

Final Report

Project WFD49

WFD49 (Rivers)

**A new impact assessment tool to support river
engineering regulatory decisions**

Technical Report

Aug 2006

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Dissemination status

Unrestricted

Research contractor

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Use of this report

The development of UK-wide classification methods and environmental standards that aim to meet the requirements of the Water Framework Directive (WFD) is being sponsored by UK Technical Advisory Group (UKTAG) for WFD on behalf its member and partners.

This technical document has been developed through a collaborative project, managed and facilitated by SEPA, Environment Agency and SNIFFER, and has involved the members and partners of UKTAG. It provides background information to support the ongoing development of the standards and classification methods.

Whilst this document is considered to represent the best available scientific information and expert opinion available at the stage of completion of the report, it does not necessarily represent the final or policy positions of UKTAG or any of its partner agencies.

Suggested citation

Greig S.M., Richardson R. and Gibson J. (2006). A new impact assessment tool to support river engineering regulatory decisions: SNIFFER Technical Report. Project No. WFD49.

Executive summary

The purpose of this report is to summarise the work undertaken for SNIFFER (Scotland and Northern Ireland Forum For Environmental Research) project WFD 49 (Rivers), “A new impact assessment tool to support river engineering regulatory decisions“.

The aim of this project was to develop a simple, practical decision support framework for determining, whether:

- (i) New river engineering activity on, or in the vicinity of, a river is likely to result in a deterioration in ecological and morphological quality;
- (ii) The extent of existing morphological alteration within the affected reach is likely to put the water body at risk of failing good ecological status.

Alterations to morphology can have significant impacts on the flora and fauna of rivers. However, our knowledge and understanding of the links between changes in morphology and ecological status are not well developed. More generally, there is no agreed way of looking at the requirements of aquatic organisms for their physical habitat.

There are currently no standards for assessing morphological impacts to rivers caused by human activities. Where regulation occurs, decisions are based on best available evidence and expert judgement.

We have therefore had to use a pragmatic approach to develop a decision-support framework that will help us to assess the risks to ecological status caused by proposed alterations to river morphology. This framework will support consistent and transparent decisions. This method has been developed with relevant experts in the field and we will continue to improve it by seeking further input from those experts and by committing to R&D to support future improvements.

This framework is based on the following concepts:

- A water body has some capacity to accommodate morphological change without changing its ecological status.
- We can set, by expert judgement, limits for changes in morphological conditions beyond which we would be concerned that ecological status would be at risk. (“Morphological conditions” refers to the list of attributes in Annex V of the Directive ie river depth and width variation, structure and substrate of the river bed and structure of the riparian zone.).

The framework relies on the following assumptions:

- There is a relationship between the extent of morphological alteration and the impact on ecological status.
- The response of a water body’s morphology (or the response of part of a water body) to an engineering pressure (or other pressure) is predictable for the type of water body.
- The response of the ecology to morphological change is predictable and depends on the sensitivity of the ecology of the river.

It is recognised that these assumptions require validation and testing.

Morphological conditions are set as limits beyond which we would be concerned that high or good ecological status would be at risk. These limits are expressed in percentage terms as a 'capacity' used. It is assumed that development beyond these limits may compromise ecological status at a local scale and further more detailed assessment is appropriate. These initial limits for morphological conditions will be refined as information from ongoing peer review, public consultation and field testing becomes available. In future, the thresholds will be revised in light of WFD monitoring and targeted scientific research.

To adapt morphological condition limits to different types of channel a "Morphological Impact Assessment Tool" ("MImAS") has been developed. This method takes account of the biological and geomorphological sensitivity of the channel type and the extent, nature and impact of existing modifications to estimate for a particular channel how much of the existing capacity has been used. This can then be used to assess whether new proposals can be permitted or whether they should be subjected to further investigation.

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Section 1

Preparatory information

1.1 Introduction

There are currently no standards for assessing the morphological impacts from engineering and other pressures on channel morphology that can be used to inform regulatory decisions. Where regulation occurs, decisions are based on expert judgement. Nonetheless, the Water Framework Directive requires UK environmental agencies to regulate morphological change to ensure that there is no deterioration in ecological status.

To allow UK agencies to assess whether new river engineering activities are likely to represent a risk of failing good ecological status, there was a requirement to develop a new tool that could be used to screen the risk posed by such activities. By providing an initial indication of the risk posed to river morphology and ecology, this new tool should promote consistent and transparent decision-making when assessing the likely impacts from existing and new engineering activities. However, the tool will not reduce the requirement for site investigations or expert advice. Likewise the tool will not avert attention from wider social and economic issues or sustainable flood management objectives. Rather, the tool is intended to sit within a larger decision-making framework that promotes balanced and proportionate regulatory decisions.

This report describes a new morphological impact assessment tool that is being developed by a team of Scottish Environment Protection agency (SEPA) and Environment Agency (EA) staff and external experts from the fields of geomorphology and freshwater ecology.

The remainder of this report is divided into three key sections (Figure 1). Section 2 provides important preparatory information concerning the drivers for the new tool and context in which it was developed. Section 3 provides a technical summary of the new tool. Section 4 summarises the application of the tool to assess morphological conditions. A set of Appendices provide additional technical information and summaries of the raw data underpinning the tool.

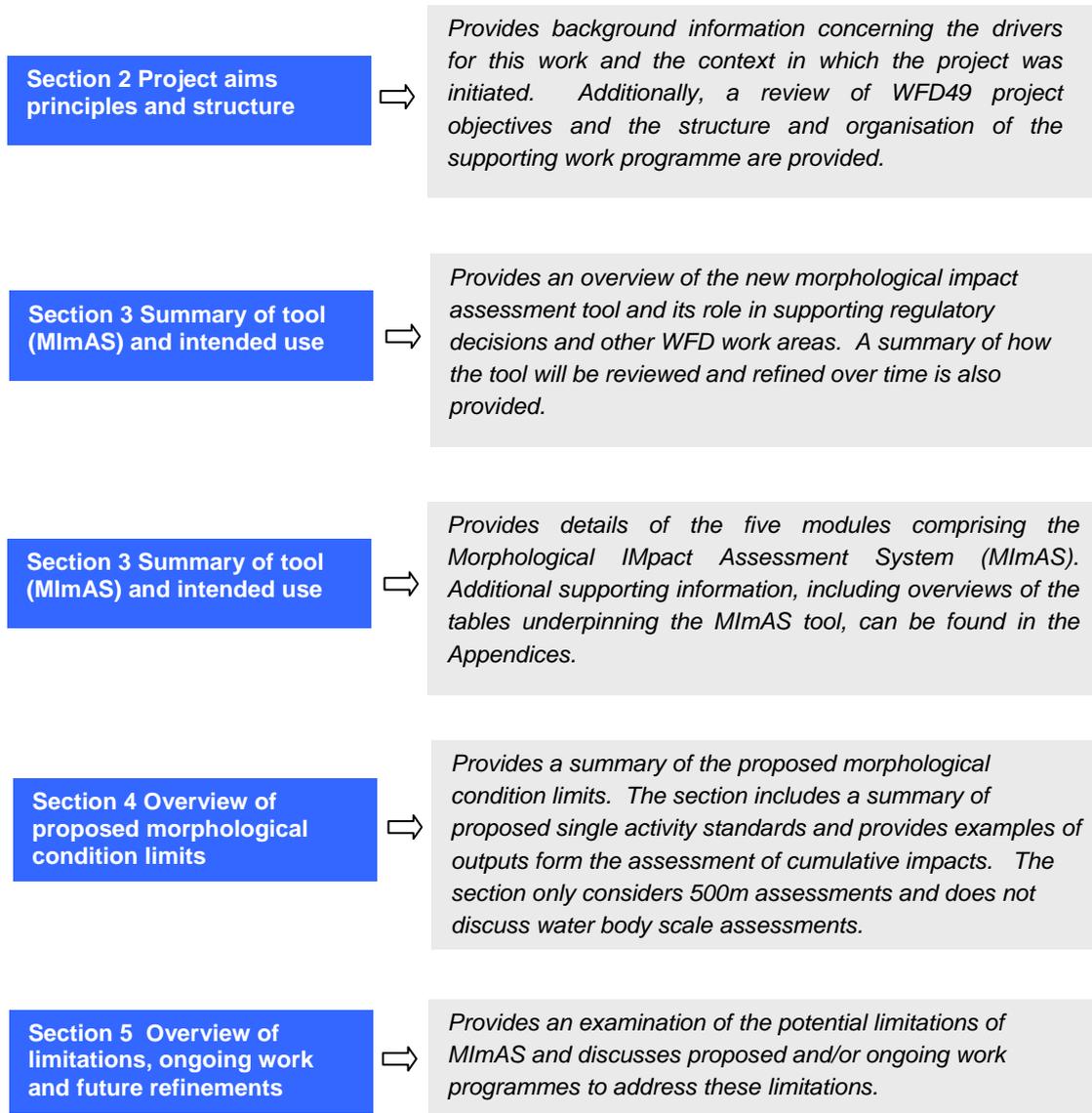


Figure 1. Summary of report content

Section 2

Project aims, principles and structure

2.1 Project aims

The overarching aim of this project was to develop a simple, practical impact assessment tool. Specifically, this tool had to be capable of determining whether:

- (i) A new river engineering activity on or in the vicinity of a surface water is liable to result in a deterioration in ecological and morphological quality;
- (ii) The extent of existing morphological alteration within the affected reach is likely to put the waterbody at risk of failing good ecological status.

2.2 Summary of overarching principles

In consultation with agency staff, UKTAG and the project steering group a set of overarching principles was defined. These principles (shown below in Table 1) were developed to help ensure that the new impact assessment tool was operationally practicable, consistent with other work areas and regulatory regimes and compliant with WFD requirements.

The impact assessment tool was developed in consideration of the following principles

1. *The impact assessment tool should provide a transparent and consistent assessment of the risk of failing good ecological status class posed by existing and future engineering activities.*
2. *The decision support framework must be capable of being used by non-specialists in surface water morphology.*
3. *The tool should be capable of assessing impacts from engineering activities in consideration of pressures within the surrounding catchment.*
4. *Risk will be judged at a local/site scale (500m), and in consideration of potential water body status.*
5. *Rivers will be managed to ensure attainment/protection of relevant WFD objectives, namely;*
 - a. *High status: morphological quality will be protected to ensure minimal human alteration.*
 - b. *Good status: morphological quality will be protected as far as is consistent with the achievement of good status biology.*
 - c. *Moderate status or less: morphological quality will be protected as far as is consistent to avoid deterioration in biological quality and to ensure future restoration potential to a condition consistent with good status biology.*
6. *In many instances, a significant degree of expert judgement will still be required to assess the likely impact of engineering activities on ecological status class.*
7. *To ensure protection of ecologically relevant river processes and features, best available information on the links between ecology and geomorphology will be adopted. Where these links are poorly understood the aim will be to protect geomorphologic processes features, and associated habitats.*
8. *The framework and methods should be adaptable, thus allowing refinement/evolution as knowledge, data and data collection techniques improve.*
9. *Heavily modified and artificial water bodies will not be explicitly considered in this work programme.*

Table 1 Summary of high level principles supporting WFD 49 work

2.3 Project structure

The work presented here was produced and developed by SEPA and EA staff, and in consultation with an external panel of experts (Figure 2). The project was part of a wider UKTAG (UK Technical Advisory Group for the WFD) work programme that was tasked with developing new tools to support implementation of the Directive and associated UK legislation and regulations.

The team of external experts from the fields of geomorphology and fresh water ecology are providing the following input to the project.

- (i) Peer review of the proposed methods, principles and assumptions
- (ii) Specific technical guidance and expert judgement input at key project junctures
- (iii) Final peer review of the proposed morphological condition limits.

The reliance on expert judgment was a result lack of scientific knowledge of the interactions between biota and their physical environment, and the lack of an organised and tested method of interpreting or assessing impacts from human activities on these requirements.

