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Towards best practice in flood warning

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Abstract

Flood Forecasting, Warning and Response (FFW&R) have been evolving towards best practice over the years. Until recently, developments were often piecemeal and opportunistic but selections of "layers" of features from each wave of refinements or reorganisations have paved the ground towards best practice. However, even now a widely accepted definition of best practice is yet to emerge. The Environment Agency (the Agency) recently commissioned an R&D project to document baseline practices in FFW&R as a guide to the development of best practice in accurate, timely and reliable delivery of flood warning information products. The project showed that, even though the practice within the Agency had evolved autonomously within its regions, it could be broken down into over 60 elements: some display the development of pan-regional best practice elements; others show region-specific elements capable of being transformed into best practice elements; and yet some lacked best practice elements. This paper builds on traditional definitions of best practice and presents it in a systems science framework. It is argued that best practice reflects the flow of information in the system and as many modern systems must have adaptive and maintenance mechanisms, these should be reflected in best practice definitions. The paper presents a tentative solution to this end.

1 Introduction

The practice of Flood Forecasting, Warning and Response (FFW&R) is not monolithic but often reducible into components, where reduction is a scientific methodology of breaking down a problem into its constituent components or building blocks. For instance, a recent study reduced the FFW&R practices in the Environment Agency for England and Wales (the Agency) into some 60 basic elements. The method of reduction differs generically from "reductive science" to "systems science", where Khatibi [1] argues that science was reductive since its formation during the industrialisation up to the 1940s, and has been shifting since then to systems science. As a benefit of this shifting, science has increasingly embraced 'holism' rooted in the General Systems Theory presented by Bertalanffy [2]. Although reduction has remained as a common feature throughout, its bearing

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on various problems is normally overlooked. Notably reductive science neglects inter-component synergies and feedback mechanisms but these are fundamental to systems science. This paper focuses on the definition of best practice, showing it to be related to reduction, inter-component synergies and feedback mechanisms.

Systems science has played an important role in the development of FFW&R practices but the paper argues that there is scope for a great deal more developments. Fundamental to systems science are **steady performance** and **adaptation to changes**. Kast and Rosenzweig [3] argue that "A system must have both adaptive and maintenance mechanisms." Steady performance is normally associated with feedback mechanisms, which control or regulate inherent natural tendencies of the system towards disorder/entropy. Adaptation is an evolutionary process and basically an internal mechanism is needed if adaptation is to take place. Mutation and natural selection together are natural mechanisms to facilitate adaptation. The main focus of this paper is to present a novel tentative solution that, developing guidelines based on "knowledge management principles" create pointers for the evolution of a practice.

As FFW&R is a lifesaving service, the provision of best practice by the various authorities/organisations is often by default but a satisfactory definition for best practice is yet to emerge. The paper presents (**i**) FFW&R services as practised by the Agency, (**ii**) a generic overview of worldwide practices and (**iii**) an overview of the emerging best practice in disaster management. It shows that best practice in disaster management does not have maintenance and adaptive mechanisms. Thus, a tentative solution is offered building these mechanisms on best practice in disaster management with a "systemic" arrangement for whole FFW&R system, where the term systemic is defined in terms of interconnecting the various subsystems/ processes with one another at clear interfaces, including their feedback mechanisms. No distinction is made between best and good or fit-for-purpose practices.

2 Overview of flood-forecasting and warning in the Environment Agency

2.1 Overview

FFW&R by the Agency is an information-based flood incident management service delivered through an organisational arrangement. It provides (**i**) essential self-help advice and support to enable people in flood prone areas to mitigate the risks when preventive measures have failed; and (**ii**) help to people in areas with no preventive defences or with low standards of protection. The basis of the service is:

- A range of decision-making "intelligence information" has been developed in each office responsible for warning including flood-forecasting results produced by forecasting teams in the Regional Offices.
- After the identification of the magnitude of a flood incident, in most cases, 1-in-100 year flood maps are taken as the basis for warning.

