TraC-MImAS Technical report

(Development and Review of a TraC Hydromorphology Decision Support Tool for (a) screening proposed new or altered activities / structures for compliance with WFD water body status and (b) classifying TraC waters under the WFD)

Produced for UKTAG Phase 2 Environmental Standards stakeholder consultation

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Project Team

Dr Mark Williams, Marine Science, Scottish Environment Protection Agency, Clearwater House, Heriot Watt Research Park, Avenue North, Riccarton, Edinburgh EH14 4AP. mark.williams@SEPA.org.uk

Dr Nick Cooper (nick.cooper@rhdhv.com), Dr Julian Carolan and Phil Williamson (philipwilliamson@rhdhv.com), Royal Haskoning, 4 Deans Yard, Westminster, London, SW1P 3NL.

Project Technical Panel

Niall Phelan, Mike Best, Lucy Taylor, Greg Whitfield and Adam Waugh (EA)

Douglas Walker (Marine Scotland)

Shane O' Boyle (EPA)

Chris Vivian (CEFAS)

Project Steering Group

Chris Vivian and Andrew Birchenough (CEFAS)

Niall Phelan, Mike Best, Lucy Taylor, Greg Whitfield, Adam Waugh, Helen Brailey and Rebecca Coales (EA)

Douglas Walker and Colin Megginson (Marine Scotland)

Shane O' Boyle (EPA)

Francis O' Beirn (Marine Institute, Galway)

Kelly Kasperczyk (Jacobs)

Mike Elliott (IECS, University of Hull)

Michael McAliskey (NIEA)

UKTAG contacts

Janet Forbes (SNIFFER)

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Introduction and background information

Under the Water Framework Directive, the UK and Ireland are now required to manage morphological change to ensure that all surface water bodies aim to achieve "Good Ecological status" and that there is no deterioration in status.

UK regulators are experienced in regulating morphological alterations, particularly in transitional and coastal (TraC) waters. Where regulation occurs, decisions are typically made on a case by case basis, using a combination of field data and expert judgement.

The initial TraC-MImAS tool development project was tasked with developing a tool to help regulators determine whether proposals to alter morphological features could risk the ecological objectives of the WFD. Tool development was based on the methodology developed for rivers (Rivers-MImAS)[1]. Although the principles underpinning the Rivers and TraC-MImAS tools are largely analogous, TraC-MImAS incorporates a number of significant customisations to suit application to TraC waters. Specifically, the tool is intended to help regulators identify those proposals that could:

- Threaten the aim of achieving 'good ecological status; or
- Result in a deterioration in ecological status

In developing a tool of this nature, it was important to recognise the current state of knowledge on the relationships between morphology and ecology. Generally, there is a lack of quantitative data describing the relationships between hydromorphological conditions and ecological health. It is clear however that many human induced hydromorphological pressures impact on aquatic ecology. Furthermore, it is recognised that different biological and morphological parameters may be more sensitive to certain hydrological or morphological processes than others, and that the relative sensitivities will differ between different TraC environments.

In response to the current lack of ecological data to support the development of 'evidence-based' Environmental Standards for morphology, a tool has been developed that uses assessments of morphological features and pressures to determine risks to ecology.

The tool is not intended to be applied in isolation, and would be used to compliment existing regulatory procedures. Similarly, the tool is not intended to replace expert judgment or existing impact assessments. The tool will compliment these areas and provide risk-based guidance to inform regulatory decisions.

[1] Details of the Rivers-MImAS approach can be found on the UKTAG website:

UKTAG (2006). UK Environmental Standards and Conditions (Phase 1)
WFD49 (Rivers) (2006). A new impact assessment tool to support river engineering regulatory decisions
WFD49 (Rivers) (2006). Peer review short summary (Aug 06)
WFD49c CRESS (2006). Trialling of MImAS and proposed Morphological Condition Limits

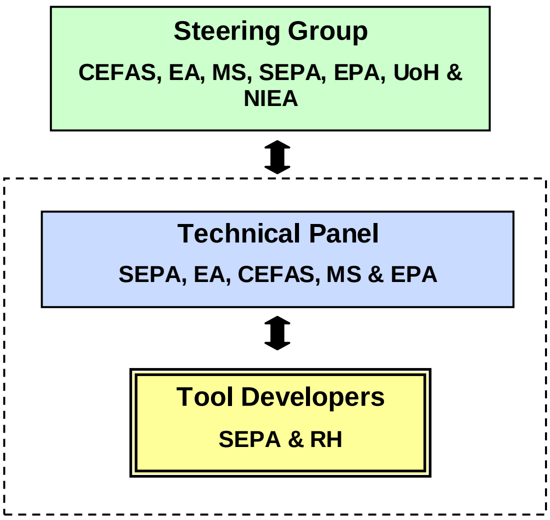
In addition to providing a method to screen risks to ecology from new morphological alterations, the tool also had to meet the following specifications:

- The tool should be capable of considering cumulative modifications
- The tool should be simple to apply by regulatory staff
- The tool should produce consistent and reproducible outputs
- The tool should not be data intensive.
- It should be possible to update and refine the tool over time as new data becomes available
- The tool should be capable of informing WFD classification decisions, particularly those decisions relating to the identification of high status sites.

The tool is not intended to:

- Provide an accurate representation of hydromorphological status
- Replace the need for detailed assessments or professional judgement
- Act as an engineering design tool
- Define remediation options
- Provide a quantitative assessment of the presence or quality of habitats
- Consider conservation requirements (protected habitats or species or special features).

The project is part of a wider UKTAG work programme tasked with developing new tools and environmental standards to support implementation of the Directive and associated UK legislation and regulations. SNIFFER commissioned Royal Haskoning to develop the existing TraC-MImAS tool in consultation with a core technical group (SEPA, CEFAS, EA and Marine Scotland) and wider steering group with experts from EA, CEFAS, Marine Scotland, EHS, EPA, Marine Institute (Galway), University of Hull and consultants from the Republic of Ireland (Figure 1).



EA - Environment Agency
CEFAS - Centre for Environment, Fisheries and Aquatic Sciences
SEPA - Scottish Environment Protection Agency
MS – Marine Scotland (formerly Fisheries
RH – Royal Haskoning
Research Services)
EPA - Environment Protection Agency (Republic of Ireland) (includes representation from Marine Institute, Galway and Jacobs)
UoH – University of Hull
NIEA – Northern Ireland Environment Agency

Figure 1 Project structure and links to steering groups.

The remainder of the report is divided into four main sections.

SECTION 1 - Provides a high level overview of the TraC-MImAS tool and the associated Morphological Condition Limits

SECTION 2 - Operational guide describing how the tool could be used to assist in regulatory decision-making.

SECTION 3 - Summarises outputs from the TraC-MImAS tool. This section provides figures, tables and case studies summarising real world limits on engineering works produced by the tool.

SECTION 4 - Conclusions and Bibliography

APPENDICES - Provide technical details of the TraC-MImAS tool and summaries of all data contained/used in each module.

Section 1

Summary of TraC-MImAS and Morphological Condition Limits

1.1 SUMMARY OF THE TRAC-MIMAS TOOL AND ITS DEVELOPMENT

Under the Water Framework Directive (WFD) the UK and Republic of Ireland are required to manage hydromorphological change as a result of human activity to prevent ecological deterioration transitional and coastal (TraC) waters. In response to the lack of ecological data to support the development of 'evidence-based' Environmental Standards, a risk-based regulatory decision-support tool was developed to help regulators determine whether proposals to alter hydromorphological features could risk the ecological objectives of the WFD.

The tool, termed TraC-MImAS (Transitional and Coastal Waters Morphological Impact Assessment System) was developed by a core of experts from the UK environment agencies as part of a wider UKTAG programme in 2007. TraC-MImAS is based on a methodology developed for rivers (Rivers-MImAS) and incorporates a number of significant customisations to suit application to TraC waters. Specifically, the tool is intended to help regulators identify those proposals that could threaten the aim of achieving 'good ecological status; or result in a deterioration in ecological status.

The TraC-MImAS tool uses the concept of 'system capacity' which assumes that as system capacity is consumed by human activities it follows that there is an increased risk that morphological and ecological conditions will degrade. The tool comprises five modules that collectively provide an assessment of the amount of 'system capacity' that has been used up in a water body. By considering impacts on system capacity, the tool can be used to allow the rapid determination of the level of risk posed by new development proposals. The outputs from TraC-MImAS provide a basis for identifying situations where extra information or more site specific assessment is required. To date the tool has been used to complement existing regulatory procedures by Marine Scotland and in the absence of other tools has been used by the environment agencies to guide the hydromorphological classification process during the first River Basin Management Planning (RBMP) cycle.

SNIFFER commissioned Royal Haskoning to develop the existing TraC-MImAS tool, set the outputs within a broader deterioration and regulatory framework and to provide a sufficient picture of likely outcomes to important habitats e.g. saltmarsh and seagrass.

The following principal changes have been made to the existing tool:-

- The pressure categories (originally without high and low change in impact categories) have been developed by expanding them to include low and high change in impact categories to take a better account of varying spatial and temporal factors i.e. magnitude and frequency of activity.

- The impact ratings have been categorised into 5 categories of sensitivity to enable impact rating comparisons to be made with ease. Originally, the sensitivity was based on 3 categories (0 – no impact, 0.5 - moderate impact and 1.0 – high impact).

- The tool has been adapted in the manner by which it assesses impounding structures and causeways, and other structures that have the potential to make a significant protuberance into the flow regime whilst having a small footprint; e.g. long breakwaters that extend across an estuary to narrow its width by 20% but occupy a small direct footprint area on the estuary bed. A simple rule has been developed any impoundment present either within or adjacent to a water body will indicate that that water body cannot be at a high status. Within the tool, any impoundment pressure will cause exceedence of the Morphological Condition Limits and therefore trigger expert assessment. Therefore, any impoundment, historic or new, should automatically trigger expert assessment.

- Impact ratings have been developed for important WFD habitats in each type by incorporating these under the 'Morphological features and substrate' attribute in the ecogeomorphic attributes module using a similar approach to those already developed within the existing tool.

- Pressure categories have been incorporated for pipelines and high voltage cabling and tidal devices. Blasting and large scale shellfish farming have not been included.

- The sensitivity of the tool has been explored by running the tool with less sensitive impact ratings and more sensitive impact ratings for some pressure categories. In developing the existing version of the tool a significant amount of effort went into making minor adjustments to the values in the tool as part of an iterative process to ensure that the impact ratings were logical and sensible.

1.2 SUMMARY OF IMPORTANT CONCEPTS AND DEFINITIONS

TraC-MImAS comprises a series of interdependent modules. Collectively, the modules provide an assessment of the level of impact to morphological conditions[2] that are likely to result from individual morphological alterations, or combinations of morphological alterations.

Morphological conditions - *Refers to the list of attributes in Annex V of the Directive. For TraC waters these attributes include- depth variation, quantity, structure and substrate of the seabed, and structure of the intertidal and sub-tidal zones.*

Morphological alterations - *Any pressures acting on the water environment that could affect morphological conditions. Examples of morphological alterations include shoreline reinforcement and dredging.*

The tool uses a concept of 'system capacity' to measure impacts to morphological conditions. In essence, this concept assumes that completely pristine TraC water have a measure of assimilative 'capacity', which can be degraded by anthropogenic activities. 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.

System Capacity - *a measure of the ability of the water environment to absorb morphological alterations. The likelihood (or risk) that morphological and ecological conditions are degraded will increase as system capacity is consumed. This concept does not infer that degradation of the environment is acceptable; rather it assumes that there is a degree to which minor changes can be tolerated by the system.*

It is assumed that different morphological alterations will use up different amounts of system capacity, with the amount of capacity being used dependant on:

- The type of alterations;
- The sensitivity of the water environment to the alterations; and
- The spatial scale of the alterations.

Where a new development is proposed, for instance a marina or some form of shoreline protection, the tools can be used to predict the impact of the proposal on 'system capacity'. By considering impacts on system capacity, the tool can be used to determine the level of risk presented by a new proposal. This information can then be used to inform regulatory decisions, for instance, to identify where more detailed assessments may be necessary, or to identify where there is a high risk of a deterioration in status, and, therefore, where a regulatory exemption test to determine if the work should proceed on the basis of benefits to human health, human safety or sustainable development may be required.

To help quantify the risk that a new morphological alteration could impair achievement of the ecological objectives of the WFD, a series of 'morphological condition limits' have been defined (Section 1.3). Details of the proposed morphological condition limits for TraC waters are provided in the following sections.

Morphological condition limits- *Thresholds of alteration to morphological conditions beyond which there is a risk that the Ecological status objectives of the WFD could be threatened. The limits are expressed in percentage capacity.*

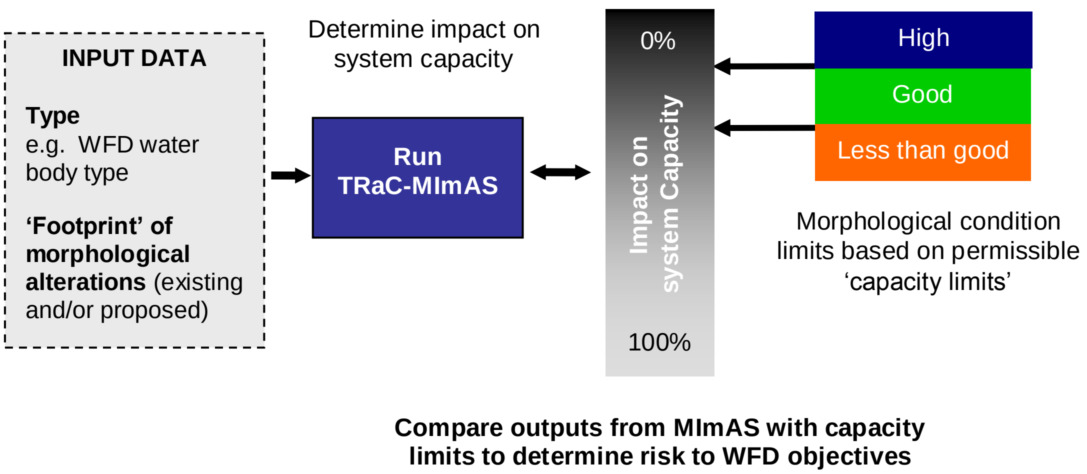


Figure 2 Summary of the capacity principle and links between TraC-MImAS and MCLs.

TraC-MImAS is underpinned by a series of assumptions:

- A TraC water has some capacity to accommodate morphological change without changes to its ecological status.
- There is a relationship between the extent of morphological alteration and the impact on ecological status.
- The response of a water body's morphology to engineering or other pressures is predictable for that type of water body
- The response of the ecology to morphological change is predictable and depends on the sensitivity of the ecology of the water body.

These assumptions will be examined as part of future testing and validation work (See Section 1.6).

1.3 SUMMARY OF MODULES COMPRISING TraC-MImAS

The TraC-MImAS tool is based on five modules (Figure 3). Collectively the modules provide an assessment of impacts to morphological conditions. All impacts are measured in terms of impacts to 'system capacity'. Each module is designed to be semi-independent of the others, thereby allowing individual modules to be updated over time as more information becomes available. The modules are briefly described below. More detailed information on each module is presented in the Appendix

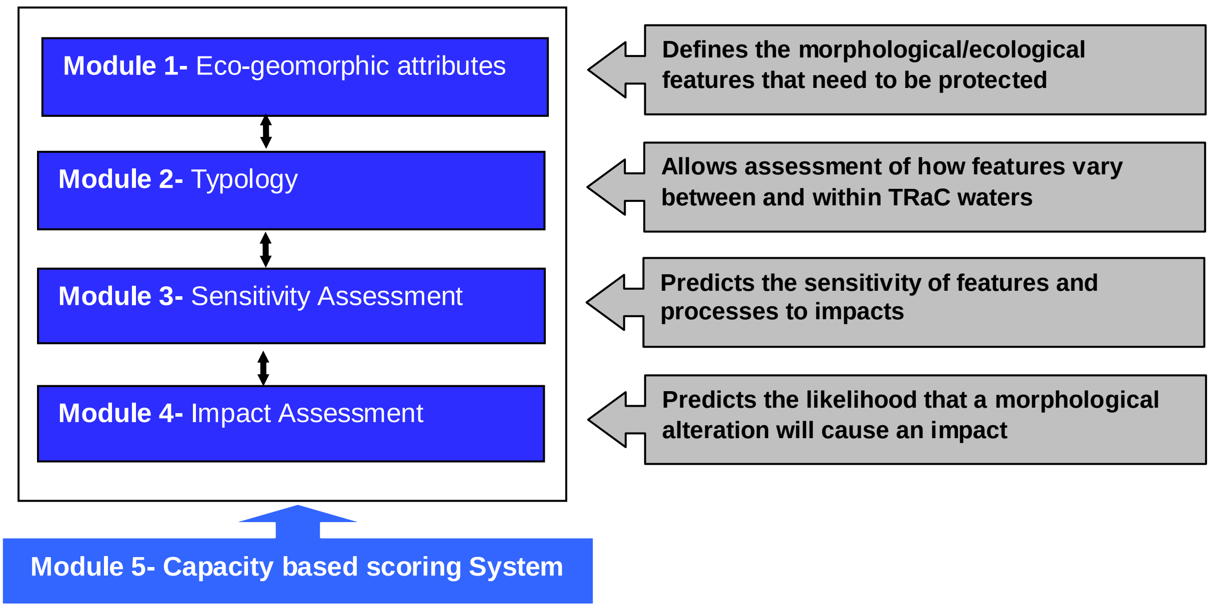


Figure 3 Overview of the modular components of TraC-MImAS.

1. The Attribute Module

This module defines a list of attributes that can be used to assess geomorphic and ecological function and condition as well as a list of potential UK BAP priority habitats which may potentially be impacted upon by a pressure/activity. The attributes are related closely to the morphological quality elements in Annex V of the Directive (Table 1). They cover such things as depth variation, flow, quantity and structure of substrate and bed, and wave exposure. Each attribute was chosen for its role in the direct or indirect support of ecological communities and the supporting processes needed to create and maintain the physical environment on which ecological communities depend. The Ecogeomorphic attributes are divided into three zones- hydrodynamic, inter-tidal, sub-tidal (Table 2) with each zone highlighting habitats for consideration within that zone (i.e. intertidal and saltmarsh; subtidal and seagrass beds). All Attributes were selected in consultation with the technical panel and project steering group. The tool does not require information on the attributes in Table 2. The core input data is pressure and water body type.

Annex V 1.1.3. **Transitional Waters**	**Annex V 1.1.4.** **Coastal Waters**
Tidal Regime: • Freshwater flow • Wave exposure	**Tidal Regime:** • Direction of dominant currents • Wave exposure
Morphological Conditions: • Depth variation • Quantity, structure and substrate of the seabed • Structure of the intertidal and sub-tidal zones	**Morphological Conditions:** • Depth variation • Quantity, structure and substrate of the seabed • Structure of the intertidal zone and sub-tidal zones

Table 1 Hydromorphological quality elements for in Annex V of the WFD.

UK BAP priority habitats are listed for each zone (intertidal and subtidal) of assessment. Habitats are identified on their typical zone of occurrence, e.g. saltmarsh being characteristic of the intertidal and seagrass being subtidal.

2. The Typology Module

For TraC-MImAS, the UK TraC typology has been simplified into six types (Table 3). Groupings were based on an assessment of similarities in physical characteristics and similarities in likely responses to morphological alterations. To improve the assessment of morphological responses to alterations, dominant geology has been incorporated into the typing of coastal water bodies. This creates three coastal water body subtypes: sheltered coastal sedimentary, exposed coastal sedimentary and coastal bedrock (sheltered to exposed). These groupings will be subject to further review through ongoing validation and testing of the tool.

The typology allows a simple assessment of the relevance of the attributes (contained in the attribute module) to the different TraC water body types. The typology module further identifies habitats characteristic of each zone (i.e. intertidal and saltmarsh; subtidal and seagrass beds). Where attributes are not relevant, they would be excluded from any assessments carried out on that water body type. For attributes that are relevant to a particular water body type, the assumption is that they will display predictable responses to morphological alterations.

Although typologies are simplified representations of complex and dynamic physical characteristics, they have been shown to be useful when assessing the likely physical and ecological responses to morphological alterations.

Ecogeomorphic Attributes	Definition
Hydrodynamics	**Describes the influence of the tides, waves and freshwater inflow**
Tidal range	*The height that the sea rises and falls over a tidal cycle*
Currents	*Currents associated with the rise and fall of the tide*
Freshwater flow	*Riverine input into TraC Waters, maybe modified by human interference of catchment hydrology/landuse changes*
Flushing/exchange	*The length of time it takes for a transitional water or sea loch to exchange its water*
Salinity/mixing/stratification	*Occurs in transitional waters and sea lochs where freshwater input is important*
Waves	*Waves are important in driving sediment transport processes*
Intertidal Zone	**Describes the size and structure of the intertidal zone**
Geometry	Describes the spatial extent and form of the intertidal zone
Planform	*Aerial view showing planar area of the intertidal zone (2D perspective). Describes the outline and spatial extent, or area of the intertidal zone which can change in response to prevailing coastal processes and/or realignment of the high water mark due to engineering activities.*
Profile	*Cross sectional form of an estuarine channel or gradient of the shoreline.*
Morphological features and substrate	Describes the shape and character of geomorphological features, and the size, structure and sorting of the intertidal sediments
Nature and extent of coastal features	*Topography and geomorphological and vegetation features of the coastal zone e.g. saltmarsh, seagrass, sand dunes, mudflats, sand bars, spits.*
Natural sediment size range	*Is the sediment size distribution natural*
Habitats	**Identifies the habitat types associated with this respective zone**
Coastal sand dunes	*Habitat type present*
Saltmarsh	*Habitat type present*
Mudflat	*Habitat type present*
Continuity and sediment supply	Assesses interruptions to coastal processes and sediment supply
Longitudinal sediment transport processes	*Describes sediment mobilization pathways i.e. transport of material by littoral drift from adjacent water bodies.*
Lateral sediment transport processes	*Includes land to sea connectivity and describes inputs and outputs of sediment from erosion of cliffs, catchment derived input from fluvial sources and material transported from offshore.*
Sub tidal Zone	**Describes the size and structure of the subtidal zone**
Geometry	Describes the spatial pattern and form of the subtidal zone
Planform	*Aerial view showing planar area of the subtidal zone (2D perspective). Describes the outline and spatial extent, or area of the subtidal zone which can change in response to prevailing coastal processes and/or engineering activities.*
Profile	*Cross sectional form of a channel or of the coastal zone perpendicular to the coastline*
Morphological features and substrate	Describes the shape and character of geomorphological features, and the size, structure and sorting of the intertidal sediments
Nature and extent of bed features	*Topography or specific features of the seabed e.g. sand banks, ripples.*
Natural sediment size range	*Is the sediment size distribution natural*
Habitats	**Identifies the habitat types associated with this respective zone**

Reefs	Habitat type present
Modiolus beds	Habitat type present
Seagrass beds	Habitat type present
Maerl beds	Habitat type present
Continuity and sediment supply	Assesses interruptions to coastal processes and sediment supply
Longitudinal sediment transport processes	*Describes sediment mobilization pathways i.e. transport of material by littoral drift from adjacent water bodies.*
Lateral sediment transport processes	*Includes land to sea connectivity and describes inputs and outputs of sediment from erosion of cliffs, catchment derived input from fluvial sources and material transported from offshore.*

Table 2 Proposed set of ecogeomorphic attributes.