A steering group comprising internal agency staff from other UK environmental agencies (inc SNH) assisted in co-ordination of the project and ensured consideration of links to other UKTAG projects.

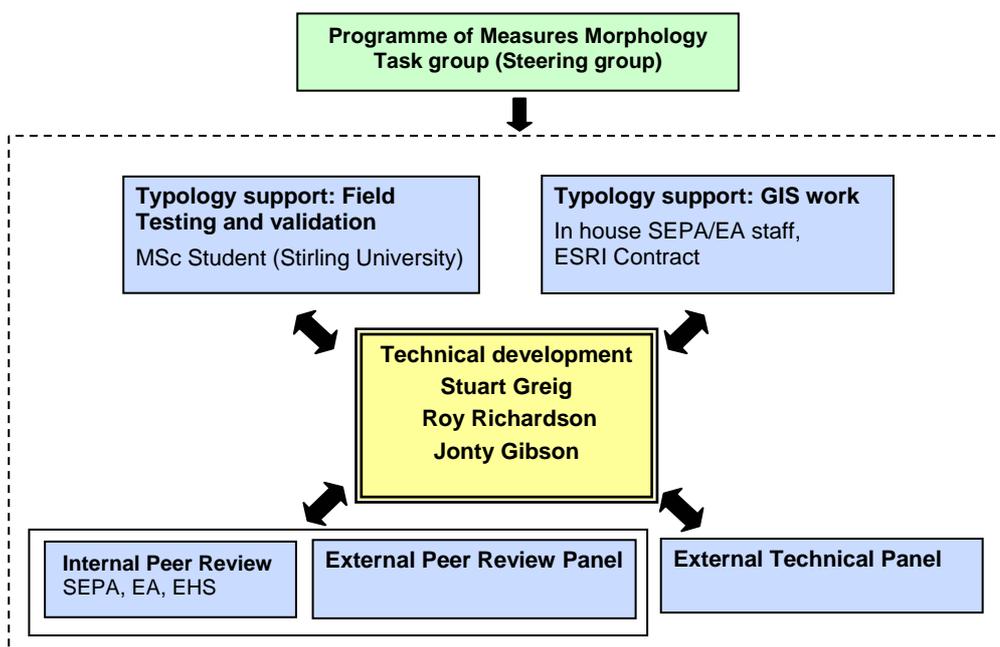


Figure 2 Overview of project set-up and contributors

Section 3

Summary of tool (MImAS) and intended use

3.1 Summary of impact assessment tool

The new impact assessment tool (termed **MImAS- Morphological IMPact Assessment System**) provides a basis for making simple, consistent assessments of likely impacts from engineering activities and subsequently identifying risks of failing to achieve good ecological status.

The tool was developed upon the following principles and assumptions:

- A waterbody has some capacity to accommodate morphological change without changing its ecological status.
- We can set, by expert judgement, limits for changes in morphological conditions beyond which we would be concerned that ecological status would be at risk. (“morphological conditions” refers to the list of attributes in Annex V of the Directive i.e. river depth and width variation, structure and substrate of the river bed and structure of the riparian zone.).
- There is a relationship between the extent of morphological alteration and the impact on ecological status.
- The response of a water body’s morphology (or the response of part of a water body) to an engineering pressure (or other pressure) is predictable for the type of water body.
- The response of the ecology to morphological change is predictable and depends on the sensitivity of the ecology of the river.

The MImAS tool comprises five modules (Table 2 and Figure 3). Details of each module are provided in Section 4. Each module is semi-independent, thereby allowing individual modules to be updated over time as more information becomes available. When integrated, the modules provide information to allow:

- (i) Identification of channel sections that display similar morphologic and geomorphic properties, support similar habitats and biological communities, and respond to pressures in similar and predictable ways,
- (ii) Assessment of the cumulative impact of different engineering activities on relevant geomorphological properties of identified channel sections, and
- (iii) Determination of critical limits for morphological conditions.

Module	Description
<i>Attribute module</i>	Defines a list of attributes used to assess geomorphic and ecological function and condition. These are related closely to the morphological quality elements in Annex V of the Directive. They cover such things as the condition of the channel substrate and the rate of channel migration. Each attribute in this module has been chosen for its role in directly supporting ecological communities (for example, the structure and extent of riparian vegetation), or for its role in supporting the processes needed to create and maintain the physical environment on which ecological communities depend.
<i>Typology module</i>	Identifies channel sections of similar physical character that respond to pressures in predictable ways. The typology reflects the presence and character of the attributes identified in the Attribute Module, their relative ability to absorb change (resistance), and their ability to recover from change (resilience).
<i>Sensitivity module</i>	Comprises two elements. First it considers the generic sensitivity to external pressures of each of the above attributes within each river type. For example, how likely is it that an attribute (such as bedform pattern) will change in response to an applied pressure (such as embankments) within each of the six river types? Second, this module considers the sensitivity of the Directive's biological quality elements to changes in each of the attributes. Again, this is done on a type-specific basis. Sensitivity is assigned on the basis of three categories (insensitive, sensitive and highly sensitive) and is defined in terms of both resistance (ability to absorb change) and resilience (ability to recover from change).
<i>Pressure module</i>	Defines the likelihood that an activity or pressure will have an impact on a given attribute, and whether or not that impact will be localised (contained within the footprint of the pressure), or be extended beyond this. Twenty pressures have been identified for this module. They range from local pressures such as 'hard' bank protection and in-stream structures, to extensive pressures such as the disturbance of the sediment regime of the catchment. The Pressure Module is not type specific. The difference in response to the pressures between types is captured in the Sensitivity Module.
<i>Scoring Module</i>	Combines the information from the above Modules to calculate the capacity used by the combination of pressures.

Table 2 Summary of modules comprising the MImAS tool

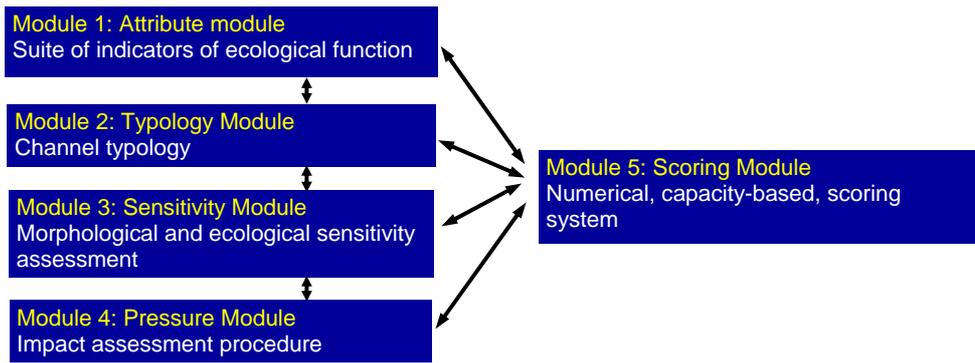


Figure 3 Overview of the Morphological Impact Assessment System (MImAS).

The five modules combine to determine the total impact on a given section of channel. All impacts are quantified in terms of an impact on ‘system capacity’. By determining how much of a systems capacity is used up by different pressures, it is possible to determine the total level of impact on a system at any point in time.

Morphological condition limits define permissible levels of impact on a system’s available capacity that are believed to be compliant with the attainment of high and good ecological status (Figure 4). These limits are expressed in percentage terms as a ‘capacity’ used. It is assumed that development beyond these limits may compromise ecological quality at a local scale and further more detailed assessment is appropriate. The limits discussed in this document were defined in consultation with the external technical panel and peer review panel. However, work is ongoing to field trial these limits. Thus, these limits are currently in draft form and may be amended based on the outputs of this work.

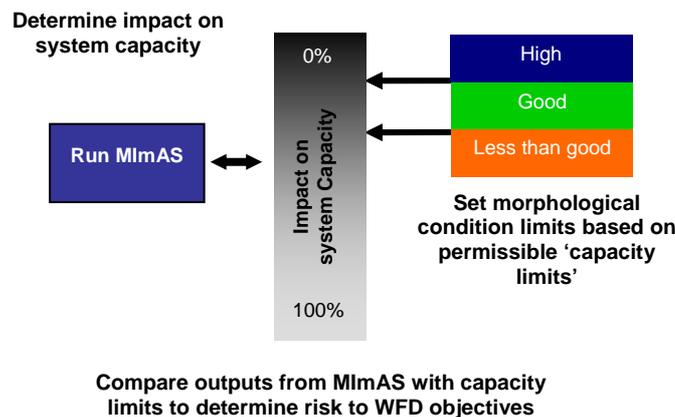


Figure 4 Summary of capacity-based system and links between MImAS and morphological condition limits

Figure 5 provides a breakdown of stages involved in developing (i) the modules, (ii) the scoring system that links the modules and (iii) defining the morphological condition limits. Also highlighted in Figure 5 are the stages where the external panel of experts were consulted for technical advice and peer review. With explicit links to the steps described in Figure 5 the sections 4.1 to 4.5 provide an overview of the work supporting the development of the MImAS and the morphological condition limits. More detailed supporting information can be found in the Appendices.

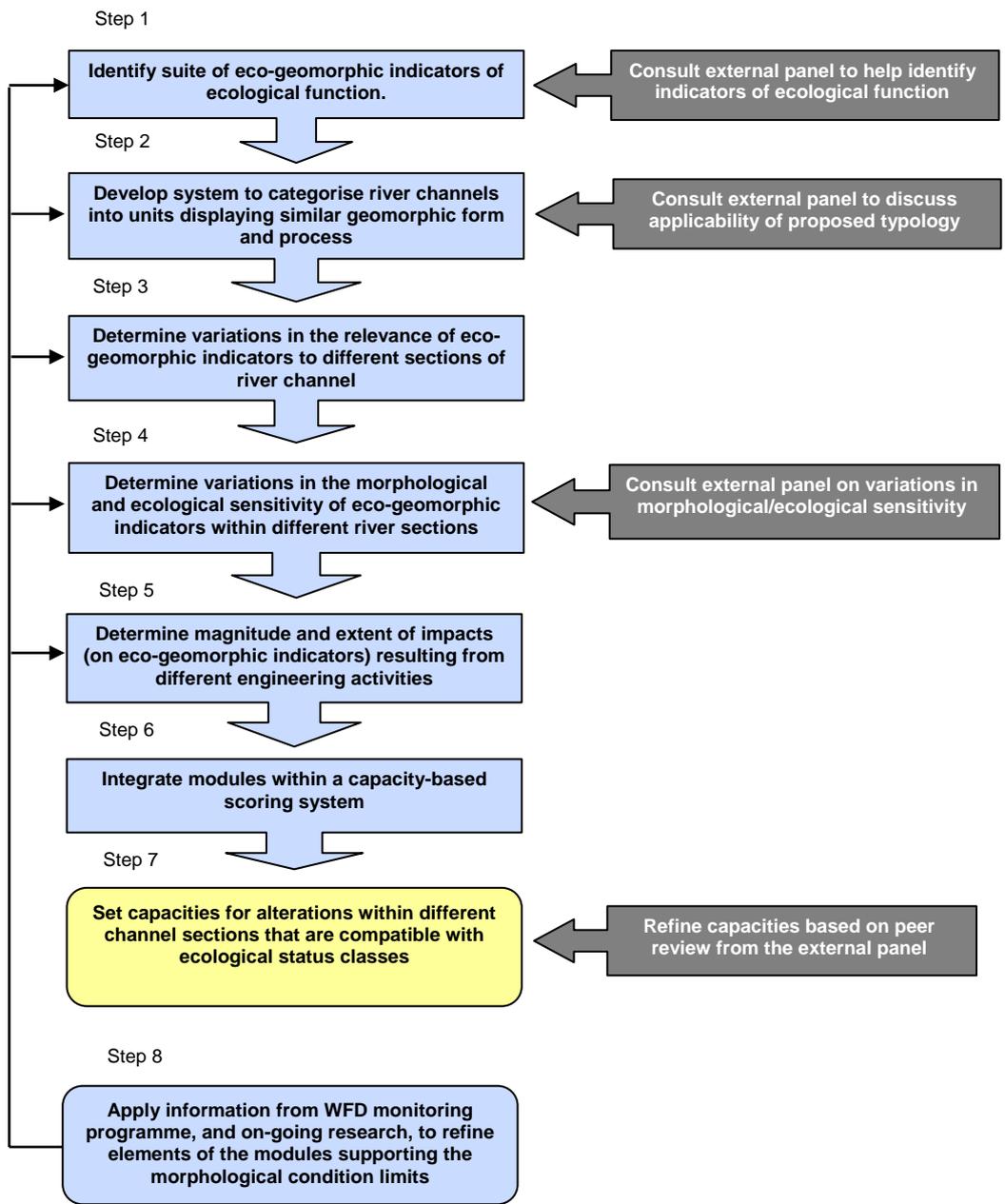


Figure 5 Summary of steps involved in determining morphological condition limits. Also highlighted are contributions from the external panel of experts.