Coverage of warning services is detailed in "Local Flood Warning Plans," a series of documents produced by the Agency for the whole areas in England and Wales, one per each "Flood Warning Area." These are maintained in the offices responsible for warning and issued to professional partners, e.g. the police, local authorities, fire service and emergency/coastal rescue services and are available for public inspection at the Area Offices.

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2.2 Current organisational arrangement

Flood warning teams in the Agency work with professional partners and with its own emergency response teams responsible for operating strategic flood defences. These organisations form a network whose aim is to mitigate the effects of flooding by co-ordinating efforts to save life and minimise damage to property and mitigate distress to the population suffering from flooding. The organisational arrangement for FFW&R was reorganised in 2000, leading to:

- The 26 Area Offices are responsible for creating readily intelligible information messages referred to as 'staged warning codes' designed to trigger clear response actions, Figure 1. They are also responsible for the dissemination of these warnings through a wide range of communication channels.

Figure 1 Staged Warning Codes

- The eight Regional Offices plus Thames Barrier collect and process forecasting data and transform them into flood forecasting results, although one region is yet to conform in 2005. These results are provided as advice to 26 Warning Teams, described above, to be transformed into warning messages.
- The National Flood Warning Centre (NFWC), launched in early 2000, plays a strategic role (i) in the development of best practice in FFW&R through co-ordinating R&D projects, and (ii) in other activities including marketing, communication and business planning. The NFWC introduced the staged warning codes in 2000 through a close liaison with the Regional/Area Offices.

The current practice draws considerably from best practice in disaster and emergency management. **Incident Management Rooms** are now dedicated to the management of FFW&R both at the Regional and Area offices. The emergence of this best practice and its origins are discussed in Section 3.2 but Section 4 shows that best practice in FFW&R can only be developed by systems science approaches.

2.3 Developmental background

Khatibi and Haywood [4] present the roadmap of milestone developments for this service in its historic context in the UK. The key message is that this service has been evolving towards a customer-orientated service through the following stages:

1. Up to 1976, the service offered by the predecessors of the Agency was often on an *ad hoc* basis. Khatibi *et al.* [5] argue that initially warning services were confined to the professionalism of nominated employee(s) with a local knowledge of the problem providing a reactive response, on behalf of responsible authorities often on *ad hoc* basis.
2. In 1976 permissive powers were given to appropriate authorities to provide and operate appropriate flood warning systems. This was an important impetus in the years up to the late 1980s, for developments on the technical dimension, e.g. the flood forecasting using empirical, blackbox or conceptual models or hydrological routing techniques; or the development of telemetry systems.
3. Since the late 1980s, systems approaches have been applied to problem-solving of FFW&R systems and as a result there has been a better appreciation of the

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role of the social dimension in the effective delivery of FFW&R services. As it is now, the best practice in emergency/disaster management, referred to as the **command-and-control** best practice was introduced into the delivery of this services in 2000 in a "preparedness" context by a programme of communicating risks through liaison meetings, public awareness campaigns and education.

4. Since 2000, there is a joined up effort to improve the service through an extensive programme of R&D works and an opportunity to restructure the delivery of the service through systems science approaches towards "safe systems (as defined in Section 5) and sustainable development.

2.4 The service offered by the Agency

The practice of FFW&R within the Agency has been emerging out of regional autonomy and therefore often influenced by piecemeal and opportunistic R&D activities or by legislative or ministerial directives. The outcome has been a regionally and locally varying practice. This is sometime a positive outcome, as regional and local features are accounted for but often counterproductive at a mature stage of developments, as this encourages fragmentation of the practice. To rationalise this, the NFWC commissioned an R&D project to review baseline practices in FFW&R and to develop best practice guidelines for accurate, timely and reliable flood warning information products. The project, completed in the early 2002, presented a snapshot view of the practice in the Agency.

The Report [6] offered a pragmatic definition for good practice, taking it to mean "a procedure used in any aspect of flood forecasting and warning process which is particularly effective in its accuracy, timeliness, reliability and cost effectiveness". Accordingly, the report showed that the FFW&R practice in the Agency could be broken down into over 60 elements, lending themselves to a further grouping. This breakdown is depicted in Figure 2.