TraC Type	General morphological characteristics	MImAS Code
TW6, CW10	TraC Lagoons	TraC lagoons
TW5, CW11,CW12	TraC Sea Lochs.	TraC sealochs
TW1 to TW4	Partially to fully mixed, meso-tidal to macro-tidal, intertidal or shallow subtidal, sand and mud	Transitional meso to macrotidal
CW7 to CW9	Sheltered, micro-tidal to macro-tidal. Sedimentary	Sheltered coastal -sedimentary
CW1 to CW6	Moderately to exposed, Macro-tidal. Sedimentary	Moderately to exposed coastal-sedimentary
CW1 to CW9	Sheltered to exposed, micro to macro-tidal	Coastal bedrock

Table 3 TraC types used in TraC-MImAS.

3. Sensitivity Module

The Sensitivity Module is divided into two parts- ecological sensitivity and morphological sensitivity. Within TraC-MImAS, sensitivity incorporates consideration of the resistance to change (ability to absorb change) and the resilience to change (ability to recover from change). For the morphology component, the assessment considers the intrinsic sensitivities of each attribute to physical disturbances. This is carried out for each TraC water body type. For the ecology component, the assessment considers whether a degradation of community or species integrity is likely to occur in response to a disturbance to individual attributes. Again, this is carried out for each TraC water body type. The ecological assessment considers all WFD biological quality elements- fish, benthic invertebrates and phytoplankton. As with the attribute and typology modules, the sensitivity module also identifies habitats characteristic of each zone which shall require consideration within the assessment via expert judgement and local knowledge.

All assessments within the sensitivity module are based on professional judgement, and were informed by contributions from the technical panel and steering group. This was necessary given the current lack of empirical data on the links between biology and morphology. Testing and validating the sensitivity module will be a priority, and the module will be updated to reflect new evidence. Summaries of all sensitivity assessments are provided in the Appendix.

4. The Pressure Module

This module comprises two components- (i) assessment of the likelihood that a morphological alteration will have an impact on an attribute (contained within the attribute module) and (ii) an assessment of whether impacts are likely to be contained within the vicinity of the pressure, or whether the impact will extend beyond the local vicinity of the pressure. The latter assessment is termed the 'zone of Impact'. As with other modules, the pressure module also identifies those habitats which are likely to be impacted upon by each respective pressure. Details of these assessments can be found in the Appendix. These assessments are distinct form those contained in the sensitivity module. The sensitivity module assess the intrinsic sensitivity of attributes within different types, the impact assessment is a type independent assessment of likelihood of impacts from different alterations. The pressure and sensitivity modules combine to provide a type specific impact assessment for a range of pressures.

It would not be possible to develop a tool that considered every morphological alteration or design. To reduce the number of morphological alterations considered by TraC-MImAS, a suite of generic alterations that cover the full range of potential physical impacts on TraC waters have been defined. Rules have been developed that allow a wider range of morphological alterations to be mapped to this suite of generic pressures (these rules are described in Section 2.2.2, Table 11).

Fifteen generic pressures have been incorporated (Table 4). They include shoreline pressures such as 'hard' engineering for bank protection, and pressures such as barrages and dredging. The Pressure Module is not type specific. All pressures have a corresponding high and low impact category for data input. The difference in response to the pressures between TraC water body types is captured by combining the Sensitivity Module with the Pressure Module.

Specific pressures	Description
Land Claim	Historical (typically > 50 years) enclosure of intertidal or subtidal areas within impermeable banks followed by infilling for use by agriculture, housing, port or industry. The system may have partially recovered to a more "stable" natural condition since the land claim initially took place. Any new enclosure of intertidal or subtidal areas within impermeable banks followed by infilling for use by agriculture, housing, port or industrial use. The modification may destabilise the system.
Historic tidal river realignment	Historical (typically >50 years ago) alteration to course or planform of upper estuaries where the channel remains river-like. Includes straightening and removal of meanders to increase channel gradient and flow velocity (e.g. Ribble Estuary; See van der Wal et al., 2002; Fig 3.). This category can also include land claim.
New tidal river realignment	Any new alteration to course or planform of upper estuaries where the channel remains river-like.
Dredging (capital or maintenance)	Capital dredging for navigation purposes is the excavation of sediments to increase depths in an area, usually but not always for the first time, to accommodate the draft of vessels. May include maintenance dredging for the routine periodic removal of material in approach channels to port and harbour basins to maintain widths and depths in previously dredged areas to ensure the safe access for vessels.
High Voltage (HV) cables and Pipelines	The installation and subsequent protection of any cable (seabed) or pipeline (coastal to marine) for the transfer of electricity or discharge of effluent
Disposal of Dredgings (sea and intertidal)	The deposit of material dredged during maintenance and capital dredging campaigns into the marine environment or onto intertidal and subtidal areas for the purposes of disposal.
Impoundment	Impermeable barriers that extend either across the entire width of an estuary or embayment removing tidal influence (e.g. Cardiff Bay Barrage) or across coastal sounds and straits (e.g. South Ford Causeway, Outer Isles (Figure 10)). A structure that extends across a river channel that is used to impound, measure or alter flow (e.g. weirs, sluices).
Barrages	A semi-permeable impoundment that lets natural processes operate most of the time (e.g. barrage). Storm surge barriers may be built across estuaries in built up areas to reduce the risk of flooding during storm surges (e.g. Thames Barrier). Tidal barrages are constructed across estuaries with strong currents and large tidal range to harness tidal energy (Figure 11).

Flow and sediment manipulation structures	Hard engineering structures built to stabilise waterways for navigation and counter the effects of longshore drift. These include breakwaters, piers, groynes, flow deflectors, training walls etc. Ports, harbours and marinas are protected anchorage sites, often with extensive piers and breakwaters projecting into the adjacent water body (Figure 12).
Shoreline Reinforcement – Hard Engineering	The use of consolidated materials, e.g. rock armour, man made armour, revetments, retaining walls, gabion baskets, seawalls, wharves, quays, sheet piling etc. to protect vunerable coastlines or harbours from erosion (Figure 13).
Shoreline Reinforcement – Soft Engineering	Stabilisation of the shoreline using beach material to maintain beach levels and dimensions. May include synthetic materials (Figure 14).
Flood Defence Embankment	An artificial bank of earth or stone created to prevent inundation of estuarine and coastal floodplains.
Piled Structures	A range of structures raised on one or more foundation structures extending out into the adjacent water body e.g. bridge and pier supports. This category also includes wind turbine monopiles and outfalls (Figure 16).
Tidal devices	Any device which exploits the natural ebb and flow of coastal/marine tidal waters including horizontal axis turbines, cross axis turbines, oscillating hydrofoils and enclosed tips (venturi) energy extraction devices.
Other seabed uses	Any other pressures that could directly affect the bed morphology or substrate character.

Table 4 Definitions of generic categories of morphological alterations used in TraC-MImAS.

It is important to state that maintenance or refurbishment of structures is not considered as an impact where the works involve no alteration to the existing footprint. Therefore, there is no need to consider this type of activity within the tool's assessment.

5. The Scoring System

The scoring system combines the information contained in each module to calculate a numerical 'impact rating'. Each morphological alteration contained with the pressure module has its own impact score, which is specific to each TraC water body type. The impact score is calculated for each attribute in turn, and then averaged for attributes within the hydrodynamic, intertidal and subtidal zones. This value is then multiplied by the zone of impact to give an overall impact rating for each morphological alteration (pressure).

The equation used to calculate the impact rating can be summarised as:

Impact Rating	=	Relevance	X	Ecological Sensitivity	X	Morphological Sensitivity	X	Likelihood of Impact	X	Zone of Impact
		Output from typology module		Output from sensitivity module		Output from sensitivity module		Output from pressure module		Output from pressure module

To determine the percentage capacity used within a particular TraC water, the impact weightings are combined with the 'alteration footprints' of all morphological alterations present within the section of estuarine or coastal water being assessed. An alteration footprint describes the type and extent of a morphological alteration. Different alterations will have different footprints, for instance, the footprint for shoreline reinforcement is the length over which the reinforcement occurs, whereas the footprint for dredging is the area over which dredging occurs. Summaries of the rules for calculating alteration footprints can be found in Section 2.2.2.

The formula used to calculate the capacity consumed by a single pressure, or combination of pressures within a predetermined assessment area/length, can be summarised as:

$$\text{Capacity Used (\%)} = \sum n \left(\frac{\text{Impact rating} \times \text{Footprint of morphological alteration}}{\text{Length/area of assessment unit}} \right) \times 100$$

* See Section 2.1.2 for a description of assessment units

Where n is the number of morphological alterations within the assessed length/area; and ∑ ( ) is the sum of results given by the equation specified in the parenthesis for each of the 'n' alterations.

A worked example of the capacity used can be employed for the Loch Bee water body (WB200418). The water body is a 'Lagoon' type and the location of the activity is in the subtidal zone. The total subtidal area of the water body is 7km, and the pressure is 'Flow & sediment manipulation – submerged (high)' of 0.007857km^2.

The eco-geomorphic attributes for the subtidal zone for a sea loch as defined by the TraC-MImAS tool are:

- **Geometry** (planform & profile)
- **Morphological features and & susbstrate** (nature and extent of coastal features & natural sediment size range)
- **Continuity and sediment supply** (longitudinal sediment transport processes & lateral sediment transport processes); and
- **Habitats** (Sabellaria spinulosareefs, Modiolus beds, Seagrass beds & Maerl beds)

Each of these components is scored for each of the attributes that make up the impact rating. These are outlined below:

	Coastal-Transitional			
	Lagoon			
Ecogeomorphic Attributes	Relevance	Eco sense	Resistance	Generic impact
Subtidal Zone				
Geometry				
Planform	**1**	**1**	**0.5**	**0.25**
Profile	**1**	**0.5**	**0.5**	**0.5**
Morphological features & substrate				
Nature and extent of coastal features	**1**	**1**	**0.5**	**0.5**
Natural sediment size range	**1**	**0.5**	**0.5**	**0.5**
Continuity and sediment supply				
Longitudinal sediment transport processes	**0**	**0.5**	**0.5**	**0.5**
Lateral sediment transport processes	**1**	**0.5**	**0.5**	**0.5**

Habitats				
Sabellaria spinulosareefs	**0**	**0**	**0**	**0.5**
Modiolus beds	**0**	**0**	**0**	**0.75**
Seagrass beds	**1**	**0.5**	**1**	**0.75**
Maerl beds	**0**	**0**	**0**	**0.5**

Each ecogeomorphic attribute has its scores multiplied together, and then the largest impact rating is taken forward for that attribute. Therefore, the scorings taken are:

- Geometry = **0.125**
- Morphological features & substrate = **0.25**
- Continuity and sediment supply = **0.125**
- Habitats = **0.375**

An average of these scores is then taken, producing a Likelihood of impact score of **0.22**.

The Zone of Impact score for Flow & sediment manipulation – submerged (High) in the subtidal zone is **1.5**.

The two multiplied together creates an impact rating score of **0.33**.

The capacity used is calculated as such:

$$\sum n \left(\frac{0.33 \quad x \quad 0.007857}{7} \right) X\ 100$$

= 0.03704 (rounded up to 0.1% for the purposes of the TraC-MImAS tool) % capacity of the water body's subtidal zone is used by the pressure.

This low score does not use up sufficient capacity to exceed a morphological condition limit and therefore the water body remains in a High status.

HYDRODYNAMICS	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	0.38	0.38	0.38	0.19	0.06	0.06
Land claim – low impact	0.09	0.09	0.09	0.06	0.06	0.06
Historic tidal channel realignment – high impact	0.13	0.09	0.09	0.06	0.06	0.06
Historic tidal channel realignment – low impact	0.06	0.03	0.03	0.03	0.03	0.03
Recent tidal channel realignment – high impact	0.28	0.19	0.19	0.14	0.14	0.14
Recent tidal channel realignment – low impact	0.06	0.03	0.03	0.03	0.03	0.03
Dredging – high impact	0.13	0.13	0.13	0.09	0.09	0.09
Dredging – low impact	0.03	0.03	0.03	0.03	0.03	0.03
HV cable and pipelines – high impact	0.03	0.00	0.00	0.03	0.00	0.00
HV cable and pipelines – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Use of dredged material – high impact	0.03	0.00	0.00	0.03	0.00	0.00
Use of dredged material – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Impoundments – high impact	0.50	0.50	0.50	0.25	0.25	0.25
Impoundments – low impact	0.09	0.05	0.05	0.05	0.05	0.05
Barrages – high impact	0.50	0.50	0.50	0.25	0.25	0.25
Barrages – low impact	0.19	0.19	0.19	0.09	0.09	0.09
Flow and sediment manipulation, submerged – high impact	0.14	0.14	0.14	0.14	0.14	0.14
Flow and sediment manipulation, submerged – low impact	0.03	0.03	0.03	0.03	0.03	0.03
Shoreline reinforcement, hard engineering – high impact	0.19	0.19	0.19	0.09	0.09	0.09
Shoreline reinforcement, hard engineering – low impact	0.06	0.06	0.06	0.03	0.03	0.03
Shoreline reinforcement, soft engineering – high impact	0.03	0.03	0.03	0.03	0.03	0.03
Shoreline reinforcement, soft engineering – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Flood defence embankment – high impact	0.19	0.19	0.19	0.05	0.05	0.05
Flood defence embankment – low impact	0.06	0.13	0.06	0.00	0.00	0.00
Piled structures – high impact	0.19	0.19	0.19	0.14	0.14	0.14
Piled structures – low impact	0.03	0.03	0.03	0.03	0.03	0.03
Tidal devices – high impact	0.03	0.03	0.03	0.03	0.03	0.03
Tidal devices – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Other seabed uses	0.03	0.03	0.03	0.03	0.03	0.03

Table 5 Summary of impact ratings for morphological alterations- Hydrodynamic zone

INTERTIDAL ZONE	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	1.25	0.79	0.79	0.92	1.58	0.33
Land claim – low impact	0.33	0.21	0.21	0.25	0.42	0.08
Historic tidal channel realignment – high impact	0.38	0.23	0.25	0.25	0.46	0.08
Historic tidal channel realignment – low impact	0.22	0.13	0.16	0.16	0.28	0.06
Recent tidal channel realignment – high impact	0.88	0.56	0.56	0.63	1.13	0.25
Recent tidal channel realignment – low impact	0.44	0.28	0.28	0.31	0.56	0.13
Dredging – high impact	0.54	0.46	0.46	0.46	0.46	0.25
Dredging – low impact	0.08	0.08	0.08	0.08	0.08	0.04
HV cable and pipelines – high impact	0.08	0.08	0.08	0.08	0.08	0.04
HV cable and pipelines – low impact	0.02	0.02	0.02	0.02	0.02	0.00
Use of dredged material – high impact	0.41	0.28	0.28	0.28	0.28	0.13
Use of dredged material – low impact	0.19	0.13	0.13	0.13	0.28	0.06
Impoundments – high impact	1.33	0.83	0.83	1.00	1.67	0.33
Impoundments – low impact	0.22	0.13	0.16	0.16	0.28	0.06
Barrages – high impact	1.33	0.83	0.83	1.00	1.67	0.33
Barrages – low impact	0.50	0.31	0.31	0.38	0.63	0.13
Flow and sediment manipulation, submerged – high impact	0.63	0.38	0.41	0.44	0.75	0.13
Flow and sediment manipulation, submerged – low impact	0.17	0.10	0.13	0.13	0.21	0.04
Shoreline reinforcement, hard engineering – high impact	0.75	0.47	0.47	0.56	0.94	0.19
Shoreline reinforcement, hard engineering – low impact	0.17	0.10	0.10	0.13	0.21	0.04
Shoreline reinforcement, soft engineering – high impact	0.69	0.44	0.44	0.50	0.88	0.19
Shoreline reinforcement, soft engineering – low impact	0.17	0.10	0.10	0.13	0.21	0.04
Flood defence embankment – high impact	0.63	0.41	0.44	0.44	0.81	0.19
Flood defence embankment – low impact	0.15	0.27	0.10	0.10	0.19	0.04
Piled structures – high impact	0.75	0.47	0.47	0.56	0.94	0.19
Piled structures – low impact	0.29	0.19	0.19	0.21	0.38	0.08
Tidal devices – high impact	0.00	0.00	0.00	0.00	0.00	0.00
Tidal devices – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Other seabed uses	0.00	0.00	0.00	0.00	0.00	0.00

Table 6 Summary of impact ratings for morphological alterations- Intertidal zone

SUBTIDAL ZONE	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	1.19	0.63	0.88	0.94	1.00	0.56
Land claim – low impact	0.25	0.29	0.29	0.33	0.42	0.08
Historic tidal channel realignment – high impact	0.38	0.20	0.28	0.31	0.38	0.19
Historic tidal channel realignment – low impact	0.13	0.06	0.09	0.09	0.09	0.06
Recent tidal channel realignment – high impact	0.89	0.47	0.70	0.75	0.89	0.52
Recent tidal channel realignment – low impact	0.13	0.00	0.13	0.13	0.13	0.13
Dredging – high impact	0.69	0.63	0.69	0.81	0.50	0.56
Dredging – low impact	0.22	0.17	0.20	0.25	0.16	0.19
HV cable and pipelines – high impact	0.28	0.16	0.25	0.34	0.19	0.22
HV cable and pipelines – low impact	0.19	0.08	0.14	0.22	0.13	0.13
Use of dredged material – high impact	0.47	0.28	0.42	0.47	0.28	0.28
Use of dredged material – low impact	0.23	0.12	0.21	0.23	0.14	0.14
Impoundments – high impact	1.50	0.88	1.13	1.25	1.50	0.75
Impoundments – low impact	0.13	0.06	0.09	0.09	0.09	0.06
Barrages – high impact	1.50	0.88	1.13	1.25	1.50	0.75
Barrages – low impact	0.38	0.22	0.28	0.31	0.38	0.19
Flow and sediment manipulation, submerged – high impact	0.56	0.33	0.47	0.52	0.61	0.38
Flow and sediment manipulation, submerged – low impact	0.20	0.13	0.17	0.20	0.23	0.16
Shoreline reinforcement, hard engineering – high impact	0.38	0.26	0.30	0.33	0.38	0.23
Shoreline reinforcement, hard engineering – low impact	0.06	0.06	0.06	0.06	0.06	0.06
Shoreline reinforcement, soft engineering – high impact	0.34	0.19	0.19	0.31	0.22	0.16
Shoreline reinforcement, soft engineering – low impact	0.13	0.06	0.06	0.13	0.06	0.00
Flood defence embankment – high impact	0.06	0.06	0.06	0.06	0.06	0.00
Flood defence embankment – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Piled structures – high impact	0.56	0.30	0.40	0.52	0.52	0.28
Piled structures – low impact	0.19	0.08	0.11	0.19	0.16	0.09
Tidal devices – high impact	0.31	0.06	0.27	0.28	0.31	0.22
Tidal devices – low impact	0.13	0.03	0.13	0.13	0.13	0.13
Other seabed uses	0.16	0.06	0.13	0.13	0.16	0.09

Table 7 Summary of impact ratings for morphological alterations- Subtidal zone

1.4 MORPHOLOGICALCONDITION LIMITS (MCLs)

To help quantify the risk that a new morphological alteration could impair achievement of the ecological objectives of the WFD, a series of 'Morphological Condition Limits' (MCLs) have been defined (See Section 1.1 for a definition of a morphological condition limit).

Morphological condition limits are defined for three TraC zones- hydrodynamic, inter-tidal and sub-tidal zone. Distinguishing between these zones provides regulators with a simple method of identifying which aspect of a TraC water is likely to be impacted. This information would be useful when defining the scope of a more detailed assessment.

The morphological condition limits proposed for these zones are expressed in terms of percentage capacity used as set out in Table 8. Exceeding these limits would indicate a risk to WFD status objectives. Limits for Moderate and Poor conditions will be considered based on evidence from the trials proposed for summer 2007.

The WFD requires regulators to manage for no deterioration in WFD status. Where a deterioration in status is predicted, a regulatory exemption test to determine if the work should proceed on the basis of benefits to human health, human safety or sustainable development may be required. MCLs for all boundaries would help determine where a regulatory exemption test might be required.

	Morphological Condition Limit (% capacity)			
Zone	High*	Good**	Moderate	Poor
Hydrodynamic	**5%**	**15%**	**30%**	**45%**
Intertidal	**5%**	**15%**	**30%**	**45%**
Subtidal	**5%**	**15%**	**30%**	**45%**

Table 8 Proposals for TraC morphology condition limits. Please refer to Section 1.1 for a definition of a morphological condition limit (see below for a definition, in WFD terms, of these boundaries.

The capacity limits in Table 8 are not type specific. The differences in response between TraC water body types are taken into account within the TraC-MImAS scoring system. Likewise, as different pressures consume different amounts of capacity, the limits do not simply mean, for instance, that 15% of the shoreline can be reinforced before a risk to good status is identified.

Table 14 and 15 (Section 3) provides information on what these capacity limits mean in real world terms. These values were created by running TraC-MImAS to determine how much of an individual morphological alteration can take place before the morphological condition limits for a particularly status boundary (high/good and good/moderate) are exceeded.

The values presented in the Tables 14 and 15 are not regulatory standards. They are provided as an illustration of what 5% and 15% mean in real terms. In regulation, TraC-MImAS would be used to assess how combinations of pressures interact to threaten status objectives.

The limits in Tables 14 and 15 are in draft form and their suitability will be reviewed during the field trialling work. Based on the results of the field trialling, the TraC-MImAS and/or the MCLs may be altered to ensure that they reflect, on the basis of best available information, the WFD status definitions summarised in Table 5 (Section 1.6 provides information on the trialling work).

1.5 ROLE OF MORPHOLOGICAL CONDITION LIMITS IN REGULATION

Morphological Condition Limits (MCLs) are intended to provide risk-based guidance to inform regulatory decisions. They would be used to complement existing regulatory methods and form part of a wider decision-making-process for managing TraC waters. Specifically, MCLs are intended to help regulators determine whether the Ecological Objectives of the WFD are threatened. This will inform where more detailed assessments are required, and where a regulatory exemption test may be required. Exemptions enable consideration of over-riding benefits to human health, human safety or sustainable development (Figure 4).

In addition to using Morphological Condition Limits, regulators may use other criteria to determine if WFD objectives are threatened and whether a regulatory exemption would be necessary. This could include the use of formal Environmental Impact Assessments, other detailed assessment work and professional judgement.