3.2 Intended use of MImAS tool

3.2.1 Informing regulatory decisions

The MImAS tool provides a means of undertaking transparent and consistent assessments of new (and existing) river engineering activities. The intention is to use this tool to identify proposals that would potentially put ecological status at risk. Such proposals could then be subject to a more detailed assessment, which would consider wider flood management objectives and socio-economic concerns.

The legislation supporting WFD implementation varies across the UK. Thus, it is likely that the tool would be applied within a different decision making process within each UK Environmental Agency. However, to provide an indication of how the tool could be used to support regulatory decisions, Figure 6 summarises a hypothetical regulatory process and potential role of the MImAS tool. This figure is not intended to demonstrate any current or future regulatory regime, and is only supplied to emphasise the potential role of the tool within the context of regulatory decision making process.

Capacity thresholds are independent of channel length and the tool can be used to assess conditions across a range of spatial scales. For regulatory decisions the tool will normally be applied over a fixed river length of 500 metres. Where an application for a new modification has an impact on river length that exceeds 500 metres it is intended that the assessment would be carried out over multiples of 500 metres. To determine whether an activity presents a risk to the ecological status of water bodies, there may be a requirement to apply the tool to assess the morphological condition of water bodies.

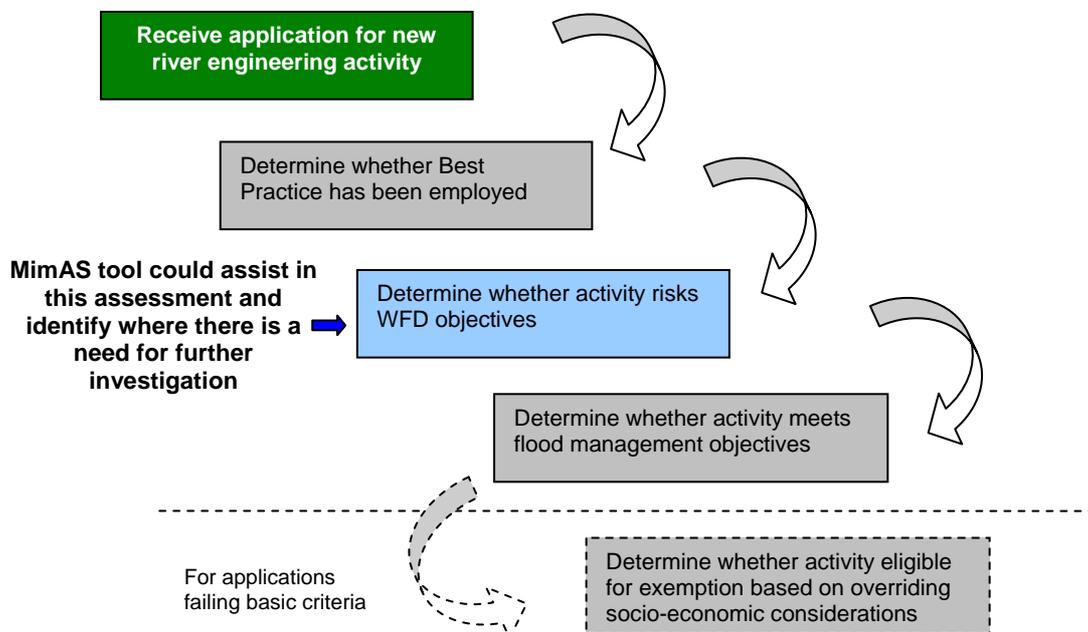


Figure 6 Summary of generic regulatory process and potential role of MImAS tool.

3.3 Overview of ongoing work and future refinements

The MImAS tool has been developed to operate within an 'adaptive management' framework that will rely on WFD monitoring and ongoing R&D to test the assumptions, principles and expert judgment underpinning the tool (Figure 7). This information could then be used to validate and calibrate the tool and morphological condition limits.

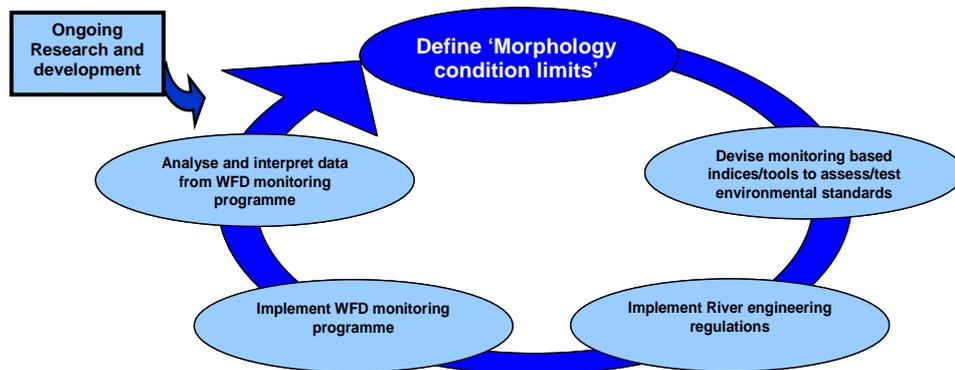


Figure 7 Application of MImAS tool and morphological condition limits within an adaptive framework

Section 4

Technical Details of MImAS tool

The following section provides details of the five modules that comprise the Morphological Impact Assessment System. The steps listed below refer to those shown in Figure 5.

4.1 Attribute Module (Step 1)

One of the fundamental assumptions underpinning the morphological condition limits is that geomorphic processes and attributes provide a dynamic template that supports the structure and function of river ecosystems (Thomson *et al.*, 2004; Harper and Everard, 1998; Harper *et al.*, 1998; Newson and Newson, 2000). Therefore, if consideration is given to factors influencing both geomorphic and ecological functioning, it should be possible to select a suite of quantifiable physical riverine attributes that can be used to assess impacts on geomorphic river condition and functioning, and provide a relevant signal about the impacts on ecosystem structure and function.

To aid selection of a suite of indicators of ecosystem function and form that could be used to assess geomorphic and ecological function and condition, it was first necessary to identify a generic set of physical attributes and processes that influence ecosystem function and form (Box 1). These attributes and processes are similar in principle to the 'vital ecosystem attributes' suggested by Aronson *et al.* (1995), the geo-indicators adopted by Fryirs (2003), and the indicators of ecosystem health suggested by McBain and Trush (1996). Together, it is proposed that these attributes and processes generate a natural and dynamic physical riverine environment that support and sustain a diverse and dynamic functioning ecosystem. In selecting these attributes, consideration was given to relevant ecological concepts, including patch dynamics, disturbance regimes, and meso and functional habitats (Wu and Loucks, 1995; Pardo and Armitage, 1997; Pringle *et al.* 1998; Padmore, 1998; Newson *et al.*, 1998; Brunke *et al.*, 2001; Poole, 2002).

In consideration of these critical habitat attributes, geomorphic processes, WFD hydromorphological quality elements and CEN guidance standards for morphology, a suite of eco-geomorphic attributes has been developed. These indicators of ecosystem function and form are listed in Table 4.

The WFD hydromorphological quality elements are:

1. River continuity
2. River depth and width variation
3. Structure and substrate of the river bed
4. Structure of the riparian zone

For high status classification, explicit consideration of these morphological quality elements is required (Table 3). The suite of eco-geomorphic indicators of ecosystem function and form are consistent with WFD normative definitions and compatible with CEN guidance standards.

In natural ecosystems, physical factors interact with ecological (population dynamics, feeding patterns) and chemical factors and processes. These interactions result in complex ecological responses. In its present form, the MImAS tool only considers how physical alteration to river form and process (morphology) affect riverine ecology. New ecological classification tools, which will consider these complex ecological interactions, are currently under development.

Status	River Continuity	Morphological Condition
<i>High Status</i>	The continuity of the river is not disturbed by anthropogenic activities and allows undisturbed migration of aquatic organisms and sediment transport.	Channel patterns, width and depth variations, flow velocities, substrate conditions and both the structure and condition of the riparian zones correspond totally or nearly totally to undisturbed conditions.
<i>Good status and below</i>	Conditions consistent with the achievement of the values specified for the biological quality elements.	Conditions consistent with the achievement of the values specified for the biological quality elements.

Table 3 Summary of WFD status criteria for morphology

Morphologic and habitat attributes

Attribute 1 Natural range of flow and morphological features

No single segment of channel bed provides habitat for all species, but the sum of channel segments provides high quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities. When considering the availability of habitats, the influence of habitat patch size and the presence of edge habitats. Larger habitat patches have been shown to support higher species richness, similarly, edge habitats, which display distinct hydrological and morphologic character, create important niche habitats.

Attribute 2 Refuge habitat zones

Organisms frequently utilise areas of the channel and floodplain that provide protection and shelter from disturbances or predation. These 'refuge areas' are therefore critical components of functioning river systems of refuge zones will affect an ecosystems ability to recover from to natural riverine processes. Examples of refuge zones include areas of the channel and floodplain that display greater resistance to disturbances, and/or zones of cover from predation.

Attribute 3 Self sustaining diverse riparian plant communities

Natural woody riparian plant establishment and mortality, based on species life history strategies, culminate in early and late successional stand structures and species diversities (canopy and understorey) characteristics of self sustaining riparian communities common to regional unregulated river corridors.

Attribute 4 Presence, abundance and distribution of in-channel vegetation

Natural channel vegetation including macrophytes and woody debris is an integral component of a functional ecosystem. In addition to their intrinsic value, macrophyte vegetation providing cover for other aquatic species, and stabilize gravels. Woody debris helps create 'forced' morphological features, including scour pools and riffles, stabilises channels and promotes overbank flow and connectivity with floodplain, and promotes the surface-subsurface exchange of water.

Attribute 5 Habitat connectivity

In addition to simple presence of habitats, a healthy functioning ecosystem requires that biota can migrate between habitat patches. These migrations may be linked to feeding or behavioral requirements, and/or changes in life stage requirement and/or recolonisation pathways, possibly after a disturbance.

Geomorphic processes and disturbance patterns

Process 1 Natural disturbance regime

All ecosystems evolve within a disturbance regime. In rivers, most disturbances are linked to high flow events that create, alter and destroy morphological features, and redistribute biota. However, other disturbances, including debris flows, inputs of coarse woody debris and droughts or low flows, also contribute to the disturbance that underpins a functioning ecosystem. The intermediate disturbance hypotheses suggests that maximum biodiversity is maintained through a intermediate disturbance regime, measured both in terms of frequency and magnitude of disturbance. * However, this model does not consider species interactions.

Process 2 Mobilisation of channel bed surface gravels

Channel bed particles of alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years. Mobilisation of surface gravels promotes cleansing of fine sediments from surface gravels, which increases the exchange of oxygenated surface water with the riverbed. Furthermore, mobilization of surface gravels reduces surface gravel compaction, which further enhances surface-subsurface exchange processes and maintains the ecological functionality for salmonid spawning.

