end of their useful life. Included within its remit and particularly relevant for the current project, is the proposal to include guidance relating to flood defence, navigation and recreation.

Operations and Maintenance Concerted Action

This project develops the basis for the R & D Programme to support the operation and maintenance of flood and coastal defences.

Summary

It should be emphasised that the current project seeks to obtain information on component failures for use in the context of the management of flood risks. Although the sources of information listed above may be difficult to obtain and interpret for the purposes of this project, it is considered these may give an independent source of information to at least partially substantiate the data being elicited via the questionnaires.

In general the projects identified above are useful in that they give information that can, and will, be used to ensure that the present project uses a consistent and compatible approach. They do not provide specific failure data that can be used directly for the current project.

It is also clear that, in the future, outputs from the present project can support a range of applications of risk assessment and management. For example the data could be used within the RASP methodology to include the effects of failures of specific flood scheme components within a linear defence system. This will support a range of decisions including development of asset inspection/ maintenance/ replacement programme-based concepts of efficient risk reduction. This concept is being reviewed within the Agency under the ‘Risk’ and ‘Engineering’ R & D Themes, with a view to developing a performance-based asset management system. Clearly data on component reliability and failure characteristics would need to be included in such a system.

4. DATABASE DEVELOPMENT

This project sets out to build a pilot database system with the aim of demonstrating whether such a system is feasible. It is envisaged that the database to be developed on this project will augment, and be used in conjunction with, the National Flood and Coastal Defence Database (NFCDD) [National Flood and Coastal Defence, 2002] to provide information of a specific nature that currently is not included in the NFCDD. This project, therefore, provides a view of a pilot system for holding and maintaining component failure data. In the longer term this type of data may be required for flood defence management decisions and potentially incorporated into future versions of the Flood Defence Management Manual (FDMM) as part of a performance-based asset management system.

In order that a pilot system can be developed without committing significant resources, a rapid prototyping technique has been used. Thus the pilot has been built on the relatively small data set gathered thus far, and against the user requirements provided by the EA.

It is intended that the pilot will have all the essential elements of a complete system, from which other data and functionality may be added relatively easily. Assuming that it is considered that a full working system could be developed from the pilot, it is likely that some modifications will be needed primarily to re-engineer the user interface to suit the eventual end users.

Development of the pilot database system is described in more detail below.

4.1 User Requirements

The user requirements, supplied by the EA and reproduced in Appendix C, suggest that there are five broad types of user each with different requirements for the outputs from the database as follows:

- strategic planners – generic failure rates for risk assessment purposes;
- operations and maintenance – prioritisation of works;
- asset management – strategic considerations and lessons learnt;
- flood warning and forecasting – systems thinking, relative importance of components within systems;
- designers (Capital projects) – scheme appraisal and design experience with different types of component.

The challenge is to meet the diverse needs of the different user groups and yet keep the system easy to use and maintain in the future. Databases of this type are only likely to prove useful if the data they contain are up to date and relevant. Thus it is essential that any database solution includes a means of adding additional data to maintain its relevance.

4.2 Database Specification

The Agency has already made a considerable investment in NFCDD as the central repository of data and information about flood and coastal defences. The database to be developed on this project must support and integrate with NFCDD. The database design was purposely kept simple to facilitate it being subsumed within, or interfaced with, NFCDD if and when desired. The simple structure reflects the needs identified for it, see Appendix C, and also to facilitate easy analysis and display of the data gathered on this project.

The present database is seen to fulfil the need to provide a system for the collation and preliminary analysis of data obtained by decentralised gathering, and facilitate the ingestion of such data into a centralised database system, such as NFCDD, as shown in Figure 4-1. The current project is, therefore, concerned with the development of a simple, stand-alone pilot data gathering database system.

In this distributed system any number of data gathering components could be remotely linked to the central system by Email or used to prepare and feed information by post on diskette. The data gathering component should be kept simple, but would ensure that information was gathered on a common and coherent basis for ingestion into the central database. It could include an electronic version of the questionnaire produced on this project, using multiple choice questions and answers, both to simplify data entry and to standardise inputs.

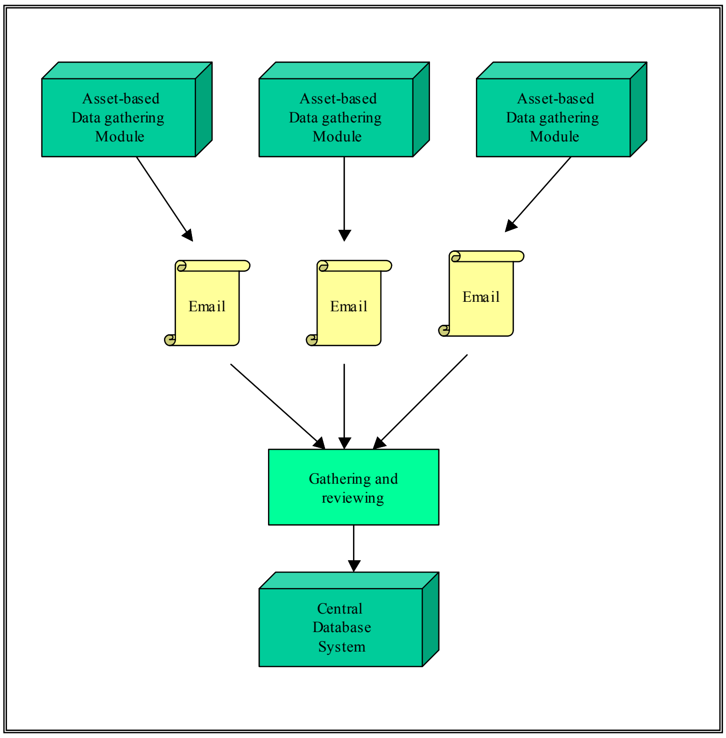


Figure 4-1: Distributed Data Gathering Architecture

The data transferred from the data gathering points would be checked and filtered manually, or automatically, prior to ingestion into the centralising data storage component. This would reduce the potential for errors or double counting of the same incident from two different sources. Centralising the data storage has the advantage of simplicity in terms of maintaining a single up to date data set. Requests for information from the central database could be made and returned by e-mail or could potentially be achieved by on-line access over the Internet or Intranet.

A brief specification for the database system is presented in Appendix D, and was used as the basis for the initial implementation of the shell of the database. The specification focuses on the top-level design aspects presented at a programmer's level of readership and relevant primarily to the pilot system. The specification is intended, however, to be flexible enough to be relevant to the longer term development of a fully operational system.

4.3 Database Structure

Figure 4-2 gives a more detailed view of the key elements of the central data storage and analysis module. It comprises the following key components:

- a customised user interface (written in Visual Basic);
- a single data storage table of failure information, both at system and component levels;
- a series of look up tables, including the taxonomy;
- search/selection facility of systems, types and components;
- module for the calculation of failure rates or probabilities of failure on-demand; and
- standard report forms for hardcopy output of details of selected data entries.

The components of the system that have already been implemented are shown as solid boxes in Figure 4-2, those that have yet to be implemented are shown dotted. Currently new data must be entered directly into the data table, but ultimately would be ingested directly from electronic information sent by e-mail as described above.

Data Flow Diagrams presented below show more specifically how failure rates and probabilities of failure on-demand are calculated from the information gathered by questionnaire and held in the database.

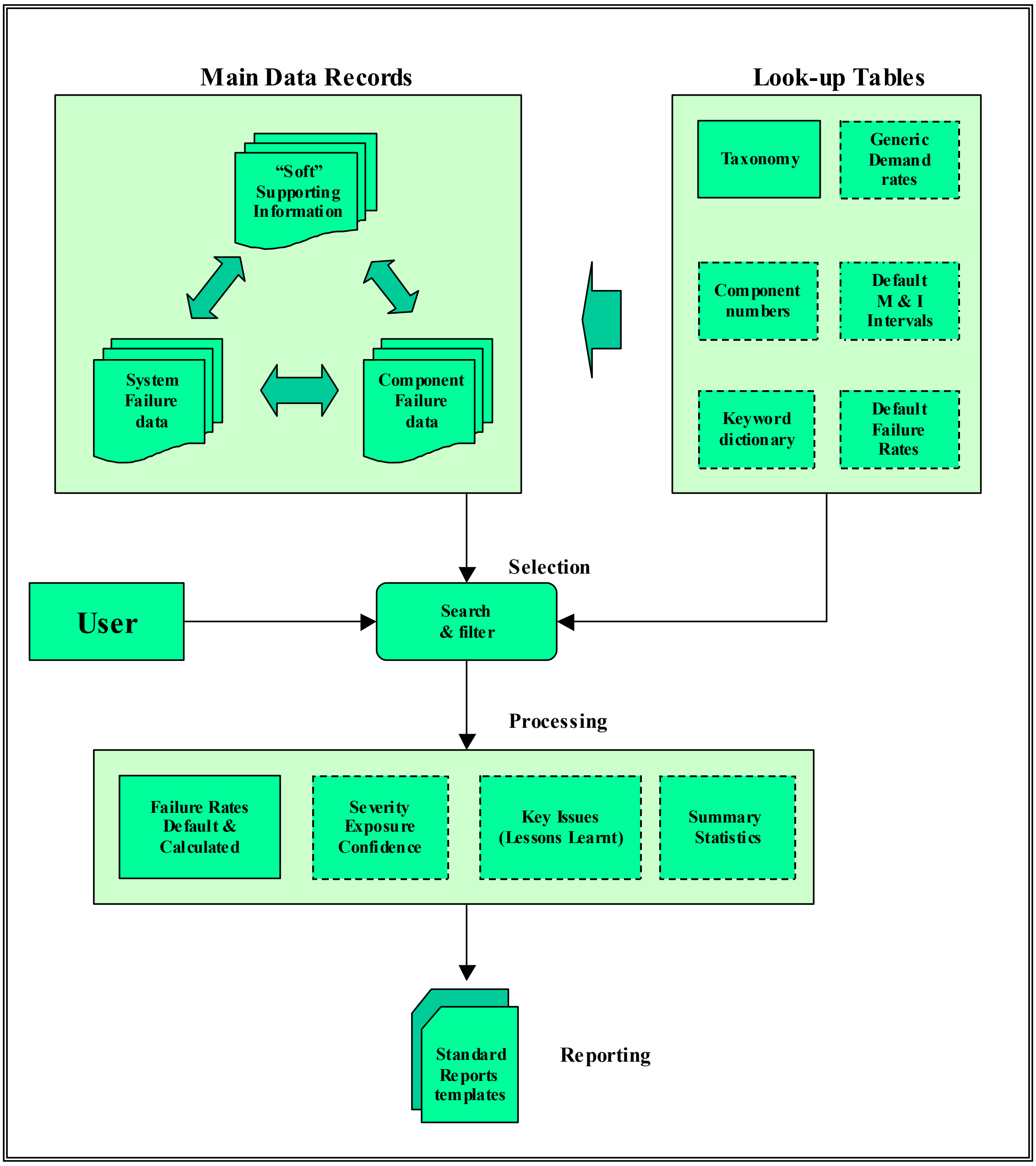


Figure 4-2: Key Elements of Database System

Note that, in Figure 4-2, the box marked "Severity Exposure Confidence" is intended to represent subjective information on the possible consequences of a failure on a chosen system, derived from records contained in the database of past incidents.

Database User Interface

Figure 4-3 gives a screen shot of the user interface for the pilot system. The three boxes in the top left hand side of the screen are used for selecting the system (in this case "Screens"), system type (in this case "Trash") and component (none selected) of interest from drop down lists. To make a selection the system of interest is selected from the drop down list and the "Calculate" button is then pressed. The remaining boxes are then populated from the contents of the database.

The lower half of the screen is split into three sections. The left most section gives failure information to be used for systems or components in continuous use. The middle section gives failure information for use with components in intermittent use. The right most section gives failure information for use with components that have an emergency function.

Each of the three sections contains three small boxes in which the minimum, mean and maximum failure rate or probability estimates are reported. The large boxes give a list of the internal coded reference of the data entries used in the calculations. The final small box in each section simply gives a count of the number of relevant entries used in the calculations.

In Figure 4-3, one entry has been found “EA-0306” for calculating failure rates for Trash Screens in continuous use giving the value of 1.67E-1 for the minimum, mean and maximum estimates. Two entries (“EA-0207” and “EA-505”) have been found for Trash Screens in intermittent use and none for emergency use.

Full details of particular entries within the database can be obtained by selecting the system, system type, or component of interest in the same way as before, and then pressing the ‘Select’ button. Alternatively, details of an individual entry listed in one of the large boxes in the lower half of the screen can be obtained by clicking directly on that entry code from the list in the box. An example of this type of standardised form output from a database record is given in Figure 4-4. It is intended that ‘free text’ descriptive details of each event stored in the database will also be available as a further output although this has not currently been populated and hence is not shown in Figure 4-4.

