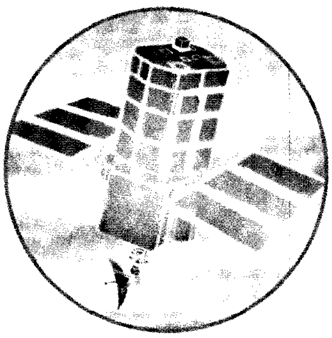
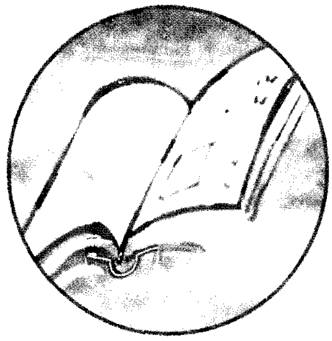
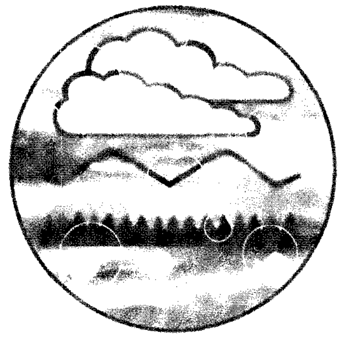

Research and Development

ENVIRONMENT AGENCY

Strategic Risk Assessment: Further Development and Trials

Technical Report
E70

Strategic Risk Assessment: Further Development and Trials

R&D Technical Report E70

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This Technical Report provides a strategic risk assessment methodology which can be used to enable the Agency to incorporate risk into its decision making at both a regional and strategic level. The method may be used with the assistance of the National Centre for Risk Analysis and Options Appraisal to prioritise issues in the LEAP process. The Project Record (E2-001/1) document is available for reference at Agency Libraries and includes the full background to the work.

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APPENDIX: FIGURES

1. INTRODUCTION

1.1 Background

RPS Clouston (RPS) was instructed under the Environment Agency's (the Agency) National R&D programme to develop a strategic risk assessment (SRA) methodology and model which could to assist in the allocation of the Agency's resources to meet the needs of substantiality. This report explains the model and software development, the various trials and the implications of the results.

This section provides an overview of the function of the Agency's and the role of SRA in helping to achieve it's goals in terms of sustainability. It also provides a background to the structure of the project, the methodology adopted and assumptions made.

1.1.1 The Role Of The Agency's And SRA

The Agency was formed in 1996 under the Environment Act 1995 which brought together the functions of Her Majesties Inspectorate of Pollution (HMIP), the National Rivers Authority (NRA), the Local Waste Regulation Authorities and parts of the former Department of the Environment. The principle aim of the new organisation when discharging its functions was to:

'protect or enhance the environment, taken as a whole, as to make the contribution that Ministers consider appropriate towards achieving sustainable development' **(HMSO 1995).**

The Authority guidance issued to the Agency in pursuance of this aim requires the Agency to use tools such as risk assessment.

The Agency's duties extend to pollution prevention control, assessing and protecting the state of water resources, water quality, flood defences and freshwater fisheries. The Agency has also been charged with compiling information to

'facilitate the carrying out of its pollution prevention control functions; and or to enable it to form an opinion of the general state of the pollution of the environment' **(Agency 1996).**

Under its principal aim and guidance from Ministers regarding sustainable development, the Agency has to develop an environmental strategy to ensure that sustainable development is achieved. To achieve this the Agency has to identify areas at most risk from the wide range of land use pressures, as well as prioritising actions to target the environment parameters considered as most sensitive to those pressures.

Accordingly, the Agency has to ensure that all its functions are discharged with respect to sustainable development. Therefore, when prioritising actions and allocating resources the Agency must adopt a consistent approach. It is important that an understanding exists about the relative scale of risks posed by all the different pressures upon the widely varying receptors. A comparative analysis of the different pressures and their associated effects, against one another is therefore, required. Furthermore, the Agency is bound to take a precautionary approach when the effects of a proposed scenario are considered as significant, irreversible or where great uncertainty may exist about the likely outcome. A strategy must therefore, be developed which is able to examine; (a), where a possible scenario will cause harm, the range of pressures exerted and to what degree; and (b) the potential environmental risks posed by the scenario by identifying the environmental parameters which are present within an affected area and their tolerance to the pressure exerted. The strategy must allow all the different risks to be compared.

An examination of the risks exerted by land uses and their associated effects on air, land and water resources at a range of scales, using a consistent methodology can be termed as SRA.

1.1.2 Project History

Prior to the formation of the Agency, its constituent parts identified the role of risk assessment as a management tool in assisting the Agency in discharging its functions, especially with respect to sustainable development. The NRA, HMIP and Department of Environment (DoE) (Waste Technical and Contaminated Land Liabilities Division) established an Ad-Hoc Group concerning Risk Assessment and Risk Management in the Environment Agency. The findings of the group were reported in Chapter 5 of the Agency's Risk Assessment and Risk Management Portfolio and formed the framework for proposed future research into an Agency SRA tool.

The Ad-Hoc group defined the individual components of the methodology as:

- **Harm Assessment** - Assessment of the links between a hazard and a pre-defined receptor. This component should examine the impact of a given level of exposure of a hazard upon a pre-defined range of receptors;

- **Risk Significance** - where harm is evaluated, the risk is placed in a geographical context in relation to the overall population of receptors, and the range of different types of receptor impacted upon;

- **Risk Uncertainty** - identifying where uncertainties exist within the data sets used; and

- **Risk Importance** - identifying the costs and benefits of various actions/organisations whilst taking account the views of society of the risk/damage brought about.

The Ad-Hoc Group drafted a SRA methodology. The key aim of the SRA was to normalise risks from all activities or potential activities on the environment. The normalised risks could then be compared to allow better targeting of resources to achieve the greatest reduction in risk. The SRA building blocks were risk expressions formulated by the Ad hoc group.

1.1.3 Method

The initial project was divided into three distinct phases. This was extended into 5 phases as the project team recognised at an early stage that it would be extremely beneficial to develop and trial the model within the formal structure of a spreadsheet.

RPS examined the individual components of the methodology in 5 phases:

I. the initial rationalisation into clearly defined relationships of the risk expressions provided in the Ad Hoc group's research;

II. the development of algorithms/statistical expressions which would allow a normalisation of the different risk expressions, including derivation of a software programme based around Microsoft Excel with add on tools provided by Crystal Ball;

III. testing the functionality of the model against data availability;

IV. required revisions to the model;

V. testing the model by scenario and at different geographical scales. The tests included: reviewing the key hazard/receptor relationships at a catchment level within a Local Environment Agency Plan; and examining the State of the Freshwater Environment at a national and regional level.

It was also recognised that the specific experience of the Institute of Terrestrial Ecology (ITE) would be a distinct advantage when identifying: key receptors and their relationship with various hazards; data availability; scientific values of hazard/receptor effects and public perception studies.

It should be stressed that the primary objective for the project is to determine 'proof of concept' for a SRA methodology to cover the issues raised by the Ad-hoc group on Risk Assessment and Risk Management in the Environment Agency. It is not intended to model every pressure on the environment. It aims to test whether it is possible to identify (a) key relationships which can be used to map broadly the different stresses and strains placed on the environment by human and natural activities; and (b) whether these relationships can be normalised to allow a direct comparison or ranking of the stresses and strains.

1.1.4 Report Structure

The report is structured to provide easy interpretation of the methodology; development of the SRA software and the results of the trials conducted. It is structured according to the chronological development of the project outlining where weaknesses were identified and the appropriate actions taken:

- Chapter 2 explains the methodology, identifying assumptions and areas not included in this study;
- Chapter 3 examined data availability and its suitability for the model;
- Chapter 4 examines the modifications to the model which were required as a result of Chapter 3 and identifies the stages required to use the model;
- Chapter 5 reviews the trials conducted, assessing the weaknesses and strengths of its structure; and
- Chapter 6 provides a summary of the project findings and recommends further areas of research.

2. DEVELOPMENT OF THE MODEL

2.1 Summary of the Ad-Hoc Risk Expressions

2.1.1 Risk Expressions

The 'risk expressions' referred to in Chapter 5 - Strategic Risk Assessment - form the criteria upon which the Risk Assessment and Risk Management Portfolio is based. Within the constraints of Chapter 5, each source of harm that is active within the boundary conditions is identified as a 'risk expression', where each risk expression is unique within the context of the SRA.

Based on the information referred to in the Portfolio, a measure of risk is assigned to each risk expression to assess the measure of risk of each Risk Index (where each Risk Index is normally composed of three independent Risk Expressions). The measures of risk for the risk indices are then rolled-up to a higher level to assign a measure of risk to each Primary Risk Index which, together, define the criteria upon which the SRA approach is based.

2.1.2 Hierarchical Structure

Due to the complexity and association of the risk expressions identified in the Portfolio, the risk expressions have been transposed into a logical hierarchical structure, see Figure 1, to represent their status in the SRA model. Figure 1 refers to the following Primary Risk Indices:

- Level of Harm;
- Risk Significance;
- Risk Uncertainty; and
- Risk Importance.

A definition of each is found in paragraph 1.1.2

2.1.3 Overview

In reviewing the hierarchical structure of the Ad-Hoc group it was necessary to separate three strands of the primary risk index 'Risk Importance' into environmental, economic and public/political factors. The integration of economic analysis with environment factors would require a monetary valuation to be placed upon any environmental risk indices and in particular any reduction in the environmental risk index. This was believed to be beyond the scope of this project. Integration of public/political perception is regarded as a relatively new area of research and again is beyond the scope of this project.

The project was, therefore, to focus on 'proof of concept' on only one of the three decision making strands. A comparable risk index based solely on environmental stresses and strains.

2.2 Linkages between the Key Risk Expressions

2.2.1 General

Figure 1 addresses the hierarchical structure of the 'risk expressions' associated with the Risk Indices in which the significant risk expressions are linked through the structure. Based on this hierarchical structure a methodology was developed to consolidate the risk expressions into a meaningful format that is both robust and transparent for the user to directly compare such risks and set environmental priorities.

2.2.2 Normalising Factors

As the risk expressions refer to a diverse range of issues and dimensions there is a requirement to consolidate each risk expression and the dimensions associated with the scenario in which it operates. For such a 'standard' to be viable at local, regional and national level, each 'risk expression' must be explicit in definition and content of the risk to which a measure is assigned. In so doing, the various issues and dimensions of each risk expression are normalised at the various stages of the analysis to enable the level and significance of harm due to the effects of risks on different receptor types to be quantified.

2.2.3 Normalising Hazards from Source

The normalising factor for each source is based on the magnitude of the hazard generated by that source which imposes a level of harm on the receptor type in question; the level of the hazard which causes harm to the receptor type is referred to as the 'target' level. Due to the many different hazard/receptor configurations, the target level assigned to each hazard/receptor is dependent on the scenario under consideration.

It is also important to note that the level of hazard on the receptor type may be above the target level even though the source of the hazard may have ceased. This is referred to as the shelf-life of the hazard. Likewise, once the hazard falls below the target level during the shelf-life, the receptor type will recover to a state of being uninfluenced by the hazard.

2.2.4 Normalising Hazards Against Receptors

The normalising factor for a receptor type is based on the tolerable number of receptors within the space under consideration that can be assigned to the hazard, when above the 'target' level, over a tolerable period of time without significant cause of concern.

As the receptor is the 'receiver' of the hazard it is important to note that the number of receptors that are assigned to tolerate the hazard at the target level is clearly defined. This is necessary because different receptor types may have totally different tolerable levels of harm when subjected to exposure to the same hazard. For example, when humans are exposed to carbon monoxide, death will not be accepted as a tolerable level of harm, whereas for birds, death (up to a defined % of the birds within the space under consideration) may be tolerated as an acceptable level of harm.

2.2.5 Level of Harm

The level of harm, within a defined space, is calculated by dividing the harm to which a number of receptors are subjected over a period of time, by the tolerable number of receptors that are assigned to tolerate that harm over a tolerable period of time. This is best demonstrated with respect to the 'bird' example referred to above.

Within a defined space containing say 100 birds, it is accepted that 10% of these birds i.e. 10 birds, may have to tolerate the hazard above a defined target level for a tolerable period not exceeding 2 hours. In the situation under consideration let us assume that 8 birds are subjected to the hazard above the target level for a period of 1¾ hours before the source of the hazard ceases. However the shelf-life of the hazard is measured at ¾ hour, with ½ hour as the average length of time for the birds to recover from the effect of the hazard. This situation is presented in Figure 2. From these figures, the level of harm (α) is based on the following:

α = level of harm
β = number of receptors exposed to the hazard in the defined space = 8 birds
χ = time when the receptors are exposed to the hazard = $1\frac{3}{4} + \frac{3}{4} + (\frac{1}{2} \times \frac{1}{2}) = 2\frac{3}{4}$ hours
δ = tolerable number of receptors that can be exposed to the hazard in the space = 10
ε = tolerable period for receptors to be in the defined space = 2 hours

Based on these figures:

$$\alpha = (\beta \times \chi)/(\delta \times \varepsilon) = (8 \times 2\tfrac{3}{4})/(10 \times 2) = 1.1$$

As $\alpha > 1$, the 'bird' situation referred to above represents a Level of Harm. Had the number of birds subjected to the hazard been 6 then, $\alpha = 0.825$ and there would not have been a unacceptable Level of Harm as the scenario under consideration is only subjected to a unacceptable Level of Harm when $\alpha > 1$.

2.3 Derivation of Analogue Model

2.3.1 General

The analogue model presented to the Agency is discussed in more detail in the Stage 1 report in the Project Record (E2-001/1). The analogue model is composed of five defining steps. These are:

- Step 1: Definition of % of Space Exposed
- Step 2: Definition of Period of Exposure
- Step 3: Definition of Number of Receptors Exposed to the Hazard
- Step 4: Definition of Level of Harm
- Step 5: Definition of Risk Uncertainty

Of these steps, the basic concept of Steps 2 to 4 have been addressed above in paragraph 2.2.5 i.e.:

- Step 2: Period of Exposure = (χ) - (average recovery time)
- Step 3: Number of Receptors Exposed to the Hazard = (β)
- Step 4: Level of Harm = (α)

Steps 1 and 5 are discussed below.