Process 3 Periodic channel bed scour

Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3 year annual maximum flood recurrences. This scour is typically accompanied by re deposition, such that net change in channel bed topography following a scouring flood usually is minimal.

Process 4 Infrequent channel resetting floods

Single large floods (e.g. exceeding 10-20yr recurrences) cause channel avulsions, rejuvenation of mature riparian stands to early successional growth stages, side channel formation, and maintenance and creation of off-channel wetlands (e.g. oxbows). Resetting floods are as critical for creating and maintaining channel complexity as lesser magnitude floods.

Process 5 Balanced fine and coarse sediment budgets

Dependant on location within the catchment, reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment within a river reach fluctuates, but also sustain channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity; most particle sizes of the channel bed must be transported through the river reach.

Process 6 Channel migration

The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers having similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber. Channel migration creates important marginal habitats, promotes growth of complex riparian vegetation and acts to supply sediment to the river.

Process 7 Hyporheic flows and conditions within the hyporeos

The continual exchange of surface water with riverbed controls a series of bio geomorphic processes, including replenishing de oxygenated interstitial waters, removing harmful toxins (e.g metabolic waste) from the riverbed, promoting cycling of nutrients and generally creating conditions within the interstitial environment that is conducive to maintenance of a healthy functioning hyporeos.

Process 8 Connected and functional floodplain

On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar river channels. These floods also deposit finer sediment onto the floodplain and low terrace. Flows to and from the floodplain allow fish and other biota to access the diverse floodplain food and habitat resources. Furthermore, flows transport of important nutrients between the floodplain and the river channel, promote deposition of fine sediments and help maintain floodplain habitats, including standing waters and wetlands.

BOX 1 Summary of indicators of ecosystem health

Eco-geomorphic attributes	Definition	Link to ecosystem attributes and processes	
		Attributes	Processes
Channel zone			
<i>Hydraulic geometry</i>	<i>Describes the size and shape of the channel</i>		
Planform	Spatial pattern and location of a channel, as viewed from above	ALL	ALL
Cross section	The cross sectional form of the channel (width-depth)	ALL	ALL
Profile (Slope)	Slope of the channel bed and the variation of that slope	ALL	ALL
<i>Substrate condition</i>	<i>Describes the size, structure and sorting of riverbed gravels</i>		
Substrate size	The size distribution of surface gravels	1, 4	2
Embeddedness	The extent to which framework gravels are covered or sunken into the silt, sand, or mud of the riverbed.	1, 4	7
Compaction	A measure of the degree of sediment imbrication and, potential mobility under normal flow conditions	1, 4	1, 2, 3,
<i>Erosion/deposition character</i>	<i>Describes trends in sediment, mobilization, transport and deposition</i>		
Lateral rate of adjustment	The extent and rate at which a channel can move in the river corridor	1, 2, 3,	1, 6, 8
Bar character	Size, distribution and stability of natural deposition features.	1, 2, 5	
Bedform pattern	Topography of the riverbed and bed features.	1, 4, 5	7
<i>In-channel vegetation</i>	<i>Describes the presence and distribution of vegetation features</i>		
Structure and extent of instream vegetation	The character and density of aquatic and terrestrial vegetation,	1, 2, 4	
Structure and extent of Woody debris	The character and density of large woody debris, linked to geomorphic structure and flow patterns	1, 2, 4, 5	1, 2, 3, 7
<i>Continuity</i>	<i>Assess artificial barriers to flow, sediment and migratory movement</i>		
Migratory movement	Ability of aquatic organisms to migrate freely through the channel	1, 5	
Sediment transport	The transport capacity of the channel. A measure of the competency of a channel to transport sediment.	1,	5
Floodplain connectivity	Ability of the channel to flood the adjacent land	1, 3, 5	5, 8
Banks and Riparian zone			
Bank morphology	The shape and character of the bank and presence of erosion features	1, 2, 3	8
Riparian vegetation structure	The character and density of vegetation, linked to geomorphic structure and flow patterns.	1, 2, 3, 4, 5	1, 5, 6, 8
Bank roughness	The roughness of the channel banks (includes consideration of materials and presence of vegetation).	1,	1

Table 4 Summary of eco-geomorphic indicators of ecosystem health.

4.2 Development of a channel typology (Steps 2 and 3)

4.2.1 Introduction: Purpose of typology

Geomorphic channel typologies can provide a basis for identifying channel sections that display similarities in morphological attributes and processes, support similar habitats and biological communities, and respond to pressures in similar and predictable ways (e.g. Kondolf 1995; Montgomery; 1999; Brierely and Fryirs, 2000).

However, the limitations of channel typologies must also be recognised. For instance, channel typologies impose artificial boundaries on a continuum of features. Also, channel typologies based on map derived variables can not consider localised controls on channel form, hence the ability of the typology to accurately predict channel features can be limited. Finally, channel typologies are simplified representations of a complex suite of process and interactions, hence they should only be considered as a means of predicting likely channel form, and should not be considered as providing an accurate representation of all channel features present in a given river section (Kondolf, 1995).

Within MImAS, the channel typology is used to predict the likely presence and character of channel features, particularly those features relating to eco-geomorphic attributes and processes outlined in Box 1. Additionally, by linking the channel typology to the sensitivity assessment described in Section 4.3, the channel types can be grouped into a smaller subset of channel types that, for the purposes of regulation and classification, are likely to display similar sensitivities in terms of pressure-impact responses. Likewise, an assessment of the sensitivity of individual eco-geomorphic indicators within different channel types can also be undertaken. This allows assessment of variations in the sensitivity of individual eco-geomorphic attributes within different channel types (Figure 8).

Combining this assessment of sensitivity (Section 4.3) with the impact assessment procedure (Section 4.4), allows assessment of the overall likelihood that an activity will affect the morphological and ecological character of a section of river.

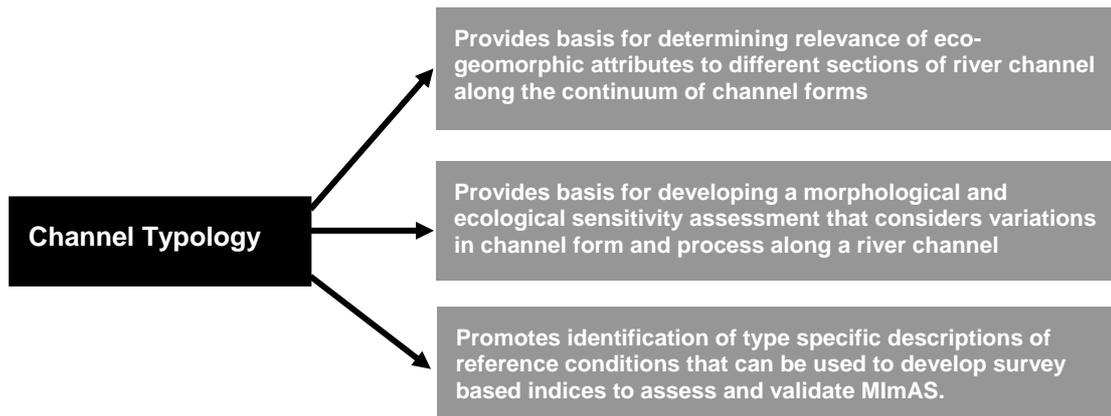


Figure 8 Summary of roles for the channel typology within MImAS

4.2.2 Summary of principles underpinning the typology

The typology adopted to support MImAS is process-based and reflects variations in sediment transport and supply (Montgomery and Buffington, 1997). The typology is based upon a system developed in North America, and has been applied extensively in North American and Australasian river management (Hogan *et al.*, 1996; Snelder *et al.*, 1999; Kline *et al.*, 2004).

A process-based typology was selected as they are better able to assess channel condition, response potential and relationships to ecological processes. The typology expands on Schumm's (1977) principles of erosion, transport and deposition, and proposes that distinctive channel morphologies reflect the relative magnitude of transport capacity to sediment supply. In brief, different channel types are stabilised by different roughness configurations that provide resistance to flow. Thus, in addition to general correlations between channel slope and morphology, the Montgomery and Buffington (1997) typology also allows for identification of channel types based on systematic trends in roughness for a given slope. In essence, the typology focuses on characterising variations in channel form that reflect variations in channel processes along the river continuum.

The typology focuses on characterising reach scale channel units (10^3 - 10^4 m). Each channel type represents a natural channel form and does not consider artificial or anthropogenically altered channel states. By focusing on natural channel types, the typology is consistent with the WFD's requirement to assess the aquatic environment against a reference condition that represents a natural/semi-natural state.

In the original system, seven channel forms were identified: colluvial, bedrock, cascade, step-pool, plane-bed pool-riffle and regime. However, as the system was developed in North America for upland channel systems, these channels do not cover the range of piedmont and lowland channels found in the UK. Thus, adopting the theoretical principles described by Montgomery and Buffington (1997), additional channel forms were added. These included wandering channels, low gradient actively meandering channels, low gradient passive meandering channels and groundwater-dominated channels. A braided channel type was also added, although these channels are uncommon in the UK. Finally, the colluvial channel type, which is not relevant to WFD classification, has been omitted from further consideration. Table 6 provides a brief geomorphic summary of the identified channel forms.

For the purposes of developing a working typology the typical channel forms identified in Table 5 have been grouped into six channel types based on energy conditions and thresholds of change to channel bed and bank based on boundary conditions.

4.2.3 Implementation of the typology

Operational constraints required that the typology be implemented using map-based data. However, when it is necessary to improve the confidence in assessment of channel type, there may also be a requirement to use field and/or remote sensing validation of the predicted channel types.

Internal and external projects have been initiated to develop a step-by-step GIS based procedure for identifying channel types from map based variables. These projects will deliver a trialled and tested GIS application to permit the typing of river channels across the UK. Additionally, field and remote sensing based methods for typing channels are also being developed through internal and external work programmes.

4.2.3 Assessment of relevance of eco-geomorphic indicators to channel types

As described in Section 4.2.1, the eco-geomorphic indicators vary in relevance between channel types. For instance, in channels without floodplains, the eco-geomorphic descriptors of floodplain conditions will not be relevant, and should not be considered further in the impact assessment procedure. Likewise, not all channels have natural in-stream vegetation. Two classes of relevance have been defined: not relevant, relevant.

For future iterations of this tool, it is envisaged that the assessment of relevance would be refined using empirical data. This would potentially allow consideration of variations in the likely occurrence, or importance, of different eco-geomorphic indicators, or combination of eco-geomorphic indicators, between channel types, thus promoting protection of those features and/or processes supporting ecosystem health.