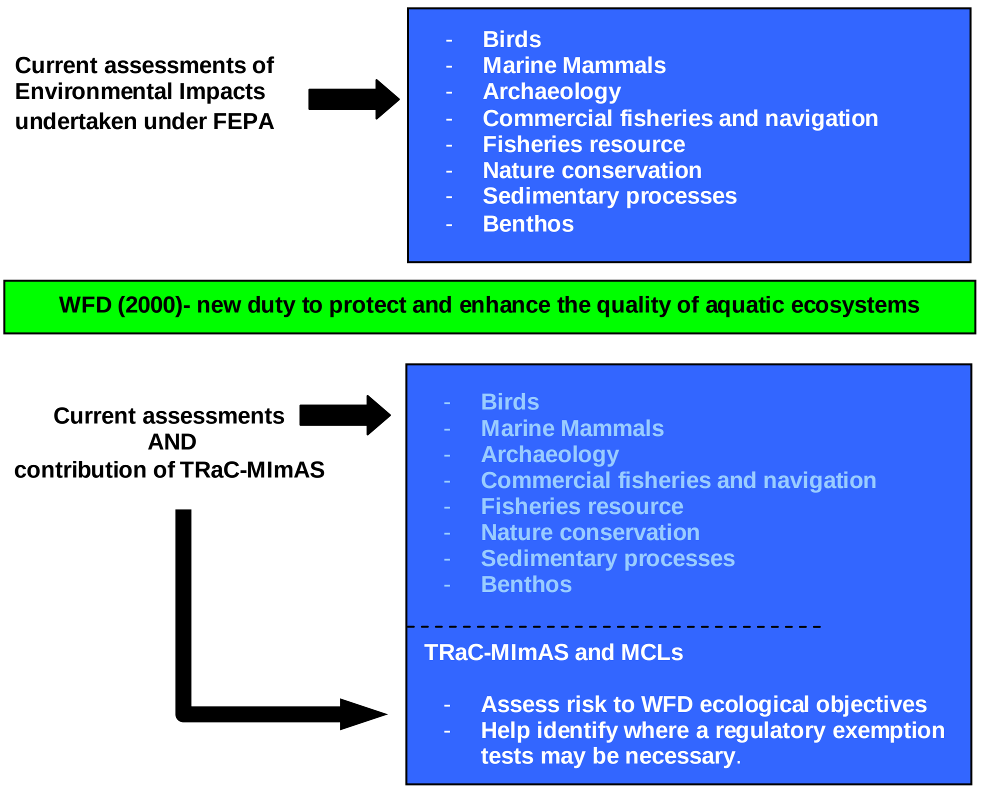


Figure 4 Summary of role of TraC MImAS and MCLs in regulation.

1.6 ROLE OF MORPHOLOGICAL CONDITION LIMITS IN WFD CLASSIFICATION

Under the Water Framework Directive, the UK is required to manage morphological change to ensure that all surface water bodies aim to achieve “Good Ecological Status” and that there is no deterioration in status. In terms of classification, the Directive specifies that hydromorphological quality elements must be explicitly considered when classifying for high status. For other status boundaries, the Directive does not require explicit consideration of hydromorphological features; however, the biological assessments of status must reflect hydromorphological conditions.

TraC-MImAS could be used to inform assessments of whether the condition of morphological quality elements is representative of high status conditions. Additionally, in recognition of the limitations of current biological tools to provide an accurate signal of the quality of morphological conditions, the TraC-MImAS tool could be used to develop risk-based morphology status maps for all status boundaries. These maps would be an extension of the work undertaken under the WFD characterisation exercise, and would identify where ecological conditions could be threatened and where investment might be targeted (through programmes of measures) to improve the quality of TraC waters such that the ecological objectives of the WFD are met. Options for using TraC-MImAS for classification will be investigated through the UKTAG classification work programme.

1.7 ONGOING WORK AND FUTURE REFINEMENTS

A revised version of the TraC-MImAS tool has been developed as part of this project. The trialling results indicate that the development and improvement of the original tool results in assessment outputs which are not materially different from the original tool. A second more basic version of the tool has also been developed with the impact ratings removed so that tool outputs can be generated without the subjectivity inherent in the use of the impact ratings,

Impact ratings for important habitats have been developed for seven habitats. The inclusion of habitats within the TraC-MImAS tool, while straight forward in principle, represents a number of problems in terms of developing a capacity used approach in line with the existing tool functionality. The TraC-MImAS tool will not incorporate these impact ratings for WFD habitats at this stage. Where a pressure has the potential to impact on a WFD habitat then this is flagged in the tool and it suggests expert assessment is required to categorise the actual impact and mitigation required. In the absence of spatial data regarding location and extent of habitats in relation to the proposed activity further work is required to finalise the approach to assessment for these habitats and the development of habitat specific Morphological Condition Limits (MCLs).

Another area for further consideration in the future is how the tool should consider new and existing impounding structures, particularly across straits e.g. Outer Hebrides, and other structures that have the potential to make a significant protuberance into a flow regime whilst having a small footprint. This task wasn’t completed during this project due to difficulty in defining the extent of impact areas for the multitude of structures that fall into these categories.

As many elements of TraC-MImAS tool are underpinned by professional judgment, it will be operated within an ‘adaptive management’ framework. TraC-MImAS will be reviewed as new evidence on the relationships between ecology and hydromorphology become available. Where necessary, the tool will be updated. The ultimate aim will be to test/validate the assumptions underpinning the tools and, where necessary, replace professional judgment with empirically tested data (Figure 6).

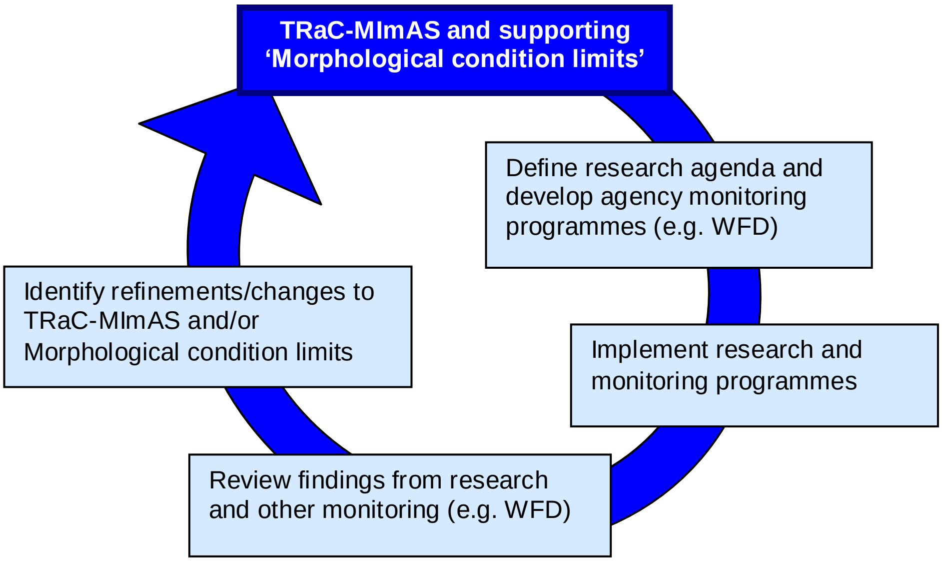


Figure 5 Application of MImAS tool and morphological condition limits within an adaptive framework.

SECTION 2

GUIDE TO USING TraC-MImAS

2.1 USING TraC-MImAS IN REGULATION

2.1.1 General approach

It is envisaged that TraC-MImAS would be applied within a two-stage regulatory screening process. This two-stage process helps support the implementation of an efficient, risk-based regulatory procedure.

Stage 1 - preliminary risk assessment. Within a Stage 1 assessment, TraC-MImAS would be applied at a local-scale to identify low risk proposals that do not threaten ecological status. Proposals that do not threaten Ecological objectives at a local scale would not require a Stage 2 assessment as it has been determined that they are low risk and would not threaten the status of the water body, even in combination with other pressures.

Stage 2 - Water body risk assessment. Reserved for proposals that exceed the morphological condition limits at a local-scale. Within a Stage 2 assessment, TraC-MImAS would be applied at a larger scale to determine if the ecology of a whole water body could be threatened by a morphological alteration, or combination of alterations.

The outputs from the Stage 1 and Stage 2 assessments would help regulators determine:

- Whether a more detailed assessment will be necessary
- The form of regulatory conditions that might be necessary
- When deteriorations in status may need to be managed, for instance, by considering a regulatory exemption on the basis of benefits to human health, human safety or sustainable development.

The most detailed assessments would typically be reserved for proposals exceeding the morphological condition limits at a water body scale. Considerations of whether an exemption test was required would be reserved for proposals failing the morphological condition limits at a water body scale (Figure 7).

> If the morphological condition limits were failed at a water body scale, additional assessments/surveys would likely be undertaken to validate that the morphological alteration would impact on the ecological status of the water body. The outcome from this could be informed by expert judgment. Where it cannot be demonstrated that the ecological objectives of the WFD are not at risk, a regulatory exemption test would be required.

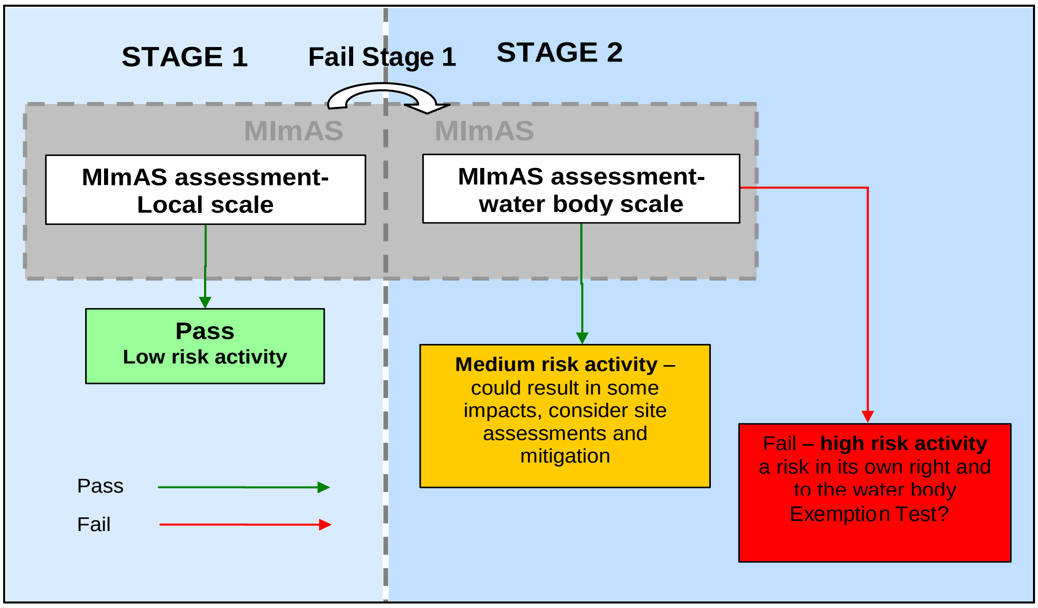


Figure 6 Summary of two stage regulatory screening process.

2.1.2 Assessment Units and scale of application

Morphological Alterations can affect the shoreline and/or the inter-tidal, sub-tidal or open water environment (Figure 8).

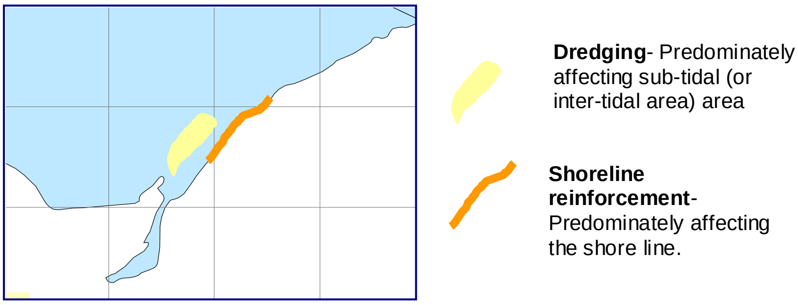


Figure 7 Summary different areas affected by morphological alterations.

It was necessary therefore to identify two assessment units:

Assessment unit A- an area based assessment for activities predominately affecting inter-tidal, sub-tidal and open water environments; and

Assessment unit B- a linear assessment for activities predominantly affecting the shoreline

As TraC waters vary significantly in size- 15m wide estuarine channel to open water coastal environments- it was necessary to develop a variable assessment unit for undertaking local (stage 1) assessments (Table 9). For water > 0.5km in width at there narrowest part, the assessment units are fixed. When assessments are being carried out in waters < 0.5km in width (e.g. narrow transitional waters), the area based assessment unit (Assessment unit B) should be reduced proportionately to the width of the environment being assessed. In reducing the size of the area based assessment unit, only the axis perpendicular to the shoreline is altered. The linear assessment unit will remain fixed at 0.5km. For new development proposal, assessments would always be centred on the location of the new proposal. If an application for a new modification was greater than the size of the Stage 1 assessment units, then the assessment would be carried out over multiples units (Figure 9).

Waters > 0.5km in width
Assessment unit **A** (Area) - 0.5km^2
Assessment unit **B** (Linear length) - 0.5km
Waters < 0.5km in width
Assessment unit **A** (Area)- channel width * 0.5km
Assessment unit **B** (Linear length) – 0.5km

Table 9 Summary of Assessment units and associated rules.

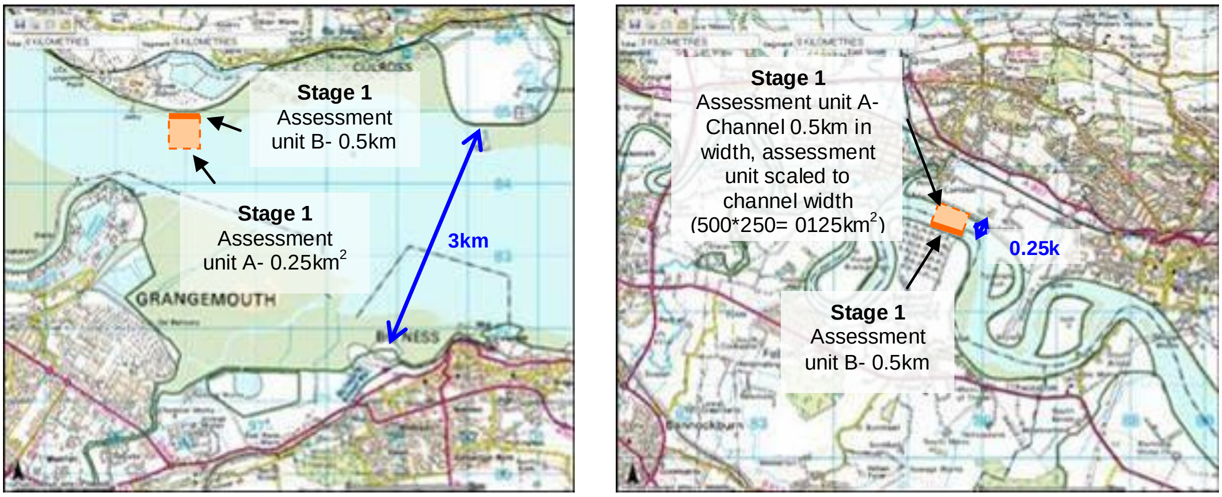


Figure 8 Summary of Stage 1 assessment.

Rules for up-scaling to assess risks to the status of a water body are being developed. It is likely that water body scale assessments (Stage 2) will be based on the application of the TraC-MImAS and associated MCLs to the entire water body area and shoreline length. As water bodies vary significantly in size, the benefits of introducing additional scale-independent rules will be investigated. Any rules developed would include an area based component and a linear shoreline component.

The rules for applying TraC-MImAS for water body scale (Stage 2) assessments could also be used to perform WFD classification assessments.

2.2 INPUTTING DATA AND TraC-MImAS USER INTERFACE

2.2.1 Using MImAS to assess different morphological alterations

As described in Section 1, it would not be possible to develop a tool that considered every engineering activity or engineering design. To reduce the number of activities considered by TraC-MImAS, a suite of generic engineering activities that cover the full range of potential physical impacts on TraC waters have been defined.

To create a suite of generic activities, some activities have been grouped together based on similarities in impacts, i.e. different activities have been assigned to a single generic alteration category (Table 10). Conversely, some more complex morphological alterations (for instance marinas and harbours) must be created by combining combinations of generic activities (Figure 10). Importantly, although the tool cannot consider every type of engineering alterations, or every type of engineering design, the tool is capable of considering variations in the size of different structures.

Generic 'Alteration' category used in MImAS	Other activities covered by this generic category
Capital Dredging	Aggregate extraction
Impoundments	Weirs, sluices
Flow and sediment manipulation structures	Breakwaters, causeways extending across part of an estuary or strait, piers, groynes, flow deflectors, training walls
Shoreline Reinforcement – Hard Engineering	Sea walls, rock armour, man made armour, revetments, gabion baskets, sheet piling
Shoreline Reinforcement – Soft Engineering	Mainly beach nourishment. (Other techniques such as using synthetic geocontainers)
Piled Structures	Bridge and pier supports, wind turbine monopiles, raised outfalls

Table 10 Summary of mapping of morphological alterations into generic alteration categories

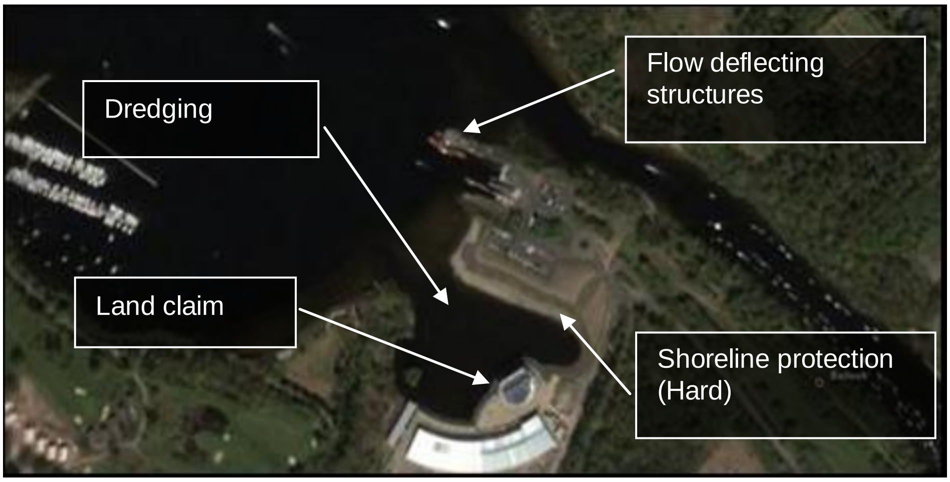


Figure 9 Example of grouping how generic activities can be combined to create more complex activities.

Each pressure has been divided into high and low pressure categories. The purpose of this is predominantly to differentiate between historic pressures and new pressures. Historic pressures are categorised as low impact, due to their existing exposure to the water body (and its likely adjustment to them over time). This includes existing structures and maintenance dredging. New pressures (those to be constructed) are categorised as high impact. These include, for example, a capital dredge or the construction of a new structure.

This historic versus new pressure categorisation applies to the following pressures:

- Land claim;
- Dredging;
- Barrages;
- Flow & sediment manipulation;
- Shoreline reinforcement – hard engineering;
- Shoreline reinforcement – soft engineering;
- Flood defence embankments;
- Piled structures; and
- Tidal devices.

The development of high and low change in impact categories has created a need to define what each pressure now includes. High and low change in impact categories for each activity pressure are stated in Table 11:

Pressure	Low change in impact	High change in impact
Land claim	Historic land claim	New land claim
Dredging	New or extended maintenance dredging	Capital dredging
Barrage / impoundments	Modification to footprint or impoundment height / length of existing structure	New structure
Flow and sediment manipulation	Modification to footprint of existing structure	New structure
Shoreline management – hard	Modification to footprint of existing structure	New structure
Shoreline management – soft	Modification to footprint of existing structure	New structure
Flood defence embankment	Modification to footprint of existing structure	New structure
Piled structures	Modification to footprint covered by existing piled structures	New piled structures
Tidal devices	Single device / demonstrator site	Commercial-scale site
HV cables / pipelines	Sub-bed	Proud of bed
Use of dredged material	New or existing licensed spoil ground	Beneficial use at site other than licensed spoil ground

Table 11 Summary of high and low footprint activities.

2.2.2 Footprint rules

All morphological alterations are input into MImAS by means of an 'Alteration footprint'. The alteration footprints typically describe the linear length over which a morphological alteration occurs, or the area over which a morphological alteration occurs (Table 12).

Generic Alteration category	Footprint rule
Land Claim	Area of claimed land
Tidal river realignment – low impact (historical)	Length of realignment
Tidal river realignment – high impact (new)	Length of realignment
Dredging	Area over which dredging occurs
High Voltage (HV) cables and Pipelines	Total Length of structure(s)
Use of dredged material (sea and intertidal)	Area over which dredging occurs
Impoundments	Automatic triggering of expert assessment
Barrages	Automatic triggering of expert assessment
Flow and sediment manipulation structures	Total Length of structure(s)
Shoreline Reinforcement – Hard Engineering	Total Length of structure(s)
Shoreline Reinforcement – Soft Engineering	Total Length of structure(s)
Flood Embankment	Total Length of structure(s)
Piled Structures	See Table 12
Tidal devices	Area of 'development' area, irrespective of number of tidal devices
Other sea bed uses	Area over which alteration occurs

Table 12 Summary of alteration footprint rules.

For some morphological alterations, it has been necessary to create 'footprint rules' to allow data to be entered into TraC-MImAS.

For Piled structures, rather than entering multiple individual footprints for each structure, generic density categories are used (Table 13).

Density category	Number of piled structures	SMALL* Footprint	Medium** Footprint	LARGE*** Footprint
Very high	>50	10	20	40
High	15-50	5	10	20
Moderate	5-15	2.5	5	10
Low	<5	1	2.5	5

* Piled structures <1m diameter
** Piled structures 1-5m diameter
*** Piled structures >5m diameter

Table 13 Footprint rules for piled structures.

For impounding structures (e.g. impoundments and barrages), the limits are based on the proportion of the assessment area that is impounded, for instance the proportion of the water body that is impounded (Figure 11). Table 14 summarises the footprints entered into MImAS.

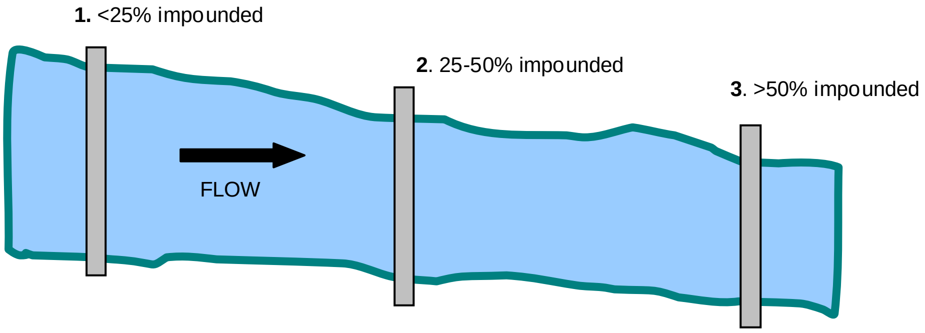


Figure 10 Visualisation of footprint rules for impoundments (see Table 13).

Proportion of assessment area impounded	Footprint	
	Impoundment	Semi-permeable barrier
1- >50%	25	10
2- 25-50%	10	5
3- <25%	5	0

Table 14 Footprint rules for impoundments.