2.3.2 Step 1: % of Space Exposed

In the example presented in paragraph 2.2.5, the number of receptors exposed to the hazard (β) was defined as 'assumed' with no explanation of the % space exposed to the hazard. The analogue model does, however, calculate the % of space exposed to the hazard (ϕ) based on:

ϕ = % of space exposed to the hazard
γ = harm space one source generates in which the hazard is > the target level
η = average number of sources that generate a hazard at the receptor > than the target level
ι = environmental space under consideration

Based on this information:

$$\phi = (\gamma \times \eta) / \iota$$

which enables the number of receptors exposed to the hazard (β) to be calculated:

$$\beta = \phi \times \text{(number of receptors in the space)}$$

2.3.3 Step 5: Definition of Risk Uncertainty

The primary risk index Risk Uncertainty (which is not represented directly in the analogue model) addresses the **probability** of a risk occurring at source, the **uncertainty** in the number and duration of receptors subject to this risk, and the **uncertainty** in the availability of input data to support the model. Due to the method of calculating β and χ above, the input values for the model to address these three areas of 'risk uncertainty' may be single figure, estimates or averages based on current data sources, results from scientific simulation models, statistical analysis, standard probability distributions or best fit distributions to a body of data. Likewise, the information may be from the locality, be it local, regional or national depending on the scenario in which the analysis is being conducted. In some cases the information may also be affected by other factors e.g. wind direction, rainfall etc., which are external to the parameters necessary to run the model but which may have some impact on the results of the analysis.

Hence, when input data cannot be defined specifically, the model provides a facility to consider uncertainty and probability on input data where such data can generate risk on the value/significance of output data. For this purpose, the model has been developed to consider risks by the user applying an uncertainty/probability curve to the input data on the relevant parameters. The model is then run iteratively using Monte Carlo simulation techniques and the probability of certain receptors exceeding the assigned level of harm can be analysed.

2.3.4 Weighting to Cover Public and Political Issues

As mentioned in paragraph 2.1.3 the model was not developed to cover public, political and other issues. Nevertheless, a facility was developed within the model to enable the User to 'weight' the normalised level of harm figures. The two 'flavours' of weighting available to the User are:

- Classification = to rank (high, medium, low) the impact of the hazard/receptor combination in environmental terms

- Political = to rank (high, medium, low) the impact of the hazard/receptor combination on political/social/issues and independent of environmental issues

2.3.5 Model Structure

The model structure is presented in the Project Record (E2-001/1)

2.4 Digital Model

2.4.1 Background

The risk expressions defined in the analogue model were subsequently incorporated into an Excel spreadsheet. The data was entered through a logical sequence of look-up tables. The procedure and type of data required for the risk expressions is identified in the Project Record (E2-001/1).

The Excel and Crystal Ball analysis software offered greater functionality, providing more information to assist in the decision making process. For example, the 'goal seeking' capability of Excel can be used to identify the critical threshold when either a receptor's condition or hazard dosage results in harm occurring. Likewise, the Crystal Ball software provides the capability to alter the hazard dosage over time, producing a more realistic scenario when compared to the linear relationships which could otherwise be employed.

The use of a computer system and the Excel spreadsheets facilitate the speed at which Risk Indexes can be calculated, presented and ranked. Furthermore the methodology offers a consistent structured approach within which to identify data and conduct the assessment.

2.4.2 Data Requirements

The risk expressions in the model require the availability of 'real' time data, concerning the:

- dosage levels of the hazards (spatially and concentration). This is considered as uniform across the affected space;
- persistence of the hazard in the different types of media;
- trigger value of the dosage of the hazard which when exceeded would cause harm to the receptor. This is an intrinsic value particular to each receptor and hazard relationship;
- number of each receptor in each space;
- the tolerable number of each receptor that can be harmed; and
- recovery time of the receptor once the hazard has been removed from the media.

2.4.3 Model Assumptions

The model makes a number of assumptions to simplify the risk expressions and derived algorithms. However, the model can be developed to increase its sophistication depending upon the project requirements. The assumptions in the model include:

- uniform hazard dosage across the affected area;
- linear relationship of hazard dosage and shelf life;
- linear rate of decline in receptor population when affected by the hazard;
- linear rate of recovery of the receptor after the hazard falls below the trigger threshold.

2.5 Summary

The SRA was divided into three separate strands of decision making: environmental risk assessment, economic analysis and public/political perception. This R&D study focused on the environmental risk assessment strand although provisions for weighting with respect to political aspects were made in the model.

Stage 1 sought to take the 'Risk Expressions', the factors which were outlined in the Chapter 5 Paper, and place those factors within a framework.

The approach to combining the risk expressions is as follows:

a) determine the percentage of the space which is exposed to a particular hazard. This is seen to be a function of a number of sources of that particular hazard multiplied by the area or volume of the hazard generated from a particular source. A target level was defined which was used to determine when an adverse effect would occur in relation to exposure for a particular hazard upon a particular receptor;

b) determine the period of exposure. This was seen to be a function of the duration of the source i.e. the length of time over which a source generates that particular hazard in excess of a target level plus the shelf life which represents the time a hazard will remain active once the source has ceased to generate the hazard;

c) determine the numbers of receptors exposed to a particular hazard which is a function of the amount of space affected by the hazard as a percentage multiplied against the total number of receptors in the space.

d) the level of harm is then calculated by multiplying the number of receptors exposed to the hazard by the period of exposure divided by the tolerable period and number of receptors in the space.

The method of normalisation is based around the ability to define a tolerable number of receptors in the space which represent the number of receptors that can be affected by a particular hazard without significant cause for concern occurring multiplied by the estimated length of time, the tolerable period, under which the tolerable number of receptors in the space can be regarded as low priority. It is expected that although an adverse effect would occur to a particular receptor following exposure to a particular hazard above a trigger level, harm would occur when a certain number of those receptors have been exposed for a certain period of time.

3. TESTING THE FUNCTIONALITY OF THE MODEL

3.1 Background

The second phase of the project reviewed the availability of suitable data which would be required to operate the model. This included:

- spatial availability including location of receptors and sources of hazards;
- level of scientific understanding of the availability of reliable trigger values for each hazard/receptor relationship; and the
- level of scientific understanding concerning the intrinsic characteristics of a receptor/hazard relationship with respect to the tolerable (number) population affected and the tolerable period of the influence of a hazard.

It is not possible to evaluate all the ecological relationships between the hazard and the individual components of the ecosystem as this would require impractical levels of data collection and analysis. Therefore, it was proposed to use key indicators within the model, which reflect the overall threat to or health of the environment. The use of key receptors may result in reduced detail, however, this is not considered significant as the SRA is considered to be a management tool 'sign posting' key areas that need attention. Once identified, the hazard and receptor relationships can be examined in more detail.

3.2 Hazard/Receptor Relationship

The project team selected a general range of hazards which were considered to be key pressures influencing environmental health (including human health) across a range of media. The selection of the hazards could then be tested to identify the level of scientific understanding concerning the relationship between the hazards and the receptors. The range of hazards selected are shown in the Project Record (E2-001/1).

ITE conducted a review of the relationship of the selected hazards with a range of media and environmental parameters to use as receptors. In their assessment, ITE drew upon their extensive research into: sustainable indicators, land cover assessment and ecological surveys.

The detailed results of ITE's research is attached in the Project Record (E2-001/1).

The following sections outline the results of ITE's study with respect to defining trigger levels, tolerable duration and tolerable populations affected.

3.2.1 Trigger Levels

There would appear to be little information regarding the trigger levels with respect to individual environmental receptors and hazard combinations. There are a comprehensive range of guidelines concerning the toxicology of hazards across various media which include: critical loads (deposition rates) to land; Environment Assessment Levels (EALs) across media;

Environmental Quality Standards (EQS) to water. These may be used to indicate the point at which exposure to a hazard begins to cause harm to the receptor within the appropriate media. This position may be rather conservative as such standards often include significant safety factors over the scientific assessments of EC_{50s} and LC_{50s}

3.2.2 Tolerable Duration

ITE concluded that there had been very little scientific research into the period which an individual receptor may tolerate general environmental exposure to a hazard. Environmental effects in the field are usually only studied after the event; research of these are concentrated on recovery rather than from onset. Accordingly, there is little consistent quantitative information available with which to run the model. Value judgements can be made on the basis of the persistence of the hazard within the environmental media. Classifications can be given in terms of acute, short term or chronic. The term 'chronic' is usually defined as "approaching the lifetime of the organism (receptor)" and is therefore, relative.

3.2.3 Tolerable Number

The tolerable number of individuals within a species that needs to be affected for a specific tolerable duration before significant harm occurs to the population is one of the principal components of the SRA methodology. Unfortunately, ITE identified that there has been little published data concerning the population effects of exposure to a hazard as it would require measured values to be undertaken following long term field analysis. Accordingly, data availability for the model is extremely sparse and only available for one or two receptor hazard combinations. Measured potential severity of the effect in population is a possible approach. Severity was presented by ITE as a function of geographical extent or distribution (receptor dependent) and ecotoxological significance or biological effect (hazard or source dependent).

3.3 Real Time Data Availability

The consistent wide spread availability of individual receptor and hazard data-sets is extremely poor. This is often due to different agencies/authorities monitoring the same parameters in different areas of the country. It is particularly acute with regard to airborne hazards where despite the collection of data from 1500 sites little is amalgamation to create a national picture. This problem is currently being reviewed by the DETR.

With respect to the water environment, the Agency conducts consistent temporal and spatial sampling of parameters relating to surface water quality. However, these are mainly reactive determinants responding to changes in the condition of the watercourse. Moreover, there would appear to be no national monitoring network directly examining specific pollutants. The Agency does directly monitor for specific Grade I and Grade II chemical substances in the water environment below consented discharges. Grade I and II substances, include some of the principal chemical hazards affecting water quality, such as pesticides and heavy metals. In some cases the Agency monitoring collects data relating to effects of hazards rather than the source eg biological sampling.

There is a wide range of national data sources, regarding land use and cover, at a variety of resolutions, which can be used as receptor data sets. Furthermore, hazards arising from consented discharges, e.g. Integrated Pollution Control, LAAPC, across all environmental media are publicly available, however the information has not been amalgamated into a national data-set or the emissions mapped to show potential dosage. It should be noted that pollution arising from many land use activities, including agriculture and transport routes, may be un-monitored due to the pollutants diffuse nature and accordingly incidents may be undetected.

3.4 Data Suitability

Even when available, the data may be compromised by the way it is collated and presented. For example, the scale at which the data is presented may not coincide with that required for use within the SRA. MAFF present data-sets against Parish, County and its regional boundaries. These spatial units do not coincide with the Agency's planning boundaries. Subsequently, the data may require some manipulation in order to be incorporated in the model, potentially resulting with a loss of accuracy.

The Agency's functions and activities cover a wide range of receptors and issues. Many of these may not fit into the defined risk structure. Typical examples include: the effect of low flows on rivers and wetland habitats; acceptable limits of flooding on domestic homes; water shortages and domestic and industrial supply and sediment damage to watercourses.

3.5 Conclusions of Data Review

3.5.1 Model Suitability

The results of the desktop review of available data suggests that a risk model based on real time data may not be appropriate for the Agency SRA model. In summary, the reasons are:

- poor availability of national data sets;
- poor scientific understanding of detailed hazard/receptor relationships; and
- many of the hazards/receptor issues addressed by the Agency do not fit into the ecotoxological risk assessment framework.

3.5.2 Model Revisions

The desk top study identified some fundamental weaknesses in the proposed SRA structure, mainly due to the lack of scientific understanding between hazard receptor combinations and the availability of spatial data sets.

A revision to the existing model was proposed where real time data was to be replaced by indices representing the significance of the hazard or receptor. It was considered that the revisions to the model did not result in a fundamental alteration of the developed risk expressions, however data linkages and input sheets did require modification.

3.6 Summary

Having produced a basic framework for the methodology, Stage 2 was set the task of assessing the availability of actual data to enable the model to be used. Three particular tasks were required which included first to determine the availability of the trigger values above which adverse effects could be said to occur, second whether it was possible to define actual tolerable periods or numbers for each hazard/receptor combination which harm could be said to exist and third whether data exists to allow the definition of the 'harm space' or the number and location of receptors within the space which could suffer an adverse effect from a particular hazard.

The conclusions were:

a) trigger levels can be set for each hazard against a broad classification of receptors such as land, and or water but not necessarily in all categories;

b) actual tolerable periods or numbers cannot be defined due to lack of specific research;

c) although the amount of hazard within a particular environment can be defined linkages back to a number of sources, and active periods of exceedence of trigger level cannot be defined and neither can the exact location of receptors within the space which could suffer harm.

It was therefore necessary to consider an alternative approach using indices rather than real data. The index approach would, however, not require a fundamental change of the structure of the model but would allow indices to be derived for each specific data input. ITE provided a basis upon which relevant indices could be established.

4. REVISIONS TO THE MODEL

4.1 Background

In light of the data review the model structure, as set out in Chapter 2, was revised to accommodate indices as a surrogate for data. This chapter reviews the process of identifying appropriate indices. Furthermore, the revised structure to the model and formulas are examined, providing an overview of how the model works. The final section outlines the basic procedure for a user.

4.2 Revised Data Requirements

The lack of applicable data required the model to be based around selected indices. These indices reflect either the state of a particular receptor (importance and distribution) or the significance (dosage and spatial) of a hazard. Furthermore, the structure of the revised model requires the integration of the scientific understanding of the hazard-receptor relationship with respect to each hazards theoretical significance to harm; geographical extent, persistence and reversibility.

4.2.1 Defining Hazard Indices

An index may be selected from a range of datasets reflecting the potential spatial coverage and dosage of a hazard. The datasets may either directly relate to the dose and extent of a hazard in the environment (the ecotoxological effect) if known or be linked to a determining factor, such as the number and types of sources generating the hazard.

The index is given a value of low, moderate, high or severe. The index used within the model are based upon research undertaken by ITE and included in Appendix 4. Typical guidance criteria are given below:

Index	Dosage/Spatial Extent	
	Ecotoxicological Effect	**No. and Type of Source**
Low	**Contamination**: Presence of contaminants with no overt effect on organisms; possible source of human exposure, possible long-term effect on wildlife	Single point source (<5% of all sources)
Moderate	**Incident**: kills of limited numbers of organisms: likely recovery fast, effect readily reversible	
High	**Population effect**: Kills of sufficient numbers to reduce populations of some organisms; recovery likely following end of exposure, timing of recovery medium term	
Severe	**Community effect**: changes in the community of organisms: recovery long-term or irreversible	Multiple Diffuse source (>60% of all sources)

An index can be selected for each hazard/receptor combination although the individual receptors are sometimes classified under broad categories.