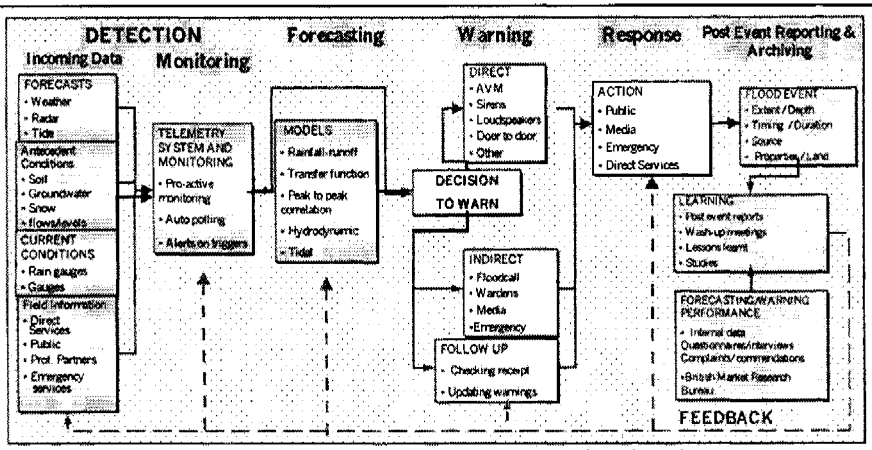

Figure 2 Baseline Best Practice Study on Flood Forecasting and Warning

The review identified that (**i**) some of the elements have emerged as a pan-regional best practice; (**ii**) a range of region-specific elements could be the starting point for Agency-wide best practice elements; (**iii**) a range of other elements are lacking best practice yet to be developed.

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In spite of an autonomous development of FFW&R within each region, it is remarkable that the regional practices lend themselves to a pan-regional systemically arranged practice. It is noted that the review was based on a snapshot view of the practices in the Agency and therefore it could not reveal the various shortfall of the practice. This paper develops on these main findings and outlines some of the shortfalls. These include:

- the performance criteria of accuracy, timeliness and reliability was not defined by then in an Agency-wide acceptable manner;
- the whole practice suffers from a range of *ad hoc* elements and procedures;
- the maintenance and adaptive mechanisms are not defined in these systems;
- improvements are often opportunistic for lacking a problem-solving method.

3 Generic overview of flood-forecasting and warning

3.1 A retrospective risk-based overview

Prior to the Industrial Revolution (mid18th–20th century), flooding risks were low. Although floods were frequent, their frequencies acted as a negative feedback mechanism, defined in terms of discouraging encroachments onto floodplains and coastlines, see Figure 3. The emerging industrial muscle made it practicable to "defend" against floods through large-scale structural measures and encouraged the exploitation of economical opportunities due to cheap land on floodplains and coastal fringes. Flood defence created the impression of winning over nature and as a result, this was followed by encroachments onto floodplains and coastal fringes, this is called a positive feedback effect. However, subsequent experiences showed that floods were not eliminated but in fact flood risks gradually increased. This was because consequences increased dramatically even though frequencies reduced.