Internal Data Flows

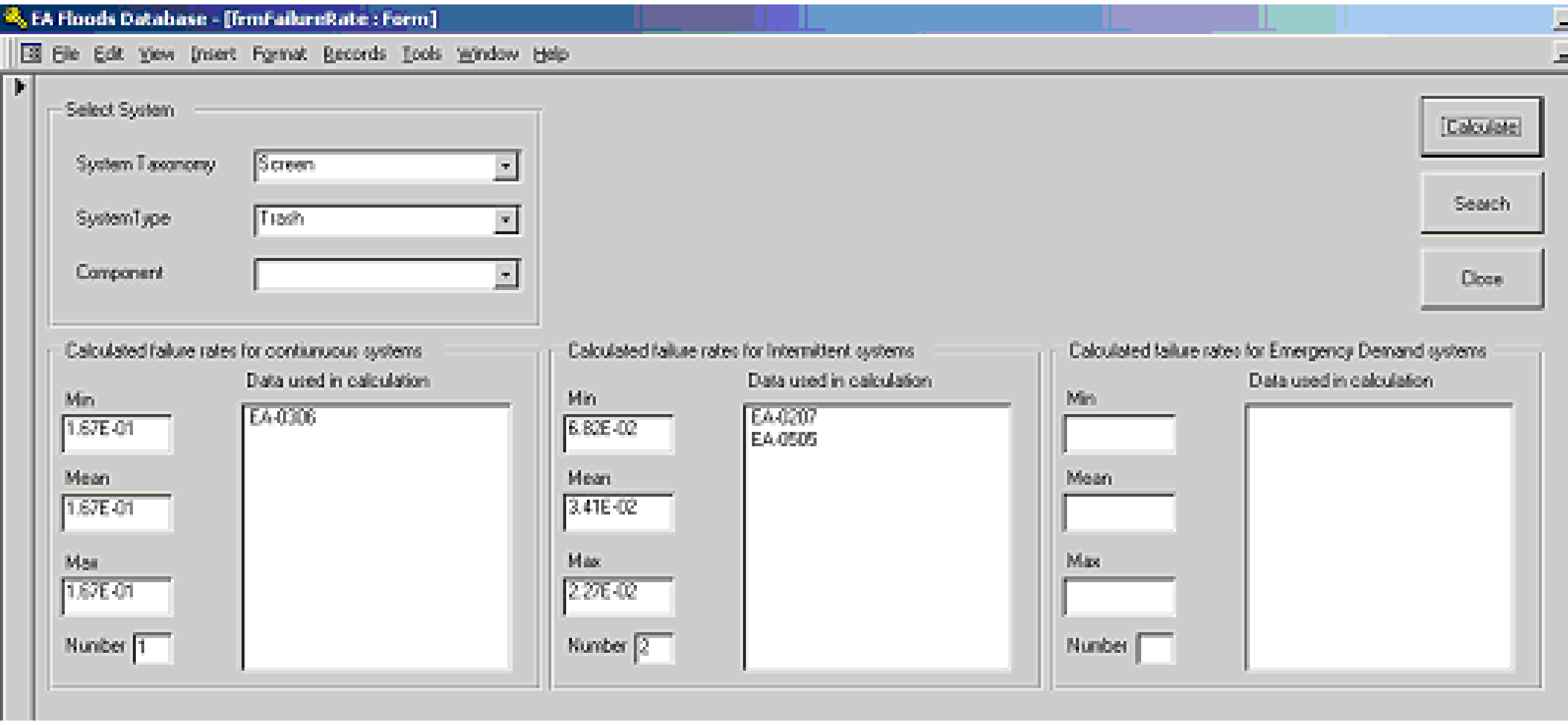
Figures 4-5 to 4-8 give top-level data flow diagrams, showing how the various outputs from the database would be derived from the data stored in the database. Figure 4-5 gives a data flow diagram for the calculation of Failure Rate and Failure Probability for components in continuous use. Figure 4-6 gives a data flow diagram for the calculation of Failure on-demand for components used intermittently and components used only in an emergency. Figure 4-7 gives a data flow diagram for calculation of Hidden Failures and Intrinsic Failure rates taking account of maintenance and inspection protocols. Figure 4-8 gives data flow diagrams that show how the more subjective supporting diagnostic information might be derived.

In these diagrams the long square rectangular boxes represent fields within the database data store. The small shaded tab on the left-hand end of these boxes indicates from where the information is derived. For example QE1 means the information comes from the questionnaire, in this case Question E1. Boxes of this type on the left hand side of the data flow diagrams are in general inputs as regards the parameter being calculated. Boxes on the right hand side are the outputs.

Rounded boxes in the data flow diagrams indicate the calculations performed in order to derive the outputs from the inputs. The folded corner boxes indicate that the item in the box to which it points is a user selectable item.

These diagrams are primarily generated as a guide to programmers involved in the implementation and customisation of the database system. They provide the designer's view of the internal workings of the database. Clearly much of the detailed internal data manipulation and translation has been omitted for reasons of clarity. These diagrams may be further developed to show the calculations performed in more detail, and are presented here only to give an insight into the internal workings of the database.

Figure 4-3: Pilot Database User Interface



Component Failure

Version 1.0

Reference	EA-0101		
Entry Date	06/02/2002		
Source	Group Interview (EA)		
Person	Trevor Carman – FDO N.Kent		
System Taxonomy	Gate		
Type	Flap		
Name of site	Thames tidal flood defence at Greenhive		
EA Number	Blank		
Min No. of Type		*Max No. of Type*	
Best Estimate No. of type	200		
Component	Hinge		
No. of Failures	1		
Reason for Failure	Poor Design		
Severity of Event (1 in N years)	Not known		
Age of Failed Component (yrs)	-1		
Description of component function	Pressure relief from groundwater in estuary wall		
Component size	Small		
Frequency of Demand	Continuous - tidal		
Location	Within linear defence		
Protected from env	Unprotected		
Working Environment	fluvial/salinated		
Number of failures text	100		
Number of failures	100	*Failures per (day, week)*	
Time to re-instate (days)	-2	*Observation period (yrs)*	10
Date failure occurred	Not Known		
Failure detected	Inspection		
Actual Consequences	Not known		
Worst case Consequences	Not known		
Time to temporary fix (days)	-1	*Annual Inspt Frequency*	4
Annual Test Frequency	-1	*Annual Maint Frequency*	-1
Improve warning of failure	No		

19 April 2002

Figure 4-4: Example of Standardised Data Entry Report Form

Page 1 of 50

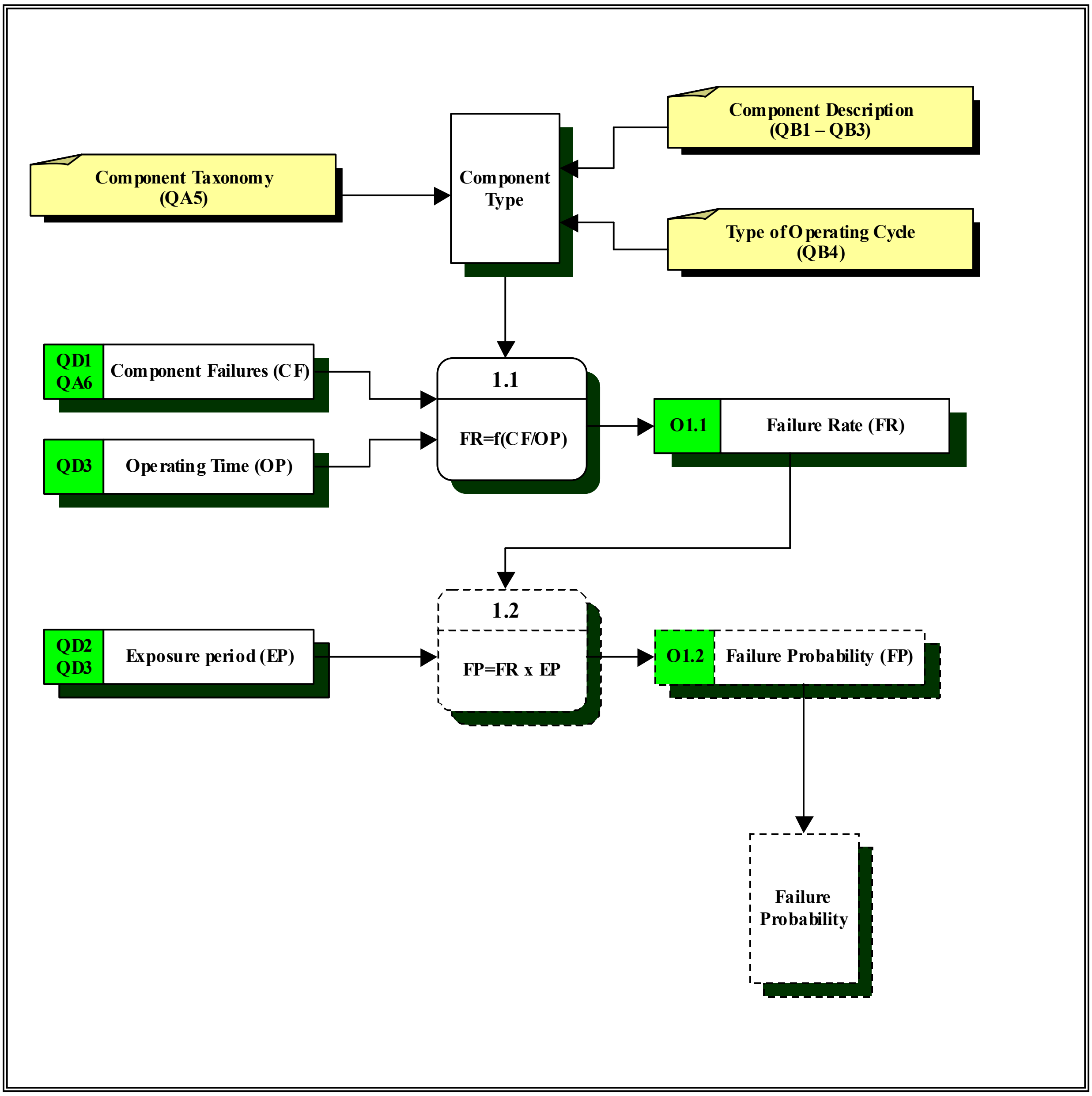


Figure 4-5: Data Flow Diagram for Failure Probability – Continuous Operation

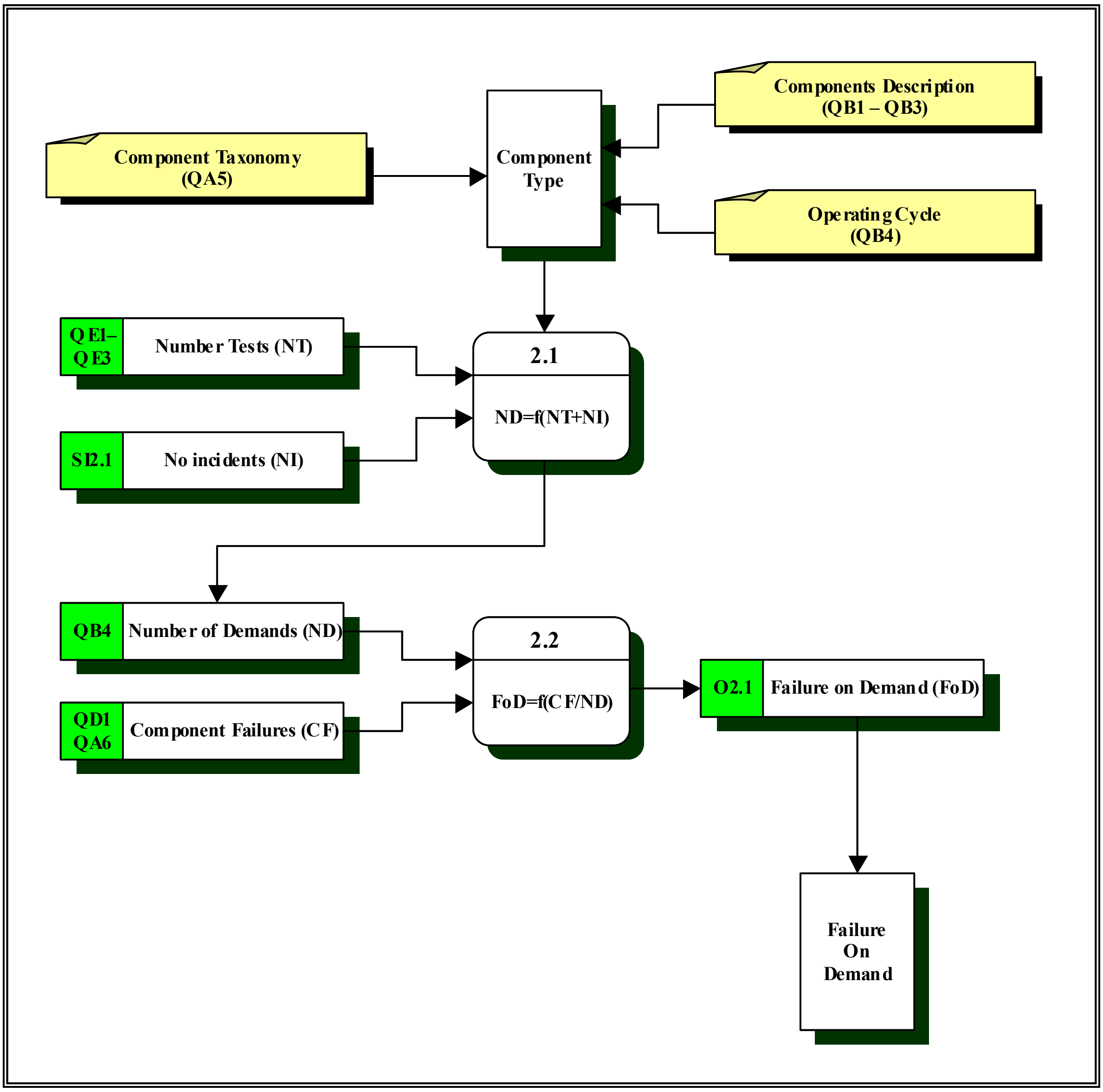


Figure 4-6: Data Flow Diagram for Failure on-demand – Intermittent and Emergency Operation