4.2.2 Defining Receptor Indices

The indices for the receptors are determined in the same manner as the hazards, identifying the most appropriate direct or indirect data-set.

The index is given a value of low, moderate, high or severe. The indices used within the model are based upon research undertaken by ITE which is included in the Project Record (E2-001/1). Typical guidance criteria are given below:

	Importance/Distribution			
Index	**Designation**		**Inherant Value**	
	Nature Conservation	**Landscape**	**Commercial (Agriculture)**	**Amenity**
Low	Local	Local Designation	Grades 4,5	<15% of available resource
Moderate	Regional	County Designation	Grades 3b	
High	SSSI	AONB	Grades 1,2,3a	
Severe	SAC/SPA	National Park	-	>80% of available resource

4.2.3 Defining the Persistence and Reversibility Indices

The persistence of a hazard in a media and the time to reverse the effects are of key importance when determining the overall risks of a hazard to particular receptors within the environment. Persistence of a hazard and the reversibility of its effects should be defined for each hazard and receptor combination. Where there is a low scientific understanding of the hazard receptor combination then the values should be inferred from the knowledge of the effects of the hazard within the wider media.

Persistence should be assessed relative to the life span of the receptor. Accordingly, the persistence of a hazard alters depending upon each receptor's life characteristics. Persistence is ranked as either: acute; short-term; medium term or chronic. In terms of the model described in chapter 2 'persistence' reflects the shelf life of the hazard within a particular media whilst 'reversibility' reflects the recovery period of a receptor.

Reversibility is categorised as either: readily reversible; medium term; long term or irreversible and again is a function of the particular hazard/receptor combination.

4.2.4 Normalising Input Indices

The defined indices will reflect the condition of a receptor or hazard within the spatial unit selected. If the SRA is being used to identify the differences in risk between the spatial units then the indices may require normalising to make the data-sets comparable. Normalising indices can be achieved through modification by a standard variable, such as river length or catchment size. For example, the area of arable land may be an indice for sediment pollution i.e. the greater the arable area the greater the potential for sedimentation. The significance of the arable area within each catchment may be normalised by estimating the proportion of a catchment which is arable land. Accordingly the normalising factor in this instance would be the overall area of the catchment.

4.3 Revised Analogue Model

The revised model calculates a normalised 'actual index of harm' for each hazard receptor combination, based on: the potential scale of the effect of the hazard; the geographical extent or status/designation of the receptor and the persistence and reversibility of the effect of the hazard on the receptor. The actual indices are ranked and scored against the criteria shown in the severity matrix in Table 1.

Table 1. Severity Matrix

HAZARD (H)	Scale of Effect	Low 1	Medium 2	High 4	Severe 8
RECEPTOR (R)	Status of Receptor	Low 1	Medium 2	High 3	Severe 4
TIME (1)	Persistence in Media	Acute 1	Short Term 2	Medium Term 3	Chronic 4
TIME (2)	Reversibility	Readily reversible 1	Medium Term 2	Long Term 3	Irreversible 4

nb. Dark line denotes the limit of tolerable harm and shading indicates where unacceptable harm would occur for each receptor.

The following sections describe how the SRA method produces a normalised risk index.

4.3.1 Defining Harm

Harm is defined as: $\sqrt{\left[H^2 + R^2 + T^2\right]}$

Where 'H' is the potential scale of effect for a hazard. 'R' is the status of the receptor and 'T' is the aggregation of persistence and reversibility (Time (1) + Time (2)).

The 'actual' level of harm can be calculated using the indices for the receptors and hazards and the persistence and reversibility of the effect of the hazard on the receptor. The indices are obtained from relevant look up tables.

A hazards 'actual' harm, however, must be normalised to allow it to be compared with other hazards and assessed accordingly. Normalising the actual level of harm is achieved by developing harm indices for each hazard/receptor relationship through a process of comparing the actual result against the acceptable limit and threshold index of harm. The process is set out below.

4.3.2 Maximum Acceptable Limit of Harm

The maximum acceptable limit of harm is the critical moment above which significant harm is considered to occur/or when the harm is no longer tolerable. This is represented by the bold black line in the severity matrix-Table 1. The numerical value is defined as:

Maximum acceptable limit of harm $= \sqrt{[4^2 + 2^2 + (1+1)^2]} = 4.9$

The position of the maximum limit across the various parameters was determined by recommendations from ITE.

4.3.3 Threshold Index of Harm

The threshold index of harm is a theoretical value derived from the latest scientific understanding of the effect and characteristics of each specific hazard against a specific receptor or within the various environmental media.

For the purposes of the trials the hazard values were determined using guidance from both the Agency and ITE and use the standard formula

$$\sqrt{[H^2 + R^2 + T^2]}$$

4.3.4 The Harm Factor

The ***harm factor*** is a theoretical value used to determine the potential of each hazard to cause damage within a media. The calculation uses the threshold index of harm for each hazard/receptor relationship compared to the acceptable limits of harm. A value less than one would identify that the hazard is unlikely to cause significant harm to a receptor and vica versa. The equation is:

$$\textbf{\textit{Harm Factor}} = \frac{\text{Threshold Index of Harm}}{\text{Maximum Acceptable Limit of Harm}}$$

4.3.5 The Actual Harm Index

The actual level of harm can be subsequently normalised by evaluating the degree to which it exceeds the acceptable limit of harm and relating it to its theoretical ability to harm (harm factor). The equations is:

Actual Harm Index = (Actual Harm - Maximum Acceptable Limit of harm) X Harm Factor

4.3.6 Scaling the Indices of Harm

To facilitate the ease of comparing a range of hazard receptor combinations the harm indices were simplified by scaling them between 0 and 200. To scale the harm index required examining it against the best and worst possible harm indices. These are:

THE WORST CASE

Calculating the maximum level of harm that can occur due to a hazard is achieved by considering the worst case scenario, namely where the potential scale of effect = 8, the receptors status is 5 and reversibility and persistence are 4. Therefore the:

Threshold Index of Harm $= \sqrt{[8^2 + 5^2 + (4+4)^2]} = 12.37.$

Maximum Acceptable Limit of Harm = 4.90

$$\textbf{\textit{Harm Factor}} = \frac{12.37}{4.90} = 2.52$$

The worst case ***Harm Index*** = (12.37-4.90) X 2.52 = 18.82

THE BEST CASE

As harm is considered acceptable up to the threshold shown in the severity matrix, the worst case is taken with respect to the value of the maximum acceptable limit of harm, namely:

$$\textbf{\textit{Threshold index of harm}} = \sqrt{\left[4^2 + 4^2 + (1+1)^2\right]} = 4.90$$

Maximum acceptable limit of harm = 4.90

$$\textbf{\textit{Harm Factor}} = \frac{4.90}{4.90} = 1.00$$

The best case ***Harm Index*** = (4.90-4.90) X 1.00 = 0.00

Therefore all significant harm will occur between 0.00 and 18.82. Subsequently, the actual harm index can be scaled to between 0 to 200 by multiplying the actual harm index by a factor of $\frac{200.00}{18.82}$, which equals 10.63.

4.4 Refined Digital Model Structure

4.4.1 Background

The new digital model is based upon the algorithms as defined in the revised analogue model. The model is based on the same software as the original computer model, although it does not use the Crystal Ball software for incorporating changes to the hazard duration or incident frequency.

The amended model structure remains based on 'look up' tables, defining:

- the potential scale of the effect of the hazard;
- the potential status of the receptor;
- the persistence of the hazard and reversibility with respect to each receptor and/or media; and the
- theoretical threshold of harm values for each hazard with respect to the appropriate environmental media or receptor.

A guide to the process of using the revised model's software is provided in the Project Record (E2-001/1).

4.4.2 Data Requirements

It is important that appropriate indices can be determined relating to both the status of the receptor and the significance of the hazard (spatially and dosage). Furthermore, it is essential that relevant thresholds can be set determining the different levels of status or significance. Information relating to the persistence and reversibility for each hazard receptor combinations should be determined using the latest scientific knowledge. Where this data is unavailable, surrogate data may be provided using the knowledge of the behaviour of the hazard within a broader definition of the receptors. Examples are provided in the Project Record (E2-001/1) for different environmental media.

4.4.3 Digital Model Assumptions

As in the original model, the revised digital software assumes that: the receptor and hazards relationships are linear with regard to rates of persistence and decay; and that the status and population of the receptor and the significance of the hazard are evenly distributed across the spatial unit being examined.

4.5 Summary

The revised model uses indices to act as proxies for the real time data required to use the original model. The proxies for each variable are shown below:

Space/No. of Sources/Extent of Hazard	No. and/or Type of Source of Hazard
No of Receptors within the space	Status (Value/Designations of Receptor)
Shelf Life of Hazard	Persistence of Hazard to Receptor or Media
Recovery Rate	Reversibility of Receptor or Media to Hazard.

Each index is stored as low, moderate, harm high or severe according to criteria established by ITE.

A normalised and scaled actual harm (or risk) index can be produced for any hazard/receptor combination. The normalising is based upon calculating a 'harm factor' which reflects the potential of each hazard to cause unacceptable damage to a receptor and/or media.

5 TRIALING THE REVISED MODEL

5.1 Background

Stages 1 and 2 demonstrated that it would be technically feasible to:

(a) normalise the risks posed to the environment across a full range of stresses and strains based on a sound scientific understanding of the inherent characteristics of hazards and their effects on specific receptors;

(b) a structure of look up tables could be defined which could be used to generate proxy indictors for key hazard/receptor relationships; and

(c) a robust methodology was avaiiable based on the fundamental principles established by the Ad-Hoc Risk Assessment and Risk Management Group which could combine and compare different stresses and strains.

A concept demonstrator was now available which could be used to:

(a) model and prioritise risks which have already been identified and evaluated by the Agency within a Local Environment Agency Plan (LEAP); and

(b) model and prioritise risks using Agency and other published base data to compare at a strategic (separate stress/strains) and regional (similar stresses/strains) level.

For the LEAP the model would allow a ranking of known issues whereas the second trial would identify and rank all potential issues from 'raw' objective information rather than the sieved information presented in a LEAP (which must, by its very nature reflect value judgement and the authors perceptions). It would also, at a national level, provide an objective overview of the existing and potential future data collection/monitoring functions of the Agency.

5.1.2 The first trial involved ranking the issues raised within the River Teign Local Environment Agency Plan. The second trial involved the modelling of the strategic risks placed on the freshwater environment.

5.2 River Teign LEAP

5.2.1 Study Context

The Agency published the River Teign LEAP Consultation Report on 11 March 1997. The consultation period concluded on 31 May 1997 and responses were collected and summarised in an Agency document. Subsequent to consultation it was proposed to publish an Action Plan for the River Teign in October 1998.

The Consultation Report provided a description of the River Teign catchment area and the environmental issues facing it. The issues were considered under a series of headings either relating to historical and potential future land uses including development, abandoned mines, mineral extraction, water supply, reservoirs, sewage discharges and farming/forestry, or specific issues such as acidification of headwaters, antifouling paints, changing ecology, spreading invasive bankside plants, lack of information (archaeology), threats to fish stocks, recreation impacts and resources. The consultation responses (70 in number) were asked to detail the 5 most important issues of which the following received nine or more votes:

Development	19
Sewage Discharges	16
Farming/Forestry	13
Ecology (low flows)	11
Water Supply (Deficit)	10
Mineral Extraction	9
Recreation (Impact)	9

Apart from the counting of votes there was no quantitative assessment or ranking of issues within the LEAP.

In addition no attempt was made to differentiate issues for which the Agency were either responsible in an statutory role or as lead agency. The approach adopted also did not provide an overall understanding of the interrelationship between hazards and receptors. It was not, therefore, possible to understand the relative state of the receptors within the catchment area or the relative importance of sources of the hazards. Targeting resources would, therefore, be difficult.

In order for an assessment to be made of the issues within the LEAP it was necessary to:

(a) consider the issues within the hazard/receptor structure of the model;

(b) identify acceptable proxy indicators for the dosage/spatial extent for the identified hazards and importance/distribution for the identified receptors;

(c) generate 'look' up tables for (b)

(d) analyse the comparative risk indices; and

(e) run test options.

The approach adopted was to use only information contained within the LEAP backed-up with face to face meetings with the authors. It was not possible to discuss the LEAP with the originators of the issues due to the timescale for the project and lack of availability of the relevant personnel.

5.2.2 Identifying the linkages

The LEAP was reviewed within the structure of a flow diagram. The analysis identified the following key hazards and receptors:

Hazards	Receptors
Sediment	Water Quality: Chemical Standards
Chlorine	Water Quality: Biology Standards
Acid Deposition	Water Quality: Failures of EC Directives
Nitrate/Nitrite (Leactate)	Nature Conservation
Zinc	Salmonid Beds
	Landscape
	Water Supplies: Human/Ecology

5.2.3 Identifying Indices for Receptors and Hazards

A detailed review of the LEAP demonstrated that a number of proxies/indicators could be used for each hazard. The range of possibilities and the potential derivation of look-up tables setting the value for the hazard and receptor indices are contained in the Project Record (E2-001/1) respectively. The persistence and reversibility for each hazard and receptor combination were set in discussion with ITE. If no specific information was available for that hazard/receptor combination a broader receptor category was used. The identified criteria are included in the Project Record (E2-001/1).

5.2.4 Identifying Threshold of Harm

The indices required for the normalisation of the different risks were agreed in discussions with ITE and based upon the information included in the Project Record (E2-001/1). For the purposes of this study only one set of criteria were established for each hazard. The indices are included in the Project Record (E2-001/1/).

5.2.5 Input Data

All the data which was entered into the model was taken from the Consultation Report. The input data has been reproduced in the Project Record (E2-001/1). The data is entered for each hazard receptor combination where there is a clear link between the source of the hazard and a potential effect on the receptors. For example the general hazard of sediment (H1), which is represented by % of arable land within the catchment area, would generally affect Water Quality (R1) which is represented by % of total river length within the catchment area which is in grade A. The higher the % of arable area and/or % river length in grade A the higher the environmental risk.

The specific hazard of sediment from Ball Clay Mining (H1B), which is represented by the scale of the pollution incident, would affect the water quality of an individual river, (R3) Aller Brook, which is classified as of biological quality c/d.