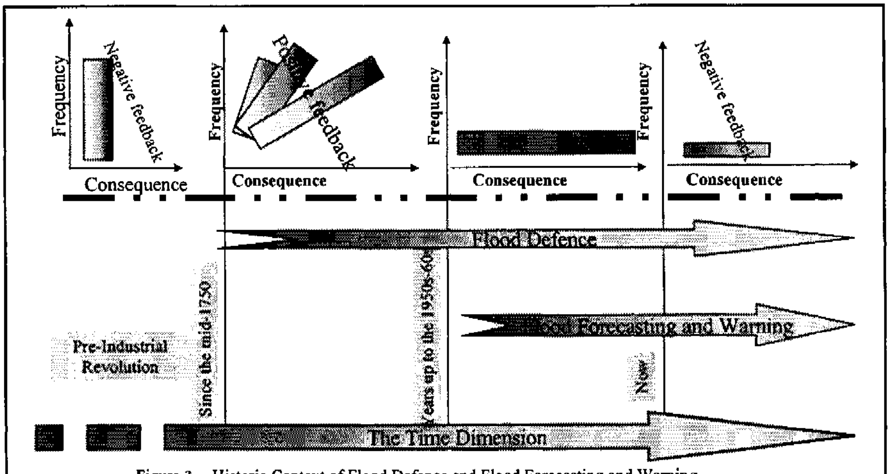

Figure 3 Historic Context of Flood Defence and Flood Forecasting and Warning

FFW&R as a service was formed in the years up to the 1960s. The formation was often within the remit of duty of care. Early services were often monolithic or lumped in the sense that a fixed form of this service was probably offered on behalf of responsible authorities often on an *ad hoc* basis. In a lumped approach, there was little flow of information, but the existence of such services provided an institutional arrangement for developments and improvements. Up to the 1980s improvements were often due to modelling and technological solutions, e.g. telemetry. Since the 1980s the importance of the social dimension was also realised. In recent years, there is an increasing realisation of the need for a risk-based approach.

3.2 Best practice under information flow in one direction

The direction of information flow is often overlooked but it is an important feature of a system. Khatibi [1] argues at the stage of reductive science, flow of information is from the technical to the social dimension but at the stage of systems science it is both from the technical to the social dimension and vice versa. This paper argues that the concept of the directions of information flows is also true in FFW&R. Up to recent years the development of FFW&R systems created a "one-way" flow of information, although current R&D activities aim at creating two- or multi-way flows of information. The paper associates (i) command-and-control best practice with one-way flow of information, as discussed in this section; and (ii) a systemic model of best practice with two-way flow of information, as discussed in Section 4.

Floods are one of many risks posed to man from natural sources and as such best practice in the management of FFW&R are considered within the broader context of best practice in emergency and disaster management, which is about organised approaches, better planning and risk communication. Consider the following categories of natural, manmade and war disasters:

- Flood frequencies (a natural disaster) acted as a negative feedback mechanism until industrialisation, as such vulnerable areas were avoided often subconsciously.
- Until recent years, natural disasters with low frequency and high consequences were often regarded as acts of god with very little organised responses.
- The scale of man-made or man-influenced disasters has grown with the development of technology; but at the same time improved technology has always been a route to increased safety through integration/co-ordination of responses in recent years [7].
- Throughout history developing technology has resulted in an exponential increase in our ability to kill each other, via the ultimate manmade disaster, war [7]. Early examples for mitigation of war impacts could be cited in the UK during the Second World War through preparedness and using certain organisational approaches, which effectively co-ordinated multiple services related to emergency services, municipal services, public utilities and health services [8].

To the knowledge of the authors, the USA Nuclear Regulatory Commission in association with the Federal Emergency Management Agency published in the 1980s is one of the first guidance towards best practice in emergency management, e.g. see [9 and 10]. According to Strutt and Lakey [11], the philosophy and structure in these guidelines are well thought out and applicable to other emergencies, as the Institute of Nuclear Power Operations issued guidelines and lecture notes [12] on emergency preparedness to enhance the performance of emergency response organisations. Such a best practice is often referred to as the command-and-control method and is organised at strategic, tactical and operational levels. This is also the basis for emergency management in the UK; was endorsed by inclusion in Home Office's publication [13]; and was adopted in FFW&R.

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It is noted that the command-and-control method is appropriate to discrete disasters for being incidental and infrequent, where the next incident is expected to be unique in place, time and magnitude. Furthermore, the inherent direction of information flow in this method of best practice is from the technical to the social dimension – one-way flow of information. However, floods are stochastically recurrent with interacting technical and social dimensions. Traditional flood management systems are often technical with a one-way direction of information flow from the technical to the social dimension but this is not tenable anymore. Thus, the search for best practice in FFW&R is still on.

4 Definition of best practice by systems science – a tentative solution

It is argued that (i) as much as command-and-control is necessary for FFW&R, this should not be a limiting framework to best practice in FFW&R, and (ii) FFW&R has been transformed into well-established professional activities with social and technical dimensions. A dictionary definition of practice is the development of skilful professionals engaged on a repeated exercise or activities requiring the development of skill. Clearly, FFW&R is now a practice because skilful practitioners are engaged in this practice as their day job. This paper holds that best practice should reflect the directions of information flows facilitated by:

- modularising the system;
- the treatment of *ad hoc* elements in the practice and professional procedures;
- the incorporation of the maintenance and adaptive mechanisms;
- a provision of organisational arrangements expediting self-improvements.