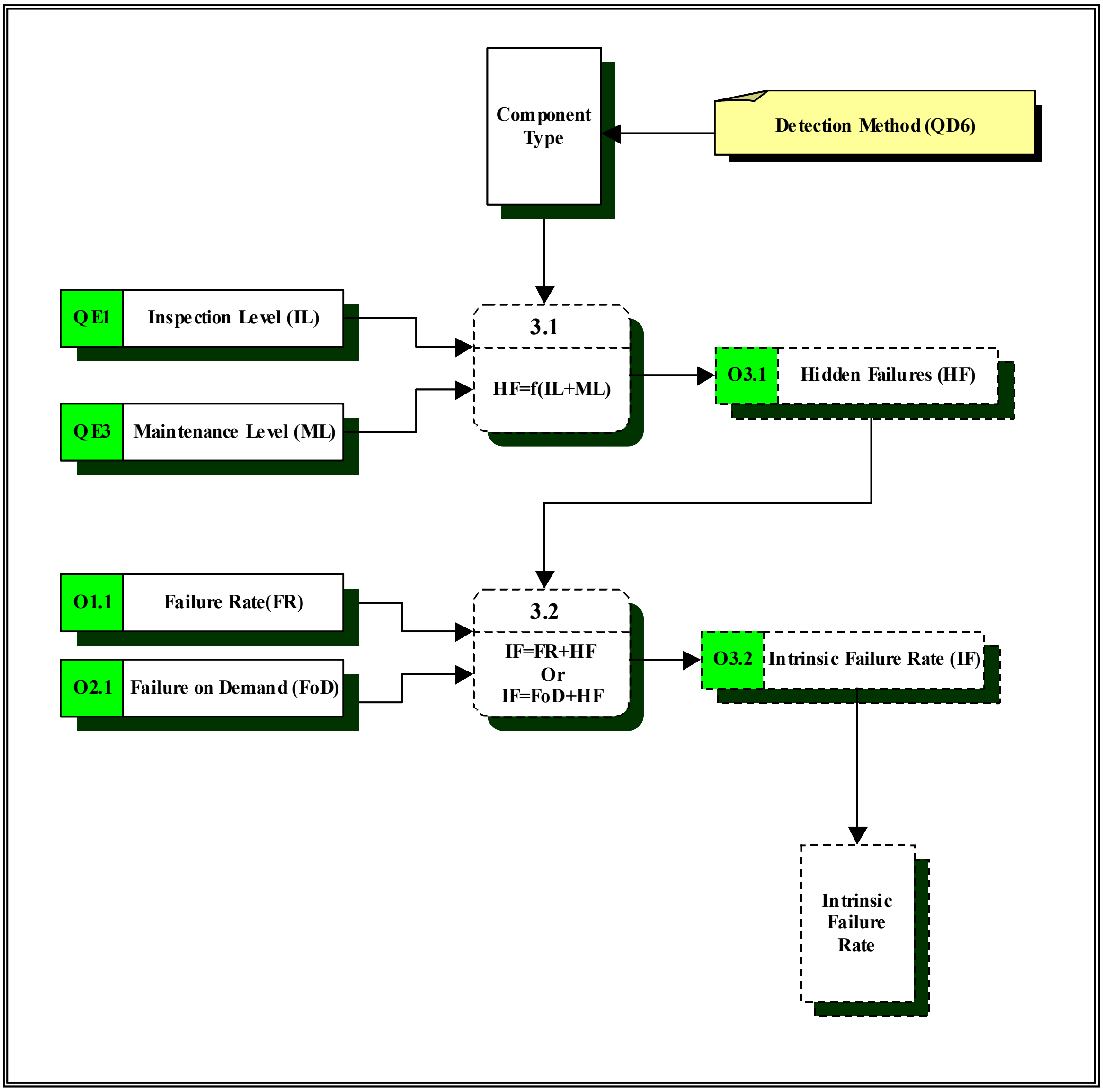


Figure 4-7: Data Flow Diagram for Hidden Failures and Intrinsic Failure Rate

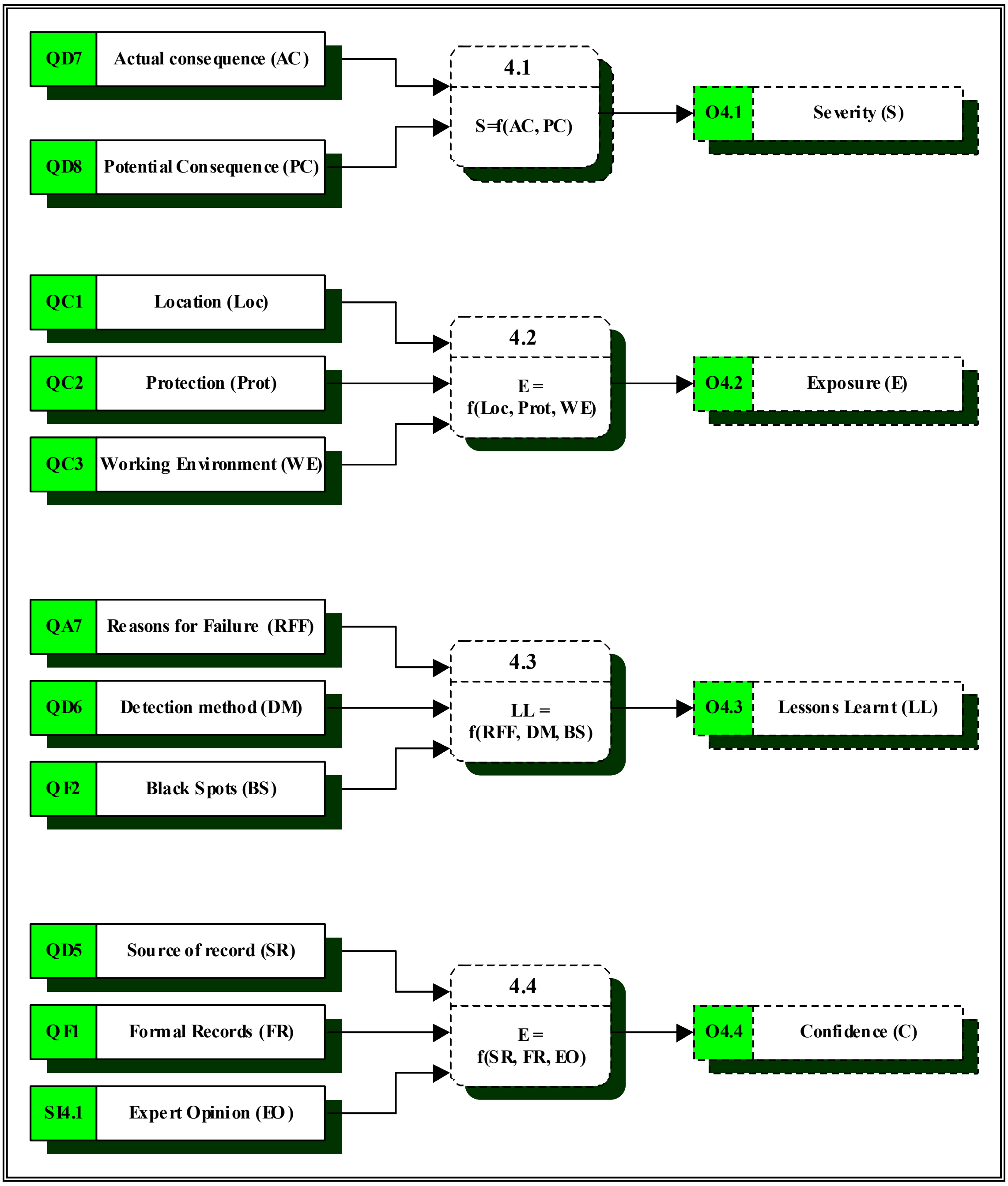


Figure 4-8: Data Flow Diagrams for Supporting Functions

A brief overview of the typical calculations performed within the database is given below. It should be noted that the mathematical formulations presented below have been simplified for the purposes of illustration. For example, in the database failure rates are adjusted to take account of all similar components that have not failed over the observed period of operation. It is also possible to explore the effect of under reporting of failures within the database. These issues are discussed in Section 4.7.

4.4 Typical Data Manipulations – Continuously Operating Components

The main calculation of failure rates for components that are under continuous demand (Figure 4-5) is obtained from:

$$FR(c) = \Sigma_{i=1,n} (CF(i)) / \Sigma_{i=1,n} (OP(i))$$

Where:

c	represents a particular type of component from the taxonomy;
i	represents a particular component within the population of all components of that type;
n	is the population of components of type ‘c’, including those that have not failed;
FR(c)	is the component failure rate (units T^{-1});
CF(i)	is the number of times each component of type ‘c’ fails within a given operating period (OP(i));
OP(i)	is the operating period for each component of type ‘c’ over which failures are recorded (units T).

For example if there is a total of 2 failures in 100 operating years experienced by a particular component, the component failure rate would be 2 in 100 years or 0.02 per year.

Failure probability over a given period of exposure is:

$$FP(c) = FR(c)\ EP(c)$$

Where:

FP(c)	is the probability that a component of type ‘c’ fails within a given period (EP(c)) (units - none);
EP(c)	is the period of exposure of interest (units T)

Clearly this simple calculation neglects any seasonal variation in factors, which might influence the likelihood that the component fails, such as increased component loading during the wet months of the year.

The failure rate of a system which comprises several components will be a function of the number of components and how those components interact and will, in general, require more complex derivation, typically using an Event/Fault tree approach.

4.5 Typical Data Manipulations – Intermittent and Emergency Operation

The main calculation of component failures that operate intermittently or under emergency conditions (Figure 4-6) is defined in terms of a Failure on-demand, obtained from:

$$FoD(c) = \Sigma_{i=1,n} (CF(i)) / \Sigma_{i=1,n} (ND(i))$$

Where:

c, i and n	are defined above
FoD(c)	is the component failure on-demand (no units);
CF(i)	is the number of times each component of a particular type fails within a given number of demands on the component to operate (ND(i));
ND(i)	is the number of demands placed on the component to operate

The number of demands placed on a component during its operating life is generally assumed to be the sum of the number of incidents, which result in a demand, and the number of functional tests made on the component.

For example a component type (c) that failed 3 times having experienced 20 demands and having been functionally tested 10 times has a failure on-demand of 3/(20+10) = 0.1.

An equivalent failure probability (FP(c)) can then be derived by multiplying the failure on-demand by the number of demands experienced within a specific period, (typically annual), i.e.:

$$FP(c) = FoD(c) \times ND(i)$$

4.6 Use of Failure Probability in Risk Calculations

Failure rates as obtained from the above expressions can then be used in combination with consequence analysis to estimate risk on a site-specific basis.

4.7 Adjustments for Incomplete Data

Owing to the lack of formal recording of component failures within the water industry, and flood management sector in particular, it has been necessary to elicit failure information from those working in the industry. It is likely that not all failure incidents will be recalled in this way. In particular minor incidents that happened several years ago are quite likely to be forgotten.

In order to take account of this potential for under-reporting and incomplete capture of failure incidents, a subjectively assigned parameter (no. of reports/no. of failures) is provided to allow this effect to be explored. This parameter is currently internally set to 0.25. The effect of this parameter may be removed by giving it a value of 1.0, which is equivalent to full reporting of all incidents.

Failure rates of systems, sub-systems and component types must take account of the total operating life of all such systems, sub-systems and components, including those that have not failed to date. Best estimates of the total number of systems within the regions surveyed were obtained from Agency records. Numbers of sub-system and components were estimated using expert knowledge within the project team. It should be emphasized that these numbers are purely estimates and component numbers are particularly difficult to determine. To take account of the uncertainty in these subjectively derived data a range of +/-15 % was imposed on the number of systems, +/-25 % on sub-system numbers and +/-40 % on component numbers when calculating the maximum and minimum failure rates. The results presented in this report were obtained using the uncertainty ranges quoted above, however, these can easily be revised in the database given better information.

A typical average operating life of 10 years was assumed for systems, sub-systems and components for the purposes of adjusting failure rates for under-reporting and for systems, sub-systems and components that have not failed to date. Variability in the operating life of systems, sub-systems and components is assumed to be accounted for within the upper and lower bounding numbers of systems, sub-systems and components used.

5. PRELIMINARY RESULTS

5.1 Failure Rate Prediction

Failure rates and probabilities of failure on-demand generated for selected flood defence systems are presented in Table 5-1. The quoted failure rates have been adjusted to take into account the probable numbers[1] of each component type, many of which have not failed to the knowledge of those involved in providing the data. These results have been generated without substantiation of the data from independent sources.

Table 5-1: Preliminary Failure Data for Selected Flood Component Systems

System	Continuous (C) Intermittent (I) Emergency Operation (E)	Minimum Failure Rate (T^{-1}) or Probability of failure on-demand (-)	Mean Failure Rate (T^{-1}) or Probability of failure on-demand (-)	Maximum Failure Rate (T^{-1}) or Probability of failure on-demand (-)
Barrier	C	-	-	-
	I	6.40E-3	6.67E-3	6.98E-3
	E	-	-	-
Culvert	C	3.23E-5	3.72E-5	4.37E-5
	I	3.52E-6	4.05E-6	4.77E-6
	E	-	-	-
Gate	C	8.68E-3	9.87E-3	1.14E-2
	I	7.14E-4	8.14E-4	9.45E-4
	E	1.66E-3	1.91E-3	2.25E-3
Outfall	C	-	-	-
	I	-	-	-
	E	2.83E-5	3.11E-5	3.44E-5
Pumping Station	C	5.11E-3	5.86E-3	6.88E-3
	I	2.06E-3	2.30E-3	2.60E-3
	E	2.22E-3	2.55E-3	2.99E-3
Screen	C	1.62E-4	1.87E-4	2.19E-4
	I	7.48E-5	8.51E-5	9.85E-5
	E	-	-	-
Spillway	C	3.14E-3	3.61E-3	4.24E-3
	I	-	-	-
	E	-	-	-
Warning System	C	3.92E-3	4.50E-3	5.29E-3
	I	-	-	-
	E	-	-	-

Figure 5-1 gives a breakdown of the main reasons for the failures recorded to date. Neglecting incidents for which the reason for failure is unknown, the most common

[1] The population of each component type is defined as an upper and lower bounding estimate. These populations are currently only estimates generated by the project team from their own records. These estimates could be refined in the future by extracting the information from Agency records (e.g. from NFCDD).

causes of failure seem to be age, excessive duty and debris causing damage or preventing proper operation of flood defence systems.