All impounding structures would fail a Stage 1 assessment, regardless of the presence of other alterations. Therefore, if any impoundment is present, entering a nominal figure (can be a random number) into the tool to represent impoundment will automatically trigger the requirement for expert assessment.

For tidal devices (e.g. arrays of energy-generating devices), the limits are based on the 'development' area of the devices, the perimeter of which is located at a distance from the outer devices that is equivalent to the device spacing within the array (see **Figure 12**). This represents an overestimation on the actual footprint of the turbines. This is to consider the down current tail effect the turbine will have on the coastal hydromorphological processes. Arrays are designed so that the effects from one device to not affect the tidal stream energy reaching other devices nearby. This is dictated by the overall footprint area of the devices, and not by the density of turbines. Because of the diversity of tidal devices, which would result in a large variety of modelled impacts, it is necessary to create a more general footprint rule.

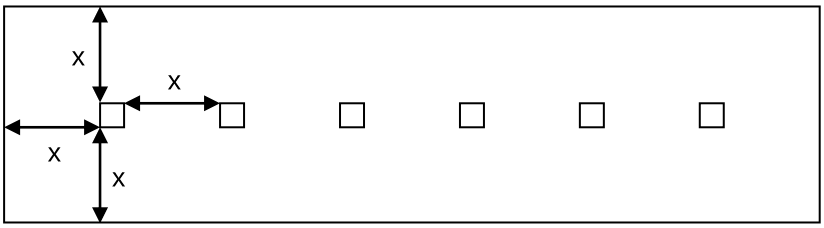
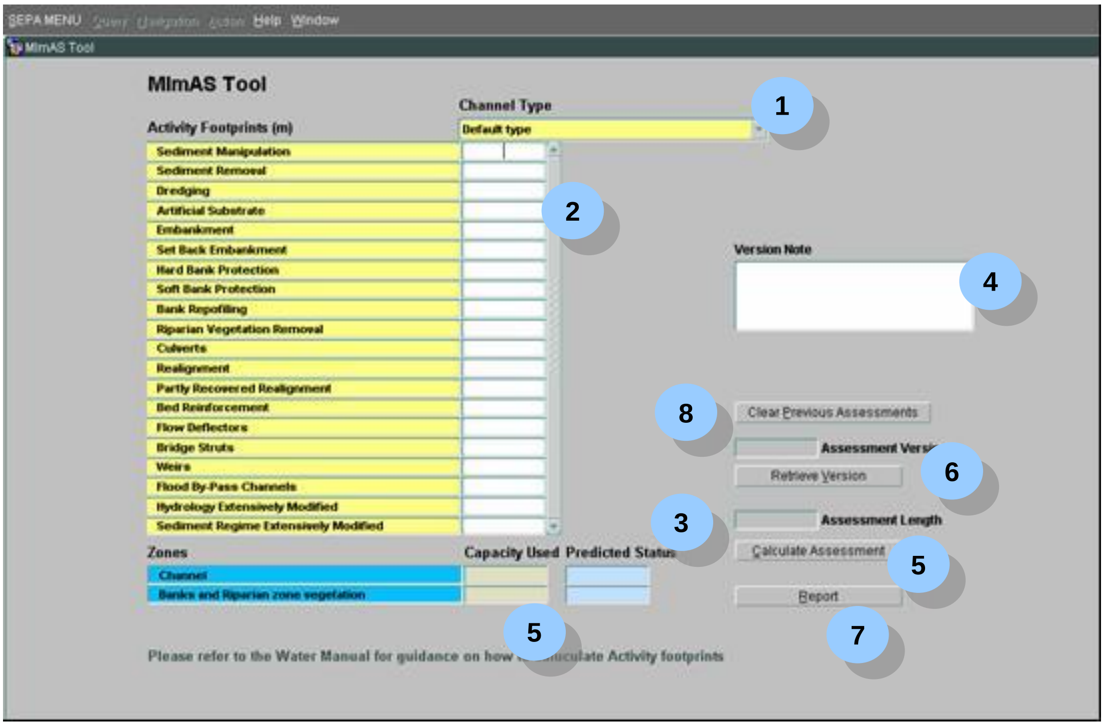


Figure 11 Suggested footprint rule for tidal devices (x = device spacing).

2.2.3 User Interface

Presently, TraC-MImAS is embedded in a series of excel worksheets. The Rivers tool has been bcoded into an Oracle™ application (Figure 12). A snap shot of the River-MImAS tool is provided below.



1. The user selects the 'Channel Type' from the drop down list. Please ensure that either type B or Type C is selected.
2. The activity footprint values should be entered in the relevant box in the column with the white background.
3. The default 'Assessment Length' value is Xm, though the user is able to change this by entering the new length (metres) in the appropriate item.
4. The 'Version Note' item is available for text input relating to the specific Assessment calculation that is to be performed.
5. The Assessment process is activated by selecting the 'Calculate Assessment' button. This will result in values being determined and then displayed in the 'Capacity Used' and the 'Predicted Status' items.
6. Subsequent Assessment calculations can be performed, with the number of these indicated by the value of the 'Assessment Version' item. The user is able to retrieve previous Assessment calculations to the screen by entering the required version number in the 'Assessment Version' item and selecting the 'Retrieve Version' button.
7. A report (PDF File) of the Assessment calculations can be activated by selecting the 'Report' button. The report summarises all versions of the current Assessment calculations and includes the information input into the version note box.
8. To start a new Assessment calculation process the user should select the 'Clear Previous Assessments' button.

Figure 12 Snapshot of River-MImAS user interface. A similar interface could be created for TraC-MImAS.

SECTION 3

MImAS outputs and Case studies

3.1 OVERVIEW

The following section provides details of key outputs from the TraC-MImAS tool. The section is divided into three parts-

- A summary of outputs from key modules within TraC-MImAS

This section provides insights into the impact ratings produced by TraC-MImAS. These impact ratings are a critical aspect of TraC-MImAS and, when combined with the Morphological Condition Limits, directly influence the limits produced for different morphological alterations.

- A summary of limits on individual morphological alterations

Although TraC-MImAS was developed to assess combination of pressures, the tool can also be used to produce limits on individual activities. These limits represent the amount of a single alteration that would put a TraC water at risk of deteriorating across a WFD status class. These values are not regulatory standards. They are provided to illustrate what the MCL mean in terms real world limits on morphological alterations.

- A selection of case studies demonstrating the application of MImAS to real-world situations

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. To provide information on the use of TraC-MImAS to assess multiple applications a series of real-world case studies have been produced.

3.2 SUMMARY OUTPUTS FROM TraC-MImAS MODULES

One of critical elements of the TraC-MImAS tool is the impact ratings that it produces for different morphological alterations. When combined with the capacity-based scoring system and the Morphological Condition Limits, the impact ratings help create limits on activities that can be used to determine risk to WFD status objectives. In developing the TraC-MImAS tool, a significant amount of effort has gone into ensuring that the impact ratings are logical and sensible and based on the best available information. The project team, steering group and technical panel have been involved in developing and agreeing the information underpin the impact assessments.

The impact ratings are created by combining the outputs from the typology modules, sensitivity modules and impact assessment modules. The ratings reflect the relative impact of different activities, on each zone (hydrodynamic, intertidal, subtidal), in each TraC type.

There are around 300 individual impact ratings (15 pressures, 3 zones and 6 types). To summarise the general trends and key aspect of these impact ratings, a series of figures and tables have been produced:

Figure 13- Summary of impact ratings from different activities in a 'Transitional type'

This Figure provides a summary of the impact ratings produced by TraC-MImAS for a particular TraC type (transitional). The figure summarises the relative impact rating assigned to each morphological alteration assessed by TraC-MImAS. The impact ratings are created by combining the information contained in the ecogeomorphic attribute module, the typology module, the sensitivity module and the impact assessment module. In the MImAS tool, impact ratings for three separate zones are produced (hydrodynamic, intertidal, subtidal). For simplicity, the maximum impact rating across these zones is presented. This value is not used in TraC-MImAS; however, it provides a useful summary to help interpret the outputs from MImAS.

Figure 14- Summary of impact ratings from different activities for all TraC types

Similar to Figure 13. In this figure impact ratings for all pressures and all TraC types are shown. This figure highlights the variation in impact ratings for different morphological alterations within TraC types and between TraC types. TraC-types that are more sensitive to a particular impact from a morphological alteration will display a higher impact rating than similar activities in a less sensitive type.

Figure 15- Summary of impact ratings organised by type and zone

TraC-MImAS creates impact ratings for three separate zones (hydrodynamic, intertidal, subtidal). The impact ratings for these zones are directly linked to the Morphological Condition Limits that have been produced for these zones. This figure summarises variations in impact ratings between these zones and between TraC types. Morphological alterations that have a dominant affect on a particular zone will have a high impact rating in that zone.

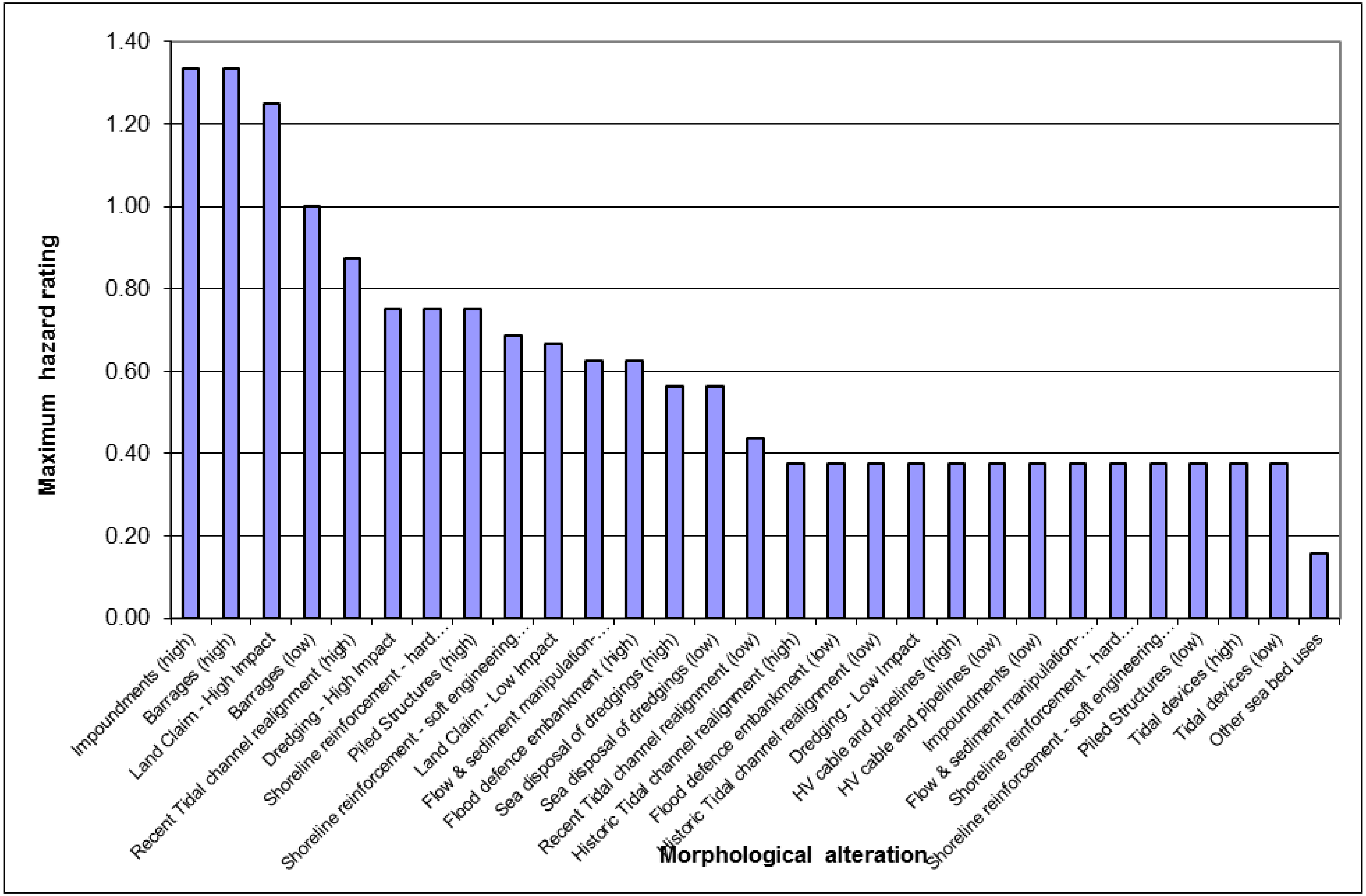


Figure 13 Summary of impact ratings from different morphological alterations in the ‘Transitional type’.

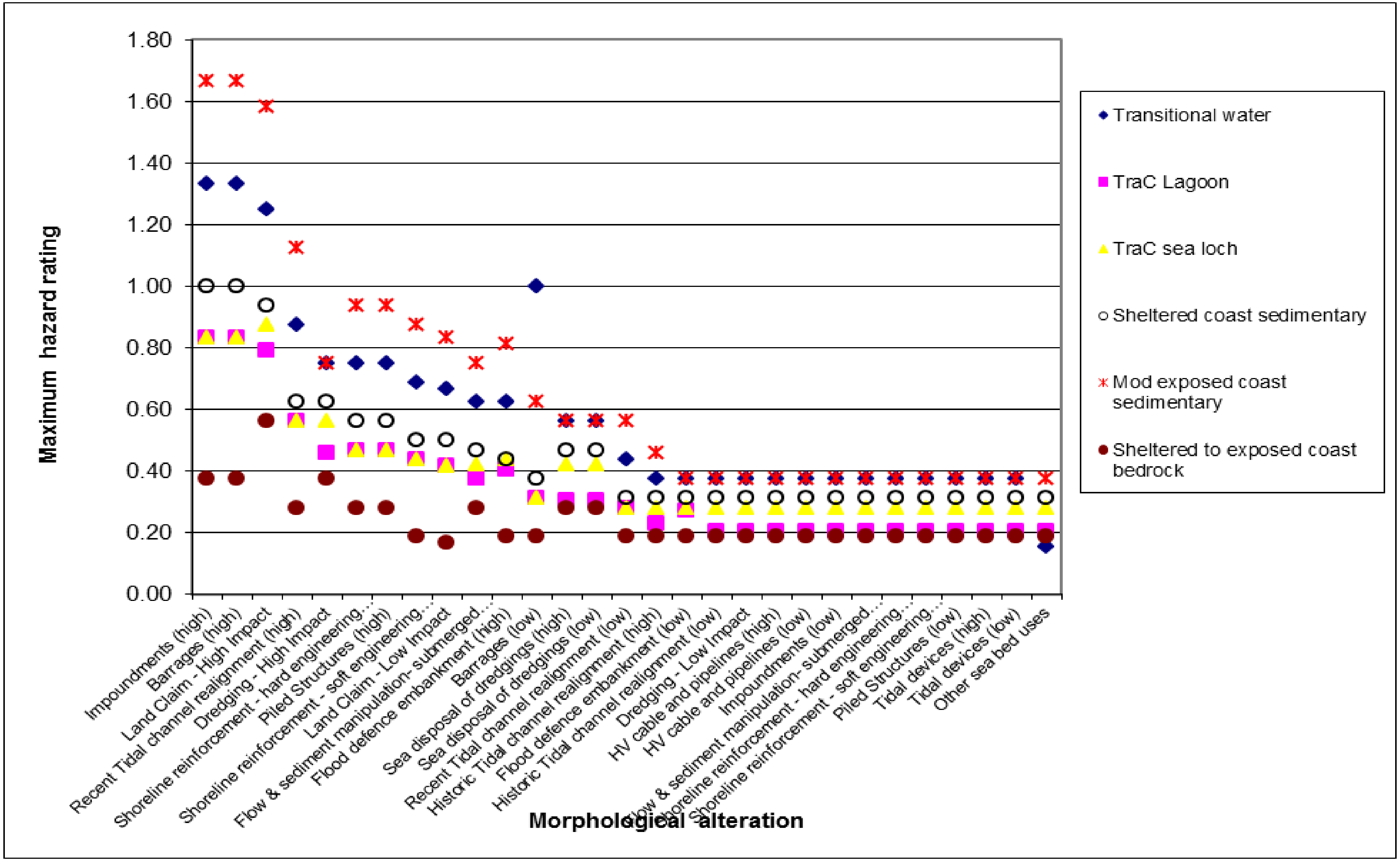

Maximum hazard rating
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Impoundments (high)
Barrages (high)
Land Claim - High Impact
Recent Tidal channel realignment (high)
Dredging - High Impact
Shoreline reinforcement - hard engineering...
Piled Structures (high)
Shoreline reinforcement - soft engineering...
Land Claim - Low Impact
Flow & sediment manipulation- submerged...
Flood defence embankment (high)
Barrages (low)
Sea disposal of dredgings (high)
Sea disposal of dredgings (low)
Recent Tidal channel realignment (low)
Historic Tidal channel realignment (high)
Flood defence embankment (low)
Historic Tidal channel realignment (low)
Dredging - Low Impact
HV cable and pipelines (high)
HV cable and pipelines (low)
Impoundments (low)
Flow & sediment manipulation- submerged...
Shoreline reinforcement - hard engineering...
Shoreline reinforcement - soft engineering...
Piled Structures (low)
Tidal devices (high)
Tidal devices (low)
Other sea bed uses
Morphological alteration
Transitional water
TraC Lagoon
TraC sea loch
Sheltered coast sedimentary
Mod exposed coast sedimentary
Sheltered to exposed coast bedrock

Figure 14 Summary of impact ratings from different activities for all TraC types.

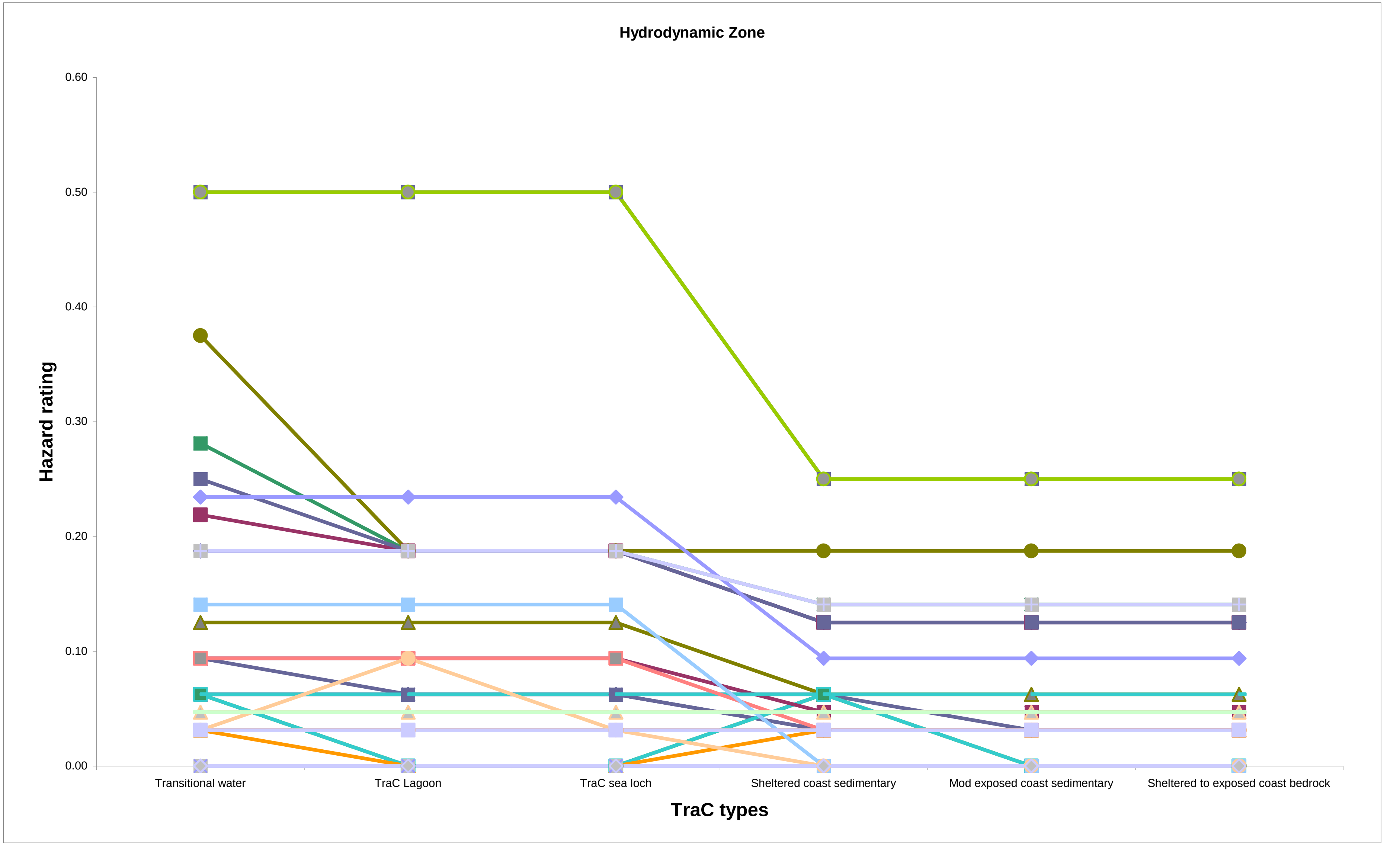


Figure 16 Summary of impact ratings - hydrodynamic zone.