5.2.6 Results

The results of the assessment are shown in Figure 3. An overall score of environmental risk has been produced for each hazard receptor combination. A 'no score' implies that the hazard does not pose a risk upon that particular receptor, according to the content of the LEAP.

The scores for each hazard and receptor have been totalled to enable a broad comparison of which hazards pose the greatest risk (stress) and which receptors are under greater pressure (strain).

The analysis shows that:

(a) abandoned mines, through acid deposition and zinc run off, pose the most significant threat;

(b) sedimentation run-off from roads poses a particular risk upon Stover Lake due to the existing very high (grade a) biological quality and national designation (SSSI) for nature conservation;

(c) water quality, both within the catchment area and individual rivers, is under most threat;

(d) water supplies are also under threat due to general contamination of ground water from abandoned mines and the specific chlorine contamination arising from the Waddeton Industrial Estate.

A number of iterations were undertaken to reflect possible actions which could be implemented to reduce the environmental risks. One such iteration involved reducing risks from sedimentation arising from agriculture through a reduction in the amount of arable land. It became clear that only relatively small changes occurred in the risk index for relatively large changes in the area of arable land. Further investigation recorded that due to the persistence of the sediment within rivers it required actions to the receptor, i.e. clean up, to reduce the environmental risk. Similar results occurred when dealing with other ground water threats.

The model was, therefore, seen to be driven by the time factors, such as persistence and reversibility.

5.2.7 Conclusions

The results of using the model to analyse the risks to the environment produced a structured analysis of the stresses and strains in a way not revealed within the LEAP. A comparison of the analysis to the consultation responses demonstrates some inconsistency but with possible explanations available from the analysis undertaken by the model.

In particular, abandoned mines do not appear in the consultation list yet appear to pose the greatest risk to the environment. Clearly some of the inconsistencies occur due to the generality of the titles. "Development" for instance covers a wide range of possible causes and effects and does not, therefore, have any real meaning. Within the LEAP Development includes:

Receptors - poor biology in Aller Brook

Existing land uses - pollution from industrial estates to water courses

Historic land uses - pollution from closed landfill

Proposed land uses - affecting flood plain and environmental resources

Recreation - litter

The structured approach forced through the use of the model provides significantly more clarity and focus. In particular, it would allow better targeting and prioritising rather than solely listing and describing all environmental concerns. It was apparent during discussions with the Agency that issues were included based on discussion rather than an analysis of base data. A limited analysis of some base data demonstrates that meaningful results can be produced.

5.3 Trial 2. State of the Freshwater Environment

5.3.1 Study Context

In 1996, the Agency began a review into the state of the freshwater environment in England and Wales, culminating in a draft report, its publication is expected in mid 1998. The study accumulated and examined data regarding the various stresses placed upon the freshwater environment in the context of a range of perspectives, including conservation, recreation and water provision for anthroprogenic uses. The study provides an opinion on the current state of the freshwater environment, its current management and how it is currently being protected to meet the needs of the future generations. The report concludes with an overall opinion upon the state of the freshwater environment and identifies a set of priority issues that require further management to bring about improvements.

RPS were provided with a copy of the background assessment which had been used in drafting the report. The potential environmental impacts had been ranked by a single weighting procedure based upon 4 criteria (reversibility, spatial scale, risk magnitude and scientific uncertainty). The individual rankings have been generated using informed judgement.

It is considered that the model could offer a more rigorous, quantitative approach. It could also direct information gathering for future work of this type.

The freshwater environmental data-sets represent a far more comprehensive compilation of physical, chemical and biological information. This presents an opportunity to:

(a) run the model on 'raw' objective information;

(b) develop a tiered series of more scientifically based and more complex look-up tables; and

(c) test the options/policies currently being developed by the Agency;

The trial was conducted under 8 stages;

(a) identify hazards (sources), receptors and pathways through the production of a pathway flow-diagrams;

(b) determine principal (simplified) hazard-receptor relationships for inclusion within the model and identify the nature and character of sources;

(c) determine most appropriate criteria for evaluating 'scale of effect' for each source for each hazard;

(d) determine most appropriate criteria for evaluating 'value/significance' for each receptor;

(e) generate look-up tables for the criteria determined in steps (c) and (d) above, specifying the range of values and banding with reference to (for example) planning designations, RQOs, biological water quality classifications and other published/accepted standards;

(f) determine the threshold of harm index for each hazard-receptor relationship (i.e. determine component index values based on published studies/information, EQS' etc);

(g) input data into the model and run the 'State of the Environment' scenario checking/adjusting for errors, anomalies and sensitivities within the calculations;

(h) compare results with 'weightings' in draft 'State of the Freshwater Environment' report, identify and account for differences, methodology or data difficulties and any implications for development of the model further.

The study was conducted at a regional level due to Agency datasets generally only being available at that scale. A national dataset was compiled through an aggregation of the regional datasets.

5.3.2 Identifying Linkages

A draft copy of 'The State of the Environment of England and Wales: Fresh Waters' was used to identify the source pressures, associated hazards, potential receptors and the effects upon them. The main relationships are shown in Figure 4.

The sources, hazards and effects were further refined through collaboration with the Agency authors of the Fresh Water Report. The refined linkages are shown in Figure 5. Shaded squares denote a potential effect between a hazard and receptor. No shading implies a rare or absent effect.

5.3.3 Identifying Indices and Normalising

Appropriate indices for the regional analysis were selected from Agency data sources, principally from the 'State of the Environment in England Wales: Fresh Waters' report, but supplemented by information provided in the confidential 'Key Facts' document (Agency 1996).

Where appropriate the selected indices were normalised to allow comparisons and amalgamation of the regional data. Normalising parameters included the area of the region, total river length and drainage density.

The indicators chosen for each key hazard/receptor are set out in Table 2.

Table 2. Key Hazards and Receptors Indices

KEY HAZARDS	KEY RECEPTORS
Lowering of Groundwater Levels *Estimated fresh groundwater abstraction compared to total water abstracted*	**Wetland Habitat Condition** *Number of wetland SSSIs*
Lowering of Surface Water Flows *Estimated fresh surface water abstraction compared to total water abstracted*	**Surface Water Quality** i) Biological
Surface Water Pollution	ii) Fish
i) Sedimentation *Proportion of arable land in the study area*	**Groundwater Quality** *Proportion of major aquifer compared to regional area*
ii) Nutrient Enrichment - Nitrate *Number of substantiated farming and sewage pollution incidents*	**Groundwater Abstraction** i) Potable *Proportion of groundwater abstraction supplied for potable use*
iii) Nutrient Enrichment - Phosphate *Population equivalents for organic and sewage loading*	ii) Agriculture *Proportion of groundwater abstraction supplied for irrigation and agriculture use*
iv) Pesticides *Number of eqs failures to pesticide levels*	iii) Industry *Proportion of groundwater abstraction supplied for industrial use*
v) Heavy Metals *Number of eqs failures due to metal compounds - grades i and ii*	**Surface Water Abstraction** i) Potable *Proportion of surface water abstraction supplied for potable use*
vi) Acidification *Exceedences of critical pH loading*	ii) Agriculture *Proportion of surface water abstraction supplied for irrigation and agriculture use*
vii) Hydrocarbons *Number of substantiated fuel and oil incidents compared to national total*	iii) Industry *Proportion of surface water abstraction supplied for industrial use*
viii) Organic Loading *Number of substantiated organic pollution incidents compared to national figure*	**Urban Area at Risk of Flooding** *Percentage of each regions built up area affected by freshwater flooding*
Groundwater Contamination i) Nitrate *Area of NVZ compared to region* ii) Pesticides *Proportion of arable land in the study area* iii) General *Number of Waste Disposal IPC authorisations* **Freshwater Flooding** *Projected Change in Run-off rates*	**Aesthetic Value** *Percentage of river channels visited with 'semi-natural or predominantly unmodified' channels*
Channel Disturbance *Number of sites 'obviously to heavily extensively' modified*	

Guidance look up tables were produced and agreed with the Agency. The tables, reproduced in the Project Record (E2-001/1), provide the thresholds by which input data is allocated into a low, medium, high or severe category. For the purposes of this study the thresholds have been chosen to generate a normalised distribution on the input data. When using the model in a risk operational capacity these thresholds would be set by the client/user.

5.3.4 Identifying Theoretical Threshold of Harm

In order for a comparison to be made between the different risks theoretical thresholds of harm have been identified for all hazard/receptor relationships. In discussions between the Agency and ITE it became apparent that only one threshold could realistically be set for each hazard against a general receptor such as on water or land. The model is capable of using thresholds of harm for all specific hazard/receptor combinations should data become available. The agreed threshold values are reproduced in the Project Record (E2-001/1).

5.3.5 Input Data

The data which was inputted into the model, within the structure of the look-up tables described in paragraph 5.3.3, for each of the regions is included in the Project Record (E2-001/1). The data has been referenced to the relevant tables/figures within the State of the Freshwater Environment Report and the Key Facts report. Input data is identified within the shaded column.

5.3.6 Results

The model generated a matrix of environmental risk/harm indices for each hazard/receptor combination for the 8 regions and an aggregated total for the national picture. Due to the overall size of the results sheets it was necessary to produce a series of post processors spreadsheets. A description of this system is included in the Project Record (E2-001/1). In simple terms the spreadsheets:

(a) amalgamate a number of hazards under 2 broad headings of Surface Water Pollution and Ground Water Pollution;

(b) amalgamate a number of receptors under 3 broad headings of Freshwater Environment, Groundwater Abstraction and Surface Water Abstraction;

(c) present results as either totals (which adds every entry in the individual risk matrices) or an average score (which is the mean value of all entries within the broader headings). This could remove a potential bias for surface water pollution as compared to groundwater pollution which due to the currently more intensive monitoring programme of surface water generates more entries within each risk/harm matrix; and

(d) allows weightings to be attached to individual hazards and receptors. These would be set by assigning a value of 1 to the lowest valued hazard/receptor as a base, then the relative importance of the other hazard/receptor can be set accordingly; e.g. a value of 2 would imply a hazard to be twice as important as the base.

The following section provides a summary of the results by reference to various output presentation figures.

Figure 6: shows the ranking of receptors within each of the 8 regions:

- In all regions groundwater abstraction is the receptor under greatest strain with groundwater quality being second in most cases;
- The receptors under least stress, in all cases, is urbanisation in the flood plain.

Figure 7 shows the ranking of hazards within each of the 8 regions:

- There is a clear district between the top 3 hazards and others. Groundwater levels and pollution of surface water and groundwater are always the hazards causing greatest stress apart from in Wates.
- Freshwater flooding is generally the hazard causing least stress.

Figure 8 shows the relative national harm/risk indices for all hazard/receptor combinations:

- Any combination involving either a groundwater hazard or groundwater receptor results in the highest index.
- Channel disturbance and freshwater flooding pose the lowest relative risks to any receptor.

Figures 9A, 9B and 9C show the different risk/harm indices profiles for Anglian, Thames and Wales. Some relative differences are identified below:

- Surface water pollution is a more important issue in the Wales.
- Groundwater levels is a more important issue in the Anglian region.
- Groundwater contamination is the most important issue within the Thames region.

A number of sensitivity tests were undertaken in order to reflect possible weightings which would need to be applied to change the rankings and to reflect possible actions which could be undertaken to reduce environmental risks. One particularly important conclusion occurred which suggested that a weighting of 10 would be required to flooding as a hazard in order to lift that particular hazard to the highest risk, although this occurred only in three regions Anglian, Midlands and Thames. In all other regions it remains as the lowest environmental risk index.

5.3.7 Conclusions

The model was able to be populated with enough information to enable an analysis of hazards which place stresses on a range of receptors. The model was also able to identify the relative strains being incurred on receptors. Furthermore, the analysis enabled a comparison between the risk profiles for different regions.

A comparison can be made with the ranking of the impacts at a national level undertaken for the State of Freshwater Report and the ranking generated by the model.

Figure 10 shows the relative ranking of the indices for each hazard/receptor combination at a national level. It is evident that groundwater pollution/ground water abstraction is the most important issue which is common to the Agency ranking. Groundwater issues dominate the second tier of issues interspersed with the effects of low surface water flows on surface water quality and visual value. The visual aspect of the freshwater environment featured as the lowest ranking issue within the Agency assessment.

The model suggest that channel disturbance and freshwater flooding are the lowest ranking issues which correlates reasonably well with the Agency assessment although the relative differences are far more pronounced within the model.

It is more difficult to go beyond this brief comparison due to the approach in identifying the impacts within the State of Freshwater Environment Report. For instance there is a mix of cause and effect which tends to lead to double counting e.g. low quantities of water/low flow rivers can lead to habitat change/loss of flora/decline in fauna etc. Ranking issues within this Agency frame work could therefore be somewhat misleading. This particular aspect is discussed in more detail in the concluding section to the report.

Figures 11A and 11B shows the ranking of receptors and nationally hazard indicies across all regions relative to the highest and lowest. This analysis demonstrates how the model can extends the analysis to targeting specific issues within regions but within the national context. Groundwater quality and abstraction are the issues facing all regions apart from Wales and particularly within Anglian and Southern. Beneath this layer most regions are faced with different problems in relation to hazards and receptors. This suggests that apart from a national strategy relating to groundwater, specific strategies to deal with environmental risks are required within the sub regions. The most pronounced example being Wales

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 The Methodology

The objective of the project was to establish a methodology which would allow the Agency to allocate resources, both human and capital, through the targeting of policies and specific actions which could provide the most significant demonstrable reduction in environmental risk. Such a methodology would then allow the Agency to discharge it's functions in a sustainable manner. The methodology would at it's core need to allow a direct comparison of environmental risks which occur from different sources.

Any methodology would need to meet a number of tests including transparent, credible and defensible based upon sound scientific understanding, reproducible, user friendly and cost effective.

The framework for the methodology was derived by the Ad-Hoc Group concerning Risk Assessment and Risk Management.

It was possible to demonstrate that a normalisation procedure did exist based upon the ability to define a tolerable number of receptors and tolerable period of time which it is deemed acceptable to expose those receptors to different hazards. In this respect the study sought to extend the principal of EQSs to being applied to a far more detailed range of potential receptors rather than broad media or 'test species'. The first version of the model sought to use 'real time' data as the necessary input. Investigations by ITE revealed that the level of data and in particular the lack of geo-referencing consistently through all datasets suggested that the model would need to find an alternative approach. In addition and more importantly the tolerable numbers and periods, required to normalise the different types of environmental risk could not be set due to the lack of specific research.