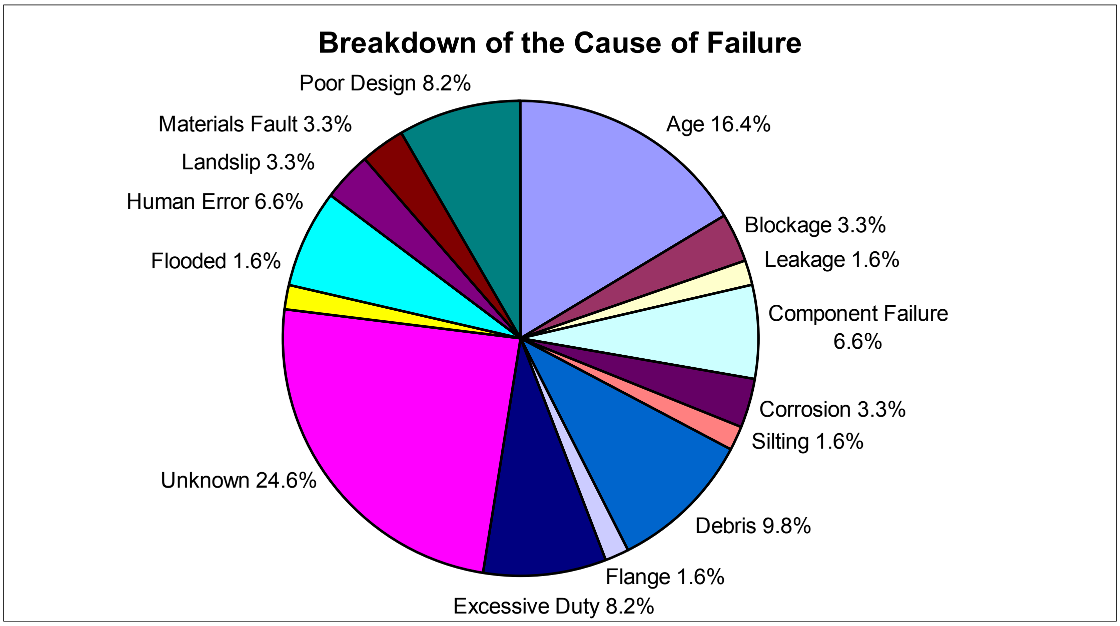


Figure 5-1: Breakdown of Reasons for Failures

Figures 5-2 and 5-3 give a breakdown of the causes of failure for gates and pumping stations respectively. For both of these systems, age and poor design are cited as the most common cause of failure. These figures are derived from the responses given to question A7 on the questionnaire (Appendix B) - "Reason for failure (e.g. excessive duty, blockage, corrosion etc)?"

It has not been possible to account for dependency or overlap between these categories 'Corrosion' for example, could be closely related to 'Age'.

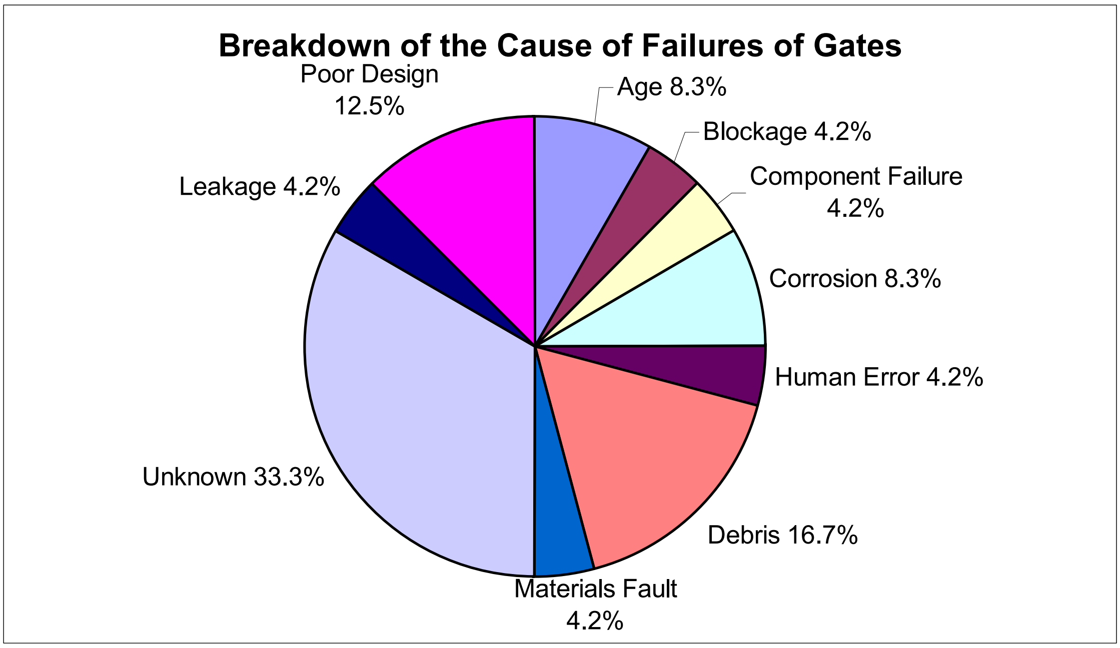


Figure 5-2: Breakdown of Causes of Failure for Gates

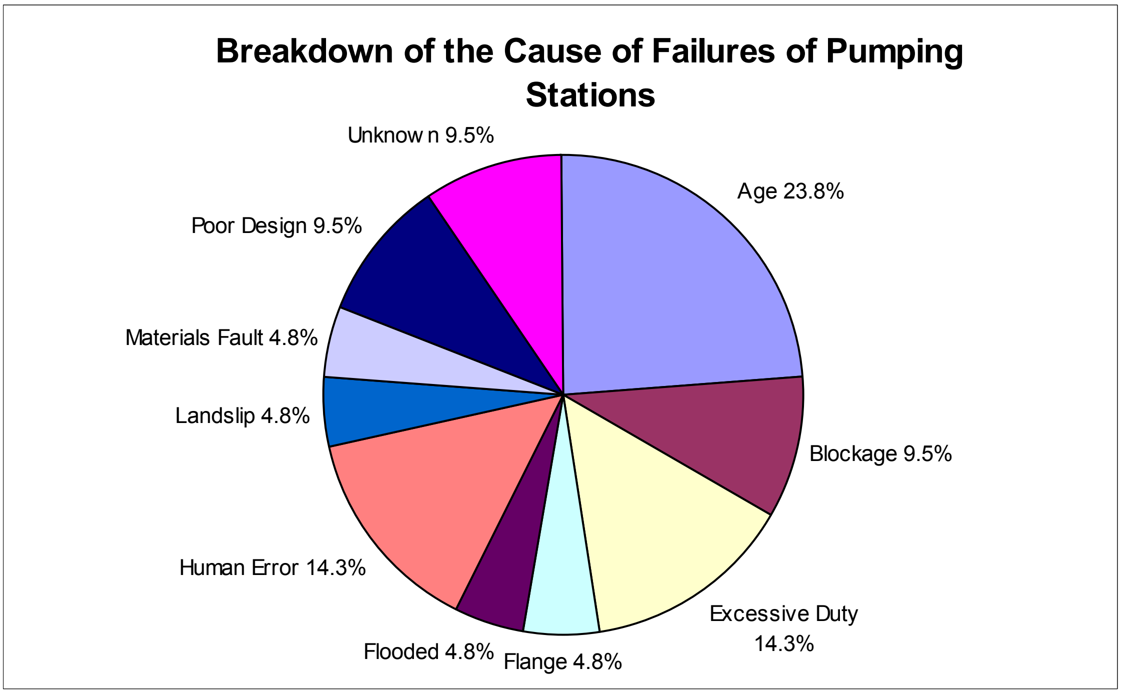


Figure 5-3: Breakdown of Causes of Failure for Pumping Stations

Treatment of Uncertainty

The lack of depth in the failure data means that it will not be possible to derive statistically significant failure rates, only mean estimates. At this stage uncertainty in the data is indicated by giving a range of possible failure values. The minimum value is that derived for the most reliable component of its type, the maximum values from the least reliable of its type. It should be emphasised that this is only a very crude indication of the uncertainty because the data sets are very small and in many cases there is only a single data entry in the database from which to derive a failure rate. (In which case the minimum, maximum and mean are equal). More sophisticated methods of computing confidence intervals on the predicted failure rates can be derived when larger data sets have been obtained and/or expert opinion used to augment the observed incident data.

The least number of assumptions has been made in order to derive the failure information presented here. What assumptions have been made have been recorded. Ultimately the database may be provided with the ability to indicate where assumptions have been made in deriving failure rates or probabilities of failure on-demand. It may be possible to significantly reduce the level of uncertainty in predicted failure rates by verifying the numbers of systems, sub-systems and components in each region; by obtaining information on typical operating lives, and establishing more justifiable estimates of the under-reporting of failure incidents. Such information could be improved by a combination of more in-depth analysis of Agency asset records and further expert elicitation.

Link Between Failures and Maintenance

It is clear that from the information gathered to date there is a relatively high level of maintenance applied to many of the flood defence components, and that sometimes this maintenance is reactive rather than planned. It is suggested that instances of reactive maintenance could be used as an indicator of additional failures not currently recorded.

There is clearly a trade off between high reliability of a system (which generally means high capital cost) versus high levels of maintenance (which generally means high operating costs). This is a key issue on which it is hoped the database will help to provide invaluable information.

Classically, component failures are assumed to be random and time independent, however it is clear from the data obtained so far that there are some strong time dependent factors. These influences require more detailed consideration in order to ensure that the most appropriate assumptions are made in deriving and presenting generic failure data.

5.2 Lessons Learnt

The main lessons learnt from the data obtained and from the wider discussions of current practices are identified below:

- There is a general lack of documentary information on failures of flood defence scheme components within the EA and elsewhere.

- There are instances of failures being identified by telemetry systems, however it is not always clear if such incidents always count as failures. If a flood occurs as a result then it is clear that a failure of the system has occurred. If, however, telemetry identifies a problem but no flooding occurred at that time, it is less clear whether this should be classed as a failure since this may simply be fortuitous. This uncertainty is compounded by the fact that flooding may or may not occur depending on the time available for corrective action to be taken before the incident escalates.
- With reference to the preceding bullet point, telemetry appears to be used as a primary means of defence against system failures, but there are a number of complex issues that require further consideration, possibly in the next phase of work.
- The reliance on the knowledge of field staff for recollection of failure information means that recent failures tend to be more easily and more accurately recalled and described.
- The data is patchy because the information is distributed amongst different stakeholder groups. It has not been possible to make contact with representatives from all of these groups within the current phase of work (e.g. lock keepers).
- There are a number of instances of design failures, suggesting the need for more robust design 'best practice' guidance. This finding tends to support the long-term aims of this project.

5.3 Summary

A first pilot database system has been developed and preliminary results generated; however the work to date has been based on a relatively small data set. The failure estimates produced from the database at this stage are calculated by averaging across the entries relevant to a chosen system or component in the Taxonomy. They are higher than might be expected because they currently do not account for similar components that are in operation that have not failed. Corrections for this will be undertaken in the next phase of work.

It is estimated that between 12 % and 15 % of failure incidents that have occurred over the past 10 years have been captured to date. This suggests that there is a potential for increasing the size of the data set by at least 6 times. This, together with other methods of 'adding value' to the data (discussed in Section 6), indicates that potentially there should be enough data to formulate reasonable estimates of component failure rates that would be 'fit-for-purpose' (see Appendix C). As well as capturing numeric data for calculating failure rates, other general knowledge of the causes and potential severity of incidence has been captured. This knowledge base offers an invaluable resource to aid in the development of guidance in best practice in the future.

Records of system and component failures are not routinely kept within the Environment Agency or elsewhere. However, the review of possible sources of information suggests that further relevant data exists, but that it is dispersed amongst different stakeholders around the country. Unfortunately data gathering under such conditions can be very time consuming and this largely explains why more data was not obtained within the timescales of the first phase of work. However, given that more hard data and/or subjective views can be added these estimates could be significantly improved and confidence limits applied to the results, providing essential information for use in risk assessment studies. Section 6 that follows presents options for the next phase of work, leading to a practical approach for assimilating knowledge of component reliability into a range of decision-making tools.

6. PROPOSALS FOR PHASE 2

The original project programme (RM Consultants and Peter Brett Associates, 2001) for phase two of the project needs to be modified in the light of the findings from the first phase. The outstanding issues requiring further attention are discussed in Section 6.1 below. Of these issues, the need for additional data gathering in particular, means that the original programme for phase 2 can no longer be achieved within the allocated time and resources. A new schedule of tasks for the second phase of the project is given in Appendix E and options for undertaking these tasks within the allocated resources are posed in Section 6.2.

6.1 Issues Requiring Further Consideration

The main issues that require additional attention beyond that originally proposed within the Phase 2 programme of work are discussed below, including:

- consolidation and further data gathering;
- data checks for spurious or anomalous entries;
- additional analysis to add value to the data;
- recording of future failures; and
- further development of the database.

Consolidation and Further Data Gathering

There is clearly a need for more failure data, and in particular for locks and weirs. In addition, however, there is a need for more detailed information on generic failure rates, the numbers of components within specific regions, their normal maintenance and inspection regimes.

Some potential sources of non-specific data have been identified, however, further meetings with other stakeholder groups is potentially the best means of obtaining details of additional incidents. It is felt that the postal and web-embedded survey should be extended and the response improved by telephone contact before and after sending a questionnaire. This approach has been successful on other projects, but is more labour intensive and time consuming. It is also anticipated that eventually useful contacts may be obtained from the project web-page especially if links to this page are added from others associated with the flood project.