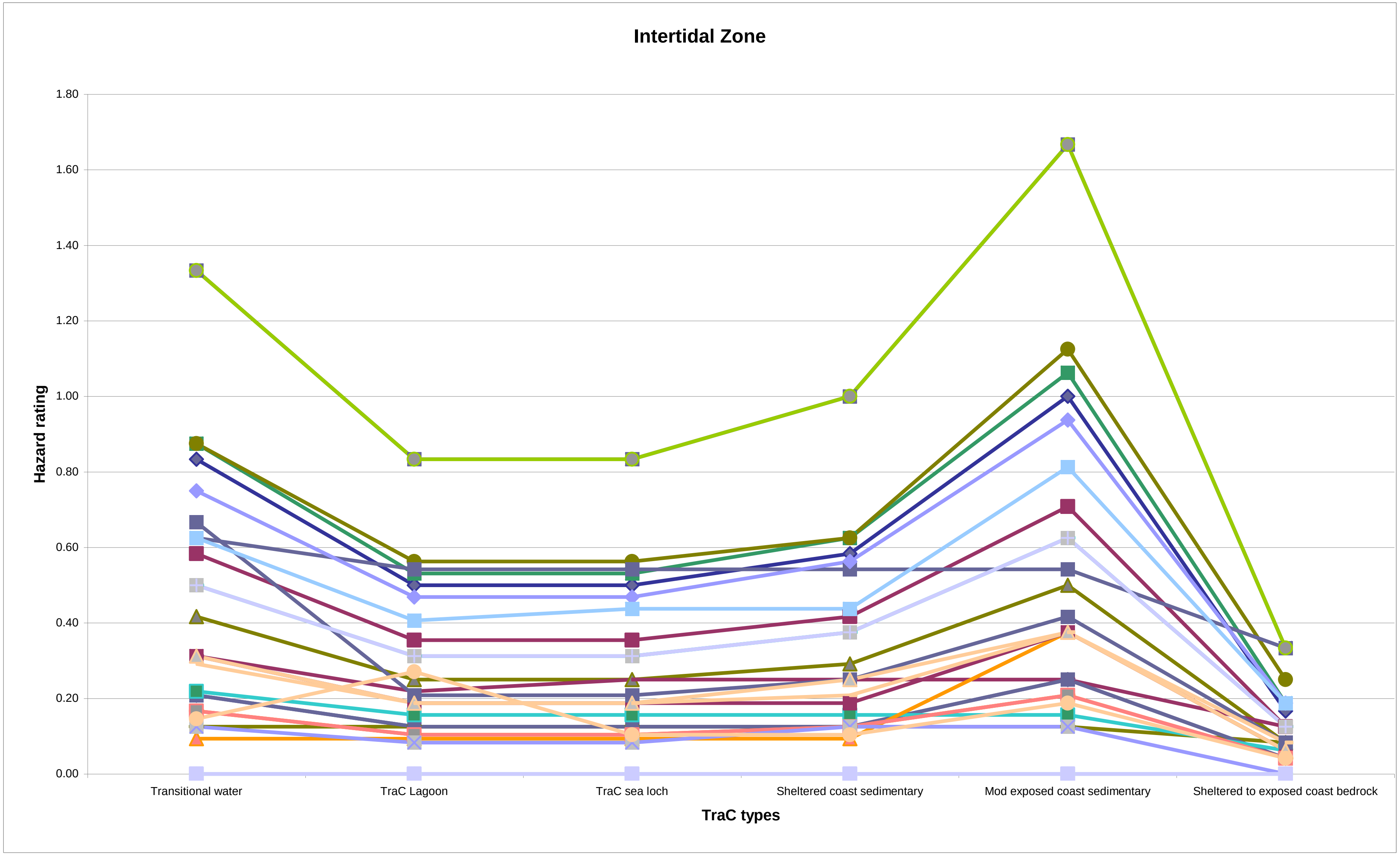


Figure 17 Summary of impact ratings - intertidal zone.

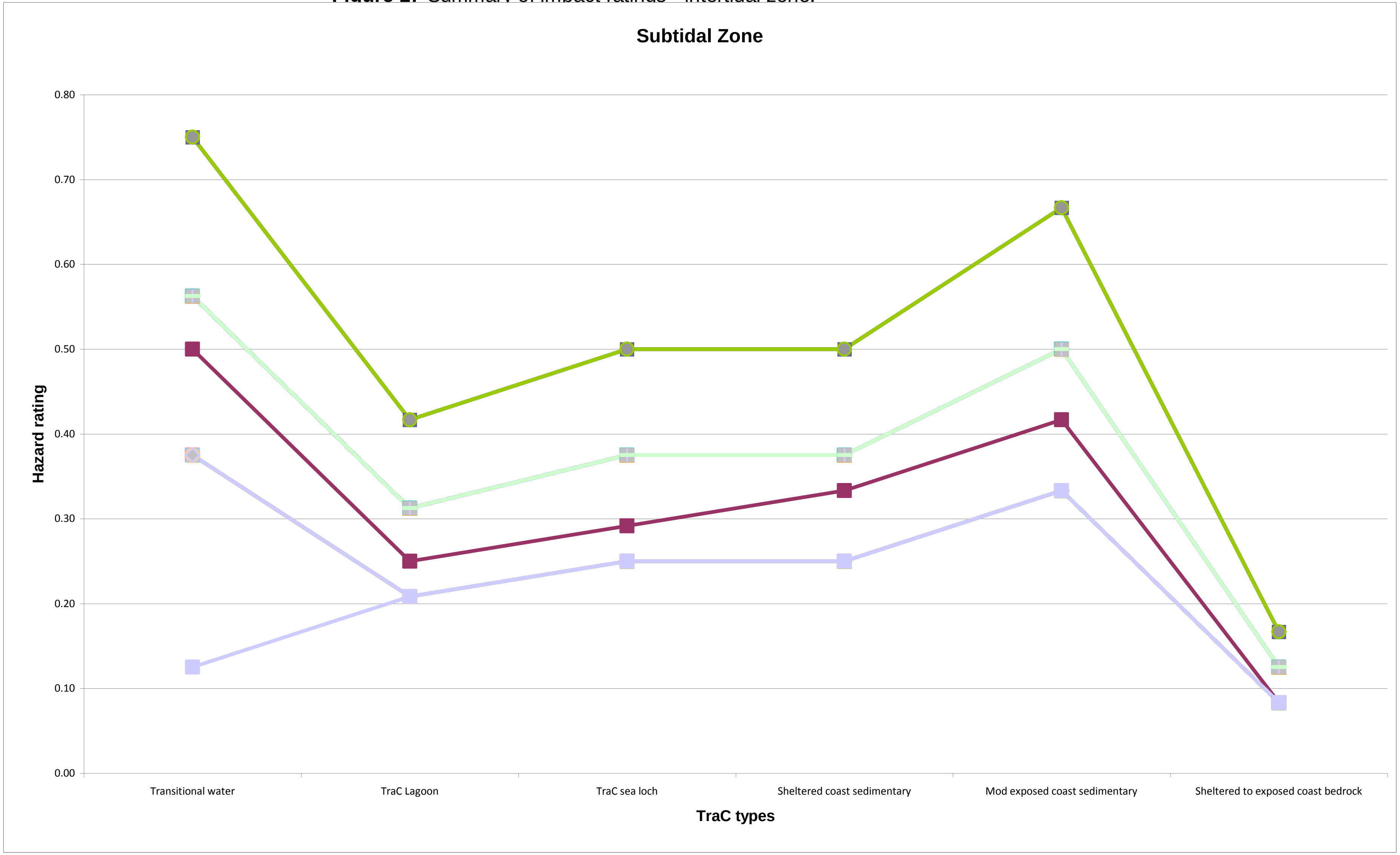
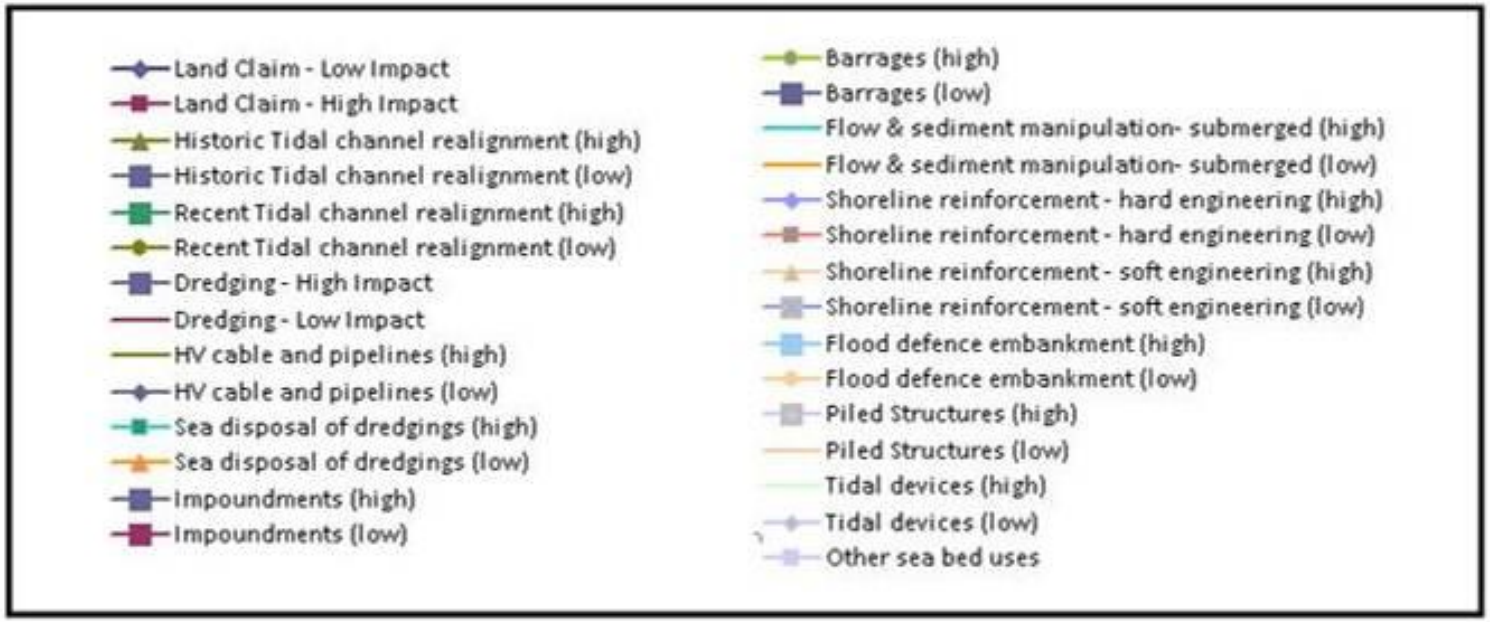


Figure 16 Summary of impact ratings - subtidal zone.



Key to impact ratings shown in Figures 16–18.

3.3 LIMITS ON INDIVIDUAL ACTIVITIES PRODUCED BY TraC-MImAS

Table 15 and 16 provide information on what the Morphological Condition Limits (Section 1.3) mean in real world terms. These values were created by running TraC-MImAS to determine how much of an individual morphological alteration can take place before the morphological condition limits for a particularly status boundary (high/good and good/moderate) are exceeded. This can be achieved by rearranging the equation on page 16 to determine the size of footprint for an individual alteration that would exceed a morphological condition limit. Examples of using MImAS to assess combination of alterations are provided in Section 3.4.

The values presented in the Tables 15 to 16 are not regulatory standards. They are provided to illustrate what 5% and 15% mean in terms of risk-based limits on morphological alterations. In regulation, TraC-MImAS would typically be used to assess how combinations of pressures interact to threaten status objectives. This information would inform where more detailed assessment work is required and where consideration of WFD exemption tests may be necessary.

The limits on individual activities are presented as ***percentage limits***

Percentage limits –These are spatially independent and apply equally to Stage 1 and Stage 2 assessments. For alterations primarily occurring in (or affecting) the hydrodynamic zone or the seabed (intertidal or subtidal), the limits are based on % area of seabed. For alterations primarily affecting the shoreline, the limits are based on % length of shore.

For a Stage 1 assessment, the percentage limits apply to assessment units described in Section 2.1.2. Rules for applying the MCLs to assess risk to water body status are currently being considered, and will form part of the trialling work. For the purposes of illustrating what the morphological condition limits mean in real terms, it should be assumed that the MCLs would be applied directly to a whole water body.

Guide to interpreting the information in Tables 15 and 16

Table 15 indicates that 26.67% high impact capital dredging can occur in a transitional water body before a risk to the High status boundary is identified. In a Stage 1 assessment ($0.5km^2$), this would mean that $0.133km^2$ (26.67% of $0.5km^2$) of dredging could occur before a local-scale risk to WFD objectives would be identified, and a stage 2 assessment undertaken. This assumes that there are no other pressures present within the stage 1 assessment unit. Importantly, this assessment does not consider site specific features of special importance. These would be assessed through other regulatory procedures- e.g. an assessment of risks to conservation objectives.

If an application for more than $0.15km^2$ of dredging was received, a Stage 2 assessment would be undertaken to determine if the water body was placed at risk. If the water body was $40km^2$ in size and no other pressures were present, $10.67km^2$ of dredging could occur before a risk to the High status objective is identified (26.67% of $40km^2$). If greater than $10.67km^2$ of dredging was proposed, a more detailed assessment would be undertaken, possibly including an EIA. A separate examination of whether the Ecological objectives of the water body are threatened may also be undertaken. Where it is demonstrated that the ecological objectives are threatened, a regulatory exemption test would be required to determine if the work should proceed on the basis of benefits to human health, human safety or sustainable development.

PERCENTAGE HIGH CLASS LIMITS FOR STAGE 1 ASSESSMENt (%)	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	13.33	21.82	20.00	20.00	10.91	35.56
Land claim – low impact	13.33	13.33	13.33	26.67	17.78	26.67
Historic tidal channel realignment – high impact	5.71	8.89	8.89	8.00	4.44	20.00
Historic tidal channel realignment – low impact	11.43	17.78	17.78	16.00	8.89	40.00
Recent tidal channel realignment – high impact	9.23	10.91	10.91	10.91	10.91	20.00
Recent tidal channel realignment – low impact	60.00	60.00	60.00	60.00	60.00	120.00
Dredging – high impact	26.67	26.67	26.67	53.33	53.33	53.33
Dredging – low impact	34.29	40.00	48.00	48.00	26.67	120.00
HV cable and pipelines – high impact	12.31	17.78	17.78	17.78	17.78	35.56
HV cable and pipelines – low impact	26.67	40.00	40.00	40.00	17.78	80.00
Use of dredged material – high impact	3.75	6.00	6.00	5.00	3.00	15.00
Use of dredged material – low impact	22.86	40.00	32.00	32.00	17.78	80.00
Impoundments – high impact	3.75	6.00	6.00	5.00	3.00	15.00
Impoundments – low impact	10.00	16.00	16.00	13.33	8.00	40.00
Barrages – high impact	8.00	10.00	10.00	11.43	6.67	20.00
Barrages – low impact	4.00	6.32	6.32	5.45	3.16	15.00
Flow and sediment manipulation, submerged – high impact	6.67	10.67	10.67	8.89	5.33	26.67
Flow and sediment manipulation, submerged – low impact	22.86	40.00	32.00	32.00	17.78	80.00
Shoreline reinforcement, hard engineering – high impact	5.71	8.89	8.89	8.00	4.44	20.00
Shoreline reinforcement, hard engineering – low impact	11.43	17.78	17.78	16.00	8.89	40.00
Shoreline reinforcement, soft engineering – high impact	8.00	10.91	10.91	10.91	6.15	20.00
Shoreline reinforcement, soft engineering – low impact	34.29	18.46	48.00	48.00	26.67	120.00
Flood defence embankment – high impact	17.14	26.67	26.67	24.00	13.33	60.00
Flood defence embankment – low impact	12.31	17.78	17.78	17.78	17.78	35.56
Piled structures – high impact	26.67	40.00	40.00	40.00	17.78	80.00
Piled structures – low impact	22.86	40.00	32.00	32.00	17.78	80.00
Tidal devices – high impact	3.75	6.00	6.00	5.00	3.00	15.00
Tidal devices – low impact	13.33	21.82	20.00	20.00	10.91	35.56
Other seabed uses	13.33	13.33	13.33	26.67	17.78	26.67

Table 15 Percentage high Class Limits for a Stage 1 assessment (%)

PERCENTAGE GOOD CLASS LIMITS FOR STAGE 1 ASSESSMENT (%)	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	40.0	65.5	60.0	60.0	32.7	106.7
Land claim – low impact	40.0	40.0	40.0	80.0	53.3	80.0
Historic tidal channel realignment – high impact	17.1	26.7	26.7	24.0	13.3	60.0
Historic tidal channel realignment – low impact	34.3	53.3	53.3	48.0	26.7	120.0
Recent tidal channel realignment – high impact	27.7	32.7	32.7	32.7	32.7	60.0
Recent tidal channel realignment – low impact	180.0	180.0	180.0	180.0	180.0	360.0
Dredging – high impact	80.0	80.0	80.0	160.0	160.0	160.0
Dredging – low impact	102.9	120.0	144.0	144.0	80.0	360.0
HV cable and pipelines – high impact	36.9	53.3	53.3	53.3	53.3	106.7
HV cable and pipelines – low impact	80.0	120.0	120.0	120.0	53.3	240.0
Use of dredged material – high impact	11.3	18.0	18.0	15.0	9.0	45.0
Use of dredged material – low impact	68.6	120.0	96.0	96.0	53.3	240.0
Impoundments – high impact	11.3	18.0	18.0	15.0	9.0	45.0
Impoundments – low impact	30.0	48.0	48.0	40.0	24.0	120.0
Barrages – high impact	24.0	30.0	30.0	34.3	20.0	60.0
Barrages – low impact	12.0	18.9	18.9	16.4	9.5	45.0
Flow and sediment manipulation, submerged – high impact	20.0	32.0	32.0	26.7	16.0	80.0
Flow and sediment manipulation, submerged – low impact	68.6	120.0	96.0	96.0	53.3	240.0
Shoreline reinforcement, hard engineering – high impact	17.1	26.7	26.7	24.0	13.3	60.0
Shoreline reinforcement, hard engineering – low impact	34.3	53.3	53.3	48.0	26.7	120.0
Shoreline reinforcement, soft engineering – high impact	24.0	32.7	32.7	32.7	18.5	60.0
Shoreline reinforcement, soft engineering – low impact	102.9	55.4	144.0	144.0	80.0	360.0
Flood defence embankment – high impact	20.0	32.0	32.0	26.7	16.0	80.0
Flood defence embankment – low impact	51.4	80.0	80.0	72.0	40.0	180.0
Piled structures – high impact	36.9	53.3	53.3	53.3	53.3	106.7
Piled structures – low impact	80.0	120.0	120.0	120.0	53.3	240.0
Tidal devices – high impact	11.3	18.0	18.0	15.0	9.0	45.0
Tidal devices – low impact	68.6	120.0	96.0	96.0	53.3	240.0
Other seabed uses	11.3	18.0	18.0	15.0	9.0	45.0

Table 16 Percentage good Class Limits for a Stage 1 assessment (%).

3.4 APPLICATION OF TraC-MImAS TO ASSESS COMBINATIONS OF PRESSURES

MImAS can also be applied to assess combinations of activities and determine whether these combinations exceed the defined morphological condition limits. 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. To provide information on the use of TraC-MImAS to assess multiple applications a series of real-world case studies have been produced.

Each case study assesses a combination of activities through MImAS and determines whether this combination of activities would exceed the morphological condition limits. To carry out these assessments, data on footprints of the existing and proposed morphological alterations were input into the TraC-MImAS tool to calculate the capacity used. The examples include both stage 1 screening and stage 2 water body assessments. It should be recognised that the GIS data does not include exhaustive data on all pressures, thus the assessments may be underestimating impacts.

Case study 1 - Stage 1 assessment of existing morphological alterations.

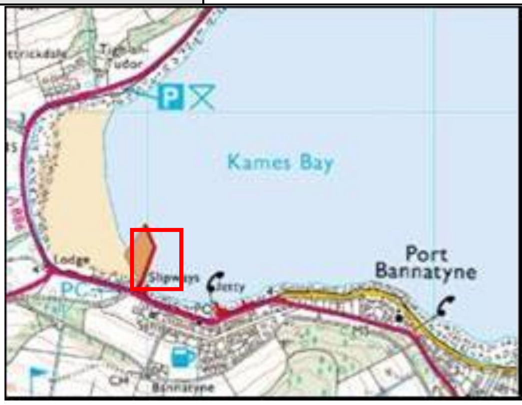
Case studies 2 and 3 - Stage 1 (Local scale) assessment of existing morphological alterations and an assessment of a suite of proposed alterations. Proposed alterations are based on previous FEPA licenses.

Case studies 4 to 7 - Stage 2 (water body scale) assessments of existing morphological alterations

Case studies 7 to 9 - MImAS was also run on a selection of provisionally designated heavily modified water bodies as a check to see that the designations and MImAS results (case studies 7-9) were in agreement.

Case Study 1	**Newburgh Quay, Ythan Estuary (WB ID 200113)**
Water body Area	2.6 km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 1. Preliminary assessment scale - 0.25 km^2 (red box)
MImAS Type	Transitional
Existing Alterations	
Quay (land claim)	0.01km^2
Zone	**Capacity Used**
Hydrodynamics	0.7% (Below 5% high status MCL)
Intertidal	1.9% (Below 5% high status MCL)
Subtidal	1.6% (Below 5% high status MCL)
Overall Status	**High**

The Ythan estuary is one of the least modified estuaries in Scotland with little evidence of industry apart from at the quay at Newburgh. The width of the estuary at this location is 0.35 km. The present degree of modification would be consistent with high ecological quality.

Case Study 2	**Port Bannatyne (WB ID 200030)**
Water body Area	24.3km^2
TraC Type	CW8 (Sheltered, meso-tidal)
	
MImAS Scale of Assessment	Stage 1. Preliminary assessment scale - 0.25 km^2 (red box)
MImAS Type	Coastal, sheltered, sedimentary
Existing modifications	
Existing jetty	0.002 km^2
Zone	**Capacity Used**
Hydrodynamics	0% (Below 5% high status MCL)
Intertidal	0% (Below 5% high status MCL)
Subtidal	0.1% (Below than 5% high status MCL)
Current Status	**Not at risk (High status)**
New modifications	
Proposed new pier	0.003 km^2
Proposed capital dredging	0.01 km^2
Zone	**Capacity Used**
Hydrodynamics	0.2% (Below 5% high status MCL)
Intertidal	1.6% (Below 5% high status MCL)
Subtidal	1.4% (Below 5% high status MCL)
Predicted Status	**Not at risk (High status)**

Port Bannatyne is located on the Isle of Bute and is located in the Rothesay water body in the Firth of Clyde. This stage 1 assessment is based on a FEPA licence application for the disposal of capital dredgings as part of a proposed marina development. The case study assesses the capacity used by existing modifications before assessing these in combination with the proposed engineering works. The capacity used by the existing jetty, and the proposed new pier and capital dredging would be consistent with high ecological quality and no further assessment would be required. However, if a new proposal were received that would exceed the 5% (high status) limit, a risk of a deterioration in status would be identified, and further assessment of the proposal to determine if the water body was at risk would be undertaken.

Case Study 3	**Don Estuary to Souter Head (Aberdeen) (WB ID 200105)**
Water body Area	50.2 km^2
TraC Type	CW5 (Moderately exposed, meso-tidal)
	
MImAS Scale of Assessment	Stage 1. Preliminary assessment scale - 0.25 km^2 (red box)
MImAS Type	Coastal, moderately exposed to exposed
Existing Modifications	
Hard shoreline reinforcement	0.5km
Groynes	0.5km
Zone	**Capacity Used**
Hydrodynamics	17% (Exceeds good stats MCL)
Intertidal	63% (Exceeds good stats MCL)
Subtidal	50% (Exceeds good stats MCL)
Current Status	**Less than good**
New Modifications	
Proposed beach nourishment	0.6 km
Proposed breakwaters	0.2 km
Zone	**Capacity Used**
Hydrodynamics	23% (Exceeds good stats MCL)
Intertidal	100% (Exceeds good stats MCL)
Subtidal	74% (Exceeds good stats MCL)
Predicted Status	**Less than good**

This case study is a stage 1 assessment based on a FEPA licence application to replenish the beach at Aberdeen. The intertidal area at Aberdeen beach has been subject to a large degree of modification in the past with installation of man made armour and a groyne field. Due to ongoing problems of coastal erosion it was proposed to replenish the beach with sediment dredged from the South Esk Estuary at Montrose. The works to stabilise the beach also included the installation of rock 't' head groynes. The existing modifications fail the preliminary assessment and therefore would require a stage 2 assessment at the water body scale.