Channel type	Geomorphic Description
Bedrock channels:	Most commonly found in upland areas, though bedrock lined reaches can occur in certain lowland environments. They generally contain little, if any, bed sediment and have limited hydraulic connection with the riparian zone. Channel gradients tend to be high, resulting in a high transport capacity but limited sediment supply. These factors, together with the high degree of bank strength, result in quite stable channels.
Cascades	Are restricted to upland areas with steep slopes and are characterised by disorganised bed material typically consisting of cobbles and boulders constrained by confining valley walls. The riparian zone is usually extremely small in extent and interactions with the channel are limited. The large size of bed and bank material, together with high levels of energy dissipation due to the bed roughness, dictates that the largest bed load only becomes mobile in extreme floods (ca. >25 year return interval). Bedrock outcrops are common, and small pools may be present among the boulders.
Step-pool channels:	Has a steep gradient and consists of large boulder clasts which form discrete sediment accumulations across the channel, forming a series of "steps" which are separated by intervening pools containing finer sediment (typical spacing 1-4 channel widths). The stepped channel morphology results in zones of turbulence interspersed by more tranquil flows. As with cascade reaches, the high degree of channel roughness, and large sediment on the channel bed and banks results in stable channels that respond only in very large flood events. The stream is generally confined by the valley sides, and there is little/limited development of terraces or floodplain.
Plane bed channels:	Generally moderate gradient streams with relatively featureless gravel/cobble beds, but include units ranging from glides, riffles and rapids. Sediment size and channel gradients are smaller than step-pool channels and deeper pool sections tend to be lacking. The river bed is generally armoured and, thus, mobilized in larger floods. Although channels are typically stable, they are more prone to channel change than any of the preceding channel types. Thus, with relatively more frequent bedload movement, they represent transitional channels between the more stable types listed above and the following more dynamic types of channel. Channels are generally straight and may be confined or unconfined by the valley sides. However, the banks- which generally comprise material resistant to lateral migration- constrain the channel from migrating laterally and developing alternate bars/riffles.
Pool-riffle and Plane-riffle channels	Meandering and unconfined channel that, during low flow, are characterised by lateral oscillating sequences of bars, pools and riffles, resulting from oscillations in hydraulic conditions from convergent (erosive) to divergent (depositional) flow environments (typical spacing 5-15 channel widths). The gradient of such channels is low-moderate and the width depth ratio high. The bed is predominately gravel, with occasional patches of cobbles and sand. Accumulation of sediments in gravel bars indicates increasingly transport-limited conditions, though most large floods will produce some bedload movement on an annual basis, thus reducing the stability of the channel. In such channels, interactions between the stream and the riparian zone become more obvious with extensive over bank flood flows and wetland areas often characterising the riparian zone. The banks are typically resistant to erosion, and lateral migration of the channel is limited, resulting in relatively narrow and intermittently deep channels. Plane-riffle channels form an intermediate channel form between plane-bed and pool riffle channels. They retain many of the attributes of pool-riffle channels, however, they generally have less defined pools, coarser (armoured) substrate and less extensive bar features. They are a common channel form in UK, although it is unclear whether their presence is natural or whether they represent a degraded form of the pool-riffle channel. For management purposes, it is suggested that they are treated as a pool-riffle channel type.
Braided channels:	Braided reaches can occur in a variety of settings. They are characterised by relatively high gradients (but ones that are less than upstream reaches) and/or abundant bedload. Sediment transport is usually limited under most conditions and the channel splits into a number of threads around instream bars. Nevertheless, poor bank strength renders them highly dynamic and channels will generally change even in relatively small flood events.
Wandering channel	These reaches exhibit characteristics of braided and meandering channels simultaneously, or, if studies over a number of years, display a switching between divided and undivided channel types. Wandering channels may also be susceptible to channel avulsions during high flow events, where the channel switches to a historical planform. Wandering channels typically occur where a reduction of bed material size and channel slope is combined with a widening of the valley floor. In sediment transport terms such reaches are bedload channels, but the number of competent transport events in any year will vary greatly according to bed material size and the associated entrainment function. Generally, they can be viewed as a transition channel type between braided and lowland meandering channels.
Low gradient actively meandering	Are unconfined low-gradient meandering channels with a bedload dominated by sand and fine gravel. Hence, the channel bed has marked fine sediment accumulations that are mobile in most flood events. These occur in higher order (ie typically lowland) channels exhibiting more laminar flow hydraulics, with turbulent flows being uncommon. The fine bed sediment erodible banks and unconfined settings means that such channels are dynamic and prone to change, they also often have extensive riparian zones and floodplains which are linked to the channel. Bars and pools may be present, and are associated with bends and crossing of the meander pattern.
Groundwater dominated channels	Groundwater-dominated rivers low gradient channels and are characterised by a stable flow regime; although limestone rivers with cave systems may display hydrological characteristics similar to freshet rivers (Sear <i>et al.</i> , 1999). This stable regime is a product of the pervious catchment geology, and consequent reduction in overland flow that characterises groundwater-dominated streams (Burt 1992; Sear <i>et al.</i> , 1999). Bed movement is infrequent and sediments are predominantly transported in suspension (Sear <i>et al.</i> , 1999; Walling and Amos 1999). Typically, sediments are derived from catchment sources, although large macrophyte beds provide a source of in-stream organic detritus (Burt 1992; Sear <i>et al.</i> , 1999). As bed disturbance is infrequent, deposited sediments may remain in the gravel for extended periods, promoting the accumulation of large quantities of fine sediment. Substrate generally comprises gravels, pebbles and sands, and glides and runs are the dominant flow types (or morphological units). Localised areas of riffle may be present, particularly where woody debris is available.
Low gradient passively meandering	These channels are typically found at lower extremities of the channel system. Generally they flow through high resistant materials, for instance clays and coarse deposits. They are generally sinuous, however, as the banks comprise materials that are resistant to erosion, they are typically 'fixed' in their planform geometry. Thus, these channels are often incised and display low width depth ratios. The beds typically comprise fine sedimentary materials (sands and silts), although pockets of gravel can be present, particularly in poorly formed bar deposits. These channels are typically deep and flows are dominated by glides, although runs may be associated with meander bends. Riparian vegetation is influenced by the clay soils and is often more sparse than in other channel types, fairly comprising grasses shrubbery and smaller pockets of woody growth. Primary production is strong in these channels and, coupled with stable beds, allows extensive growth of macrophyte vegetation.

Table 5 Geomorphic summary of typical channels used to aid development of the typology.

4.3 Sensitivity assessment (Step 4)

4.3.1 Conceptual model of sensitivity

To allow assessment of the likelihood that a channel section (or eco-geomorphic attribute) would respond to an engineering activity, a simple method for assessing morphological and ecological sensitivity was developed.

With reference to common geomorphological and ecological concepts of sensitivity (e.g. Grimm and Wissel, 1997), a conceptual sensitivity model was developed. The model focuses on the concepts of resistance to change and resilience to change. Resistance to change describes the ability of a channel (or morphological feature) to remain essentially unchanged in the presence of a disturbance (or pressure). Resilience describes the ability of a channel to recover (return to its original state) after a disturbance. For the purposes of this work programme, disturbances are defined as any anthropogenic activities that affect riverine processes or attributes.

Within this resistance/resilience framework, channels (or ecological communities) of increasing resistance and resilience are described as less sensitive to disturbances, whereas channels (or ecology) of decreasing resistance or resilience are described as more sensitive. In fluvial geomorphologic terms, these sensitivities describe the ability of a channel to retain morphological features and processes that are representative of a natural channel state. Although resistance and resilience would likely form a continuum of responses, three classes of resistance and resilience have been defined (low, moderate and high) (Table 6). Combining different resistance and resilience permutations generates nine total sensitivity combinations (Figure 9).

Resistance class	Definition
Low	System/feature likely to respond to disturbance
Moderate	System/feature will potentially respond to disturbance
High	System/feature unlikely to respond to disturbance

Resilience class	Definition
Low	System/feature unlikely to recover to a pre-disturbance state or dynamic
Moderate	System/feature will potentially recover to a pre-disturbance state or dynamic
High	System/feature will likely recover to a pre-disturbance state or dynamic

Table 6 Summary of classes of resistance and resilience applied in the WFD49 work programme.

The assessment of resistance and resilience is qualitative and many assumptions in assessing the likely sensitivities of different environments or systems have been made. Furthermore, this type of assessment cannot aim to accurately model complex physical or ecological responses.

It is therefore important to recognise that the proposed sensitivity assessment is a high level exercise that has been developed to underpin a simple system for assessing the likely risk posed by an engineering activity. A more complete assessment of sensitivity would also have to consider a variety of additional factors that can only be assessed through a more detailed site specific analysis of the river channel. Additional factors influencing sensitivity include:

- (i) rate of return to a reference or previous state,
- (ii) whether a channel (or ecological community) is already close to crossing an extrinsic threshold that would result in creation of a new system dynamic,

- (iii) whether existing alterations make a channel more sensitive to additional disturbances or activities,
- (iv) the presence of unstable upstream/downstream sections.

Over time, additional elements like the presence of riparian vegetation, floodplain landuse, and existing engineering activities could be added to the assessment. Furthermore, as described in Section 3.3, ongoing research and WFD monitoring could be used to develop an empirically based quantitative assessment of sensitivity.

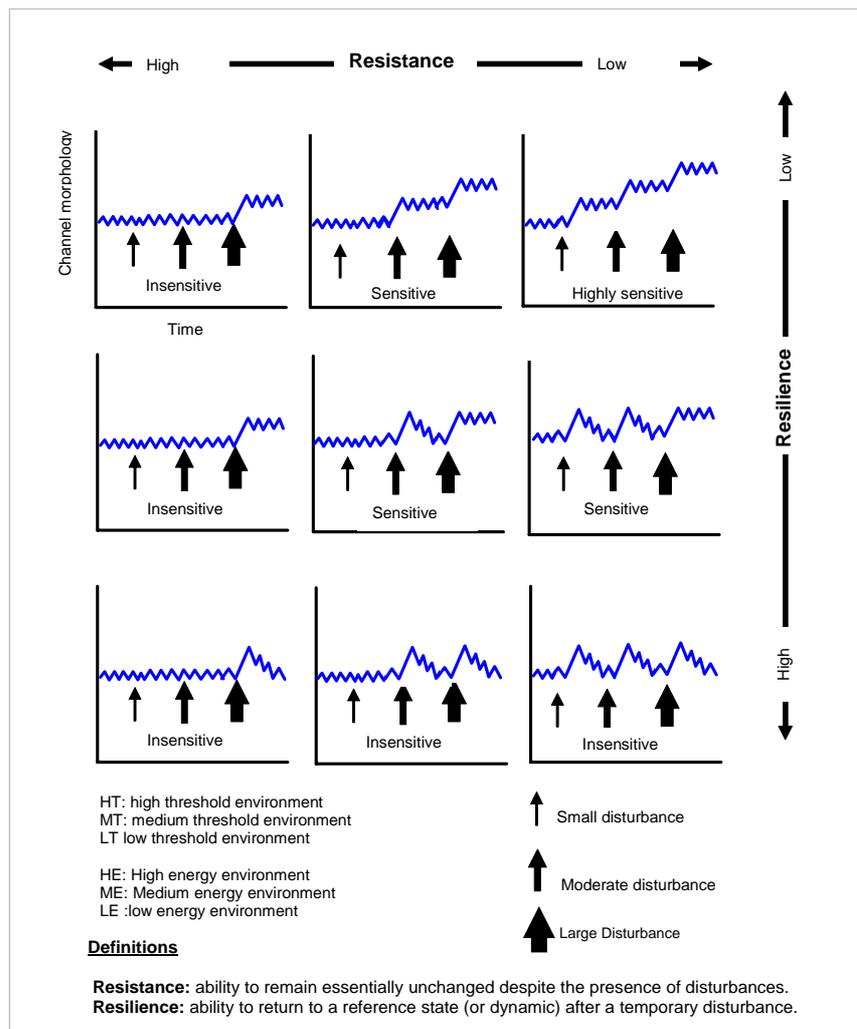


Figure 9 Theoretical model of resistance, resilience and sensitivity

4.3.2 Morphological sensitivity assessment

This model of resistance/resilience was applied to the range of typical channels listed in Table 5, section 4.2. This analysis was undertaken for two purposes:

- (i) To group channels into a smaller subset of channel types that will be used within MImAS
- (ii) To allow assessment of variations in the sensitivity of the eco-geomorphic indicators between the grouped set of channel types.

To group different channels, variations in the resilience and resistance to change of the channel bed and banks were qualitatively assessed and scored following the three class system outlined in Table 6. The results of this grouping into the typology that underpins the tool are shown in Table 7. This assessment was based on an understanding of the boundary conditions and energy environments of each channel type, and was completed in consultation with the external technical review group.

To assess resistance, the boundary conditions of a channel were separated in bed and bank units, thus allowing appreciation of variations in the resistance of channel beds and banks within the identified channels. Resilience to change was qualitatively assessed based on an understanding of variations in stream energy between channels and by considering the frequency of bed and bank sediment entrainment. The rationale was that channels with higher stream energy and lower boundary resistance conditions are more active and are thus more likely to recover from system perturbations. As stream energy (power) information is not available for UK rivers, similarities in channel slope were used as a surrogate for stream energy.