In order to significantly improve the depth of the data, however, it is suggested that structured elicitation of generic system and component failure rates be sought from groups of experts. Here the emphasis would be on asking experts to give estimates of how often particular components have failed in their experience, rather than asking them to recall specific failure incidents.

This would provide a more direct approach for deriving failure rates from the experts subjective views. The expert views may then be combined with the observed information using a Bayesian updating methodology. The Bayesian paradigm offers a means of updating understanding of, in this case, component failures, with new information to give a revised or posteriori understanding of failures. Here expert opinion could be used to derive the initial understanding of component failures, the records of incident represent the new information (the likelihood), which when combined with the expert views give a revised, hopefully improved, estimate of such failures. It is possible that tools developed within the CMAM project could be applied in this context.

Another way of augmenting the sparse observation data could be to use generic information for similar components, used under similar operating conditions from other industries and, or relevant information from other countries. Care would need to be taken to ensure that the components and their operating conditions are sufficiently similar to justify the use of such data for the water industry. For example a pump with equivalent duty used within the oil industry will in general be subjected to different working conditions, because it pumps oil not water or has a continuous rather than seasonal duty cycle.

The information derived from other industries would be maintained separately within the database and used to give default failure rates for use in the absence of more specific information.

Data Checks for Spurious or Anomalous Entries

Before failure rates can be used with confidence it will be necessary to undertake a process of substantiation of the data from independent sources. For practical reasons this is likely to be limited to comparing observed failure rates against industry norms to identify possibly spurious data entries. It may be possible to establish these industry norms by sampling works logs or Drainage Board minutes to ascertain typical levels of reactive maintenance, which could be taken as indicative of the underlying failure rates.

Data Analysis

In addition to the technical aspects of raw data analysis already proposed, it would be informative to explore more knowledge-based aspects of component reliability and consequences such as the seasonal time and event dependent influences on failures. This will enable guidance to be developed as to the most appropriate use of failure rates in different contexts and will help support asset management. Further analysis of component reliability could also help prioritise improvements in component design and maintenance.

Given that it is possible to augment the existing data sets by the means discussed above, it will then be possible to derive confidence limits on the failure data representative of the true uncertainty, even if only one or two field observations exist.

It is intended that the database would perform all the necessary calculations, invisibly to the user, but would give the user information on the data used to derive the failure estimates if requested. It will then be possible for the user to check that the reported failure rates are not unduly dependent on one or two data entries or inappropriate defaults for example.

Future Population of Database

It is evident that there is a lack of reliable data on failures on-demand within the flood defence community. To ensure that such data are available in the future, for design of new defences and also to aid in prioritisation of asset-based risk assessment, a system must be established for recording such failures in the future.

A formal means of recording failures in the future will ensure that the database is maintained with the latest up to date information. To be successful, such data should be captured by asset operations personnel in the Regions. This could be either a paper-based or preferably an electronic-based system or both. In any event the success of this type of data recording system relies heavily on perceived need and benefits for stakeholders and the user friendliness of the systems themselves.

Further Database Development

It is proposed that the remaining functional elements and facilities of the database, given in the system specification, should be completed. This includes the development of the component for remote data entry and an improved User Interface. Feedback on the design of the user interface would be sought from potential users of the system. The revised database will need updating to include the ability to ingest data derived from the subjective views of experts and additional default information generated from anecdotal sources and data derived from other industries.

6.2 Revised Programme for Phase 2

A revised schedule of tasks for phase two of the project is given in Appendix E. In this revised programme of work, tasks 2.1 to 2.3 have been added, while tasks 2.4 to 2.7 are taken from the original programme of work.

Alternative options for undertaking these tasks within the allocated resources are outlined below. Each of these options involves elements of all tasks identified in Appendix E, but places different emphasis on the tasks such that the work can be achieved with the resources already allocated.

Option 1. Undertake the full programme of tasks, including expert elicitation of component failures, further database system development and proposals for future recording of failures as outlined in Appendix E, but considering only two out of the current 10 systems, e.g. gates and weirs.

Option 2. Continue the programme, covering all 10 flood scheme systems currently being considered, but placing the major emphasis on obtaining more data to the detriment of other tasks. This would involve reducing the scope of work under Tasks 2.5 and 2.6 as outlined in Appendix E. The scope of these tasks could be reduced by providing only the framework for the use of failure information in the analysis of importance of failures, i.e. limit the scope of the risk assessment aspects of these tasks.

Option 3. Continue the full programme, considering all flood scheme components but including only the more cost effective data elicitation techniques, and a limited development and demonstration of how failure information might be used. This reduced programme for Task 2.1 and Tasks 2.5 and 2.6 will allow a greater emphasis to be placed on the full specification and piloting of methods for recording future component failures. The emphasis here will be establishing a working system with limited data, but that will grow as new data is supplied in the future.

Option 4. Exploit knowledge and existing data to support the development of a performance-based asset management system:

- Review component types, failure mechanisms, consequences and systems with other experts.
- Identify key failure categories for different components.
- Develop approach for pilot implementation.

At this stage option 4 is preferred since it could be carried out as a key part of the PAMS project currently being developed, leading to a vision and practical demonstration of the future of the Flood Defence Management Manual for flood and coastal defence asset management. This would provide a strong user drive and focus for the work. This is also in line with the Agency R & D programme requirements to develop the underlying concepts and tools while ensuring that there is a ready route for uptake/implementation - in this case through the Flood Defence Operations and Management Group.

7. REFERENCES

DETR, Environment Agency, IEH 2000 *Guidelines for Environmental Risk Assessment and Management*. The Stationery Office.

Dunderdale, J A L and Morris J, 1998 *Flood Defence Management Manual (FDMM), Environment Agency, see: Evaluation of FDMM.* Environment Agency R & D Technical Report; W134.

Hughes A, *et al*, 2000 *Risk Management of UK Reservoirs* CIRIA.

Halcrows, Thames Weir Strategy Project, 2001.

Institution of Civil Engineers 2001 *Learning to Live with Rivers*. ICE, London.

RM Consultants and Peter Brett Associates, Nov 2001 *Proposal for the Project: Failure On-demand of Flood Defence Scheme Components* RMC (Ref: E3646 EA Ref: RC980\CD\MS).

Defra / Environment Agency, 2002 *Risk, Performance and Uncertainty in Flood and Coastal Defence - A Review.* R & D Technical Report FD2302/TR1, HR Wallingford, July 2002.

National Flood and Coastal Defence Database (NDCDD) 2002 http://www.defra.gov.uk/environ/fcd/hltarget/nfcdd.htm.

HR Wallingford, 2002 *Risk Assessment for Flood Defence Systems for Strategic Planning* (*RASP*) (Project currently on-going).

Appendix A

Brochure

Environment Agency

R & D Project W5-031

Failure 'on demand' of Flood Defence Scheme Components

Introduction

Effective flood defence depends on successful operation of components such as gates, valves, pumps, and associated control systems. Research is needed into the ways in which these and other components fail, and to estimate the likelihood of failure during flood events (or 'on demand'). Within the combined DEFRA / Environment Agency Flood and Coastal Defence R&D Programme, the Agency has commissioned a project to:

- collect and collate data on the performance of components;
- define methods of assessing failure rates of different components and systems in a range of environments; and
- develop methods for assessing the importance of particular components.

This is one of a number of ongoing and planned R&D projects into performance and risk evaluation, which will significantly improve our ability to assess and manage risk.

Aims

This research will support risk assessment and decision-making in the following areas:

- Maintenance planning for optimum risk reduction
- Operations - 'what if' assessments and decision support for emergency planning
- Capital projects - appraisal and specification of components
- Engineering design - selection of components, contribute to development of best practice
- Risk assessment and management - provide data for improved assessments of flood risk.

Programme

The project is divided into 2 phases. The first – the collection of data, development of a taxonomy and building of an inventory and failure database, is to be completed by April 2002. The second – analysis of failures and their impacts, and subsequent proposals and recommendations is due for completion by August 2002

<u>Phase 1 - Development of Taxonomy and Database</u>

- Information gathering, interviews and data collation, principally Environment Agency data, but including other operating authorities and manufacturers where appropriate. If you feel you can contribute please contact us at the address shown
- Development of taxonomy - a classification based on existing Environment Agency / DEFRA databases

- Development of the database suited to reliability data of flood defence components
- Data collection - populating the database, including statistical techniques to 'fill the gaps'
- Dissemination of the database and supporting reports to end users.

Depending on the quantity and quality of data found, a decision will be made on whether to progress to Phase 2:

Phase 2 – Analyse Data, Develop Methodologies and Produce Guidelines

- Data analysis - statistical analysis of the data, looking to identify correlations with season, lifecycle, maintenance etc., the most frequent failures, the most severe failures, common causes for failure.
- Risk assessment - to provide the design for a model of risk based on estimates of failure and their impacts on the needs of flood defence, navigation and flood warning.
- Development - the risk model developed in Task 2 will be used to determine the importance of various components - in terms of contributions to risk. This will be achieved using sensitivity analysis software and probabilistic modelling.
- Operational recommendations - practical recommendations to improve the efficiency and effectiveness of flood risk management.

The Team

The work will be carried out by a team from RM Consultants and Peter Brett Associates.
RM Consultants have over 20 years experience in developing and analysing reliability databases used in various fields, as well as experience across the environmental area.

Peter Brett Associates are engineering consultants with extensive knowledge of flood and coastal defence components, systems and procedures.

The Results

The project aims to deliver to the Environment Agency and other stakeholders:

- A flood defence component reliability database, suitable taxonomy;
- A set of risk assessment tools to support design, management and operation of flood defence components;

Data and information to support integration of component failure risk with other risks within an

For Further Information please contact:

Risk Evaluation / Understanding Uncertainty Theme Leader
Ian Meadowcroft, **Environment Agency**,
Tel: 0118 953 5247
email: ian.meadowcroft@environment-agency.gov.uk

Main Contact and Project Manager for RMC
Steve Oldfield, **RM Consultants**, Suite 7 Hitching Court, Abingdon Business Park, Abingdon, Oxfordshire. OX14 1RA (Tel. 01235 555755, Fax. 01235 525143, e-mail: sgo@rmchost.demon.co.uk)

Main Contact for PBA
Richard Dawson, **PBA Consulting Engineers**, 16 Westcote Road, Reading, Berkshire. RG30 2DE (Tel. 0118 950 777, Fax. 0118 950 8198, e-mail: rdawson@pba.co.uk)

Appendix B

Questionnaire

Our Ref: J3646/SGO/jm

Graham Jones
London Borough of Harrow
PO Box 21
Civic Centre
Harrow
HA1 2UJ

13 March 2002

Dear Sirs

Failure On-demand of Flood Defence Scheme Components

RM Consultants Ltd and Peter Brett Associates are acting on behalf of the Environment Agency of England and Wales in seeking to set up a database on failure data for flood defence scheme components. The objective of this database will be to provide statistical information that may be used to help improve the overall reliability of flood defence schemes in the future. The present study is specifically targeted at 'discrete' components (e.g. weir) within a flood defence scheme, not 'linear' components (e.g. walls and embankments). These will be covered by other studies.

Your assistance would be much appreciated in providing information that you may have on past component failures by completing the attached questionnaire. Please complete a separate copy of the questionnaire for each failure event. This information will be invaluable in building a picture of the reliability of the individual components within a flood defence system. In turn this will give insight into those systems or components that are vulnerable to failure and why.

If you have any difficulties with the questionnaire please do not hesitate to contact me. If you have information in a different format (e.g. electronic database, written documents, etc), to save you time please contact us and we will endeavour to make alternative arrangements for abstracting the relevant data.

Please send completed questionnaires to the address given on the questionnaire. Alternatively, if you would like to complete the questionnaire electronically please contact us, thank you.

Yours faithfully

Dr S G Oldfield
For and on behalf of
RM Consultant Ltd
Tel: (01235) 555755/Fax: (01235) 525143
Email: sgo@rmchost.demon.co.uk

Flood Defence Failure on-Demand Data Questionnaire

Instructions

The questionnaire is designed to extract information about each flood defence component failure that could have resulted in a flood, or could have made a flood event worse, whether or not it actually did in practice.

You will see that the questionnaire is in five main parts as follows:

Part A: Concerned with details of the system containing the component that failed.
Part B: Concerned with details of the component that actually failed.
Part C: Concerned with the operating environment of the component that failed.
Part D: Concerned with details from which a failure rate can be derived.
Part E: Concerned with the assets maintenance and test regime.
Finally we have provided an opportunity for you to make any other comments you wish to add to the information you provide.

It may not be clear to you why we need all the information requested on each failure. You will understand, however, that in order that the data may be interpreted in a meaningful way we need to understand the context within which the component normally functions. It is also necessary to ascertain the period of operation, or level demand that the component is subjected to under normal and or emergency conditions.

Please bear in mind that in order to draw relevant usable statistics from the information that you provide, it is important that you answer as many of the questions as possible. However, if you are unsure of your answer, or do not know an answer to a particular question you should indicate this in your response.

Please return completed questionnaires to:
RM Consultants Ltd, Suite 7 Hitching Court, Abingdon Business Park, Abingdon, Oxfordshire, OX14 1RA or Email to sgo@rmchost.demon.co.uk

For the purposes of this project the following definition of failure is used:-

Any occasion in which a flood defence system was unable to cope with a flood event,

Including:

- Failures on-demand and failures in operation
- Failures on test
- Failures discovered during inspection & maintenance
- 'Surcharge' Failures – i.e. demand exceeding capacity
- Wear and tear failures – i.e. old age, premature ageing as a result of poor design
- If in doubt – please give details so that the event can be included if appropriate

Exclusions:

- Large and complex structures (e.g. Thames Barrier, Leigh barrier)
- Solely linear structures (i.e. coastal walls, embankments etc)
- Temporary mobile structure (e.g. sandbags)

We are also interested in failures of essential electronic systems and power supplies and telemetry outstations associated with specific flood control components.