The performance criteria, depicted in Figure 4, are defined in terms of accuracy, timeliness and reliability, but these are refined to expedite a feedback mechanism in the practice. Although FFW&R has traditionally been broken down into detection, flood forecasting, warning, dissemination and response processes, this systemic arrangement can be made transparent by inserting the following interfaces:

- Interface 1 between Detection – Flood Forecasting,
- Interface 2 between Flood Forecasting – Warning (decision-making),
- Interface 3 between Warning – Dissemination, and
- Interface 4 between Dissemination – Response.

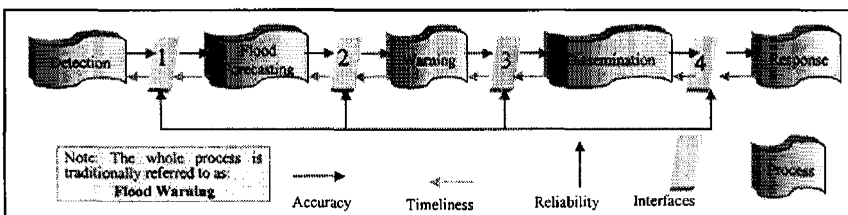

Figure 4 Interconnecting technical drivers with Social drivers

Accuracy represents the flow of information from the technical to the social dimension and is defined as the expected technical performance of the system at Interfaces 1–2–3–4. Timeliness represents the information flow from the social to the technical dimension and is defined in terms of the expected requirements of the population at risk of flooding at Interfaces 4-3-2-1. Reliability will be defined in terms of accuracy and timeliness at the interfaces. Arguably, in this systemic arrangement **(i)** the various subsystems are interconnected; **(ii)** the technical drivers are interconnected with the social drivers and can be tuned to social requirements and; **(iii)** this two-way information flows can facilitate the performance monitoring.

This paper proposes a tentative approach for the development of a systemic best practice in FFW&R, as illustrated in Figure 5. In this approach, guidelines play a pivotal role to treat a range of *ad hoc* elements through the formalisation of the whole practice. The approach involves:

- Modularising the system through a systemic arrangement with clearly defined interfaces inserted in between the processes and performance measures;
- Developing a series of guidelines for each of the processes;
- Rolling out solutions for each process for each individual area at risk of flooding;
- Using the solutions to deliver the service with built-in monitoring procedures.

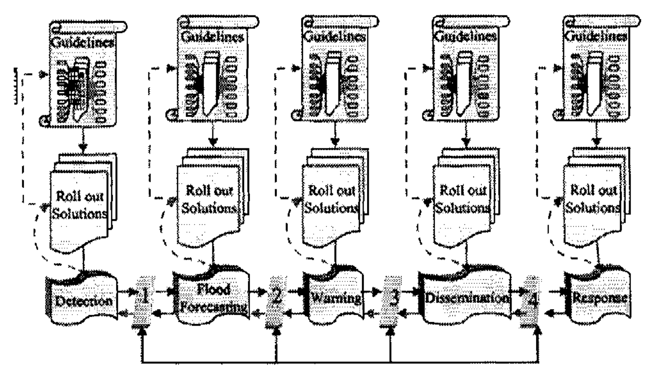

Figure 5 Interconnecting technical drivers with other drivers

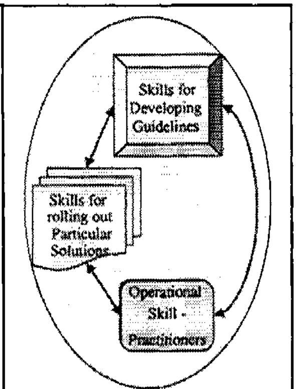

Figure 6 **Organisational Arrangement for Best Practice**

The following knowledge management principles are the foundation for the development of guidelines: **(i)** delivering customised solutions using categorisation as a problem-solving tool, **(ii)** providing a framework to challenge the inherent assumptions; and **(iii)** reviewing the organisational arrangements; see [1] for further details. Among these principles, the contribution of categorisation is highlighted further. Categorisation unravels generic patterns by deliberately disregarding minor individual differences and is particularly an effective tool when the various methods/ tools/products/outputs diversify. It can also reveal generic steps in the resolutions for the various categories of problems, which can serve as a pointer towards the identification of improved solutions; see also [14].