<i>Resistance/resilience classes</i>	<i>Channel types</i>	<i>Terminology</i>
High resistance (bed and bank) – Low resilience (bed and Bank)	Bedrock, Cascade	A
High resistance (bank) Medium resistance Bed - Low resilience (bank) low resilience bed	Step-Pool, Plane bed	B
Medium resistance (bed and Banks) Low resilience (bed and banks)	Low gradient passive meandering	F
Low resistance (bed and Bank) – medium resilience (bed and Bank)	Plane-riffle, Pool-riffle, Braided, Wandering	C
Medium resistance (bank) low resistance (bed) Low resilience (Bed and Banks)	Groundwater dominate (Chalk)	E
Low resistance (bed and Bank) Low resilience (Bed and Bank)	Low gradient active meandering	D



Table 7 Grouping of channel types based on resistance and resilience to change of channel boundary conditions (bed and bank).

The sensitivity assessment described above was then extended to assess variations in the resistance and resilience of the eco-geomorphic indicators. Although this is a judgement-based and qualitative assessment, the assessment was undertaken in consideration of the theoretical principles underpinning the typology and with reference to information provided by the external panel of geomorphologists. As with other elements of this new tool, the intention is for this assessment to be validated/refined using data generated from the WFD monitoring programme.

When applying this sensitivity assessment within the scoring system that underpins the MImAS, consideration was given to whether the activity would result in (i) a temporary destabilisation of a system (e.g. increased erosion) followed by re-stabilisation or (ii) a permanent destabilisation of a system. For those activities that would likely result in a temporary disturbance, the assessment of sensitivity considered both system resilience and resistance. However, for activities that would result in permanent features/disturbances, only system resistance was considered.

4.3.3 Ecological sensitivity assessment

Like river channels, ecological systems do not display simple cause and effect relationships and may express response to pressures/disturbances through multiple degrees of freedom (Grimm *et al.*, 1992). In appreciation of variations in the sensitivity of different species, different communities and of different life stages, an assessment of ecological sensitivity has been integrated into MImAS.

For the purposes of assessing ecological sensitivity, the same model of sensitivity applied in the morphological assessment was adopted. However, unlike the morphological sensitivity assessment, which explicitly considered the morphological resistance and resilience to change of each eco-geomorphic indicator, a more implicit consideration of resilience and resistance was adopted within a general assessment of overall sensitivity. For the purposes of undertaking the ecological sensitivity assessment, the following definition of sensitivity was applied:

'The risk of degradation of the intactness, integrity or naturalness of communities, or impacting on important organisms, thereby threatening ecological status.'

Therefore, when considering ecological sensitivity, the primary consideration was whether a degradation of community or species integrity, intactness or naturalness is likely to occur. In considering an impact on eco-geomorphic indicators, no reference has been made to direction of change, for instance increase or decrease in compaction, rather, the assessment simply considers a likely movement away from characteristics associated with a reference conditions.

To assist in the ecological sensitivity assessment, the external panel of ecologists were asked to provide information on the likely sensitivities of the WFD biological quality elements to impacts on the eco-geomorphic attributes. The panel of ecologists were asked to make their assessments based on the two classes of ecological sensitivity listed in Table 8, for each of the six channel types.

Unfortunately, while useful information was provided in response to this request, it was not possible to reach a consensus regarding the sensitivity of different biological quality elements. Also, some ecologists commented that the complex relationships between physical habitat and riverine ecology are too poorly understood at present to enable completion of the ecological sensitivity tables for each attribute, river type and WFD biological quality element. Given these limitations only a rudimentary ecological sensitivity assessment was incorporated. This assessment assigned all eco-geomorphic attributes in all channel types to sensitive unless more than one expert identified an attribute as 'highly sensitive', in which case the attribute was assigned as 'highly sensitive' (See Appendix).

<i>Sensitivity</i>	<i>Description</i>
Sensitive	A moderate to large impact on a eco-geomorphic indicator of ecosystem health is likely to affect the intactness, integrity or naturalness of communities, or impact upon important organisms.
Highly sensitive	A small impact on a eco-geomorphic indicator of ecosystem health is likely to affect the intactness, integrity or naturalness of communities, or impact upon important organisms.

Table 8 Summary of classes of ecological sensitivity.

4.4 Morphological impact assessment procedure (Step 5)

4.4.1 Introduction

Engineering activities can affect channels in variety of ways. These impacts frequently affect multiple channel attributes. Moreover, impacts often extend beyond the zone of activity, typically in a downstream direction, although upstream impacts can also occur. The impact assessment procedure determines the likelihood that an activity will impact on the eco-geomorphic indicators, and provides a simple assessment of likely the extent of impact (zone of impact).

4.4.2 Summary of Engineering Activities and morphological pressures

MImAS must consider the full range of engineering activities that are currently licensed, and/or, will be licensed under forthcoming regulations. Furthermore, MImAS must consider other factors that affect the physical condition of rivers. Thus, it was also important to consider how alterations to the condition of the riparian corridor, the surrounding floodplains and the wider catchment can affect morphological and ecological conditions.

A suite of generic engineering activities that cover the full range of potential physical impacts on a river system are defined in Table 9. Engineering activities have then been assigned to one, or more, of the generic activities. For instance, to assess impacts from a bridge with piers and bank reinforcement, an assessment of bridge struts and hard Bank protection would be undertaken (Figure 10).

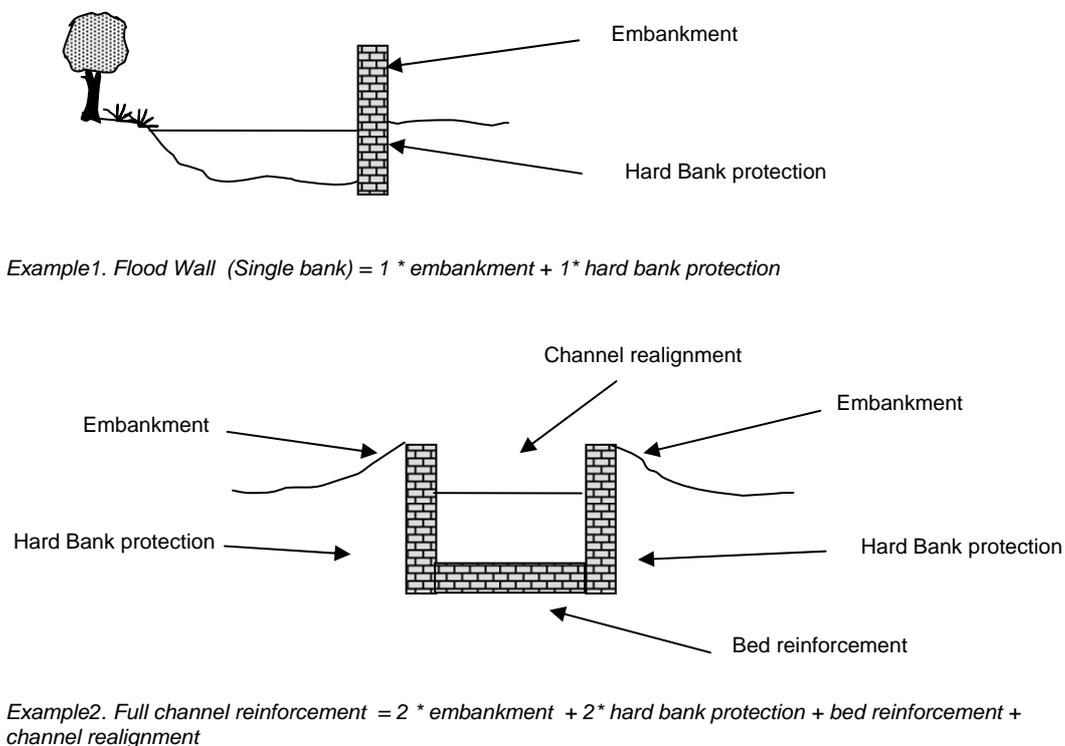


Figure 10 Examples of how generic activities are used to assess range of engineering activities.

It is not clear how impacted hydrology and sediment regimes will be assessed. However, it was considered important to include them as a pressure and assess impacts against a generic description of the pressure. Discussions are ongoing as to how best these issues can be addressed and incorporated into the tool.

Generic activity	Description
Sediment manipulation	Manipulation of sediment contained in the active channel, including bars, without a net loss of sediment from the river.
Sediment removal	The removal of gravel (alluvial material), from the river channel, including bar features. Does not extend across greater than 50% of channel width.
Artificial substrate	Placement of artificial substrate within the river channel.
Dredging	Removal of channel substrate across the entire width of the channel. Generally results in channel deepening and often causes impacts to channel banks.
Embankment	An artificial mound of stone or earth created to hold back water from the floodplain.
Set back embankment	As for embankment, but created a distance back from the channel that allows partial flooding of the floodplain to occur.
Hard bank protection	The use of consolidated materials, e.g. rip-rap, concrete, retaining walls, sheet piling etc. to protect banks from erosion. Also includes the use of rip-rap placed over the majority of the bank height
Soft bank protection	A suite of environmentally sensitive bank protection options, including tree planting and toe protection using large stone (rip-rap).
Bank reprofiling	Any alteration to the topography of the river banks. Includes creation of two stage channel.
Riparian vegetation removal/loss	Removal of vegetation within the riparian zone or loss/simplification of natural complex of riparian vegetation.
Culverts	A closed conduit for the conveyance of water under infrastructure or land. Includes culverting used for river crossings.
Realignment	Any alteration to a rivers course or planform.
Partly recovered realignment	Historical re-alignments that are recognised to have recovered to a more natural condition. Designed river diversions or restorations where the created channel mimics a stable 'natural' condition.
Bed reinforcement	Use of consolidated material (concrete, grouted block work, gabion blankets) intended to protect from scour.
Flow deflector	An in-channel structure that affects natural flow patterns.
Weir	A structure that extends across a river channel that is used to impound, measure or alter flow. Includes passive and managed impoundments.
Bridges with in-channel supports	In channel bridge support struts.
Flood by-pass channel	Secondary channel created to receive high flows, and reduce overbank flows
Hydrology (ext. modified)	Modification to the timing and duration of sediment mobilising flows - high flow regime – e.g. Q5 and greater
Sediment regime (ext. modified)	Excessive inputs of fine sediments outside of normal range directly attributable to human disturbance to catchment sediment dynamics – normally associated with intensive landuse changes.

Table 9 Descriptions of generic engineering activities

4.4.2 Assessment of Likelihood of impact

Based on an understanding of the different ways in which channels respond to engineering activities, an assessment of the likelihood that engineering activities will impact upon the eco-geomorphic indicators was undertaken. Three classes of likelihood of impact have been defined (Table 10). All engineering activities covered by UK river engineering regulations¹ were assessed, and the results of this analysis are presented in the Appendix.

<i>Impact class</i>	<i>Definition</i>
Likely	In most cases, this activity will result in an impact on a eco-geomorphic indicator.
Possible	In some cases, this activity will result in an impact on a eco-geomorphic indicator
Unlikely	In most cases, this activity will not result in an impact on a eco-geomorphic indicator

Table 10 Summary of classes of likelihood of impact.

In addition to assessing impacts from engineering activities, channels are also affected by the condition of the riparian zone, the floodplain and the surrounding landscape. Furthermore, the impacts to the surrounding landscape (including the riparian zone) can exacerbate the impacts, or increase the likelihood that impacts from engineering activities will occur. At present such broader-scale landscape pressures are not included in the assessment tool but different methods for assessing the condition of the riparian zone, floodplain and wider catchment do exist and these could be incorporated into the tool at a future date.

4.4.3 Defining the extents of impacts (zones of impact)

Engineering activities affect the physical riverine environment in a variety of ways. Some of these impacts remain localised. However, other impacts propagate through systems and can have a considerable affect in upstream and downstream directions.