Part A Details of the System that Suffered a Failure

The following answers will help us identify the component and system that suffered the failure and guard against double counting of failures reported from independent sources.

A1. Short description of the role of the system in which the failure occurred (e.g. pumping station for land drainage):

If the failure is specific to a single system or asset, please answer A2 and A3, and then go to A5. If the failure is generic to a type of asset or component please go to question A4.

A2. Name of site or flood defence scheme – Region, area, watercourse, reach or description (e.g. Medway defences):

A3. Environment Agency Flood Defence Management Manual Number (if known):

A4. How many of these systems are there in your area (e.g. 3 of this design, 200 of a similar capacity):

A5. What component in the system failed first (e.g. pump, valve, controller):

A6. How many of the systems/components suffer from this type of failure (e.g. typically 4-6 are down at any one time, 10/yr):

A7. Reason for Failure (e.g. excessive duty, blockage, corrosion, etc):

A8. Please give an indication of the severity of the event associated with the failure, (where applicable):

a) Not in flood…………………..

b) Typical winter flood………...

c) Typical 10-year flood……….

d) Typical 30-year flood....…….

e) Typical 100-yr flood..…..…...

f) Highest recorded flood……...

Other (please specify):

Part B Details of the Component that Failed

The following answers will help us to categorise the failure for the generation of generic failure rates for the relevant category of component.

B1. Component manufacturer or, if not known, brief description of component that failed:	
B2. Description of component function or duty (e.g. standby generator, emergency lift pump, etc):	
B3. Size, rating or capacity of component (e.g. no. cumecs, valve size, rated power for motor, diameter of outfalls, etc.):	

B4. Component Operating Cycle (please complete relevant boxes):

a) Continuous use………..		If so	Period (e.g. tidal, 12hr)…...	
b) Intermittent use………..		If so	Frequency (e.g. seasonal)…	
c) Emergency demand…...		If so	Demand (e.g. 10yr flood)…	

Other (please specify):

Part C Details of the Environment in which the Component Operates

The following answers will help us to understand the environmental context within which the component operates.

C1. Physical location of component on site (please mark relevant boxes):

a) On, or adjacent to, a watercourse....		c) Within a linear sea defence……..	
b) Distant from a watercourse……….		d) Within a flood plain…………...	

Other (please specify):

C2. How is the system protected from the environment (e.g. Unprotected, in a building, cabinet, etc.):	

C3. Working environment for the Component (please mark relevant boxes):

a) Fluvial water………………….. ☐ c) Foul/combined water……….. ☐

b) Surface water………………. ☐ d) Salinated water……………... ☐

Other (Please specify): ☐

Part D Number and Type of Failures

The following answers are important in establishing a common basis on which to calculate component failure rates from their operating duty.

D1. Number of times the component has failed to your knowledge: ☐

D2. How long was taken to repair the system to fully functional status? (e.g. 1 hour, 1 day, 1 year etc.): ☐

D3. Period over which the failures have been observed, or period the system has been in operation without major replacement (e.g. 5 years): ☐

D4. Date(s) failure occurred: ☐

D5. Source of record of failure if available (please mark relevant boxes):

a) Anecdotal only………………. ☐ c) Day-works register…………… ☐

b) Site log..……….…………….. ☐ f) Purchasing records…………….. ☐

Other (please specify): ☐

D6. How was the failure detected (please mark relevant boxes):

a) On test…………….………….. ☐ d) Automatic warning system……. ☐

b) On Inspection………………. ☐ e) Reported by the public……….. ☐

Other (please specify): ☐

D7. What were the actual consequences of the failure? (e.g. none, small flood major flood ,none):

D8. What were the potential 'worst-case' consequences for the failure (please complete relevant boxes):

a) Flooding of non-critical area….. [ ] Severity….(Minor/Major)….. [ ]

b) Flooding of critical area……….. [ ] Severity….(Minor/Major)….. [ ]

c) Loss of water table…………….. [ ] Importance.(Minor/Major)…. [ ]

Further Comment (e.g. Number of properties damaged, legal or environmental issues etc):

In some instances temporary measures are put in place while the failed component is repaired or replaced. If so, then please answer questions D9 and D10.

D9. How long before temporary measures were in place and functional (e.g. Sykes pumps in place within 24hr, dual pump system, no delay built in redundancy):

Please give an indication of how effective the temporary measure was in replacing the component that failed.

D10. What was the efficiency, capacity or success of the temporary measures? (e.g. the 50% pumping capacity was ample, the temporary dam held):

If the alternative or standby measures itself failed please fill out another failure data record

Part E Scheduled Maintenance & Testing

The following answer will help us to better understand whether a different maintenance or testing schedule would prevent such a failure in the future.

E1. How often is the component that failed inspected such that a failure would be noticed? (e.g. never, once a day, once a week, once a month, etc):	
E2. How often is the component that failed functionally tested, at least partially? (e.g. e.g. valve opened on test once a month, once a year, etc):	
E3. How often has the component maintained? (e.g. never, once a year, every five years):	
E4. Could early warning of a failure in this component be improved, and if so how? (e.g. by remote sensing, more regular inspection, etc.):	

Part F Other Relevant Information

F1. Are you aware of any formal records of component failures? If so please give details:		
F2. Are you aware of any particular high-risk areas within your responsibility or 'black spots' that require your attention on a regular basis. If so please give details:		
F3. Please give your job title and responsibility (e.g. catchment, river, reach, etc):		
F4. Please indicate if you would like feedback on this project and a contact point if not already given (e.g. name, telephone, email, etc):	Yes No*	

* Delete as applicable

F5: Please add any comments that you wish to make on any aspect of this questionnaire:

Thank you for your assistance.

<u>Please return completed questionnaires to</u>:
RM Consultants Ltd, Suite 7 Hitching Court, Abingdon Business Park, Abingdon, Oxfordshire, OX14 1RA or Email to sgo@rmchost.demon.co.uk

Reference Number	

Please leave blank for our reference

Appendix C

Preliminary Assessment of Typical User Needs

Failure 'on-demand' of flood defence scheme components
Preliminary Identification of User needs

User – e.g. FD process	Why needed (i.e. areas that this project can contribute towards) (note many of these will require further guidance / development to be fulfilled)	What needed from this Project (i.e. specific output / outcomes to support these activities)
Strategic planning	• Prioritisation – risk associated with components based on broad knowledge of failure rates - support strategic planning / policies e.g. decision between high maintenance / low maintenance options • Assessment of risk associated with flood defence components (to be integrated with defence reliability through systems analysis) • Identification of 'hot spots' i.e. areas where component reliability critical to FD performance • Data requirements for future phases of NFCDD	• 'Default' figures for reliability of different component types (in different environments) • Data / information to input into risk assessment of whole defence systems
Operations / maintenance (incl. emergency response)	• Support maintenance planning by identifying maintenance / reliability relationships • Support asset management decision-making (repair / replace / maintain depending on reliability / risk / cost relations) • Risk management decision making (e.g. review of systems operations, identifying critical components, redundancy in systems design / operation / fail safe design / operation) • Identification of components prone to failure during emergencies - support emergency planning and emergency response	• Component reliability / maintenance / environment relationships • Reasons for failure - lessons learnt • Guidance on how to approach risk assessment of components and associated systems (e.g. sensors) (i.e. context for the failure data and how to use it to, definitions of 'on-demand' etc.)

User – e.g. FD process	Why needed (i.e. areas that this project can contribute towards) (note many of these will require further guidance / development to be fulfilled)	What needed from this Project (i.e. specific output / outcomes to support these activities)
	• Enable reporting of failures / near misses for future performance evaluation	
Flood forecasting / warning (FF&W)	• FF&W is a system of operationally critical sequence of processes. So something going wrong somewhere can have a system-wide impact • Good practice on FF&W is emerging and this study nature can support this by identifying hidden risks • There is a whole range of regional differences that can be integrated - we are in the process of doing so but what are risks? There are a few processes for which we do not have good practice defined, e.g. post-event analysis, so what risks are there to the practice of FF&W?	• A strategy towards "safe systems" by developing a model of FF&W, which integrates the 8 regions on their commonality but allows them to differ in their region-specific features • Component thinking and systems thinking • Both partnering and ownership through "systems approach"
Capital projects	• 'Default' values for component failure rates (hence economic risk) for use in project appraisal studies • Support design best practice design of components and associated control systems • Possible identification of 'best value' components on the basis of risk / cost • Possible development of design criteria based on failure rates	• Database of failures • Experience with different component types / environments • Design experience

Appendix D

Database Specification

Failure on-demand Flood Defence Scheme Components Database

Brief Outline Specification

Host System:	Single user low specification modern desk-top PC.
Software:	MicroSoft™ Access database 2000 or 1997 with Visual Basic front-end. Wherever possible the database system and its user interface will be constructed from pre-defined software components (e.g. ActiveX).
User Interface:	Standard windows style, comprising pre-defined forms, dialogue boxes, drop-down menus for user selectable options, data manipulations and reports generation.
Inputs:	Once the database has been set up interrogation of the database by a user to produce outputs will be via the user interface. It is assumed that data updates would be performed by direct addition to the database records by a person suitably conversant with MS Access database applications.
Outputs:	Facilities will be provided for pre-defined reports generation, tabular and summary outputs. Outputs will be formatted for export into consistent versions of MicroSoft Office compatible produces (e.g. Word, Excel).
Data Security:	Key data tables will be password protected to avoid accidental corruption.
Data Structures:	Pre-defined relational data tables containing stored failure data information, comprising of a number of numeric, semantic/coded, date and textual data fields for each event record. Look-up tables for the component taxonomy, key word search dictionary etc.
Basic Facilities:	On-line help on database functionality and data definitions. Data entry search on selected coded, semantic and textual data fields. Filtering of data against predefined criteria. User-friendly error messaging and controlled system exits will be provided wherever possible.
Testing:	Each component of the database system will be unit tested and the entire system checked to ensure robustness and accuracy.

Trials of the system will be sought with EA representatives to obtain feedback on its user friendliness and 'Look and Feel'.

Test records will be maintained for future reference, but only summary results are to be published.

Configuration Control: The database system code will be version numbered to ensure traceable maintenance record. Whenever a stable version of the database system is released the version number will be incremented. Code change between releases will be tracked using a paper-based change control procedure.

The database user interface and any reports generated from it will display the current version number and the last time the data was updated.

Documentation: The system will be designed with an open architecture and as far as is practical a self-explanatory user interface.

A brief installation, maintenance and user guide will be provided, including a guide in best practice in using and generating outputs from the database.

System Maintenance: The database is to be generated as a pilot system only, as such, further development to a fully self-contained 'commercial' product beyond the life of the current project and its long term maintenance have yet to be established.

The system is, however, to be designed such that it is easy to upgrade its functionality and maintain the data stored within it.