The ITE research did, however, provide a basis for deriving a methodology which could use indices for data inputs and a severity matrix which could be established for a range of hazards and receptors for the normalisation procedure. The normalising procedure could use a 'harm factor' which reflects the potential for each hazard to cause unacceptable damage to a receptor or media. The four key inputs for the methodology are indices which reflect: the number and type of sources of each hazard; the status or value of the receptor; the persistence of a hazard within a particular media or receptor and the reversibility of a receptor or media to a hazard. Each index is scored as low, medium, high or severe. The scoring is provided through a series of look-up tables which have been derived with ITE and agreed with the Agency.

6.1.2 The LEAP Trial

The methodology was trialed by using data and information which formed the basis of the River Teign LEAP. The objective was to model and prioritise the environmental risks within the River Teign catchment area. The analysis revealed a ranking of issues which did not reflect the general views expressed within the LEAP and in particular the issue of sedimentation and zinc pollution from run off from abandoned mines did not appear as a significant issue in the LEAP bit was clearly identified by the model as the most significant risk to the environment.

It was evident that the LEAP contains a vast amount of information about the catchment, about many different subjects and provides a natural starting point for many forms of environmental analysis. This information enabled the model to be run effectively.

The LEAP did not, however, contain any analysis and interpretation of the data. There was no attempt for instance within the LEAP to provide a weighting or ranking of issues. The current and expected state of environment is also unclear. The consultation responses went some way to attempting to identify the most important issues but included headings which encompassed both cause and effects.

For these reasons a direct comparison with the analysis within the LEAP was difficult. Any comparison which was possible was clearly influenced by the fact that the LEAP reflects the prejudices and concerns of both the author's and the most influential professional body or individuals rather than the detailed analysis which should be undertaken of the base data.

The methodology forced a structured analysis of the data. It adds in the best scientific understanding which exists currently. Through the use of indices it also provided a clear state of the environment from which overall aims can be derived , performance measures set against this state and monitored. Without doubt more accurate or better tailored data could be input into the model but it is evident that enough base data exists to allow at least a strategic overview to be taken of the environmental risks within this particular catchment.

6.1.2 Freshwater Trial

The freshwater trial provided an opportunity to consider a much larger range of potential environmental risks. It also provided an opportunity to examine the capability of the methodology to provide a comparison of risks within regions, across all regions and at a national level i.e. at different geographical scales.

The model structure, data input and setting of relevant thresholds was undertaken in conjunction with the Agency. The model therefore made use of all the currently available information both in terms of input data and standards. It was however evident that consistent and relevant data sets were not always available to cover the potential range of environmental risks. It was therefore necessary to use data sets which could be regarded as a 'best fit'. This requirement did however beg the question as to what information is currently used to allocate spending in these areas.

An example related to the environmental risks posed by flooding (the hazard) upon housing (the receptor). There appears to be no published record of areas of actual catchment which flood nor records of different land uses within the flood plain. The model therefore uses 'projected change in run off rates' for each region as an indication of likely flooding with this data being derived by the Agency to cover the likely influences of climate change. The receptor data set used was 'percentage of each regions built up area which is located within the flood plain' a statistic which came from in-house. Other examples included the lack of a criteria for measuring ground water quality hence the 'best fit' was the 'proportion of major acquirer compared to catchment area'; lack of a criteria for assessing the amenity value of receptors hence the 'best fit' was 'proportion of river channel with semi-natural or predominantly unmodified channels' following the river habitat survey.

With these caveats it was considered that, at this level of assessment, the data sets which were derived would allow a meaningful analysis.

The results demonstrated a better relationship to the conclusions which were produced within the draft report provided to the study team as compared to the LEAP trial. It was evident that far more analysis of the base data had been undertaken within the Freshwater Report and appeared to provide the foundation for the conclusions. It must however, again be stressed that the ranking of issues which had been undertaken by the Agency was confusing. The potential impacts which were identified covered similar events. Ranking could not therefore be methodologically correct. In addition there is no 'scale of difference' between the ranking which is an important concept in determining the level of resource allocation. Finally the report did not again set standards or establish the state of the various receptors within the environment.

The results of the analysis generated what could be considered a clearer understanding of the issues. By considering these issues within the hazard/receptor framework all potential interrelationships could be taken into account thereby providing a full picture of the state of the freshwater environment. The hazard/receptor framework also allows a closer analysis of possible actions in terms of policies or specific targeting. These actions do not necessarily dovetail into the current series of Agency Action Plans. Some actions transcend the various plans and also require input from other organisations.

The methodology would allow a new approach to analysing possible actions. Such an approach is set out on Figure 12. The approach requires the source of environmental harm to be placed into a type described as active or passive. Active sources being controllable at the source as compared to passive ones which would not be controllable at source but would require direct actions close to the receptor to prevent harm occurring. Adopting this approach to each environmental risk would demonstrate direct lines of responsibility to 'partners or stakeholders' within the loop of environmental harm under consideration. It would also focus the application of existing 'tools' both in terms of legislation, education, investment to reducing environmental harm. Although the 'control loop' was beyond the scope of this project it has been included here to provide an indication of a possible application of the methodology.

Finally it was possible to demonstrate how the model can provide guidance on areas which would need a strategic approach at a national level such as ground water contamination/quality. And also how individual regions will require specific targeted approaches.

The overall conclusions are:

- ***a methodolgy can be produced which allows a direct comparison to be made between a variety of risks to the environment. This methodology could use existing data sets if collection were better targeted to a strategic model such as this;***
- ***an alternative approach can be used to overcome data deficiencies which uses indices. There is a good scientific foundation to the indices;***
- ***testing the model, using existing data sources, demonstrates that where analysis is undertaken by the Agency on a conventional approach the issues which are identified are similar;***
- ***the model can however provide a scaled ranking to these issues and allow a comparison between regions and across regions. The model can therefore be used at a variety of geographic scales;***
- ***the model places a structured approach to the analysis of environmental problems and generates a framework for ongoing setting of objectives and prioritising and monitoring.***

6.2 Recommendations

The recommendations which stem from this R&D project are set out below:

1. the possibility of generating geo-referenced data sets should be considered to enable actual physical links to be established between hazards and receptors. The use of satellite imagery and GIS systems should provide the initial focus of this research;
2. new data sets should be established for monitoring amenity value of receptors and also for identifying the actual sources of flooding, extent of and also potentially affected receptors;
3. investigate the possibility of integrating non environmental factors into the model. These factors could include the public perception and awareness of particular hazard/receptor relationships;
4. establish whether the hazard and receptor indices could form the basis of sustainability indicators for monitoring the state of the environment;
5. use the model to provide structured guidance on the approach to be adopted in the preparation of LEAPS including the collection and analysis of base data, identification of data deficiencies, prioritising of environmental issues for which the Agency has sole responsibility through to assisting other parties, producing action plans against the indices/indicators within the model; and
6. apply the model to the establishment of priorities for the preparation of LEAPS between regions and then within each region.

APPENDIX Page

FIGURES

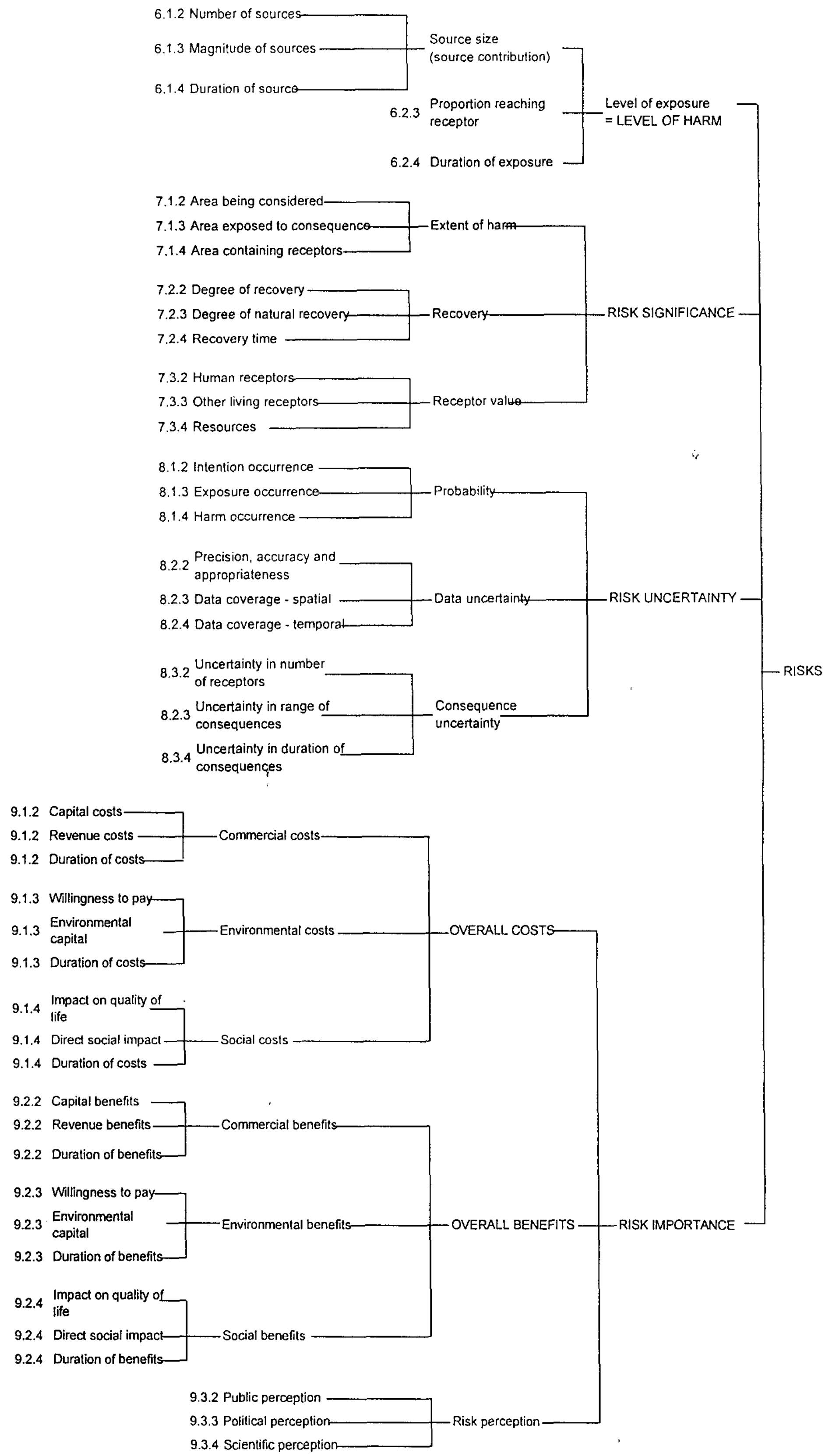

Figure 1: Hierarchy of Risk Expressions

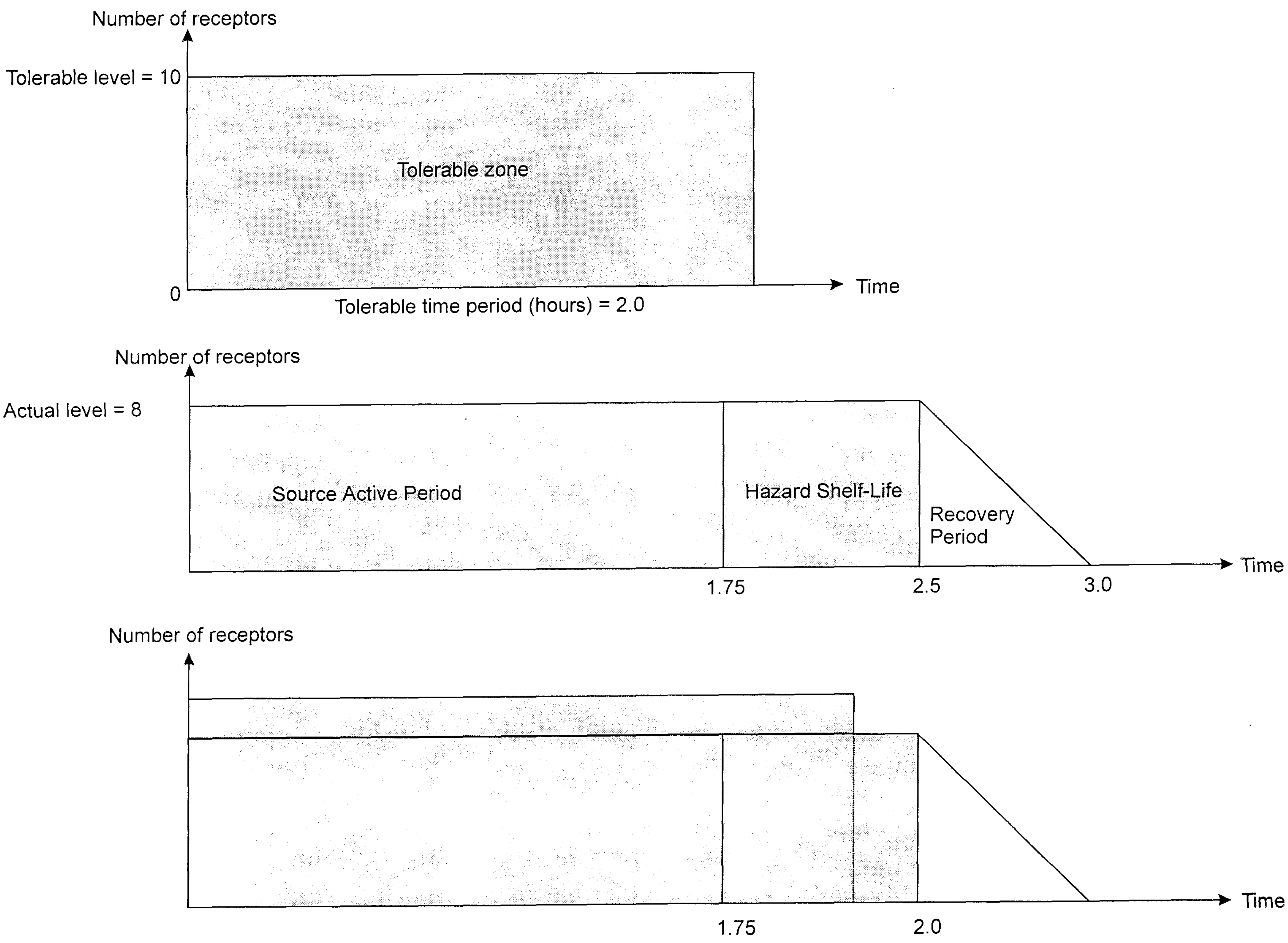

Figure 2: Examples of Levels of Harm

RESULTS AND RANKINGS

Receptor	R1. Water A RQO - Chem % of Total Rivers in Grade A	R2. Water B RQO - Bio: % of Total Rivers in Grade A	R3. Water C Individual River Quality GQA (biological)	R4. Water D % of Failures EC Directive	R5. Water E Nature Conservation Designation	R6. Human Number of Homes Affected	R7. Environment Landscape Designation	R8. Human/Environment Water Supplies	R9. Salmoniod Beds	R10.	Total
H1. Sediment Agriculture	112.1										112.07
H1. Sediment Ball Clay Mining/Aller Brook			105.6								105.64
H1. Sediment Construction A30/ Scotley/Fingle Brook			106.8						105.6		106.79
H1. Sediment Roads/Stover Lake			112.1		112.1						224.14
H2. Chlorine	99.7										99.68
H2. Chlorine Coventry farm/Aller Brook		99.7									99.68
H2. Chlorine Waddeton Industrial Estate/G Water								98.1			98.08
H3. Acid Deposition Abandoned Mines	152.4							147.3			299.69
H3. Acid Deposition			121.2								121.25
H4. Nitrate/Nitrite (Leachate) Landfill	112.1										112.07
H4. Nitrate/Nitrite (Leachate) Broadmeadow LF/Teign Estruary			110.6								110.55
H5. Zinc Run Off	136.4							128.1			264.51
Receptor Score	612.62	99.68	556.30		112.07			373.48	105.64		1754.15