To allow consideration of the extent of impacts resulting from different activities, a simple procedure for assessing the zone of impact from different activities has been developed. In summary, simple classes of impact extents have been defined, with each class representing a likely proportion of river affected by an activity, including consideration of impacts extending beyond the channel section under assessment (Table 11). This assessment is independent of the channel typology.

Although it is recognised that the extent of impacts resulting from engineering activities may vary depending on the type of activity and the physical characteristics of particular stretch of channel, for the purposes of assessing zones of impact, a non-channel-type-specific assessment has been undertaken. Similarly, the approach does not consider how other activities in combination could affect the potential zone of impact. Finally, as with channel sensitivity, the extent or magnitude of impacts resulting from activities can be influenced by upstream and downstream channel conditions and by conditions within the wider floodplain and catchment. It has not been possible to explicitly consider these types of complex interactions to date.

¹ Based on similarities in impacts, some activities have been grouped.

<i>Zone of impact</i>	<i>Description</i>
Contained	Impacts unlikely to extend beyond the local vicinity of the activity
Partly contained	Impacts may propagate upstream or downstream through the system
Pervasive	Impacts likely to propagate upstream or downstream through the system

Table 11 Definitions of zone of impact classes

In addition to considering the likely zone of impact, consideration has also been given to whether an activity is likely to have similar impacts the left and right bank and riparian zones, (Figure 11). This information is applied within the scoring procedure outlined in Section 4.5.

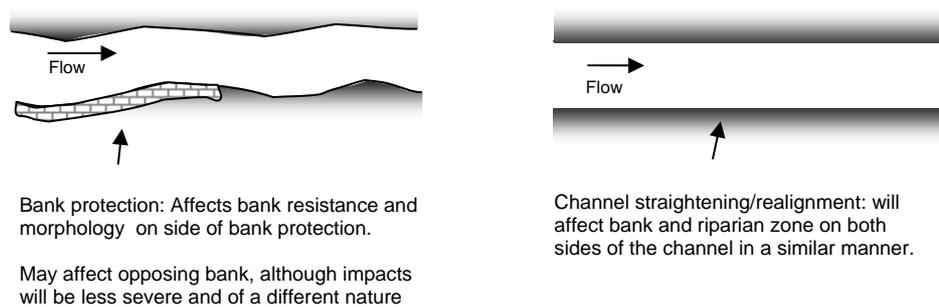


Figure 11 Overview of differences in impacts of activities on the bank and riparian zone.

4.5 Scoring system (Step 7)

4.5.1 The capacity concept

The modules described in the preceding sections have been integrated within a qualitative scoring system to assess the total impact resulting from different engineering activities and morphological pressures. This scoring system is underpinned by the concept of 'system capacity'. In essence, this concept assumes that systems have a 'capacity' to absorb impacts, and that anthropogenic activities within rivers or in the surrounding landscape, consume some of a systems available capacity. By determining how much system capacity is used up by different pressures, it is possible to determine the total level of impact on a system at any point in time. Morphological condition limits define levels of impact on available capacity that are compliant with high and good ecological status class requirements, as is illustrated in Figure 12. For instance, a morphological condition limit of 5% means that up to 5% of the total system capacity can be used before a deterioration in ecological status might be expected. To operate, this approach requires determination of impacts on system capacity and comparison of this information with a set of predefined morphological condition limits.

As described in Section 3, each zone (Channel, Bank and Riparian) can be managed independently. This ensures that deterioration in the quality of any single zone would be sufficient to trigger a failure of the morphological condition limits, regardless of the status of other zones.

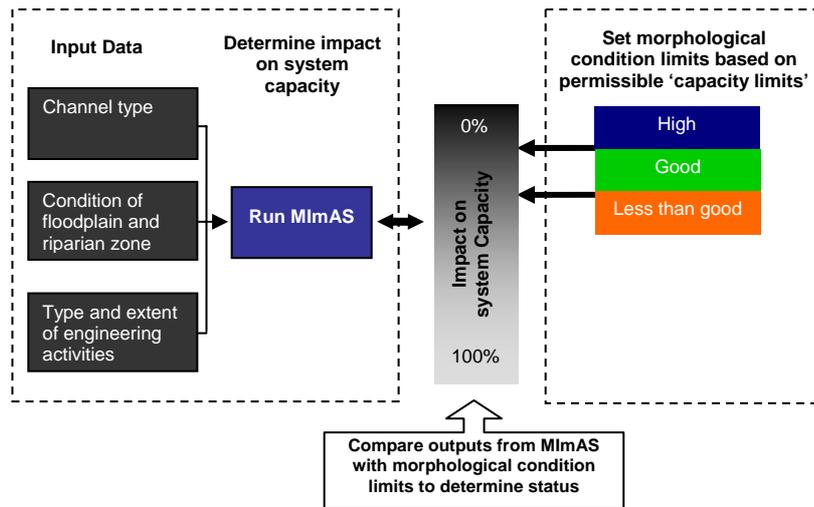


Figure 12 Summary of capacity-based system and link between MImAS and morphological condition boundaries

Procedures are also being considered to allow assessments of potential impact on water body status. It is envisaged that an assessment at the water body scale would be undertaken for those activities that are likely to exceed the morphological condition limits at the 500m scale. By assessing potential impacts on WFD ecological status, the water body scale assessment would help inform regulatory decisions and ensure that they align with WFD objectives.

4.5.2 The scoring procedure

A simple scoring system has been developed to allow assessment of impacts on a river channel's 'capacity for alteration'. To assist in regulatory decision making, all capacity assessments are first carried out over 500m sections.

The scoring system works by applying numerical values to the qualitative assessments of relevance, sensitivity and impact described in the preceding sections. All numerical values have been defined to work within a percentage-based system, and are scored from 0-1². The Scoring System combines the information from the above Modules to calculate the capacity used by the combination of pressures. The amount of capacity used by a pressure in a given type is based on the following equations:

$$\text{Capacity Used (\%)} = \text{Activity Impact Score} \quad \times \quad \text{Activity Footprint}$$

where an Activity Impact Score is calculated as:

$$\text{Ecological Sensitivity} \quad \times \quad \text{Morphological Sensitivity} \quad \times \quad \text{Likelihood of Impact} \quad \times \quad \text{Zone of Impact}$$

The Activity Impact Score is calculated for each attribute in turn, then averaged for attributes within zones. This gives a score for each activity or pressure within each zone.

² In recognition of impacts beyond the section of channel being assessed, when scoring extents of impacts, a scoring system of 0-2 is applied, with 2 representing impacts that are likely to propagate through a system.

The activity footprint describes the length of channel over which activities take place and should not be confused with the zone of impact, which describes the likelihood that impacts will extend beyond the local vicinity of the activity. For activities like bank protection and channel realignment, the activity footprint simply describes the length of channel over which bank protection or channel realignment extends. For other activities that are not naturally measured in terms of channel length, for instance gravel extraction and flow deflectors, rules have been devised to determine an activity footprint that is compatible with the capacity-based scoring system (Table 12).

Activity	Rules for determining footprint
<i>Bank protection</i> <i>Dredging</i> <i>Channel realignment</i> <i>Embankment (inc set back)</i> <i>Bed reinforcement</i> <i>Flood by-pass channel</i> <i>Artificial substrate</i> <i>Sediment manipulation</i> <i>Culverts</i>	Length of channel, parallel to banks, over which activity occurs.
<i>Flow deflectors</i>	10m or 1 channel width- whichever is greater.
<i>Bridge with inchannel support</i>	10m or 1 channel Width- whichever is greater.
<i>Sediment Removal</i>	Volume Removed/(0.5m*0.5Channel Widths) or if volume data is unavailable, simply use length of channel over which sediment removal takes place.
<i>Alteration to hydrology</i> <i>Alteration to sediment inputs</i>	500m

Table 12 Rules for determining activity footprint

To assess riparian vegetation loss, MImAS requires creation of a footprint for 'loss of riparian vegetation'. The following tables propose a simple method for identify footprints for riparian vegetation loss. These footprints can be input directly into MImAS to determine the loss in 'capacity'. The footprints described are based on a 500m length of channel

		Dominant Structure			
		Complex	Simple	Uniform	Bare/ Plantation
Density of natural woody vegetation	Continuous/Semi-continuous	0	25	N/A	N/A
	Scattered	25	50	N/A	N/A
	None	N/A	100	200	500

(a)

		Dominant Structure			
		Complex	Simple	Uniform	Bare/ Plantation
Density of natural woody vegetation	Continuous/Semi-continuous	0	50	N/A	N/A
	Scattered	50	100	N/A	N/A
	None	N/A	200	400	1000

(b)

Table 13 Proposed rules for calculating activity footprints for riparian vegetation loss. Values represent footprints for both banks (i.e. 1000m of bank).

(a) Channel Types A and B (Upland channels);

(b) Channel Types C to F. The values represent the total activity footprint for each 500m reach, and include consideration of both banks.

Where,

Riparian zone- land within 10m of bank top.

Continuous/semi continuous: > 50 % natural woody vegetation

Scattered: > 5- 50% natural woody vegetation. This category should also be used when there is a single line of trees.

Complex- >3 dominant vegetation types present, with one vegetation type woody.

Simple: 1-3 dominant vegetation types present, with one vegetation type woody.

Uniform: only one vegetation type present.

Plantation or bare should only be used if it covers >50% of a bank. Plantation must be within 2m of the banktop edge, otherwise, one of the other categories should be used.

Section 5

Summary of morphological condition limits

5.1 Introduction

Morphological condition limits define permissible levels of impact on system capacity. These limits are expressed in percentage terms as 'capacity' used. It is assumed that development beyond these limits may cause a deterioration of ecological status class and, as such, there would be a requirement for further more detailed assessment prior to permitting further engineering activities.

The limits discussed in this document were proposed by the project team in consultation with the external technical panel and the peer review panel. Presently, work is ongoing to field trial the morphological condition limits and so these should be viewed as draft, and, based on the outputs of ongoing work programmes, the limits may be amended.

5.2 Proposed morphological condition limits

For the first iteration of MImAS, there was a requirement to define a set of expert judgment-based morphological condition limits. These limits represent best available knowledge of the amount of alteration to a river channel that can be permitted without risk of failing good ecological status. Over time, the WFD monitoring programme and ongoing research will provide empirical datasets that can be used to validate and/or calibrate these morphological limits, and/or the qualitative data sets underpinning MImAS.

The morphological condition limits proposed by the project team are shown in Table 14. Limits to protect high and good ecological status are proposed. The following sections provide examples of what these limits mean in terms of absolute values of different engineering activities.

ZONE	Capacity Used	
	High-Good	Good-Moderate
Channel	5%	15%
Banks and riparian	5%	15%

Table 14 Proposed morphological condition limits

5.3 Limits on engineering activities and combinations of activities

5.3.1 Overview

MImAS is a tool for assessing cumulative impacts. Given the wide variety of different combinations of engineering activities and landscape pressures, it is not possible to provide an overview of all potential scenarios that these limits represent. However, it is possible to provide examples of what these limits mean in terms of the amount of engineering activity that would be permitted. The following section provides examples of single activity limits and case study examples of combinations of activities.

It is recognised that the MImAS is a mechanical processes that can not fully consider all relevant issues, for instance, the importance of protecting marginal or rare habitat features. Thus, there is a requirement to define a series of 'system overrides' that allow an additional level of expert based knowledge to be applied to the decision making-process. For instance, Type A channels (Bedrock) have proven difficult to assess in terms of impacts from some engineering activities. Therefore, although it is uncommon for activities to take place in these channel environments, there is a requirement to review the suggested activity limits and define new limits where the limits suggested by MImAS are inappropriate.

It is recognised that additional rules will be required to overcome some of the limitations of the tool. Such rules are under consideration.