Case Study 4	**Peterhead (WB ID 200131)**
Water body Area	46km^2
TraC Type	CW2 (Exposed, meso-tidal)
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Coastal, exposed, bedrock
Existing modifications	
Port and Harbour land claim	0.5 km^2
Dredging	0.1 km^2
Spoil Disposal	0.6 km^2
Zone	**Capacity Used**
Hydrodynamics	0.1% (Below 5% high status MCL)
Intertidal	0.2% (Below 5% high status MCL)
Subtidal	0.2% (Below 5% high status MCL)
Overall Status	**High**

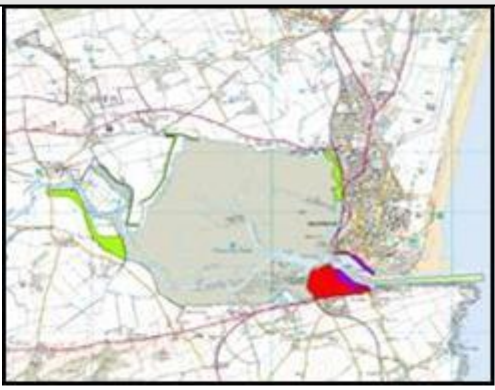
* Not all pressures picked up from GIS. Likely to be at High Status according to TraC MImAS.

This stage 2 assessment considers the existing modifications at Peterhead. The present degree of modification would be consistent with high ecological quality. However, if a new proposal were received that would exceed the 5% (high status) limit, a risk of a deterioration in status would be identified, and further assessment of the proposal to determine if the water body was at risk would be undertaken.

Case Study 5	**Lower Forth Estuary (WB ID 200435)**
Water body Area	38.6km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Existing modifications	
Port and harbour land claim	1.5 km^2
Dredging	0.3 km^2
Bridges	6 large in channels supports
Zone	**Capacity Used**
Hydrodynamics	0.7% (Below 5% high status MCL)
Intertidal	2.5% (Below 5% high status MCL)
Subtidal	2 % (Below 5% high status MCL)
Overall Status	**High**

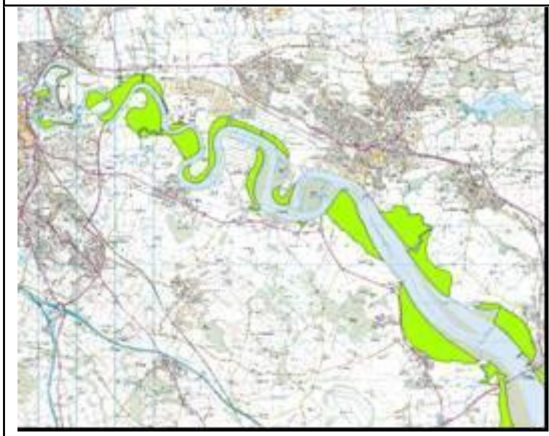
* Not all pressures picked up from GIS. Likely to be at High Status according to TraC MImAS.

The lower Forth Estuary consists of a straight channel with the Rosyth naval dockyard being the only area of significant land claim. Unlike the upper and middle Forth Estuary water bodies, this water body is not designated provisionally heavily modified. Based on the available information, this stage 2 water body assessment puts the overall status of the upper Forth at high status.

Case Study 6	**Montrose Basin (WB ID ~ 200079)**
Water body Area	8.5km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Existing modifications	
Maintenance dredging	0.2 km^2
Bridges with piers	2.7 km
Agricultural land claim	0.2 km^2
Port and harbour land claim	0.4 km^2
Flood defence embankment	3.1km
Zone	**Capacity Used**
Hydrodynamics	1.8% (Below 5% high status MCL)
Intertidal	8.2% (Below 15% good status MCL
Subtidal	4.4% (Below 5% high status MCL)
Overall Status	**Good Status***

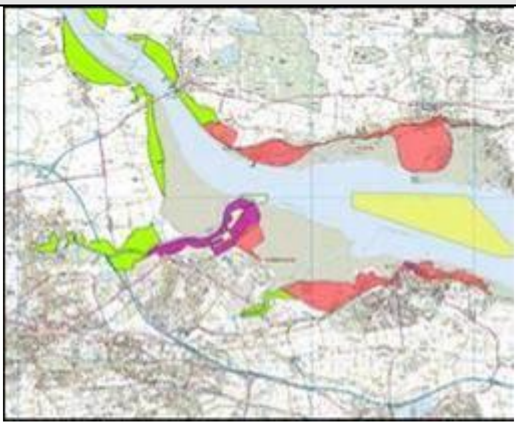
* Not all pressures picked up from GIS. Likely to be at Good Status according to TraC MImAS.

Montrose Basin is the estuary of the South Esk. There is land claim within the main basin and port and harbour development alongside the channel which drains the basin. This stage 2 water body assessment suggests that the basin is likely to be at good status.

Case Study 7	**Upper Forth Estuary (WB ID 200437) (Provisional heavily modified)**
Water body Area	9.7km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Existing modifications	
Agricultural land claim	7.6 km^2
Zone	**Capacity Used**
Hydrodynamics	12% (Below good stats MCL)
Intertidal	34% (Exceeds good stats MCL)
Subtidal	29% (Exceeds good stats MCL)
Overall Status	**Less than good***

* Not all pressures picked up from GIS. Likely to be at less than Good Status according to TraC MImAS.

The upper Forth Estuary consists of a meandering channel fringed by significant areas of land claimed for agricultural purposes. Owing to these modifications the water body is designated provisionally heavily modified. A stage 2 assessment puts the status of the upper Forth at less than good status.

Case Study 8	**Middle Forth Estuary (WB ID 200436) Provisional Heavily Modified**
Water body Area	38.2km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Exisitng modifications	
Agricultural land claim	3.2 km^2
Recent Industrial land claim	6.8 km^2
Dredging	0.4 km^2
Sea disposal	4.9 km^2
Zone	**Capacity Used**
Hydrodynamics	9% (below good stats MCL)
Intertidal	30% (Exceeds good stats MCL)
Subtidal	21% (Exceeds good stats MCL)
Overall Status	**Less than Good***

* Not all pressures picked up from GIS. Likely to be at less than Good Status according to TraC MImAS.

The middle Forth Estuary contains significant land claim for industrial and port and harbour purposes along with the Bo'ness sea disposal site. Owing to these modifications the water body is designated provisionally heavily modified. A stage 2 assessment puts the status of the middle Forth at less than good status.

Case Study 9	**Inner Clyde Estuary (WB ID 200510)** **Provisional heavily modified**
Water body Area	4.4km^2
TraC Type	TW2 (Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud).
	
MImAS Scale of Assessment	Stage 2. Water body assessment scale
MImAS Type	Transitional
Existing modifications	
Port and Harbour Land Claim	5.1 km^2
Dredging	0.5 km^2
Zone	**Capacity Used**
Hydrodynamics	18% (Exceeds good stats MCL)
Intertidal	54% (Exceeds good stats MCL)
Subtidal	45% (Exceeds good stats MCL)
Overall Status	**Less than Good**

The Inner Clyde has been extensively canalised in the past and contains extensive areas of land claim for port and harbour purposes. Owing to these modifications the water body is designated provisionally heavily modified. A stage 2 assessment puts the status of the Inner Clyde at less than good status.

SECTION 4

Conclusions

To help regulators quantify the risk that a new morphological alteration could impair achievement of the ecological objectives of the WFD, a series of 'Morphological Condition Limits' (MCLs), and a tool to determine where these condition limits could be threatened (TraC-MImAS), have been developed.

Morphological condition limits- *Thresholds of alteration to morphological conditions beyond which there is a risk that the Ecological status objectives of the WFD could be threatened. The limits are expressed in percentage capacity.*

Morphological Condition Limits (MCLs) are intended to provide risk-based guidance to inform regulatory decisions. They would be used to complement existing regulatory methods and form part of a wider decision-making-process for managing TraC waters. Specifically, MCLs are intended to help regulators determine whether the Ecological Objectives of the WFD are threatened. This will inform where more detailed assessments are required, and where a regulatory exemption test may be required. Exemptions tests enable case specific consideration of benefits to human health, human safety or sustainable development.

Morphological condition limits have been defined for three TraC zones- hydrodynamic, inter-tidal and sub-tidal zone. Only MCLs for the High/Good and Good/Moderate boundaries are being considered at this time. The WFD requires regulators to manage for no deterioration in WFD status, and work is ongoing to define MCLs for other status boundaries.

In addition to using Morphological Condition Limits, regulators may use other criteria to determine if WFD objectives are threatened and whether a regulatory exemption would be necessary. This could include the use of formal Environmental Impact Assessments, other detailed assessment work and professional judgement.

A similar approach is already in use in Scotland (River-MImAS) and a Lake-MImAS tool is under development.

The TraC-MImAS tool and associated morphological condition limits are currently in draft form. A programme of field trialling and formal peer review will be undertaken over the summer of 2007. Based on the results of this work, a thorough review of the performance of the tool and morphological condition limits will be undertaken.

As many elements of TraC-MImAS tool are underpinned by professional judgment, it will be operated within an 'adaptive management' framework. TraC-MImAS will be reviewed as new evidence on the relationships between ecology and hydromorphology become available. Where necessary, the tool will be updated. The ultimate aim will be to test/validate the assumptions underpinning the tools and, where necessary, replace professional judgment with empirically tested data

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APPENDIX 1

TraC MImAS: SUMMARY OF MODULES

2.1 REVIEW OF MODULES COMPRISING TraC-MImAS

The TraC-MImAS tool comprises five modules (Figure 19). Collectively the modules provide an assessment of impacts to morphological conditions. All impacts are measured in terms of impacts to 'system capacity'. Each module is designed to be semi-independent of the others, thereby allowing individual modules to be updated over time as more information becomes available. The modules are briefly described below.

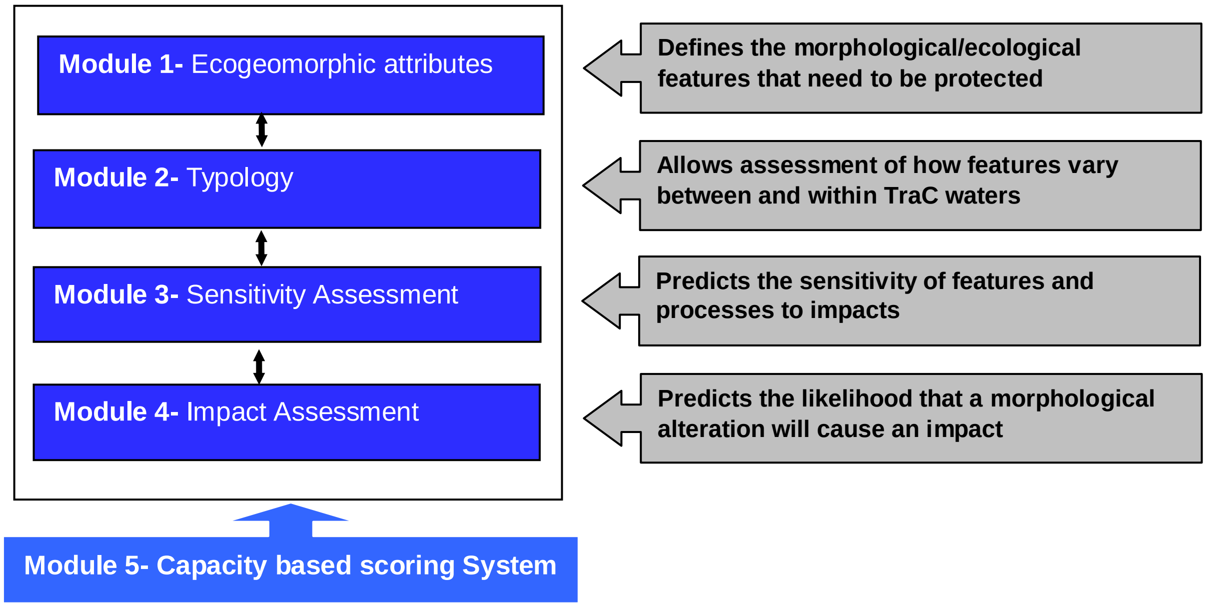

Figure 18 **Overview of the modular components of TraC-MImAS.**

Figure 20 provides a breakdown of stages involved in developing the modules comprising TraC-MImAS and the associated MCLs. Highlighted on the right of the diagram are those steps which have, or will, be subject to contributions from the technical panel, steering group and peer review. The iterative nature of the development process is vital to building consensus in the value of the approach and increasing confidence in the tool performance.

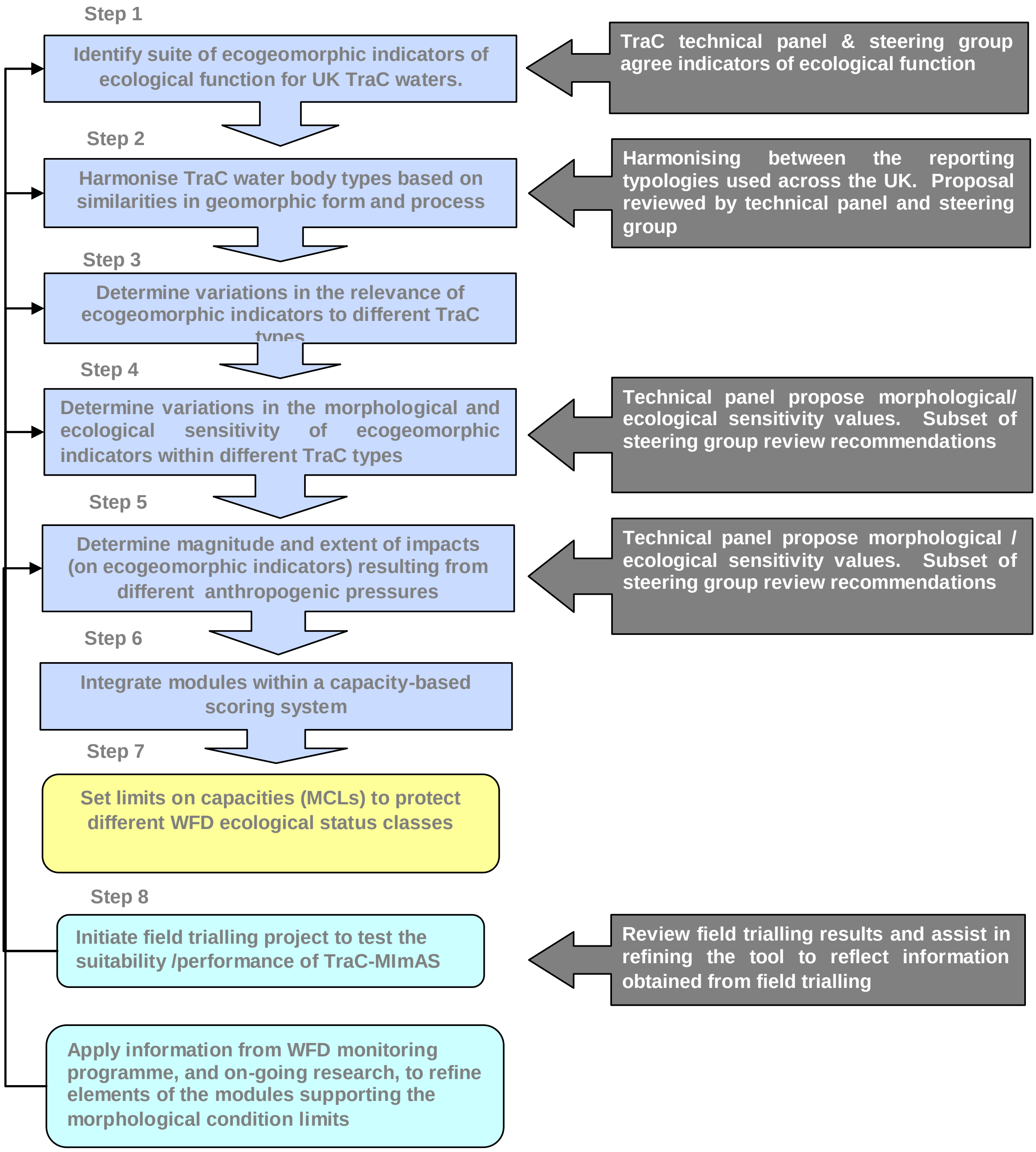

Figure 19 **Summary of steps involved in determining MCLs for UK TraC water bodies.**

2.1.1 Module 1 – Ecogeomorphic Attributes

A particular marine species tends to live within a certain environment; that is, it has a preference for a combination of environmental factors such as substrate type, temperature, salinity and hydrodynamic conditions. Figure 21 provides a conceptual framework which is founded on the concept that the landform is the principal integrator of hydromorphological pressures and ecological function.

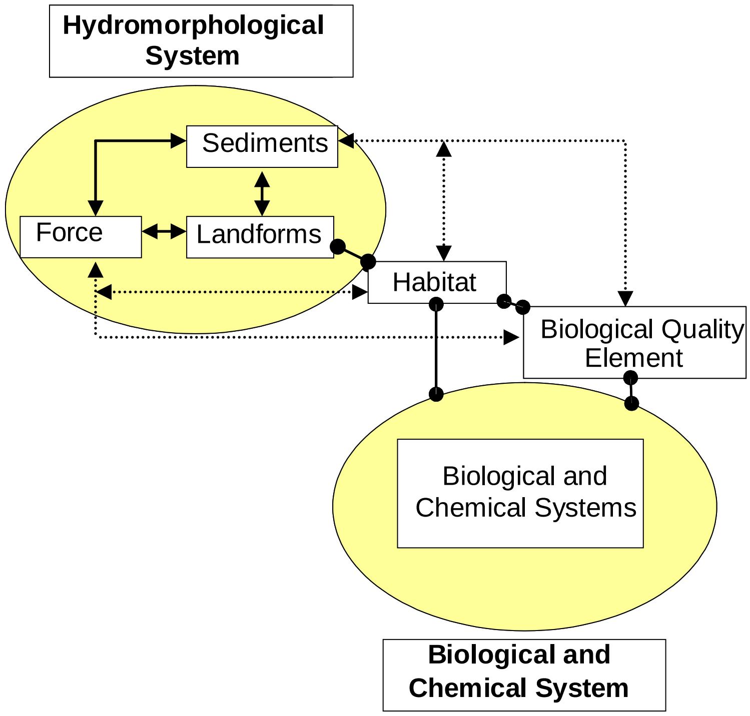

Figure 20 **The proposed conceptual framework (after Cooper *et al.* 2005).**

One of the fundamental assumptions underpinning the TraC-MImAS tool is that geomorphic processes and attributes provide a dynamic template that supports the structure and function of ecosystems (Little, 2000; Viles and Spencer, 1995). It follows, therefore, that if consideration is given to factors influencing both geomorphic and ecological functioning, it should be possible to select a suite of physical process and attributes that will provide a signal of impacts to ecosystem structure and function.

To help select a set of ecogeomorphic attributes, it was first necessary to identify a suitable suite of indicators of marine ecosystem health (**Box 1**). These indicators of ecosystem health were divided into two categories:

- Morphological and habitat attributes;
- Ecogeomorphic processes and disturbance patterns

Morphologic and Habitat Attributes

Attribute 1 - Substrate type
The type of substratum, mainly determined by the dynamics of water movement at the site, is highly important in structuring community composition, although salinity may become more critical in upper estuarine conditions. The rock or sediment type is significant in two respects as it affects the nature and extent of coastal features present in a given waterbody.

Attribute 2 - Natural range of flow and coastal features
Strong offshore currents affect many coasts and have a particularly marked influence on circalittoral communities, with lessening effects in shallow water and on the shore (where the influence of wave action predominates). However constricted sections of some inlets, particularly the narrows in sealochs, can have very strong currents which affect both the shallow subtidal and the lower shore zones, significantly increasing species richness. These, along with wave action, contribute to determining sediment grade and consequent community type.

Attribute 3 - Zonation: emersion/immersion on the shore
In beach and mudflat locations the degree of wetting and drying will have physiological consequences for the species inhabiting these environments. Along rocky coasts the intertidal communities are vertically zoned due to the variability and unpredictability in physical factors such as salinity, temperature and availability of food and nutrients which are related to tidal level and wave action.

Attribute 4 - Refuge habitat zones
Organisms frequently utilise seabed features that provide protection and shelter from disturbances or predation. These 'refuge areas' are therefore critical components of functioning marine ecosystems e.g. rock crevices, rock pools and reefs.

Attribute 5 - Presence, abundance and distribution of macrophytes and macroalgae (e.g. seagrass, kelp beds and saltmarsh)
Macrophytes and macroalgae are integral components of a functional marine ecosystem. In addition to their intrinsic value, macrophytes and macroalgae provide natural coastal protection by the dissipation of wave energy and provide cover for other marine species where depth allows light penetration to the seabed.

Attribute 6 - 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. These can be interrupted by developments that fragment morphological zones and increase the fragmentation within inter-tidal zones (i.e. separating two areas of inter-tidal).

Ecogeomorphic Processes and Disturbance Patterns

Process 1 - Natural disturbance regime from astronomical and meterological driven forces
Changes in astronomically-driven (i.e. tidal) and meteorologically-driven (i.e. river flow) forces result in natural degrees of change in sediment depth, composition and structure within a functioning ecosystem. Natural disturbances can result from storm events which can create, alter or destroy morphological features, and redistribute biota. Shallow subtidal and intertidal sediments e.g. beach deposits reflect a high degree of wave disturbance.

Process 2 - Longitudinal sediment transport processes
Where waves break obliquely to the coast, a current is created in the surf zone which, when acting with the stirring action of the waves, results in the transport of material parallel to the shore. The rate and direction of such movements are influenced not only by the prevailing hydraulic processes, but also by the bathymetry and the physical characteristics of the beach and the threshold of movement of the sedimentary material. This "longshore current" or "Littoral drift" is a dominant influence in shaping the coastline and is the major cause of coastal erosion and/or accretion particularly where the dynamic equilibrium of the drift regime is altered in any way by natural changes or due to anthropogenic influences.

Process 3 – Lateral sediment transport processes
Reduced or increased sediment supply, or changes in the type of sediment supplied to a water body will ultimately result in morphological changes in the sub or inter-tidal morphology. Sediment input into the coastal zone arises from the erosion of cliffs and coastal slopes, material transported by littoral drift from adjacent water bodies, catchment derived input from fluvial sources and material transported from offshore sinks. Changes can be caused by natural changes (e.g. reductions in contemporary supply as sources have become exhausted throughout the Holocene) or human influences.

Process 4 – Chemical Processes
Communities living in intertidal zones are relatively tolerant of changes in salinity, temperature and turbidity. Salinity is an important community structuring factor in the upper reaches of estuaries and lagoons. Changes in salinity, nutrient enrichment, pH, oxygen, redox potential and drainage in the sediment column are important factors in determining community structure in sediments. These processes are strongly influenced by hydrodynamic factors such as changes in freshwater discharge. Organic enrichment can alter community structure and lead to increased numbers of opportunist species. Severe deoxygenation significantly reduces species richness. Shallow subtidal sediments reflect a high degree of temperature/salinity fluctuations, with increasingly more stable conditions with depth. The overall hydrographic regime and water quality characteristics of an area play an important role in determining community composition.

Process 5 – Biological processes
It is important not to ignore the biological interactions that operate in the marine environment such as competition and predation. There is a complex relationship between sediment characteristics and biological interactions that play an important role in determining community structures.