H3. Acid Deposition Abandoned Mines
H5. Zinc Run Off
H1. Sediment Roads/Stover Lake
H3. Acid Deposition
H1. Sediment Agriculture
H4. Nitrate/Nitrite (Leachate) Landfill
H4. Nitrate/Nitrite (Leachate) Broadmeadow LF/Teign Estruary
H1. Sediment Construction A30/ Scotley/Fingle Brook
H1. Sediment Ball Clay Mining/Aller Brook
H2. Chlorine

R1. Water A RQO - Chem % of Total Rivers in Grade A
R3. Water C Individual River Quality GQA (biological)
R8. Human/Environment Water Supplies
R5. Water E Nature Conservation Designation
R9. Salmoniod Beds
R2. Water B RQO - Bio: % of Total Rivers in Grade A
R4. Water D % of Failures EC Directive
R6. Human Number of Homes Affected
R7. Environment Landscape Designation
R10.

Figure 3: LEAP Trial Results

FLOW DIAGRAM OF RISK ASSESSMENT

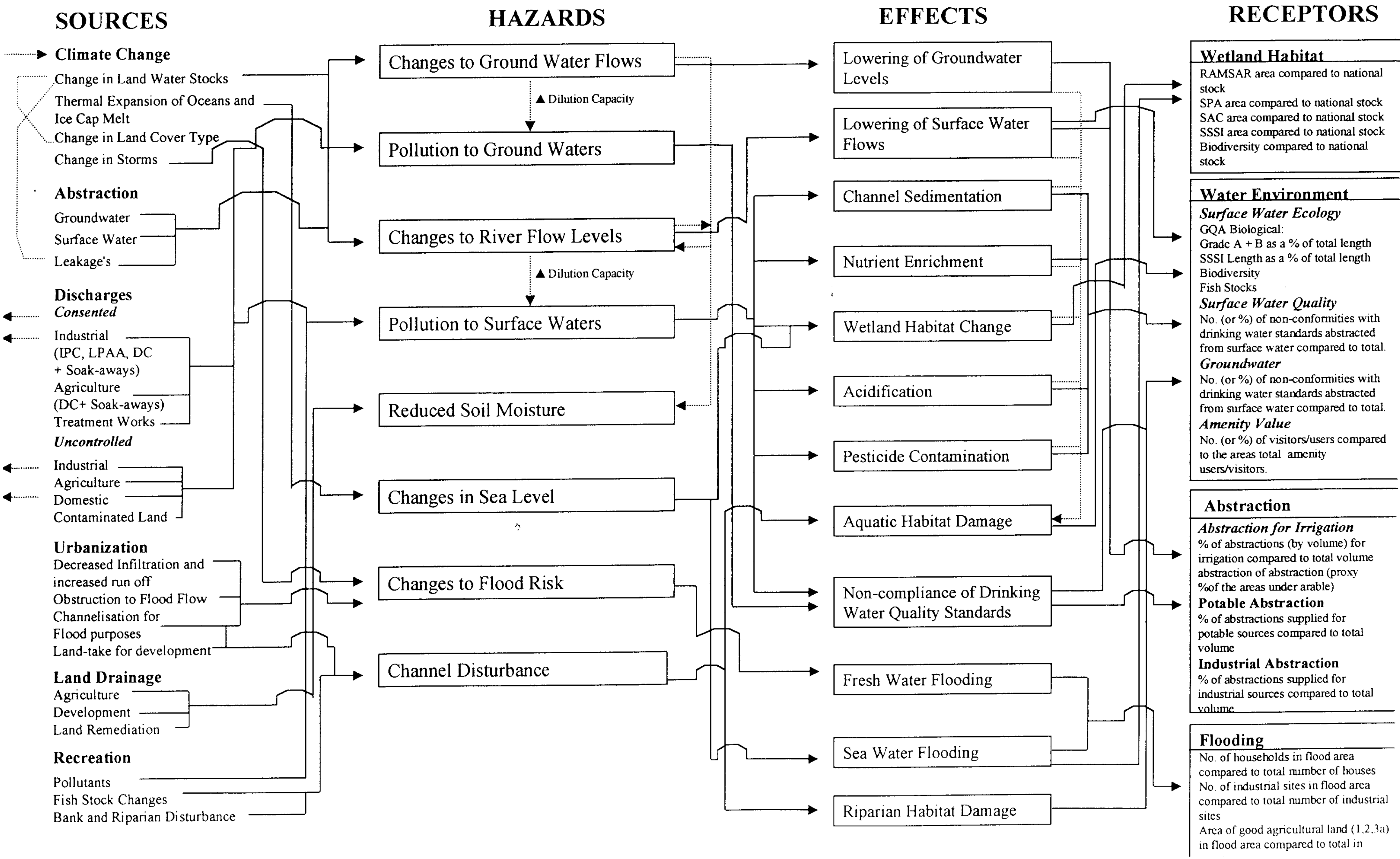

Figure 4: Freshwater Trial: Hazard/Receptor Linkages

Receptor	R1 Wetland Habitats	R2 Freshwater Environment: Surface Water Biological Quuality	R3 Freshwater Environment: Surface Water Quuality Fish	R4 Freshwater Environment: Groundwater Quality	R5 Groundwater Extraction: Potable	R6 Groundwater Extraction: Agriculture	R7 Groundwater Extraction: Industry	R8 Surface Water Extraction: Agriculture	R9 Surface Water Extraction: Potable	R10 Surface Water Extraction: Industry	R11 Urbanisation within Floodplain	R12 Freshwater Visual Value
H1. Lowering of Groundwater Levels												
H2. Lowering of Surface Water Flows												
H3. Surface Water Pollution i) Sedimentation												
H4. Surface Water Pollution ii) Nutrient Enrichment - Nitrate												
H5. Surface Water Pollution iii) Nutient Enrichment - Phosphate												
H6. Surface Water Pollution iv) Pesticides												
H7. Surface Water Pollution v) Heavy Metal												
H8. Surface Water Pollution vi) Acidification												
H9. Surface Water Pollution vii) Hydro-Carbons												
H10. Surface Water Pollution viii) Organic												
H11. Groundwater Contamination - Nitrate												
H12. Groundwater Contamination - Pesticides												
H13. Groundwater Contamination - General												
H14. Freshwater Flooding												
H15. Channel Disturbance												