The systemic model of best practice seeks the ability to tune the technical dimension into the requirements of the social dimension. Such a model has the following built-in maintenance and adaptive mechanisms:

- An active negative feedback mechanism is facilitated to **maintain the performance** by the virtue of a two-way flow of information through performance measures of accuracy, timeliness and reliability. The performance of the service can be measured after each incident, which is currently feasible but not routine.
- A medium-term feedback mechanism emerges to **adapt** the performance of the FFW&R solutions stemming from the guidelines. A capability for adapting selected solutions should emerge through guidelines compiling hierarchical

categories of possible solutions. This is not feasible currently but inherent in the flood forecasting guidelines being developed by the Agency.

- A long-term feedback mechanism emerges to **adapt** guidelines when the solutions have to be improved frequently. This has implications on firming up the science base of FFW&R, as well as on educating the public in terms of managing their expectations. This course of action is currently non-existent.

The above model relies on knowledge management within guidelines and on an organisation arrangement distinguishing different levels of skills for developing guidelines, rolling out solution and implementing the practice, see Figure 6.

5 Discussions

The ultimate solution for this service will be the delivery of 'safe systems' defined as a strategy for ensuring that all hazards in all locations are identified, quantified and assessed. According to current capabilities, safe systems in FFW&R are not feasible. However, the architecture proposed for best practice opens up the doors for the realisation of safe systems in FFW&R practices.

Guidelines, as promoted in this paper, are developed by one or more organisation(s) to create transparency in a particular practice and as such they are one step of improvements compared with their prior *ad hoc* practices. If guidelines are by "compromise," they can encourage incompatible practices. On the other hand, if guidelines allow for firming up their science base suffering from *ad hoc* procedures, an intense period of learning should be envisaged. The authors regard the development of guidelines as a process of formalising the practice towards the development of standards rather than as a single and final act. The usual evolutionary path from *ad hoc* to standard practices is through the development (i) guidelines, (ii) manuals/handbooks (iii) codes of practice, and (iv) standards.

6 Conclusion

It is morally indefensible not to provide protection to the public against major hazards over which they have no control [7]. Owing to this moral obligation, best practice is often opted for by default. The paper argues that the nature of best practice is revealed depending on directions of information-flows. Thus, command-and-control, as a best practice, is associated with one-way flow of information; and building on it, the paper presents a systemic model of best practice in FFW&R towards two-way flows of information. The combined effect is a model of best practice with the following outcomes:

- The service is modularised and *ad hoc* elements and procedures are treated through the development of guidelines and formalising the various procedures.
- Maintenance/adaptive mechanisms are developed through knowledge managed guidelines and performance measures, allowing a two-way flow of information.
- Appropriate organisational arrangements are in place.

The paper promotes the development of guidelines as a framework for adaptation in a systemic model of best practice with the combined outcomes capable of:

- The performance of the service can be measured after each incident – this is currently feasible but not routine.
- The performance of a particular solution can be reviewed in the medium-term for improvements through using the guidelines – not feasible currently.

- The performance of the guidelines can be assessed in terms of the frequency of improving modelling solutions – a course of action currently non-existent.

Acknowledgement

The ideas shared in this paper by the authors will influence the FFW&R services delivered by, but they do not limit the policies formulated, in the Agency. Gratitude is expressed to Mr Les Moseley, the head of the Disaster Management Centre at the University of Coventry, UK, for reviewing and commenting on parts of this paper. Thanks are also due to Mr Kevin Tarling of PB Ltd, UK, for his review of the paper and to Miss Joanne Reilly of the NFWC for commenting and proof reading.

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