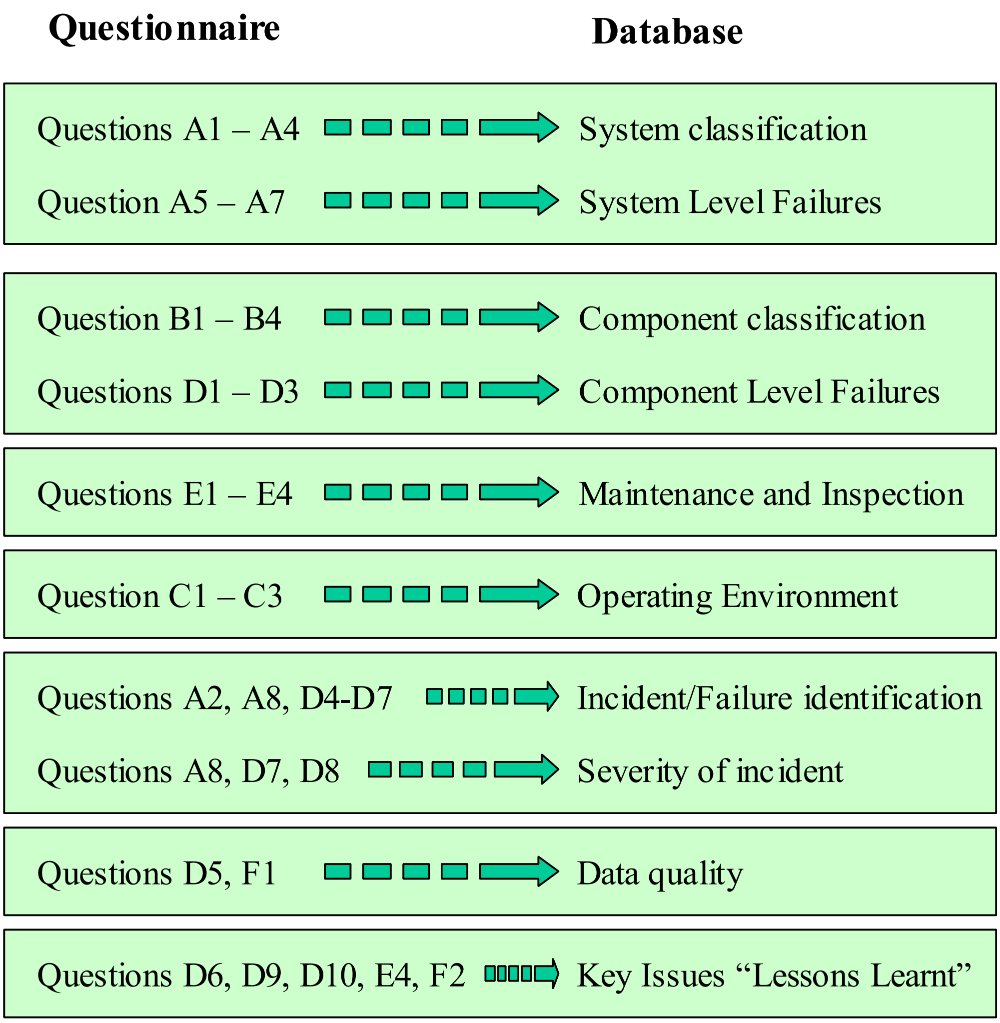


Figure D-7-1: Translation of Questionnaire Responses to Database Elements

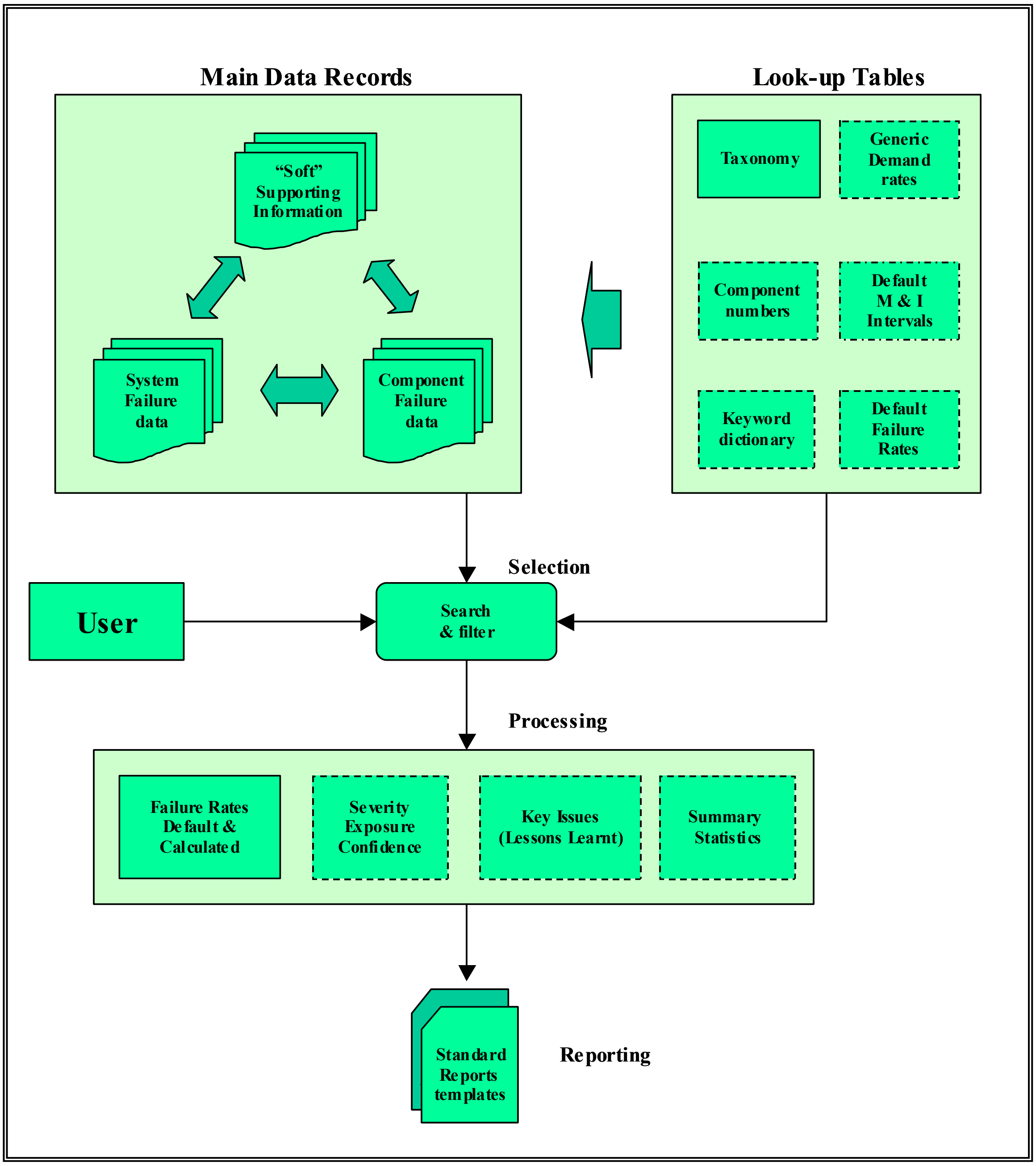


Figure D-7-2: Schematic of Database Architecture

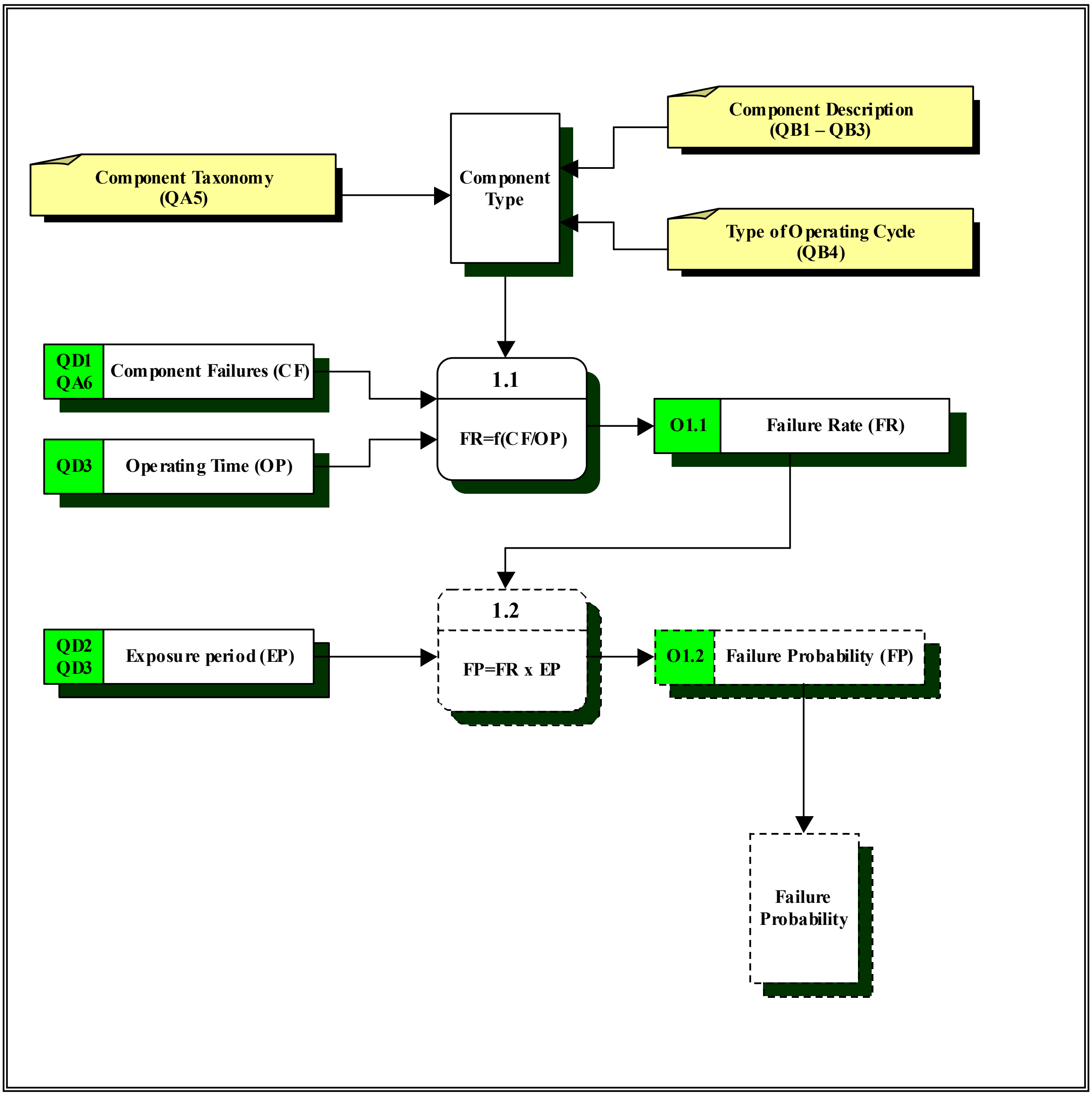


Figure D-7-3: Data Flow Diagram for Failure Probability – Continuous Operation

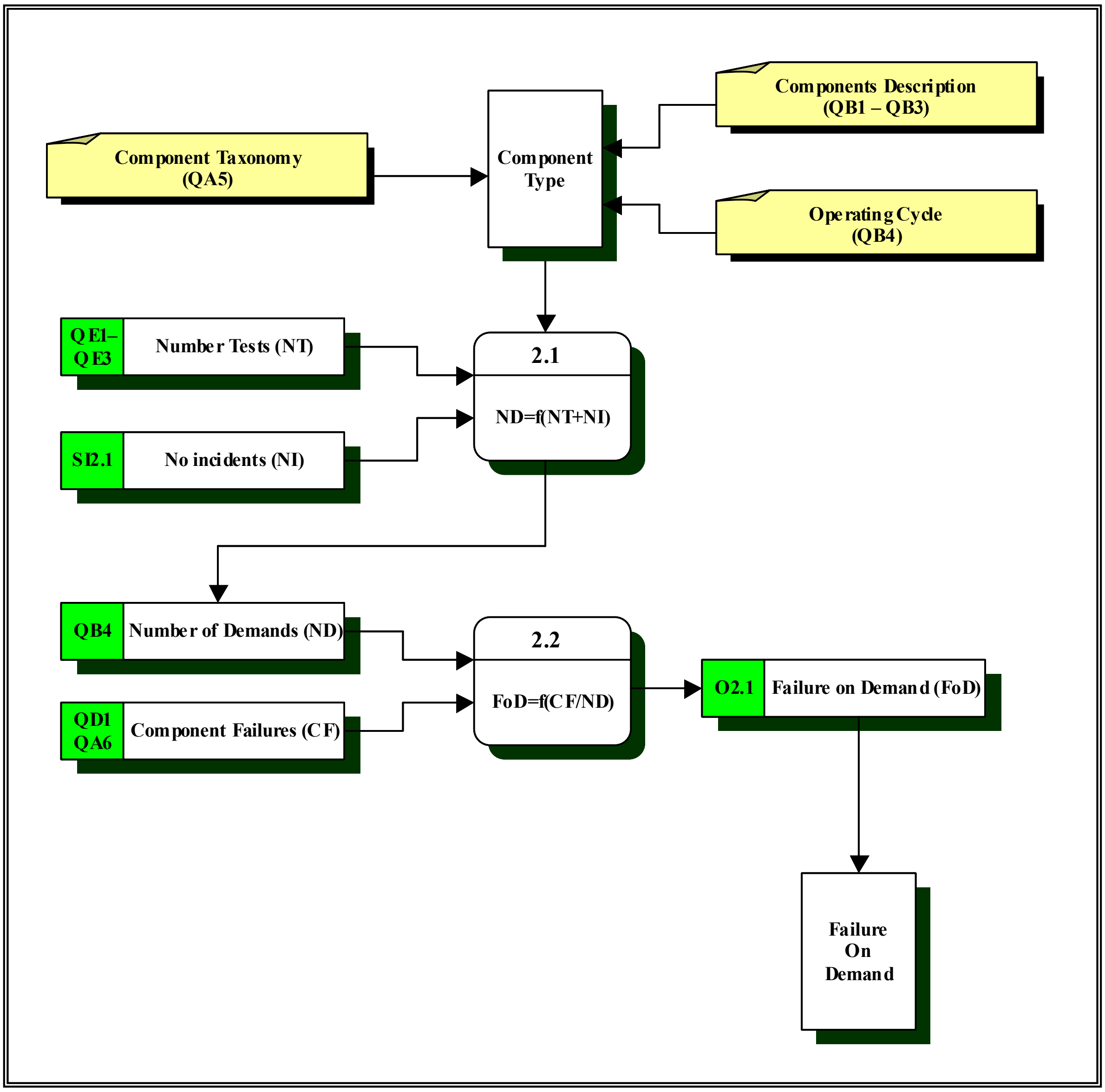


Figure D-7-4: Data Flow Diagram for Failure on-demand – Intermittent and Emergency Operation