Figure 5: Freshwater Trial: Key Hazard/Receptor Relationships

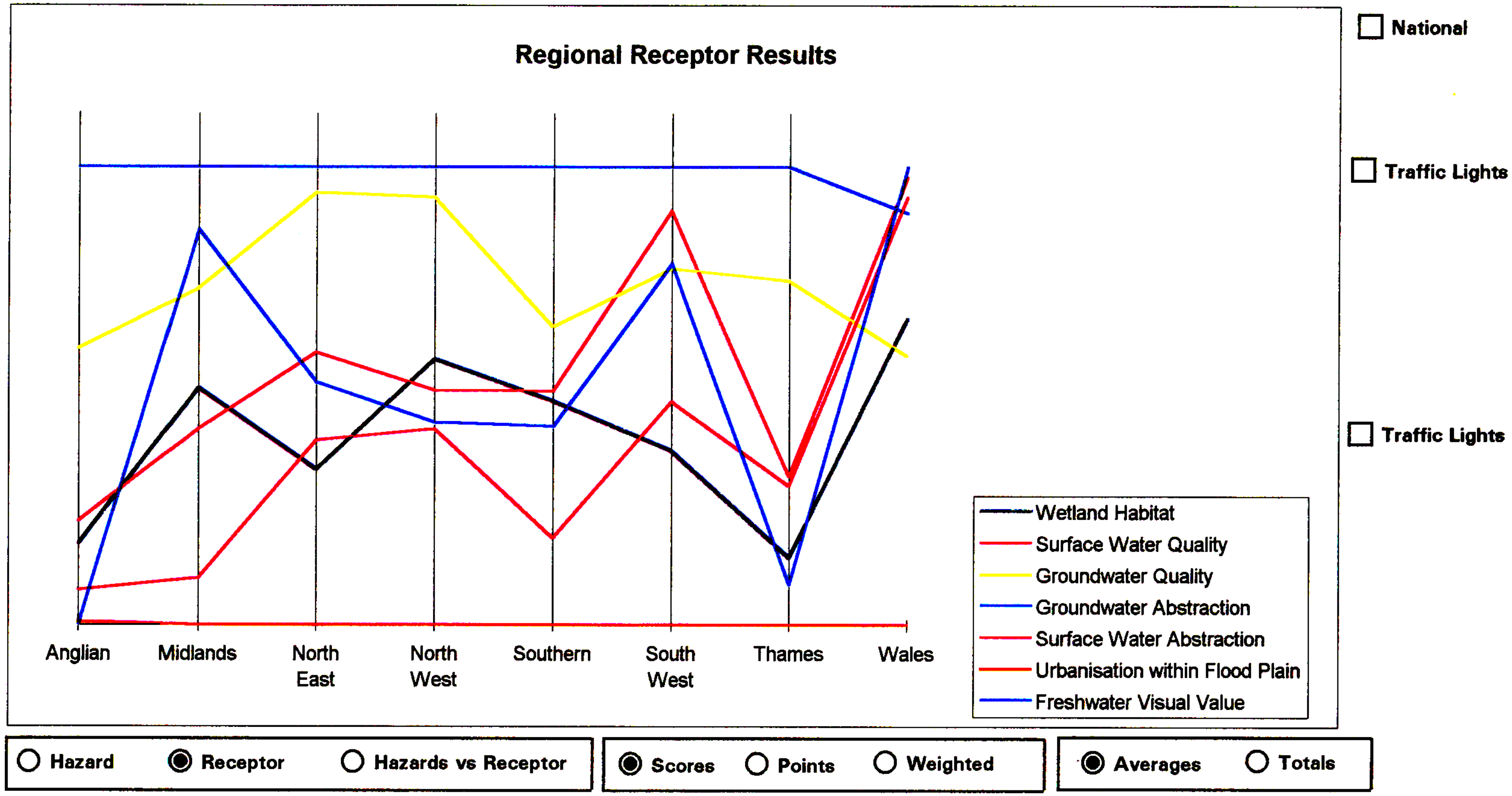

Figure 6: Freshwater Trial: Ranking of Receptors within each Region

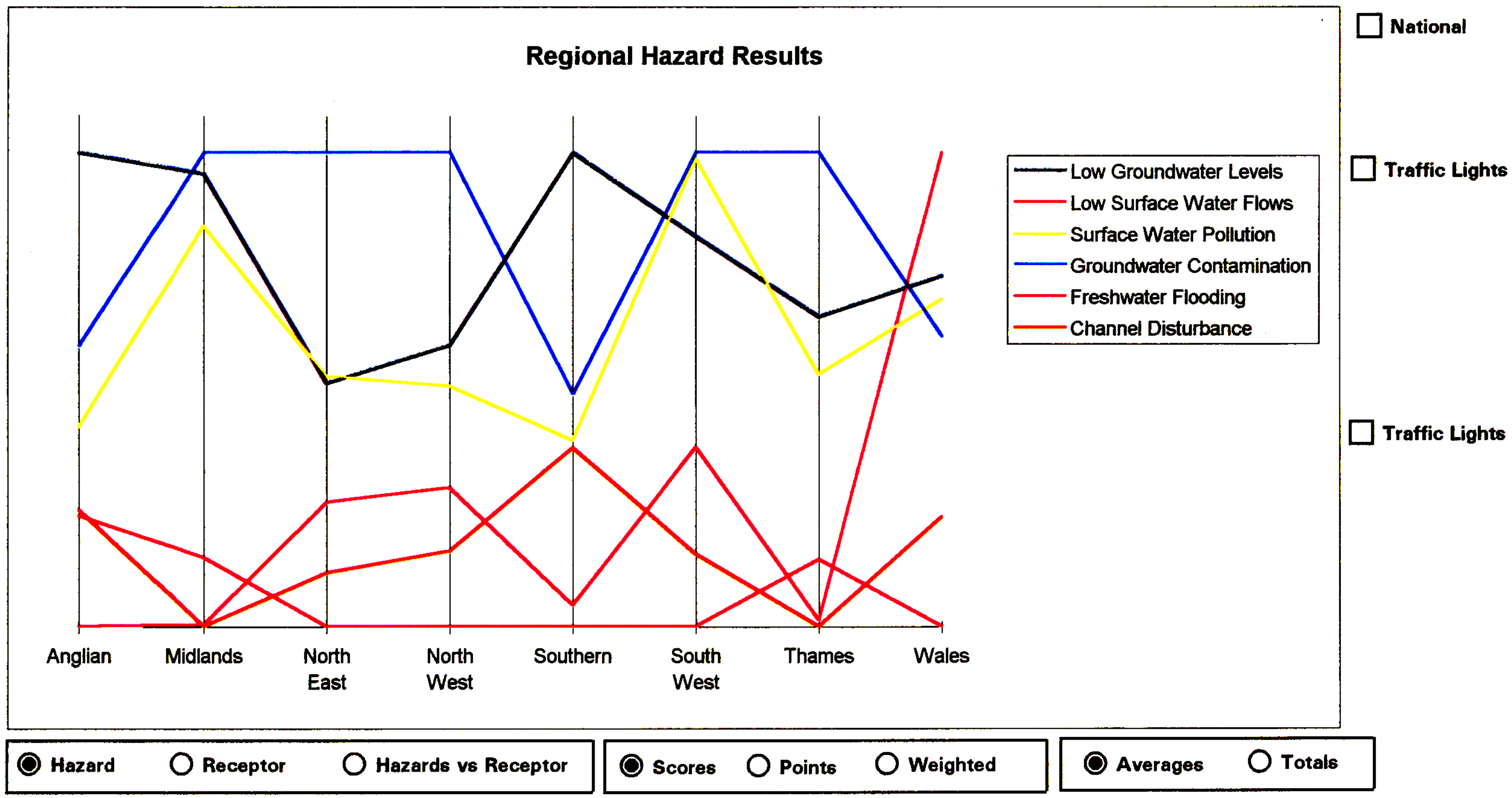

Figure 7: Freshwater Trial: Ranking of Hazards within Regions

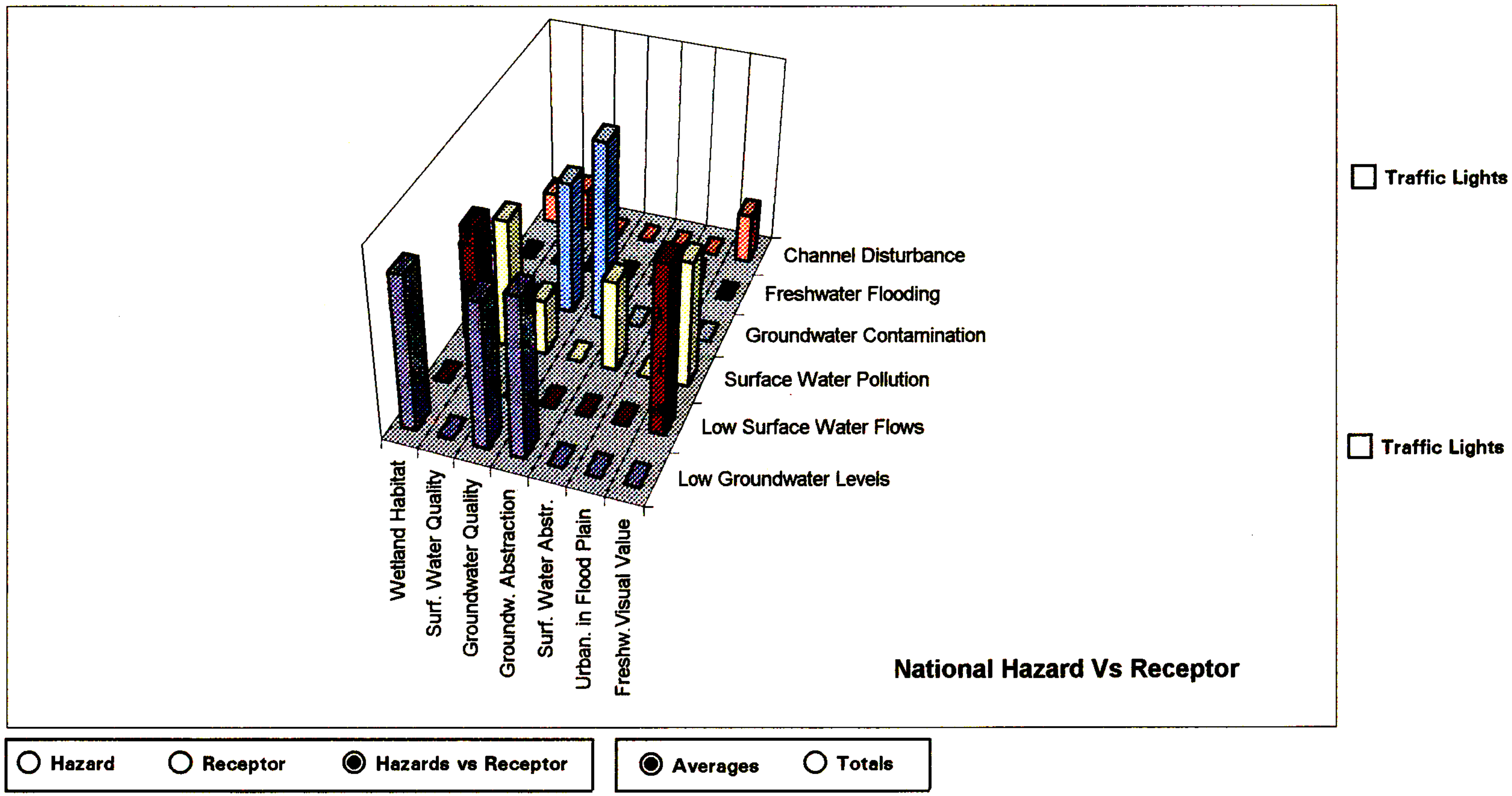

Figure 8: Freshwater Trial: National Harm/Risk Indices

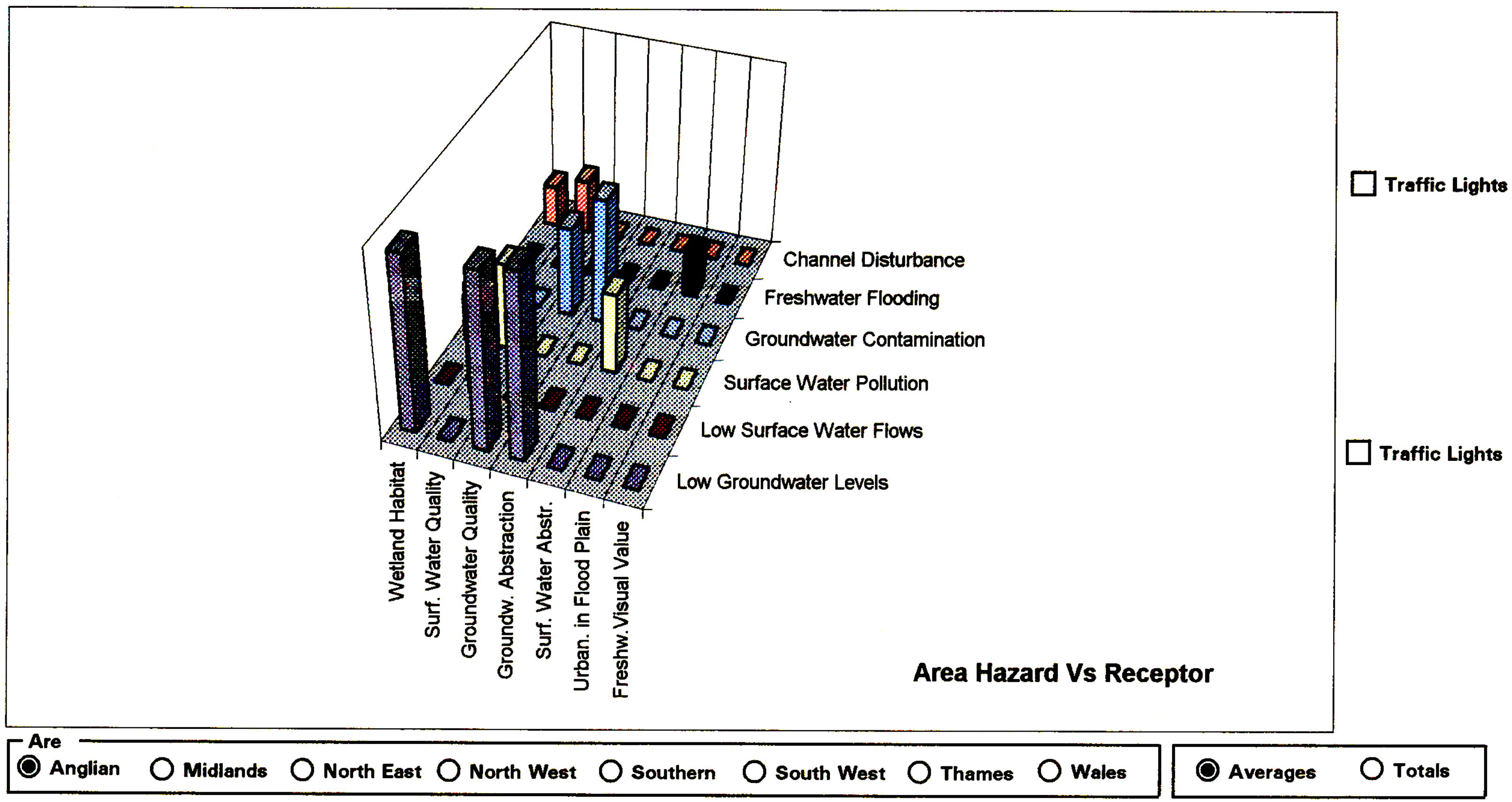

Figure 9A: Freshwater Trial: Harm/Risk Indices for Anglian

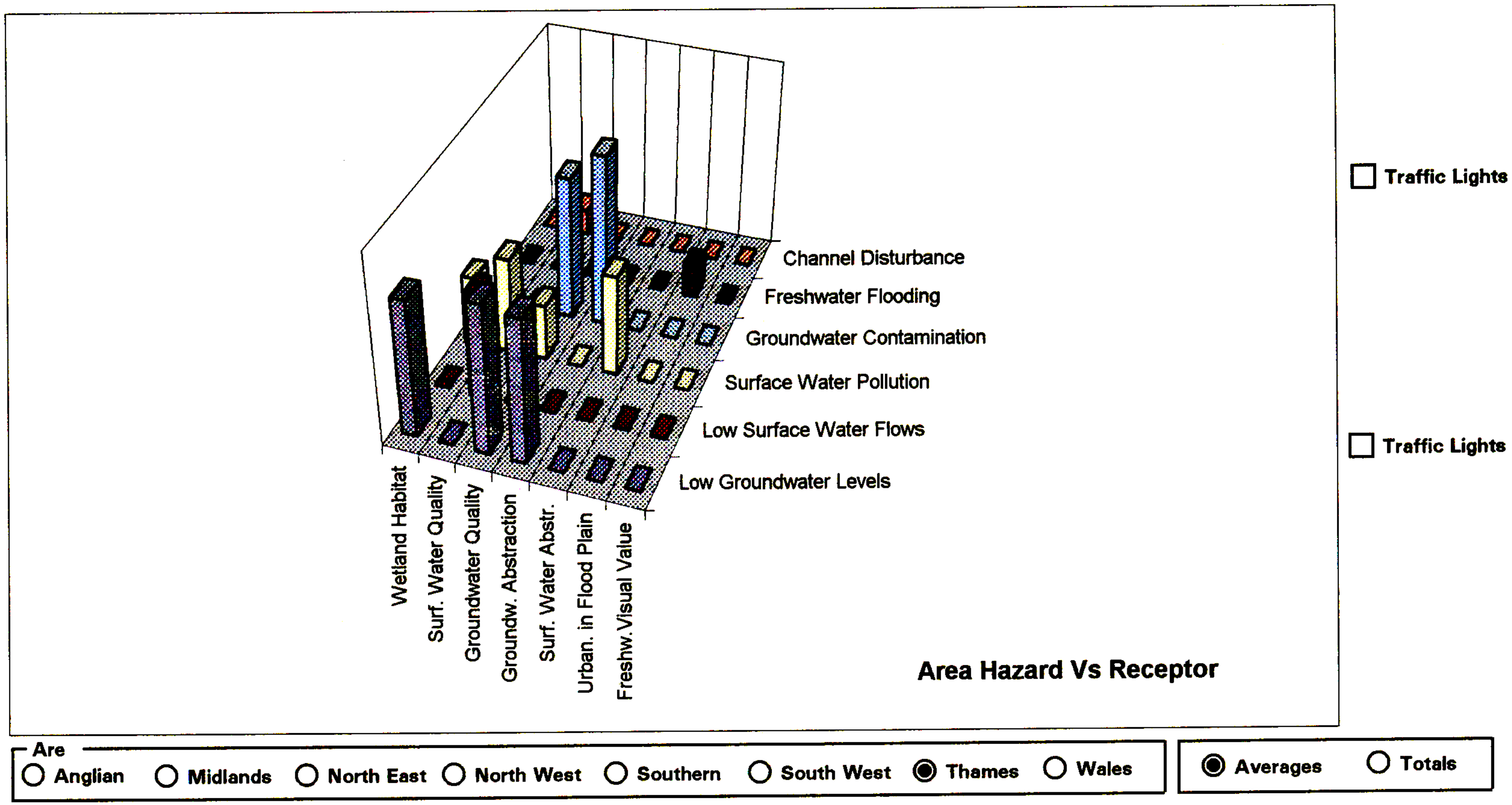