Box 1 Summary of indicators of ecosystem health for TraC Waters.

With reference to the information summarised in Box 1 and the full range of hydromorphological quality elements contained in Annex V of the WFD (**Table 17**), a set of ecogeomorphic attributes have been selected (**Tables 18, 19 and 20**). Each ecogeomorphic attribute has been chosen for its role in supporting the processes needed to create and maintain the physical environment on which biological quality elements exist (e.g. food webs or species interactions/competition). The attributes were selected to reflect the physical processes and attributes, biological and chemical processes/attributes have not been incorporated within TraC-MImAS. The tool does not require data for each ecogeomorphic attribute but uses this data to assess the relevance and sensitivity of each ecogeomorphic attribute to change. This core input data that the tool requires is pressure and water body type. The attributes are divided into the three dominant TraC zones:

- Hydrodynamics (**Table 18**) - Describes the influence of the tides, waves and freshwater inflow
- Intertidal (**Table 19**) - Describes the size and structure of the intertidal zone
- Subtidal (**Table 20**) - Describes the size and structure of the subtidal zone

Annex V 1.1.3. Transitional Waters	**Annex V 1.1.4. Coastal Waters**
Tidal Regime: • Freshwater flow • Wave exposure	**Tidal Regime:** • Direction of dominant currents • Wave exposure
Morphological Conditions: • Depth variation • Quantity, structure and substrate of the seabed • Structure of the intertidal and sub-tidal zones	

Table 15 **Hydromorphological quality elements for TraC Waters in Annex V of the Directive.**

Ecogeomorphic Attributes	**Definition**	**Link to ecosystem attributes and processes**	
Hydrodynamics	*Describes the influence of the tides, waves and freshwater inflow etc, on TraC Waters*	Attributes	Processes
Tidal range	*The height that the sea rises and falls over a tidal cycle*	2,3	1,2,3
Currents	*Currents associated with the rise and fall of the tide*	2	1,2,3
Freshwater flow	*Riverine input into TraC Waters maybe modified by human interference of catchment hydrology*	2	1,2,3
Flushing/exchange	*The length of time it takes for a transitional water or sea loch to exchange its water*	2	1
Salinity/mixing/ stratification	*Occurs in transitional waters and sea lochs where freshwater input is important*	2	1
Waves	*Waves are important in driving sediment transport processes and can be altered or induced by morphological alterations*	2	1,2,3

Table 16 **Summary of ecogeomorphic attributes and links to indicators of ecosystem health - Hydrodynamics.**

Ecogeomorphic Attributes	Definition	Link to ecosystem attributes and processes	
Intertidal Zone	Describes the size and structure of the intertidal zone	Attributes	Processes
Geometry	Describes the spatial extent and form of the intertidal zone		
Planform	*Aerial view showing planar area of the intertidal zone (2D perspective). Describes the outline and spatial extent, or area of the intertidal zone which can change in response to prevailing coastal processes and/or realignment of the high water mark due to engineering activities (Masselink and Hughes, 2003).*	2,6	2,3
Profile	*Cross sectional form of an estuarine channel or gradient of the shoreline along a given line in a water body.*	1,2	1,2,3
Morphological features and substrate	Describes the shape and character of geomorphological features, and the size, structure and sorting of the intertidal sediments		
Nature and extent of coastal features	*Includes topographic, geomorphological and vegetation features of the coastal zone e.g. saltmarsh, seagrass, sand dunes, mudflats, sand bars, spits.*	2	1,2,3
Natural sediment size range	*Describes changes in sediment size distribution.*	1	1,2,3
Continuity and sediment supply	Assesses interruptions to coastal processes and sediment supply		
Longitudinal sediment transport processes	*Describes sediment mobilisation pathways i.e. transport of material by littoral drift from adjacent water bodies.*	1,2	2,3
Lateral sediment transport processes	*Includes land to sea connectivity and describes inputs and outputs of sediment from erosion of cliffs, catchment derived input from fluvial sources and material transported from offshore.*	1,2	2,3

Table 19 **Summary of ecogeomorphic attributes and links to indicators of ecosystem health - Intertidal Zone.**

Ecogeomorphic Attributes	Definition	Link to ecosystem attributes and processes	
Sub tidal Zone	**Describes the size and structure of the subtidal zone**	**Attributes**	**Processes**
Geometry	Describes the spatial pattern and form of the subtidal zone		
Planform	*Aerial view showing planar area of the subtidal zone (2D perspective). Describes the outline and spatial extent, or area of the subtidal zone which can change in response to prevailing coastal processes and/or engineering activities.*	1,2	1,2,3
Profile	*Cross sectional form of a channel or of the coastal zone perpendicular to the coastline*	1,2	1,2,3
Morphological features and substrate	Describes the shape and character of geomorphological features, and the size, structure and sorting of the intertidal sediments		
Nature and extent of coastal features	*Includes topographic, geomorphological and vegetation features of the subtidal zone e.g. seagrass, sand banks, ripples.*	1,2	2,3
Natural sediment size range	*Describes changes in sediment size distribution*	1,2	2,3
Continuity and sediment supply	Assesses interruptions to coastal processes and sediment supply		
Longitudinal sediment transport processes	*Describes sediment mobilization pathways i.e. transport of material by littoral drift from adjacent water bodies.*	1,2	2,3
Lateral sediment transport processes	*Includes land to sea connectivity and describes inputs and outputs of sediment from erosion of cliffs, catchment derived input from fluvial sources and material transported from offshore.*	1,2	2,3
Fish passage	*Describes pathways for fish passage – suggest this could either be incorporated into the 'Continuity' attribute, or could be moved to the hydrodynamic zone section*	6	5

Table 20 **Summary of ecogeomorphic attributes and links to indicators of ecosystem health - Subtidal Zone.**

2.1.2 Module 2 - TraC Typology

Overview

One of the most useful ways of classifying TraC waters is on morphology, tidal range, topography and the salinity distributions and flow characteristics (Dyer, 1997). Finkl (2004) presents an up to date and extremely comprehensive review of coastal classification schemes. However such classifications do not consider the interactions which occur within such environments between the morphology, hydrodynamics and ecological function.

The WFD requires all TraC waters to be assigned to ecologically distinct types, so that the ecological status of any given water body can be determined against 'type-specific' reference conditions. The UK adopted System B in coastal and transitional waters and closely followed the guidance document produced by the EU CIS Working Group 2.4 (COAST) in deriving its final typology. The typology is a simplified representation of a complex suite of process and interactions and should not be considered as providing an accurate representation of all features present in a given water body. Whilst the typology groups on some of the important physical characteristics (e.g. exposure) which affect ecological function; it is broad scale and does not sufficiently account for the different physical conditions which apply across water bodies (e.g. substrate). The obligatory physical factors used to differentiate types included four common factors for coastal and transitional waters and two additional factors for transitional waters (Table 21).

The typology is an important element of TraC-MImAS, and provides the basis for developing a morphological and ecological sensitivity assessment. The typology reflects the presence and character of the attributes identified in the Attribute Module (Tables 16 to 18), their relative ability to absorb change (resistance), and their ability to recover from change (resilience). The typology is a very useful concept when looking at the likely ecological impacts of activities, in identifying monitoring requirements and, in the future, identifying more targeted remedies. UK and Irish TraC water bodies are represented by 12 coastal types and 6 transitional types. Table 22 presents a summary of the dominant hydromorphological characteristics of each of the transitional and coastal types recognised.

Physical Factor	Transitional	Coastal
Mixing Characteristics	•	•
Salinity	•	•
Mean Tidal Range	•	•
Wave exposure	•	•
Depth	•	
Substratum	•	

Table 21 **The physical factors used to differentiate types for TraC waters.**

TraC Type	General morphological characteristics and geographical distribution
Transitional Types	
TW1	*Partly mixed or stratified, meso or polyhaline, macrotidal, intertidal or shallow subtidal, predominantly sand and mud, e.g. Parrett Estuary, England.*
TW2	*Partly mixed or stratified, meso or polyhaline, mesotidal, intertidal or shallow subtidal, predominantly sand and mud, e.g. Tees and Dart Estuaries, England.*
TW3	*Fully mixed, polyhaline, macrotidal, sand or mud substratum, extensive intertidal areas, e.g. Humber and Thames Estuaries, England; Solway Estuary (transboundary).*
TW4	*Fully mixed, polyhaline, mesotidal, sand or mud substratum, extensive intertidal areas, e.g. Southampton Water and Plymouth Sound, England.*
TW5	*Transitional Sea Lochs, e.g. Gare Loch and Loch Linnhe, Scotland*
TW6	*Transitional Lagoons e.g. Fearn Lodge Lagoon, Dornoch Firth, Scotland.*
Coastal Types	
CW1	*Exposed, macro-tidal, e.g. Carmarthen Bay and South Pembrokeshire, South Wales.*
CW2	*Exposed, meso-tidal, e.g. West Atlantic Seaboard, Ireland and North Coast, Northern Ireland.*
CW3	*Exposed, micro-tidal.*
CW4	*Moderately exposed, macro-tidal, e.g. Kent and Sussex Coast, England.*
CW5	*Moderately exposed, meso-tidal, e.g. Northumberland Coast, England and Mourne Coast, Northern Ireland.*
CW6	*Moderately exposed, micro-tidal, e.g. Sound of Jura, Scotland and Brittas Bay Southwestern Irish Sea, Ireland.*
CW7	*Sheltered, macro-tidal, e.g. Bridgewater Bay, England.*
CW8	*Sheltered, meso-tidal, e.g. Firth of Forth, Scotland and Lough Foyle, Northern Ireland/ Ireland.*
CW9	*Sheltered, micro-tidal (none in the UK).*
CW10	*Coastal Lagoons, e.g. Dubh Loch, Loch Fyne, Scotland and Kinsale Marsh, Commoge, Ireland.*
CW11	*Shallow Sea Lochs, e.g. Loch Ryan, Scotland*
CW12	*Deep Sea Lochs, e.g. Loch Fyne, Scotland*

Table 17 **Overview of the physical characteristics of the UK and Irish TraC types.**

The formulation of TraC-MImAS required the development of a harmonised typological framework capable of capturing all ‘large’ TraC water bodies (> 50 ha). Given the limited timeframe it was important to keep the tool as simple as possible and therefore a degree of aggregation has taken place. The proposed scheme is discussed further in the morphological and ecological sensitivity section.

The features present along a stretch of coast are not only dependent on tides, currents and wave exposure but are also dependent upon the underlying geology and bathymetry of the seabed and the underlying geology. All TraC water bodies have a mosaic of different habitat types from stable depositional mud to mobile sand to boulders to rock. To aid the assessment of morphological responses to alterations it became necessary to split the coastal typology into three sub types; coastal sedimentary (sheltered), coastal sedimentary (exposed) and coast bedrock (sheltered to exposed). These groupings will be subject to further review through validation and trialling.

The use of a solely physically based approach to assessing ecological impacts was an important issue raised during consultation with the technical panel. It is recognised that the typology is geomorphological and does not explicitly consider ecological drivers. The tool is not intended to provide a detailed assessment of ecological status rather the tool is intended to provide a means of identifying where ecological conditions are likely to be impaired through impacts to morphology. The simple differentiation on substrate proposed above provides the first step in making the assessment more ecologically relevant to those biological quality elements dependent upon the seabed (e.g. fish, macroalgae and invertebrates).

Linking morphological reference conditions, based on predominant sea bed characteristics, to EUNIS Level 3 habitats (http://eunis.eea.europa.eu/) provides a means of further developing the ecological approach. This tool does not have the ability to consider site specific conditions, for instance the presence of features of special interest. Proposals to modify areas of water bodies that have been identified as being particularly sensitive because of their important habitats and species will be subject to detailed assessment under existing regulations (e.g. Habitats Directive).

Assessment of relevance of ecogeomorphic attributes

Step 3 (Figure 5) in the development of the TraC-MImAS tool involved a process of elimination to resolve which ecogeomorphic indicators were relevant to which type. Two classes of relevance have been defined: not relevant and relevant (Table 23). For instance, stratification is unlikely to play an important behavioural role in coastal water bodies, and so that ecogeomorphic attribute is excluded from further consideration.

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 ecogeomorphic indicators, or combination of ecogeomorphic indicators, between different types, thus promoting protection of those features and/or processes supporting ecosystem health.

Relevance	Description
Not Relevant	A disturbance acting on a particular ecogeomorphic attribute is not likely to affect the morphology and the intactness, integrity or naturalness of communities.
Relevant	A disturbance acting on a particular ecogeomorphic attribute is likely to affect the morphology and the intactness, integrity or naturalness of communities.

Table 18 **Summary of classes of relevance.**

2.1.3 Module 3 – Morphological and Ecological Sensitivity

Overview

A fundamental component of the MImAS approach is to assess the likelihood that an ecogeomorphic attribute will respond to a specified pressure, and by extension to consider the likely impacts on TraC ecology. The definition of sensitivity that was developed as part of the Review of Marine Nature Conservation (RMNC) is defined as follows (see Laffoley et al., 2000):

"*A very sensitive habitat or species is one that is very easily adversely affected by external factors arising from human activities and is expected to recover over a very long period or not at all. A sensitive habitat or species is one that is easily affected by a human activity, and is expected to only recover over a long period*."

MarLIN adopted the term intolerance for sensitivity, and used the rationale developed below to combine intolerance and recoverability into an overall sensitivity scale (Hiscock et al., 1999; Tyler-Walters et al., 2001). Therefore, intolerance was used for all prior instances of the term sensitivity including prior sensitivity assessments. The term sensitivity now refers to the combination of intolerance and recoverability.

The rationale uses the following definitions:

- ‘Intolerance’ (was ‘sensitivity’ sensu stricto) is the susceptibility of a habitat, community or species (i.e. the components of a biotope) to damage, or death, from an external factor. Intolerance must be assessed relative to change in a specific factor.
- ‘Recoverability’ is the ability of a habitat, community or species (i.e. the components of a biotope) to return to a state close to that which existed before the activity or event caused change.
- ‘Sensitivity’ is dependent on the intolerance of a species or habitat to damage from an external factor and the time taken for its subsequent recovery. For example, a highly sensitive. species or habitat is one that is very adversely affected by an external factor arising from human activities or natural events (killed / destroyed, .high. intolerance) and is expected to recover only over a very long period of time, (10 to 25 years, .low. recoverability). Intolerance, and hence sensitivity, must be assessed relative to a specified change in a specific environmental factor.

To allow assessment of the likelihood that a type (or ecogeomorphic attribute) would respond to an engineering activity, a simple method for assessing morphological and ecological sensitivity has been developed similar to that described above. River-MImAS utilised the general principles of resistance and resilience to change building on the conceptual framework of Grimm and Wissel (1997).

Within this resistance/resilience framework, types (or ecological communities) of increasing resistance and resilience are described as less sensitive to disturbances, whereas types (or ecology) of decreasing resistance or resilience are described as more sensitive. Although resistance and resilience would likely form a continuum of responses, three classes of resistance and resilience have been defined (low, moderate and high) (Tables 24 and 25).

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

Table 19 **Summary of resistance classes.**

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 20 Summary of resilience classes.

Combining different resistance and resilience permutations generates nine total sensitivity combinations (Figure 22). 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 TraC water bodies.

Morphological sensitivity assessment

This model of resistance/resilience was applied to the range of typical TraC Types listed in Table 6. This analysis was undertaken for two purposes:

(i) To group types into a smaller subset of types that will be used within MImAS

(ii) To allow assessment of variations in the sensitivity of the ecogeomorphic indicators between the grouped set of channel types.

To group different types, variations in the resilience and resistance to change of the hydrodynamics, intertidal and subtidal zones were qualitatively assessed and scored following the three class system outlined in Tables 8 and 9. The results of this grouping into the typology that underpins the tool are shown in Table 10. This assessment was based on an understanding of the boundary conditions and energy environments of each TraC type. The principal justification for combining types is that the reference condition ecology and morphological conditions are relatively consistent and it can be anticipated that overall there will be an equivalent response to anthropogenic pressures acting on equivalent ecogeomorphic attributes.

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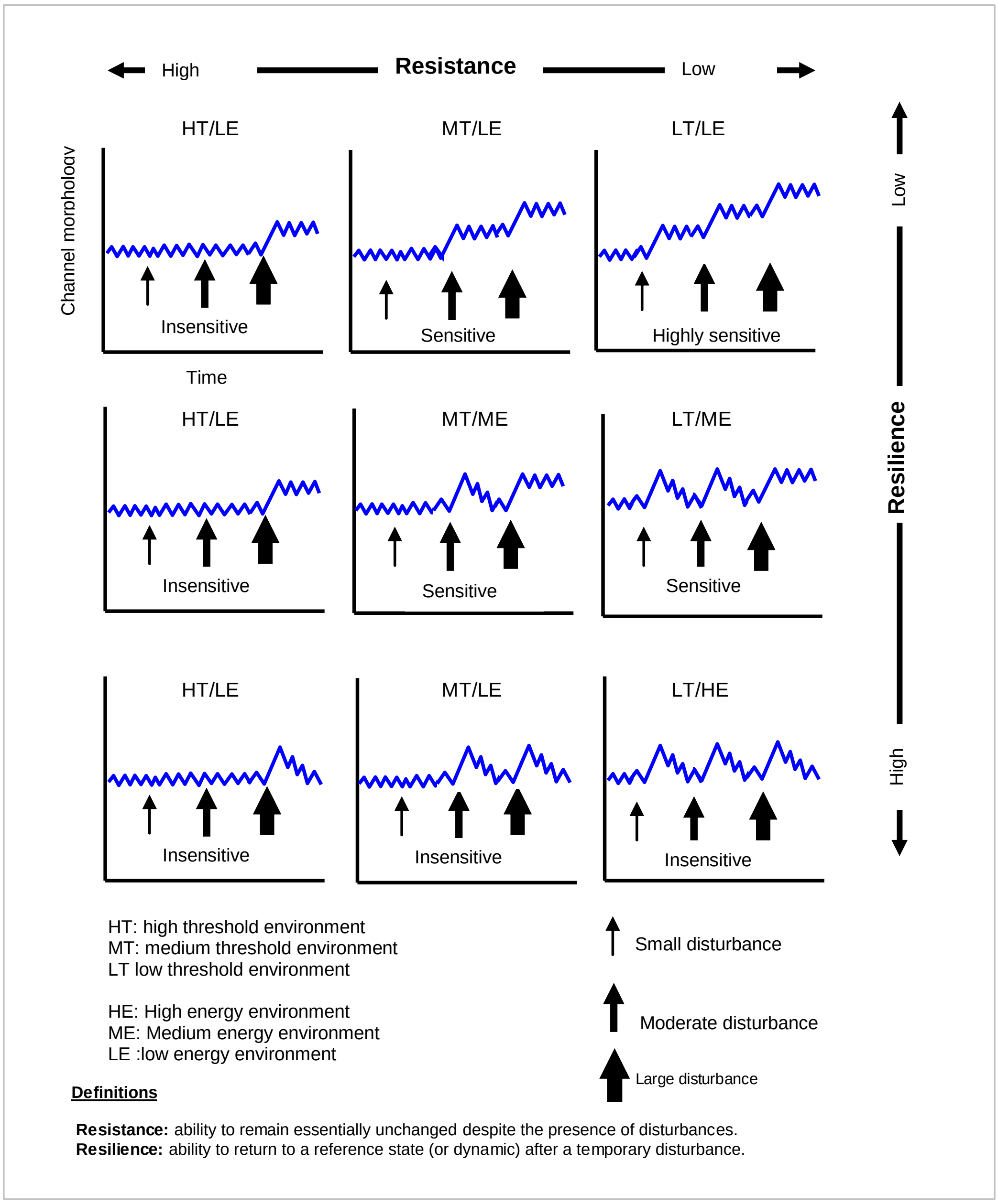

Figure 21 **Conceptual model of resistance, resilience and sensitivity**

To assess resistance, the boundary conditions of each TraC type were qualitatively assessed by the technical panel. Resilience to change was qualitatively assessed based on an understanding of variations in energy between channels and by considering the frequency of bed and bank sediment entrainment. The rationale was that TraC waters with higher energy and lower boundary resistance conditions are more active and are thus more likely to recover from system perturbations. The assessment was carried out for the three dominant TraC zones; hydrodynamics, intertidal and subtidal.

TraC Type	General morphological characteristics	Resistance/resilience classes	MImAS Code
CW1 to CW9	Sheltered to exposed, micro to macrotidal	Medium resistance, medium resilience (Hydrodynamics) High resistance, high resilience (Intertidal zone) Med resistance, high resilience (subtidal zone)	Coastal bedrock
CW1 to CW6	Moderately exposed, Macro-tidal. Sedimentary	Medium resistance, low resilience (Hydrodynamics) Low resistance, high resilience (Intertidal zone) Low resistance, high resilience (subtidal zone)	Moderately exposed to exposed coast, sedimentary
TW1 to TW4	Partially to fully mixed, mesotidal to macrotidal, intertidal or shallow subtidal, sand and mud.	Medium resistance, medium resilience (Hydrodynamics) Low resistance, high resilience (Intertidal zone) Low resistance, high resilience (subtidal zone)	Transitional meso to macrotidal
CW7 to CW9	Sheltered, micro-macrotidal. Sedimentary.	Medium resistance, medium resilience (Hydrodynamics) Medium resistance, medium resilience (Intertidal zone) Medium resistance, medium resilience (subtidal zone)	Sheltered coast, sedimentary
TW5, CW11 and CW12	TraC Sea Lochs.	Medium resistance, medium resilience (Hydrodynamics) Medium resistance, medium resilience (Intertidal zone) Medium resistance, low resilience (subtidal zone)	TraC sealochs
TW6, CW10	TraC Lagoons.	Medium resistance, Low resilience (Hydrodynamics) Low resistance, low resilience (Intertidal zone) Low resistance, low resilience (subtidal zone)	TraC lagoons

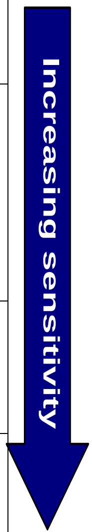

Table 21 **Grouping of TraC types based on the resistance and resilience framework.**

The sensitivity assessment described above was then extended to assess variations in the resistance and resilience of the ecogeomorphic 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 technical panel and steering group. As with other elements of the tool, the intention is for this assessment to be validated/refined using data generated from future research and the WFD monitoring programme.

When applying this sensitivity assessment within the scoring system that underpins the TraC 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. Appendix 2 provides a summary of the sensitivity assessments.

Ecological sensitivity assessment

When considering ecological sensitivity the primary consideration is whether a degradation in the integrity, intactness or naturalness is likely to occur (SNIFFER Report WFD49 (2006) (River-MImAS). 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 assessment cannot aim to accurately model complex physical or ecological relationships or specific biotopes. It is therefore important to recognise that a more complete assessment of sensitivity would also have to consider a variety of additional factors that can only be assessed through more detailed site specific analyses of TraC water body systems.