5.3.2 Single activity limits

MImAS can be applied to define single activity limits. These limits (shown in Table 15) represent the amount of a single activity that would put a section of channel at risk of degrading from high status to good status or degrading from good status to moderate status. The values are based on the difference between the Good-Moderate and the High-Good morphological condition limits and, therefore, represent 10% capacity for the channel, and banks and riparian zone.

Activity	Channel type					
	A	B	C	D	E	F
Sediment Removal	240	135	100	80	75	135
Sediment Manipulation	320	160	115	95	90	180
Dredging	120	75	60	45	45	75
Riparian Vegetation Loss	n/a	535	265	320	355	535
Embankment	220	150	65	85	75	170
Set Back Embankment	n/a	n/a	n/a	n/a	n/a	n/a
Hard Bank Protection	535	265	115	160	180	265
Soft Bank Protection	n/a	535	265	320	355	535
Bank Reprofiling	800	265	135	160	200	265
Straightening	120	85	35	45	40	100
Realignment Partly Recovered	400	265	160	135	115	230
Flood Bypass	180	145	60	75	65	200
Culverts	100	75	35	45	40	85
Croys/Flow Deflectors	400	135	55	80	95	135
Bed Reinforcement	120	85	35	45	40	100
Weirs	100	75	35	45	40	85
Artificial Substrate	400	345	300	185	185	480
Bridge Piers	265	180	65	90	80	230
Hydro Regime EXT Modified	fail	fail	fail	fail	fail	n/a
Sediment Regime EXT Modified	n/a	n/a	fail	fail	fail	n/a

Table 15 Summary of single activity limits for 500m section, rounded to nearest 5m. For bank side activities, these limits are divided between both banks. Note 1: Activity footprint rules must be applied to determine absolute limit for Activity. Note 2: There are no limits for Set back embankments as the impacts determined by MImAS are insignificant.

5.3.3 Application of MImAS to assess interactions of multiple pressures

MImAS can also be applied to assess combinations of activities and determine whether these exceed the defined morphological condition limits. The nature of this type of assessment makes it impossible to provide summaries of all potential combinations of activities but two case studies are provided. Each case study assesses a combination of activities through MImAS and determines whether this combination of activities would exceed the morphological condition limits.

CASE STUDY ONE: Channel Type C: Pool Riffle River, Channel Width = 10m

Activity	Extent	Capacity used (%)	
		Channel	Banks
Hard Bank Protection	50m	4.2	4.4
Riparian Vegetation Loss	100m	2.3	3.8
Bridge with in-channel supports	x1	1.3	0.3
Totals:		7.8%	8.5%
Available Capacity		Not at risk 7.2%	Not at risk 6.5%

New modifications that would result in a failure of the morphological condition limits at this site include: 120m of riparian vegetation loss, 65m of hard bank protection or 120m of soft bank protection.

CASE STUDY TWO: Channel Type D: Lowland Meandering River, Channel Width = 30m

Activity	Extent	Capacity used (%)	
		Channel	Banks
Hard Bank Protection	75m	4.9	4.7
Riparian Vegetation Loss	50m	1.9	1.6
Sediment Removal	20m	2.8	0
Embankment	100m	12.5	6.3
Totals:		22.1%	12.6%
Available Capacity		At risk 0%	Not at risk 2.4%

This site would have no available capacity for new modifications.

MImAS can also be used to promote mitigation for regulatory applications that fail the morphological condition limits. Were proposed activities would result in failure of the morphological condition limits, an activity could still proceed without a derogation order if the impacts from an activity could be offset by a series of mitigation measures, e.g. channel enhancement/remediation. For example, using the case study presented above, if a proposal was received for 50m of hard bank protection, 87m of riparian vegetation restoration, or the removal of 26m of embankment would offset the impact on system capacity in the channel zone.

Section 6

Summary of limitations, ongoing work and potential future refinements

6.1 Introduction

MImAS has primarily been developed as a risk assessment to inform regulatory decision by non-expert staff. The development of this system has required a number of scientific concessions in the pursuit of a set of practicable management procedures. A brief summary of the principal limitations of the devised system are provided in Table 16. With reference to ongoing and potential future work programmes, potential methods of system refinement are provided.

In addition to this information, a summary of the key responses received from the peer review panel, including an initial response from the WFD49 technical team, is provided in a separate document 'Short Summary and Response to the Peer Review'.

Identified limitation	Description of limitations and comments	Ongoing work	Potential future work
Reliance on expert judgment	As described in the preceding sections, the lack of extensive and robust empirical information on eco-geomorphic relationships and the nature of pressure-impact-response for morphological features and processes meant that there was a requirement to apply judgment-based data to support MImAS. Although efforts have been made to ensure that these judgment-based assessments are based on best available information, the traditional limitations of applying non-empirically validated assessments apply.	The system has been developed within an 'adaptive management' framework. Thus, it is intended that information generated from ongoing WFD monitoring and dedicated research projects will be used to calibrate and validate the morphological condition limits. In essence, it is the intention to replace/validate the qualitative data with empirical, quantitative and parameterised data. As part of SEPA's long term implementation strategy, a mechanism allowing data generated from WFD monitoring to be used to directly calibrate the Morphological condition limits is being developed. This system will likely use indices from GeoRHS and RHS surveys.	A targeted long-term research programme could be initiated to promote improved understanding of eco-geomorphic links. This will require systematic identification of gaps in knowledge and development of a series of integrated research programmes. Target catchments could be used to implement a series of nested research programmes that allow examination of, for instance, trans-scale ecological processes, role of disturbance regimes, issues of habitat fragmentation. Also, new modelling approaches, for instance Shearer and SIDO-UK could be used for scenario testing.
<i>Reliance on a channel typology</i>	The limitations of applying typologies to support environmental management have been extensively considered in the literature. . One of the key concepts underpinning the WFD is that of representativeness. In summary, the Directive allows member states to develop systems that allow them to assess/monitor representative sites. Information gathered from these sites can be extrapolated to similar sites. This allows member states to reduce overall resource expenditure. Thus, typologies form an integral component of WFD implementation.		The typology could be improved through application of fuzzy set theory. This would allow the development of a continuum of channel forms and remove reliance on the discrimination of distinct channel types.
<i>Technical challenges of implementing a national channel typology</i>	At present, it has only been possible to undertake limited testing of the proposed typology. Full testing has in part been hindered by resource constraint and in part by technical GIS difficulties. Given that the typology may ultimately have to be applied to around 200,000km length of river it is essential that implementation can be achieved remotely through use of a GIS.	A more complete typology validation exercise is ongoing. This project is field and GIS based and is providing empirical data that will allow refinement of the GIS implementation procedures, including identification of appropriate thresholds in the variables driving the typology. Additionally, WFD and regulatory monitoring will include field and/or Remote sensing based procedures to validate the channel types predicated from the GIS implementation procedures. This will improve confidence in our assessment of channel types.	Not yet defined
<i>Limited of consideration of site specific characteristics/ Lack of inclusion of conservation and other duties</i>	MImAS is mechanistic tool that, based on assessments of likely impacts on important physical features and processes that influence ecosystem condition, allows standardised assessment of current conditions, and/or predictions of future conditions. Beyond channel types this tool does not have the ability to consider site specific conditions, for instance the presence of features of special interest, or features that are uncommon to certain geographical areas. This may inhibit the tool's ability to protect the specific features that characterise a given channel section.	A decision support framework is being developed that will allow additional consideration of site specific characteristics. This decision support framework will identify a series of system overrides. These will range from simple rules that ensure protection of specific channel features that are not considered by the MImAS. The system will also identify where further investigation (field-based and GIS) is required and where there is requirement to involve a specialist (in Geology, Ecology and/or hydrology) in the decision making process. Stuart – as yet I don't feel this statement is true	Not yet defined

Identified limitation	Description of limitations and comments	Ongoing work	Potential future work
<i>Limited of consideration of hydrological pressures</i>	Channel morphology and hydrological regimes are intrinsically linked, and it is not possible to alter one without affecting the other. However, to allow identification of morphological condition limits for river engineering and separate standards for regulating abstraction and impoundments, it has been necessary to develop separate systems for assessing morphological and hydrological pressures.		It is intended that a project will be initiated to developed amore sophisticated method of determining impacts to hydrological regime. This project, will define levels of alteration to hydrological regime, and may consider directions of change, for instance, loss of high flows or increased flashiness.
<i>Limited consideration of landscape pressures</i>	Pressures at the landscape scale (such as those induced by land management and consequent changes in land use and the delivery of fine sediments to channels) exert significant influence on river form and function. Such pressures are typically difficult to identify and quantify; assessments commonly use coarse surrogates such as the extent of urbanisation to quantify a pressure. Such measures are not able to address specific impacts on channel form or process.		In future an additional module could be developed to refine the impact assessment process to address this issue of the significance of landscape pressures to overall sensitivity of systems to change. With further development this could look in detail at the in-combination-effects these larger scale pressures have on various engineering activities. We are unlikely to be able to examine synergistic effects through such a system, particularly given current state of knowledge.
<i>Limited consideration of scale</i>	Scale has been identified as a critical variable influencing freshwater biota and geomorphic functioning. However, MimAS currently does not include consideration of how morphological and ecological responses may vary between different sized river systems. Furthermore, at the 500m scale of assessment it is clear that different biota have different scale dependencies that are determined not only by habitat availability and quality but by factors such as mobility and range. If potential impacts are quite localised then in generalised terms fish will be less impacted by local loss of riffle than will benthic invertebrates.		The channel typology could be refined to consider variations in channel size (Drainage area). The sensitivity assessment could then be reviewed in terms on variations in channel size within the different channel types.
<i>No consideration of synergistic responses</i>	<p>The sensitivity and impact assessment tool uses several variables to determine the likely response of a given channel type to an engineering activity, both in isolation and in combination with other channel modifications that may be present in the 500m channel reach. Within this assessment we have considered the potential channel responses for a combination of 18 different engineering activities.</p> <p>It is clear though that this detailed level of examination using a fixed scoring system cannot capture the complex synergistic effects of different engineering activities. Such synergies may not even be apparent at the 500m channel scale but may only manifest themselves at reach or sub-catchment scales. There will also likely be further synergistic responses between local scale engineering activities and catchment scale pressures such as land management and sediment delivery to channels.</p>		Not yet defined

Identified limitation	Description of limitations and comments	Ongoing work	Potential future work
<i>No consideration of positive impacts</i>	Because of the need to develop a tool to help us regulate physical modifications to rivers we have focussed our first attention on the prediction of impacts that may pose a risk to ecological status. It is clear though that certain activities may have positive as well as negative impacts, whether on the presence or condition of morphological features. Furthermore, species within one biological quality element will often benefit from disturbance and change where those in other biological quality elements will suffer. These subtleties cannot yet be teased out of the impact assessment. This issue has significance because it is clear that engineering activities designed to improve morphological and/or ecological condition (river restoration, etc) must also be screened to ensure they are compatible with WFD requirements. The current assessment tool is not suitable for determination of degrees of positive impact.	None at present	There is potential in future to develop a sister tool, structured in the same way and with the same underpinning principles, to specifically allow assessment of proposed restoration activities. Some form of analysis will ultimately be required for Programmes of Measures work to determine the efficacy of different types of restoration activities in different channel types.
<i>No consideration of seasonality or life stage</i>	The impacts from any particular channel modification clearly have potential to vary at different times of the year. This is principally related to flow characteristics; the impacts of some activities will be exacerbated when flow depth and velocity are low, although most activities are most sensitive to high or fluctuating flow conditions. The significance of life stage on potential impacts to biota are considered of greater importance. To consider this issue properly, however, it would not be appropriate to focus attention at individual species rather than the biological quality elements. In the absence of detailed scientific knowledge we have assumed, given the number of species under consideration, that at least one species will be at a critical life stage at any given point in the year.	Issues surrounding seasonal differences in impacts of activities will be addressed through good practice guidance.	Not yet defined

Table 16 Overview of limitations of the tool, on-going work programmes and potential future work areas.

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