Figure 9B: Freshwater Trial: Harm/Risk Indices for Thames

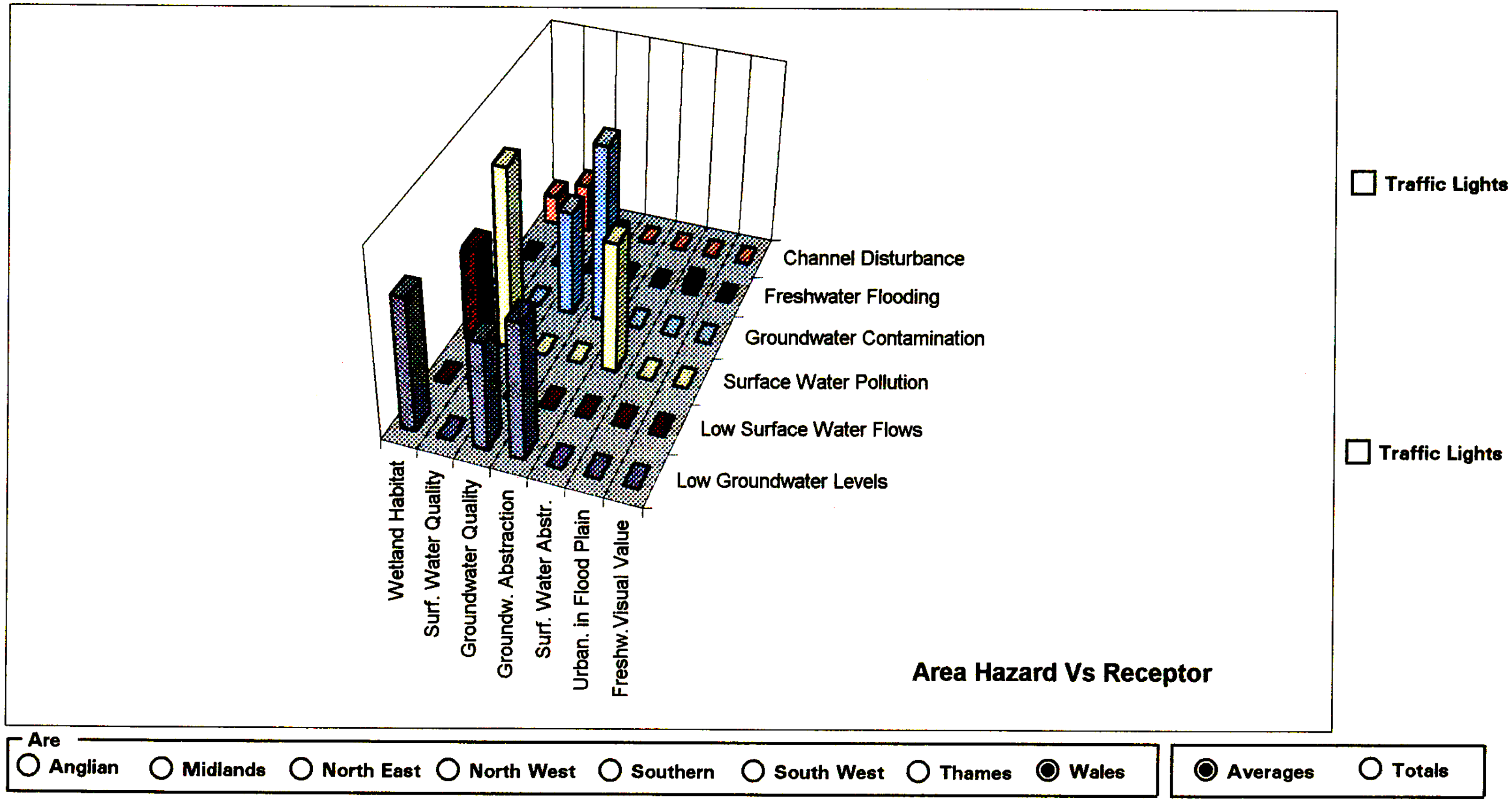

Figure 9C: Freshwater Trial: Harm/Risk for Wales

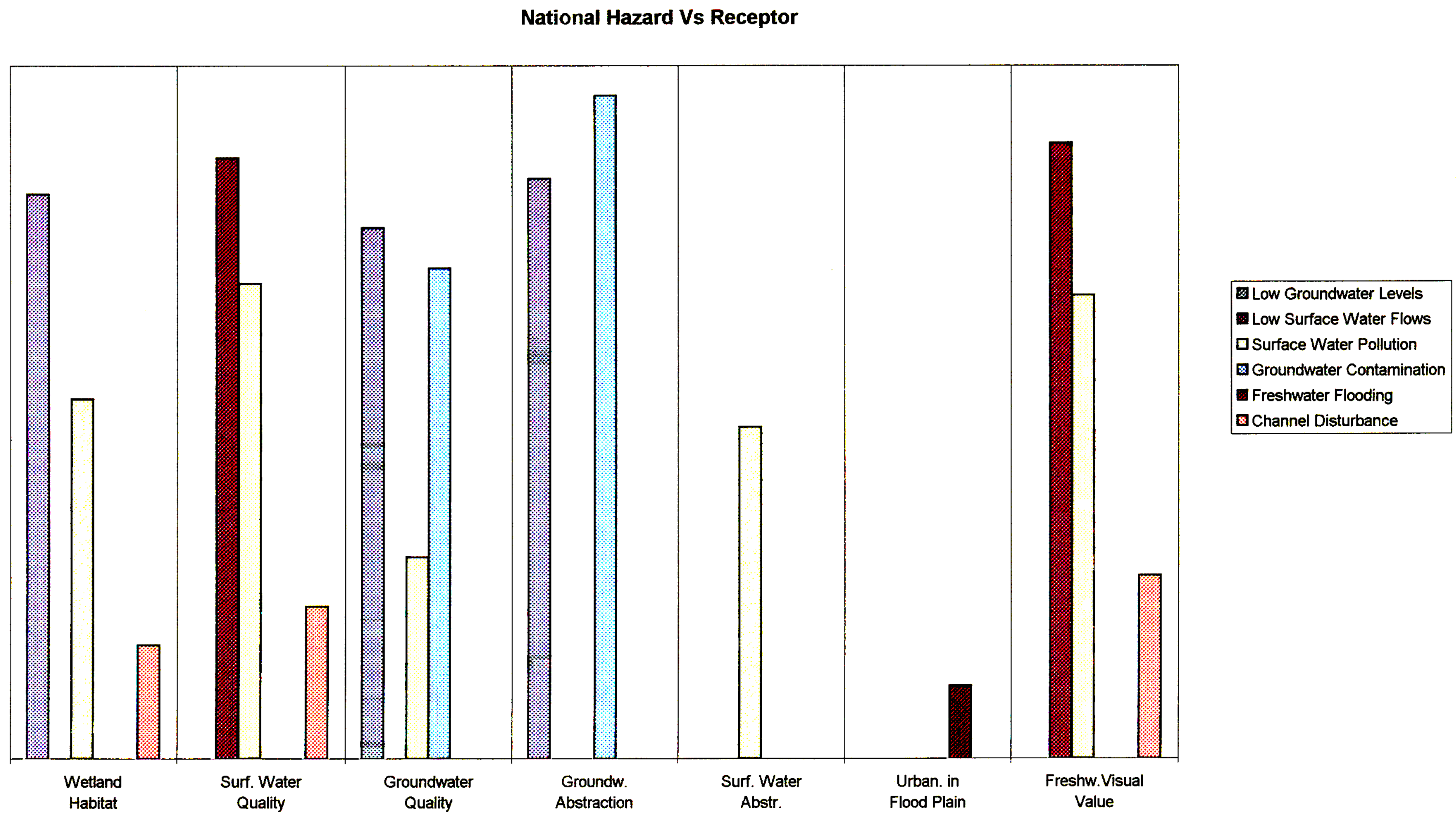

Figure 10: Freshwater Trial: Ranking of Hazards and Receptors Nationally

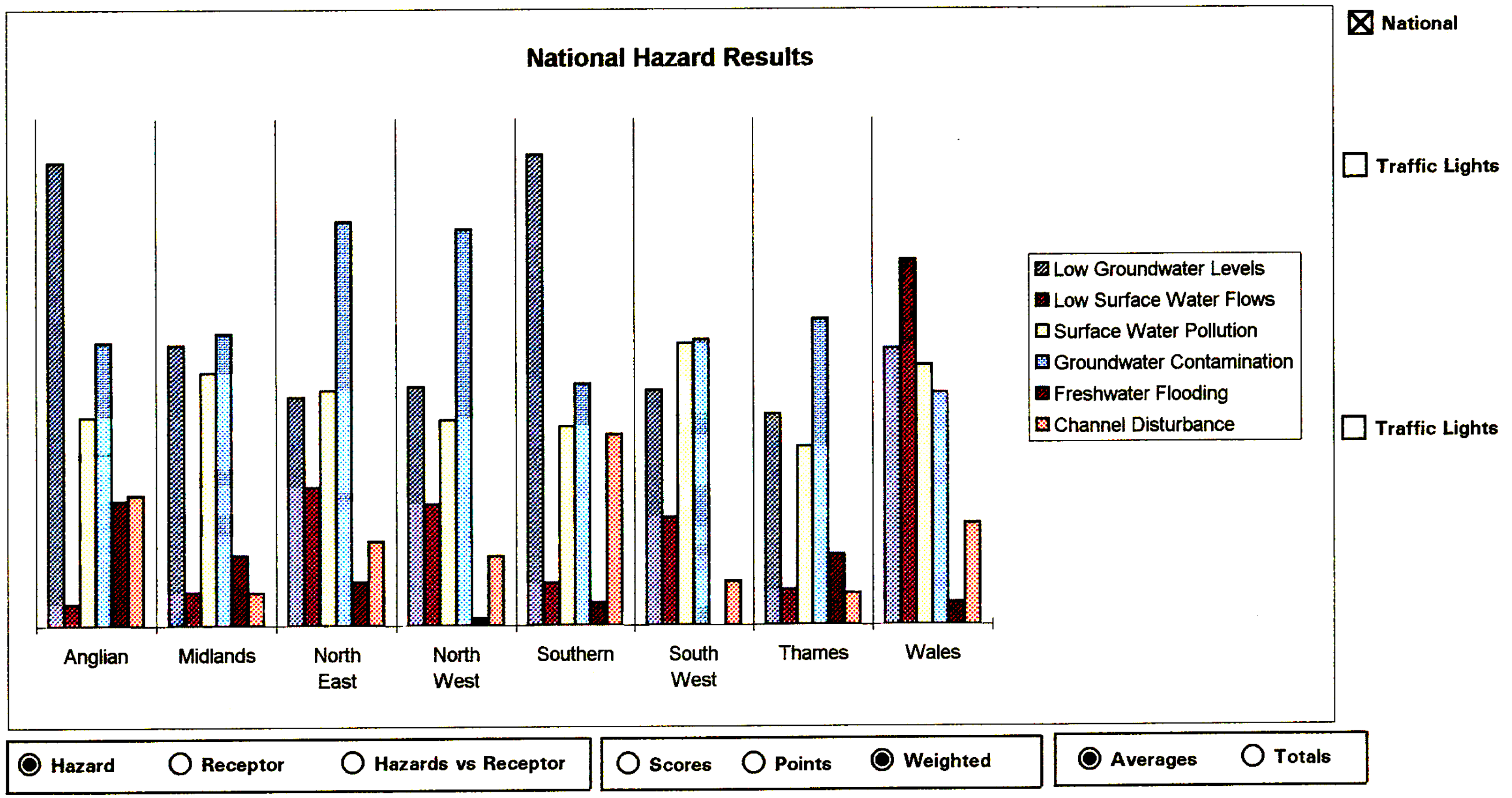

Figure 11A: Freshwater Trial: Ranking of Hazards Across all Regions

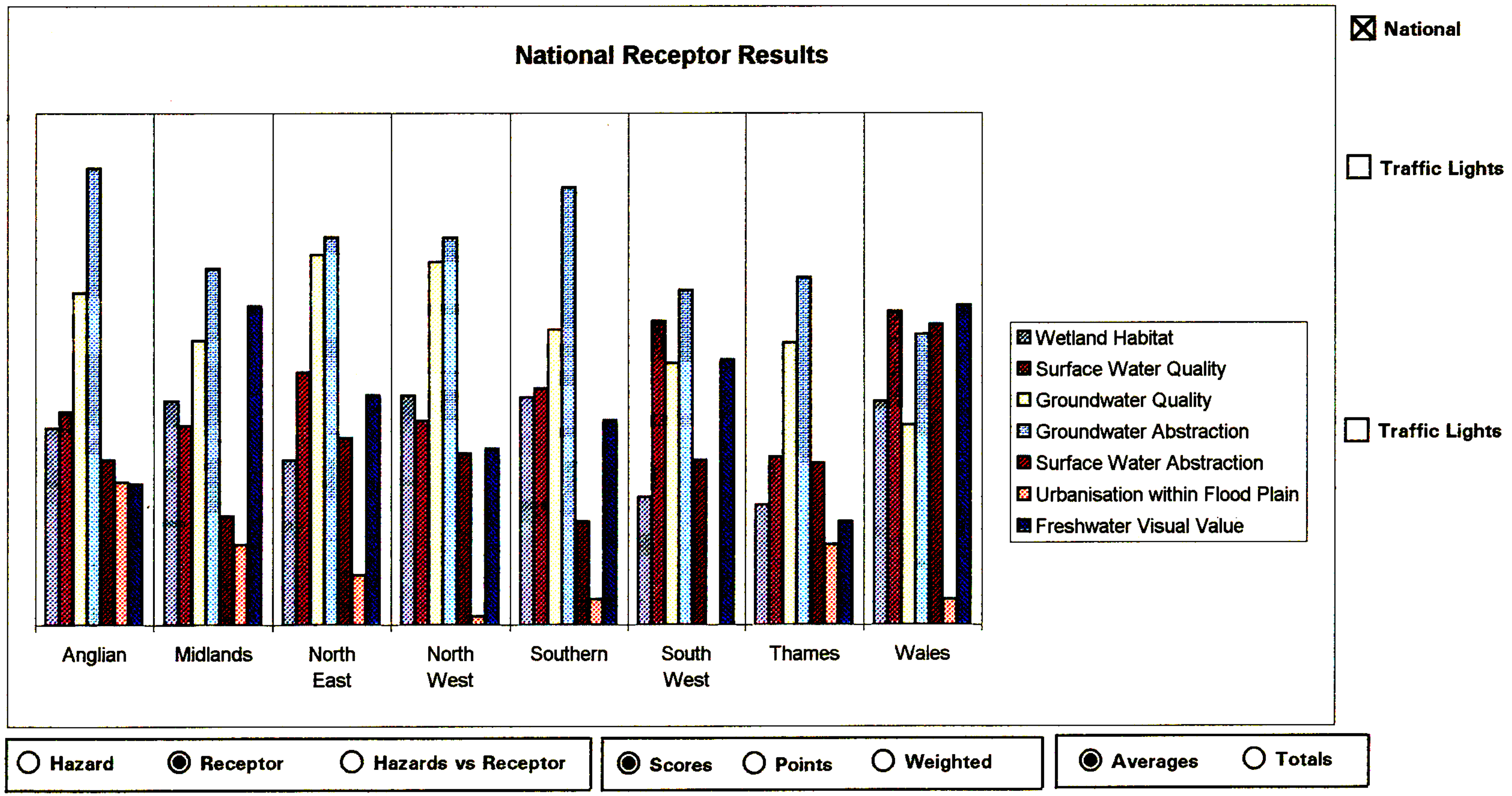

Figure 11B: Freshwater Trial: Ranking of Receptors Across all Regions