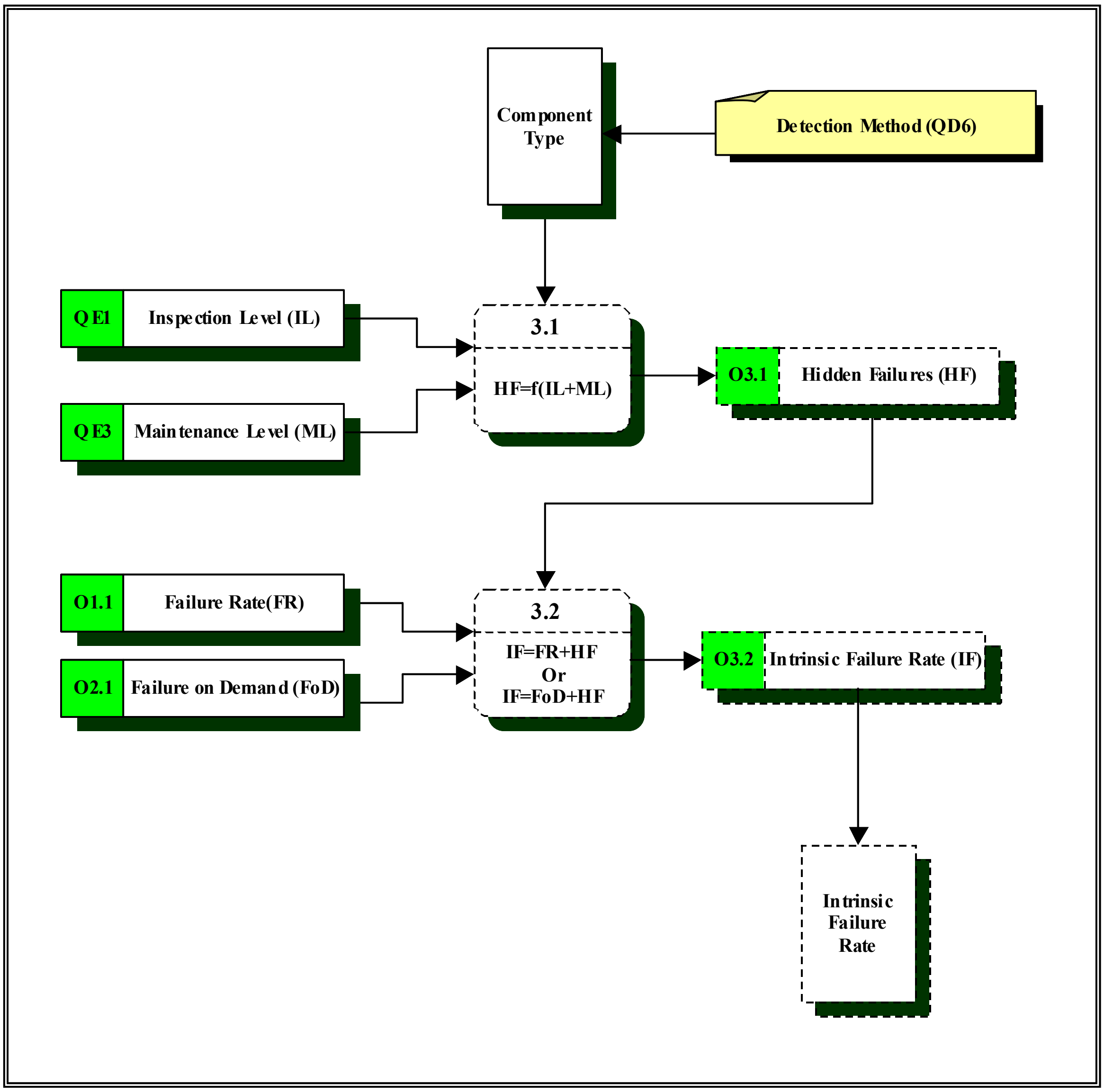


Figure D-7-5: Data Flow Diagram for Hidden Failures and Intrinsic Failure Rate

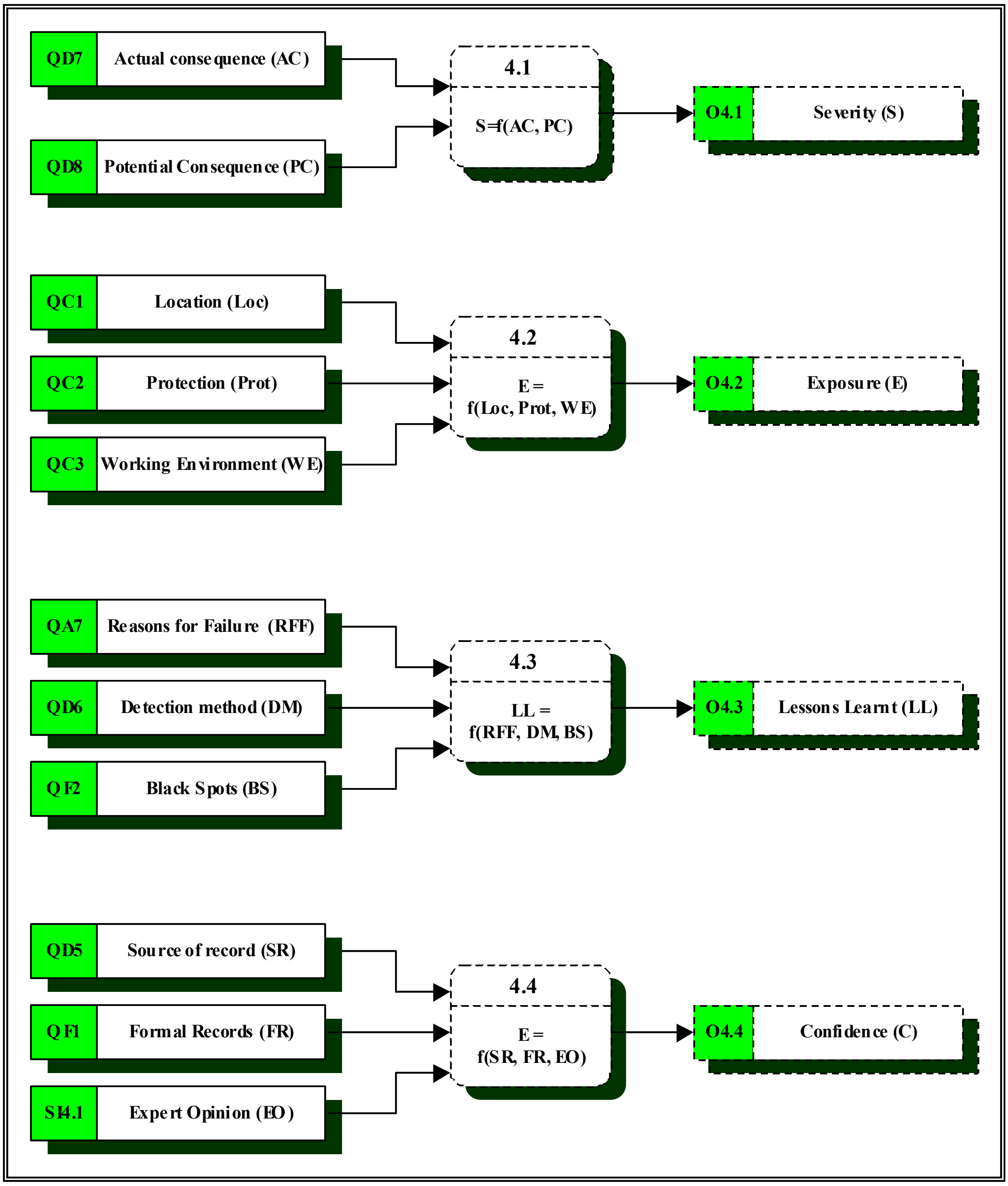


Figure D-7-6: Data Flow Diagrams for Supporting Functions

Appendix E

Tasks for Phase Two

Failure on-demand of Flood Defence Scheme Components – Phase Two

An outline of the tasks that are envisaged for phase two of the Failure on-demand of Flood Defence Scheme Components Project is given below. The tasks identified combine those identified in the original call for tender from the EA and additional tasks identified from the Phase One work.

Task 2.1. Additional Data Gathering

Phase One of the project identified a clear need to gather more data for all systems and components but, in particular, for locks and weirs. In addition to this, however, there is a need for more detailed information on generic failure rates, the numbers of components within specific regions, and their normal maintenance and inspection regimes.

The following methods are proposed for augmenting the data gathered to date, namely:

a) Further face-to-face meetings with EA representatives from the EA Regions
b) The structured elicitation of generic failure rates for components from expert knowledge through structured brainstorming sessions
c) Follow up and review, where possible, electronic and paper records of maintenance and inspection, e.g. works orders, site diaries, etc.
d) Follow up the initial postal survey with personal telephone contact where possible to encourage a better response
e) Identify sources and propose justifiable methods for obtaining failure information from other countries and other industries.

Included in this task would be the substantiation and consolidation of the data ingested into the database against independent sources where possible, e.g. comparison of the numbers of incidents recorded for particular systems or components against maintenance records or expert opinion.

Task 2.2. Protocols for Recording Future Component Failures

Methods should be put in place capturing future system and component failures. This is to ensure that the database is maintained with the latest up to date information such that the failure information may be seen to be relevant, up to date and used with confidence. Alternative methods, including both paper-based or an electronic-based system or both should be considered in collaboration with those expected to use them.

The success of this type of data recording system relies heavily on perceived need and benefits for stakeholders and the user friendliness of the systems themselves. It is likely to take several iterations and mock-ups of the systems to establish acceptable methods otherwise they will not be used effectively.

Task 2.3. Further Development of Component Failure Database

It is proposed that the remaining functional elements and facilities of the database, given in the system specification, should be completed. This includes the development of the component for remote data entry and an improved User Interface. Feedback on the design of the User Interface would be sought from potential users of the system. The revised database will need updating to include the ability to ingest data derived from the subjective views of experts and additional default information generated from anecdotal sources and data derived from other industries.

It is intended that the database would perform all the necessary calculations, invisibly to the user. It would optionally provide the user with information on the data used to derive the failure estimates if requested. If requested this information will enable the user to check that the reported failure rates are not unduly dependent on one or two data entries or inappropriate defaults, for example.

Additional outputs from the database will be provided including:

- Key lessons learnt associated with recorded incidents.
- Subjective estimates of data quality.
- Indicative measures of the importance of component failures.

These outputs will be associated with the user-selected systems or components. Additionally, a free text description of each failure incident will be included within the database, for retrieval with other data entry information.

Task 2.4. Analysis of Reasons for Failure (Previously Task 2.1)

In order to manage risk, it is important to identify and understand the causes of failure. This makes it possible to decide how far it is practicable to eliminate or minimize the causes, or whether effort is better directed towards mitigating the consequences of failure. An understanding of causal factors and operating conditions under which components have failed is also important when extracting failure data from the database for predictive purposes, in order to ensure that failure data are relevant to the particular environment and conditions of interest.

The data will therefore be analysed to extract information on the most significant causes of failure – i.e. those which occur most frequently and/or affect the most components. The analysis will also look for correlations between the occurrence of failures and operating conditions and influencing factors, such as season, location, life cycle stage of the component or maintenance and inspection intervals.

As part of this and later tasks it will be necessary to devise generic methods for taking account of seasonal and other time dependent influences on failures in some detail. This will enable guidance to be developed as to the most appropriate use of failure rates in different operational contexts.

Also included in this task would be the derivation of failures on-demand from indirect evidence, such as the proportion of maintenance and inspections in which the requirement for maintenance is discovered.

The taxonomy developed under Phase One may need to be revised to better reflect the types of incidents that have been identified, and in the light of the data analysis to be performed under this and other tasks.

Task 2.5. Risk Assessment: Estimation of Failure Rates and Impacts (Previously Task 2.2)

The original call for tender included a task to 'produce estimates of failures and their impacts on the needs of flood defence, navigation and flood warning'. In essence therefore, this task is a development of a risk assessment methodology (where risk is taken to mean the combination of the frequency of an event and the severity of its consequences).

It is proposed that a methodology be developed that is 'fit-for-purpose', consistent with current practices (in particular the NFCDD) and the quantity and quality of the data available compatible with parallel work being performed on linear flood defence systems under the RASP project.

Illustrative calculations will be presented to demonstrate the methodology for chosen generic systems and components and how it might be used to assess the consequences of failures for flood defence, navigation or warning. Risk estimates could be made for the Regional or National level, in order to give an indication of which failures is of greatest importance for the Agency as a whole.

Given that it is possible to augment the existing data sets by the means discussed above, it will then be possible to derive proper confidence limits on the failure data representative of the true uncertainty, even if only one or two field observations exist.

Task 2.6. Develop Methods for Assessing Importance of Components and Propose Further Research (Previously Task 2.3)

The risk estimation methodology developed in task 2.5 will be used to explore how important the various components are to the overall needs of flood defence, navigation and flood warning. In particular, this task will assess the sensitivity of overall risk to the failure rates of particular components. This can be achieved by means of:

- explicit sensitivity testing, in which specific failure rates are varied one at a time, and the effect on output values observed; or by
- stochastic modelling, in which the failure rates of each component, and other uncertain parameters, are sampled from probability distributions expressing the uncertainty in their values. The sensitivity of outputs to particular input values is derived by statistical analysis.

The stochastic method has the advantage of providing a truer picture of the sensitivity of the system to particular parameters because, it varies all the uncertain parameters together and so tests the effect of the parameter of interest within a whole-system context.

The methodology will be applied, at a high level, to indicate where there are gaps in knowledge and which of these gaps matter to the overall management of flood risk. Hence it will be possible to identify and indicate priorities for further research. The types of research needs that could emerge from this analysis could include (noting that these are purely for illustration):

– *"a need for better failure data collection on flap valves in tidal (saline) environments";*

– *"a need for research on best practice in reducing vandalism";*

– *"a need to research the most effective inspection and maintenance practices for certain components".*

The methods themselves would be reviewed from and chosen to be compatible with related work being performed on linear defence systems under the RASP project. It is anticipated that outputs from this project could be fed into the RASP project to explore synergies between the projects and to encourage cross-fertilisation of ideas and concepts.

Task 2.7. Provide Recommendations for Implementation of Findings (Previously Task 2.4)

This task will interpret the findings of Task 2.6, in order to make practical recommendations for implementing the findings in ways, which will improve the efficiency and effectiveness of flood risk management. These recommendations could form the basis of Agency guidance to the various stakeholders.

In particular, the risk methodology developed and applied under Tasks 2.5 and 2.6 is likely to be too complex for general use in the field. Rather, it should be used to underpin and justify the development of simplified methods, such as risk matrices, or prompt lists, or good practice guidance. These simplified methods should also be compatible with the concepts and tools with which Agency staff and other users are likely to be already familiar, such as Source-Receptor-Pathway models and the NFCDD database system.

Examples of the types of recommendations that could be made could include the following. As with the examples of possible research topics, it is stressed that these are purely for illustration:

- *Guidance to manufacturers on best practice designs which will eliminate certain causes of failure or failure modes for particular components (as, for example, in past guidance on trash screen design).*
- *Recommendations for the use of a simplified version of the risk model as an aid to option selection for flood defence designers.*
- *Guidance to on simple methods for relating the maximum acceptable failure rates of a component to the level of protection required at a particular site. Methods available include those adopted by other industries, such as matrix methods, risk graph methods and Safety Integrity Levels (as described in IEC 61508). Such methods are of use to designers in selecting options and specifying their requirements to manufacturers.*
- *Recommended minimum inspection intervals.*