Given these limitations, only a rudimentary ecological sensitivity assessment is incorporated. The sensitivity assessment is a high level exercise developed to underpin a simple system for assessing the likely risk posed by an engineering activity. Ecological sensitivity can be either classed as sensitive or highly sensitive. The assessment simply considers a likely movement away from characteristics associated with reference conditions. The technical panel helped carried out an initial ecological sensitivity assessment with some input from the steering group (Table 27).

Sensitivity	Description
Sensitive	A moderate to large impact on an ecogeomorphic 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 an ecogeomorphic indicator of ecosystem health is likely to affect the intactness, integrity or naturalness of communities, or impact upon important organisms.

Table 22 **Summary of classes of ecological sensitivity.**

2.1.4 Module 4 – Impact Assessment

Overview

Ecosystem response to anthropogenically induced change is a product of a number of complex physical, physiochemical and biological interactions. Morphological alterations affect TraC waters in a variety of ways and impacts can often propagate beyond the zone of activity. The duration and frequency and intensity of a particular activity are also important in determining the scale of impact. Land claim results in the direct loss of habitat and can result in changes to the physiographic character (e.g. planform and bathymetry) which in turn can alter hydrodynamic function. The presence of coastal defences and flow and sediment manipulation structures can result in changes to erosional and depositional patterns. These pressures can have a potential impact on habitat stability due to changes in currents or substrate availability causing a change in food supply and/or recruitment of colonising organisms. This can lead to acute or chronic impacts on the species and communities reliant on the ecosystem, ranging from macroalgae and benthos to birds and fish (Cascade Consulting, 2002).

This module comprises two components - (i) assessment of the likelihood that a morphological alteration will have an impact on an attribute (contained within the attribute module) and (ii) an assessment of whether impacts are likely to be contained within the vicinity of the pressure, or whether the impact will extend beyond the local vicinity of the pressure. The latter assessment is termed the 'zone of impact'.

Summary of engineering activities and morphological pressures

It would not be possible to develop a tool that can consider every engineering activity or design. To reduce the number of activities considered by TraC-MImAS, a suite of generic engineering activities that cover the full range of potential physical impacts on TraC waters have been defined. Rules have been developed that allow a wider range of morphological alterations to be mapped to this suite of generic pressures.

Fifteen generic pressures have been incorporated, they include shoreline pressures such as 'hard' engineering for coastal defence, and pressures such as barrages and dredging. The Pressure Module is not type specific. The difference in response to the pressures between TraC water body types is captured by combining the Sensitivity Module with the Pressure Module. A detailed description of these generic pressures is provided in **Table 28**.

Specific pressures	Description
Land Claim	Historical (typically > 50 years) enclosure of intertidal or subtidal areas within impermeable banks followed by infilling for use by agriculture, housing, port or industry. The system may have partially recovered to a more "stable" natural condition since the land claim initially took place. Any new enclosure of intertidal or subtidal areas within impermeable banks followed by infilling for use by agriculture, housing, port or industrial use. The modification may destabilise the system.
Historic tidal river realignment	Historical (typically >50 years ago) alteration to course or planform of upper estuaries where the channel remains river-like. Includes straightening and removal of meanders to increase channel gradient and flow velocity (e.g. Ribble Estuary; See van der Wal et al., 2002; Fig 3.). This category can also include land claim.
New tidal river realignment	Any new alteration to course or planform of upper estuaries where the channel remains river-like.
Dredging (capital or maintenance)	Capital dredging for navigation purposes is the excavation of sediments to increase depths in an area, usually but not always for the first time, to accommodate the draft of vessels. May include maintenance dredging for the routine periodic removal of material in approach channels to port and harbour basins to maintain widths and depths in previously dredged areas to ensure the safe access for vessels.
High Voltage (HV) cables and Pipelines	The installation and subsequent protection of any cable (seabed) or pipeline (coastal to marine) for the transfer of electricity or discharge of effluent
Disposal of Dredgings (sea and intertidal)	The deposit of material dredged during maintenance and capital dredging campaigns into the marine environment or onto intertidal and subtidal areas for the purposes of disposal.

Impoundment	Impermeable barriers that extend either across the entire width of an estuary or embayment removing tidal influence (e.g. Cardiff Bay Barrage) or across coastal sounds and straits (e.g. South Ford Causeway, Outer Isles (Figure 10)). A structure that extends across a river channel that is used to impound, measure or alter flow (e.g. weirs, sluices).
Barrages	A semi-permeable impoundment that lets natural processes operate most of the time (e.g. barrage). Storm surge barriers may be built across estuaries in built up areas to reduce the risk of flooding during storm surges (e.g. Thames Barrier). Tidal barrages are constructed across estuaries with strong currents and large tidal range to harness tidal energy (Figure 11).
Flow and sediment manipulation structures	Hard engineering structures built to stabilise waterways for navigation and counter the effects of longshore drift. These include breakwaters, piers, groynes, flow deflectors, training walls etc. Ports, harbours and marinas are protected anchorage sites, often with extensive piers and breakwaters projecting into the adjacent water body (Figure 12).
Shoreline Reinforcement – Hard Engineering	The use of consolidated materials, e.g. rock armour, man made armour, revetments, retaining walls, gabion baskets, seawalls, wharves, quays, sheet piling etc. to protect vunerable coastlines or harbours from erosion (Figure 13).
Shoreline Reinforcement – Soft Engineering	Stabilisation of the shoreline using beach material to maintain beach levels and dimensions. May include synthetic materials (Figure 14).
Flood Defence Embankment	An artificial bank of earth or stone created to prevent inundation of estuarine and coastal floodplains.
Piled Structures	A range of structures raised on one or more foundation structures extending out into the adjacent water body e.g. bridge and pier supports. This category also includes wind turbine monopiles and outfalls (Figure 16).
Tidal devices	Any device which exploits the natural ebb and flow of coastal/marine tidal waters including horizontal axis turbines, cross axis turbines, oscillating hydrofoils and enclosed tips (venturi) energy extraction devices.
Other seabed uses	Any other pressures that could directly affect the bed morphology or substrate character.

Table 23 Definitions of generic categories of morphological alterations used in TraC-MImAS.

Assessment of likelihood of impact

The MImAS approach requires an assessment of the likelihood that any specified pressure will impact upon the established list of ecogeomorphic indicators. Three classes of likelihood of impact have been defined (Table 29).

Impact class	Definition
Likely	In most cases, this activity will result in an impact on a ecogeomorphic indicator
Possible	In some cases, this activity will result in an impact on a ecogeomorphic indicator
Unlikely	In most cases, this activity will not result in an impact on a ecogeomorphic indicator

Table 24 **Summary of classes of likelihood of impact.**

Defining the extents of impacts (zone of impact)

Engineering activities affect TraC systems in a variety of ways. Some of these impacts remain localised, but others can propagate extensively. 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. Three classes of impact extents are defined from 'contained' to 'pervasive' which will be expressed over the entire TraC system (Table 30). This assessment is independent of the water body typology.

Zone of impact	Description
Contained	Impacts likely to be localised and unlikely to extend beyond the local vicinity of the activity
Partly contained	Non-local impacts may occur and may propagate throughout the system
Pervasive	Non-local impacts likely to occur and impacts likely to propagate beyond the vicinity of the activity

Table 25 **Definitions of zone of impact classes.**

Although it is recognised that the extent of impacts resulting from morphological alterations may vary depending on the type of activity and the physical characteristics of a particular water body, for the purposes of assessing zones of impact, a non-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 sensitivity, the extent or magnitude of impacts resulting from activities can be influenced by alteration out with the section being assessed. It has not been possible to incorporate these types of complex interactions within the current version of the TraC-MImAS tool.

2.1.5 Module 5 - The Scoring System

The scoring system combines the information contained in each module to calculate a numerical 'impact rating'. Each morphological alteration contained with the pressure module has its own impact score, which is specific to each TraC water body type. The impact score is calculated for each attribute in turn, and then averaged for attributes within the hydrodynamic, intertidal and subtidal zones. This value is then multiplied by the zone of impact to give an overall impact rating for each morphological alteration (pressure).

The equation used to calculate the impact rating can be summarised as:

Impact Rating	=	Relevance	X	Ecological Sensitivity	X	Morphological Sensitivity	X	Likelihood of Impact	X	Zone of Impact
		Output from typology module		Output from sensitivity module		Output from sensitivity module		Output from pressure module		Output from pressure module

To determine the percentage capacity used within a particular TraC water, the impact weightings are combined with the ‘alteration footprints’ of all morphological alterations present within the section of estuarine or coastal water being assessed. An alteration footprint describes the type and extent of a morphological alteration. Different alterations will have different footprints, for instance, the footprint for shoreline reinforcement is the length over which the reinforcement occurs, whereas the footprint for dredging is the area over which dredging occurs. Summaries of the rules for calculating alteration footprints can be found in Section 2.2.2.

The formula used to calculate the capacity consumed by a single pressure, or combination of pressures within a predetermined assessment area/length, can be summarised as:

$$\text{Capacity Used (\%)} = \sum n \left(\frac{\text{Impact rating} \times \text{Footprint of morphological alteration}}{\text{Length/area of assessment unit}} \right) \times 100$$

* See Section 2.1.2 for a description of assessment units

Where n is the number of morphological alterations within the assessed length/area; and ∑ ( ) is the sum of results given by the equation specified in the parenthesis for each of the ‘n’ alterations.

APPENDIX 2

Summary of datasets underpinning MImAS

Overview

The information in the tables was generated from expert opinion. In addition to consulting information in the literature, to assist in completing the tables the project team consulted the technical panel and steering group.

Ecogeomorphic attribute	Transitional	Coastal-transitional		Coastal		
	Transitional	Coastal-transitional		Sheltered	Mod Exp-Exposed	Sheltered-Exposed
	Micro-macro	Lagoon	Sea Loch	Sedimentary	Sedimentary	Bedrock
Hydrodynamics						
Open Water						
Tidal Range	1	1	1	1	1	1
Currents	1	1	1	1	1	1
Waves	1	1	1	1	1	1
Freshwater Influence						
Flushing/exchange	1	1	1	0	0	0
Salinity/mixing/stratification	1	1	1	1	1	1
Waves	1	1	1	1	1	1
Intertidal Zone						
Geometry						
Planform	1	1	1	1	1	1
Profile	1	1	1	1	1	1
Morphological features & substrate						
Nature and extent of coastal features	1	1	1	1	1	1
Natural sediment size range	1	1	1	1	1	0
Continuity and sediment supply						
Longitudinal sediment transport processes	1	0	1	1	1	0
Lateral sediment transport processes	1	1	1	1	1	0
Habitats						
Coastal sand dunes	1	0	0	0	1	0
Saltmarsh	1	1	1	1	0	0
Mudflat	1	1	1	1	0	0
Subtidal Zone						
Geometry						
Planform	1	1	1	1	1	1
Profile	1	1	1	1	1	1
Morphological features & substrate						
Nature and extent of coastal features	1	1	1	1	1	1
Natural sediment size range	1	1	1	1	1	0
Continuity and sediment supply						
Longitudinal sediment transport processes	1	0	1	1	1	0
Lateral sediment transport processes	1	1	1	1	1	0

Habitats						
Sabellaria spinulosa reefs	1	0	0	0	1	0
Modiolus beds	1	0	1	1	1	1
Seagrass beds	1	1	1	1	1	0
Maerl beds	1	0	0	1	0	0

Table 31 Relevance of ecogeomorphic indicators to the defined channel types. 1 - Relevant; 0 - Not Relevant.

Ecogeomorphic attribute	Transitional	Coastal-transitional		Coastal		
				Sheltered	Mod Exp-Exposed	Sheltered-Exposed
	Micro-macro	Lagoon	Sea Loch	Sedimentary	Sedimentary	Bedrock
Hydrodynamics						
Open Water						
Tidal Range	0.5	0.5	0.5	0.5	0.5	0.5
Currents	0.5	0.5	0.5	0.5	0.5	0.5
Waves	0.5	0.5	0.5	0.5	0.5	0.5
Freshwater Influence						
Flushing/exchange	0.5	0.5	0.5	0.5	0.5	0.5
Salinity/mixing/stratification	0.5	0.5	0.5	0.5	0.5	0.5
Waves	0.5	0.5	0.5	0.5	0.5	0.5
Intertidal Zone						
Geometry						
Planform	1.0	1.0	1.0	1.0	1.0	1.0
Profile	0.5	0.5	0.5	0.5	0.5	0.5
Morphological features & substrate						
Nature and extent of coastal features	1.0	1.0	1.0	1.0	1.0	1.0
Natural sediment size range	0.5	0.5	0.5	0.5	0.5	0.5
Continuity and sediment supply						
Longitudinal sediment transport processes	0.5	0.5	0.5	0.5	0.5	0.5
Lateral sediment transport processes	0.5	0.5	0.5	0.5	0.5	0.5
Habitats						
Coastal sand dunes	0.5	0.0	0.0	0.0	0.5	0
Saltmarsh	0.5	0.5	0.5	0.5	0	0
Mudflat	0.5	0.5	0.5	0.5	0	0
Subtidal Zone						
Geometry						
Planform	1.0	1.0	1.0	1.0	1.0	1.0
Profile	0.5	0.5	0.5	0.5	0.5	0.5
Morphological features & substrate						
Nature and extent of coastal features	1.0	1.0	1.0	1.0	1.0	1.0
Natural sediment size range	0.5	0.5	0.5	0.5	0.5	0.5
Continuity and sediment supply						
Longitudinal sediment transport processes	0.5	0.5	0.5	0.5	0.5	0.5
Lateral sediment transport processes	0.5	0.5	0.5	0.5	0.5	0.5

Habitats						
Sabellaria spinulosa reefs	0.5	0.0	0.0	0.0	0.5	0.0
Modiolus beds	1.0	0.0	1.0	1.0	1.0	1.0
Seagrass beds	0.5	0.5	0.5	0.5	0.5	0.0
Maerl beds	1.0	0.0	0.0	1.0	0.0	0.0

Table 32 Summary of sensitivity (based on resistance and resilience to change) of ecogeomorphic indicators within each grouping of channel types (0 - Insensitive; 0.5 - Sensitive; 1 – Highly Sensitive).

Ecogeomorphic attribute	Transitional	Coastal-transitional		Coastal		
				Sheltered	Mod Exp-Exposed	Sheltered-Exposed
	Micro-macro	Lagoon	Sea Loch	Sedimentary	Sedimentary	Bedrock
Hydrodynamics						
Open Water						
Tidal Range	0.5	0.5	0.5	0	0	0
Currents	0.5	0	0	0.5	0	0
Waves	0.5	0.5	0.5	0.5	0.5	0.5
Freshwater Influence						
Flushing/exchange	0.5	0.5	0.5	0	0	0
Salinity/mixing/stratification	0.5	0.5	0.5	0	0	0
Waves	0.5	0	0	0	0	0
Intertidal Zone						
Geometry						
Planform	1	0.5	0.5	0.5	0.5	0
Profile	0.5	0.5	0.5	0.5	0.5	0
Morphological features & substrate						
Nature and extent of coastal features	0.5	0.5	0.5	0.5	0.5	0.5
Natural sediment size range	0.5	0.5	0.5	0.5	0	0.5
Continuity and sediment supply						
Longitudinal sediment transport processes	0.5	0.5	0.5	0.5	0.5	0
Lateral sediment transport processes	0.5	0.5	0.5	0.5	0.5	0
Habitats						
Coastal sand dunes	1	0	0	0	1	0
Saltmarsh	0.5	0.5	0.5	0.5	0	0
Mudflat	0.5	1	1	0.5	0	0
Subtidal Zone						
Geometry						
Planform	1	0.5	0.5	0.5	0.5	0
Profile	0.5	0.5	0	0.5	0.5	0
Morphological features & substrate						
Nature and extent of coastal features	0.5	0.5	0.5	0.5	0	0.5
Natural sediment size range	0	0.5	0.5	0.5	0	0.5
Continuity and sediment supply						
Longitudinal sediment transport processes	0	0.5	0.5	1	0	0
Lateral sediment transport processes	0	0.5	0.5	0.5	0	0

Habitats						
Sabellaria spinulosa reefs	0.5	0	0	0	0.5	0
Modiolus beds	1	0	1	1	1	1
Seagrass beds	1	1	1	1	1	0
Maerl beds	1	0	0	1	0	0

Table 26 Summary of ecological sensitivity of defined channel type. 0 - Insensitive; 0.5 - Sensitive; 1 – Highly Sensitive.

HYDRODYNAMICS	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	0.38	0.38	0.38	0.19	0.19	0.19
Land claim – low impact	0.09	0.09	0.09	0.06	0.06	0.06
Historic tidal channel realignment – high impact	0.13	0.09	0.09	0.06	0.06	0.06
Historic tidal channel realignment – low impact	0.06	0.03	0.03	0.03	0.03	0.03
Recent tidal channel realignment – high impact	0.28	0.19	0.19	0.14	0.14	0.14
Recent tidal channel realignment – low impact	0.06	0.03	0.03	0.03	0.03	0.03
Dredging – high impact	0.13	0.13	0.13	0.09	0.09	0.09
Dredging – low impact	0.03	0.03	0.03	0.03	0.03	0.03
HV cable and pipelines – high impact	0.03	0.00	0.00	0.03	0.00	0.00
HV cable and pipelines – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Use of dredged material – high impact	0.03	0.00	0.00	0.03	0.00	0.00
Use of dredged material – low impact	0.00	0.00	0.00	0.00	0.03	0.03
Impoundments – high impact	0.50	0.50	0.50	0.25	0.25	0.25
Impoundments – low impact	0.09	0.05	0.05	0.05	0.05	0.05
Barrages – high impact	0.50	0.50	0.50	0.25	0.25	0.25
Barrages – low impact	0.19	0.19	0.19	0.09	0.09	0.09
Flow and sediment manipulation, submerged – high impact	0.14	0.14	0.14	0.14	0.14	0.14
Flow and sediment manipulation, submerged – low impact	0.03	0.03	0.03	0.03	0.03	0.03
Shoreline reinforcement, hard engineering – high impact	0.19	0.19	0.19	0.09	0.09	0.09
Shoreline reinforcement, hard engineering – low impact	0.06	0.06	0.06	0.03	0.03	0.03
Shoreline reinforcement, soft engineering – high impact	0.03	0.03	0.03	0.03	0.03	0.03
Shoreline reinforcement, soft engineering – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Flood defence embankment – high impact	0.19	0.19	0.19	0.05	0.05	0.05
Flood defence embankment – low impact	0.06	0.13	0.06	0.00	0.00	0.00
Piled structures – high impact	0.19	0.19	0.19	0.14	0.14	0.14
Piled structures – low impact	0.03	0.03	0.03	0.03	0.03	0.03
Tidal devices – high impact	0.03	0.03	0.03	0.03	0.03	0.03
Tidal devices – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Other seabed uses	0.03	0.03	0.03	0.03	0.03	0.03

Table 27 Summary of impact ratings for morphological alterations- Hydrodynamic zone

INTERTIDAL ZONE	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	1.25	0.79	0.79	0.92	1.58	0.33
Land claim – low impact	0.33	0.21	0.21	0.25	0.42	0.08
Historic tidal channel realignment – high impact	0.38	0.23	0.25	0.25	0.46	0.08
Historic tidal channel realignment – low impact	0.22	0.13	0.16	0.16	0.28	0.06
Recent tidal channel realignment – high impact	0.88	0.56	0.56	0.63	1.13	0.25
Recent tidal channel realignment – low impact	0.44	0.28	0.28	0.31	0.56	0.13
Dredging – high impact	0.54	0.46	0.46	0.46	0.46	0.25
Dredging – low impact	0.08	0.08	0.08	0.08	0.08	0.04
HV cable and pipelines – high impact	0.08	0.08	0.08	0.08	0.08	0.04
HV cable and pipelines – low impact	0.02	0.02	0.02	0.02	0.02	0.00
Use of dredged material – high impact	0.41	0.28	0.28	0.28	0.28	0.13
Use of dredged material – low impact	0.19	0.13	0.13	0.13	0.13	0.06
Impoundments – high impact	1.33	0.83	0.83	1.00	1.67	0.33
Impoundments – low impact	0.22	0.13	0.16	0.16	0.28	0.06
Barrages – high impact	1.33	0.83	0.83	1.00	1.67	0.33
Barrages – low impact	0.50	0.31	0.31	0.38	0.63	0.13
Flow and sediment manipulation, submerged – high impact	0.63	0.38	0.41	0.44	0.75	0.13
Flow and sediment manipulation, submerged – low impact	0.17	0.10	0.13	0.13	0.21	0.04
Shoreline reinforcement, hard engineering – high impact	0.75	0.47	0.47	0.56	0.94	0.19
Shoreline reinforcement, hard engineering – low impact	0.17	0.10	0.10	0.13	0.21	0.04
Shoreline reinforcement, soft engineering – high impact	0.69	0.44	0.44	0.50	0.88	0.19
Shoreline reinforcement, soft engineering – low impact	0.17	0.10	0.10	0.13	0.21	0.04
Flood defence embankment – high impact	0.63	0.41	0.44	0.44	0.81	0.19
Flood defence embankment – low impact	0.15	0.27	0.10	0.10	0.19	0.04
Piled structures – high impact	0.75	0.47	0.47	0.56	0.94	0.19
Piled structures – low impact	0.29	0.19	0.19	0.21	0.38	0.08
Tidal devices – high impact	0.00	0.00	0.00	0.00	0.00	0.00
Tidal devices – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Other seabed uses	0.00	0.00	0.00	0.00	0.00	0.00

Table 28 Summary of impact ratings for morphological alterations- Intertidal zone

SUBTIDAL ZONE	Transitional	Transitional or coastal		Coastal		
				Sheltered	Mod-exposed	Shelt-exposed coast
Morphological Alteration	Meso-tidal	Lagoon	Sea loch	Sedimentary	Sedimentary	Bedrock
Land claim – high impact	1.19	0.63	0.88	0.94	1.00	0.56
Land claim – low impact	0.25	0.29	0.29	0.33	0.42	0.08
Historic tidal channel realignment – high impact	0.38	0.20	0.28	0.31	0.38	0.19
Historic tidal channel realignment – low impact	0.13	0.06	0.09	0.09	0.09	0.06
Recent tidal channel realignment – high impact	0.89	0.47	0.70	0.75	0.89	0.52
Recent tidal channel realignment – low impact	0.13	0.00	0.13	0.13	0.13	0.13
Dredging – high impact	0.69	0.63	0.69	0.81	0.50	0.56
Dredging – low impact	0.22	0.17	0.20	0.25	0.16	0.19
HV cable and pipelines – high impact	0.28	0.16	0.25	0.34	0.19	0.22
HV cable and pipelines – low impact	0.19	0.08	0.14	0.22	0.13	0.13
Use of dredged material – high impact	0.47	0.28	0.42	0.47	0.28	0.28
Use of dredged material – low impact	0.23	0.12	0.21	0.23	0.14	0.14
Impoundments – high impact	1.50	0.88	1.13	1.25	1.50	0.75
Impoundments – low impact	0.13	0.06	0.09	0.09	0.09	0.06
Barrages – high impact	1.50	0.88	1.13	1.25	1.50	0.75
Barrages – low impact	0.38	0.22	0.28	0.31	0.38	0.19
Flow and sediment manipulation, submerged – high impact	0.56	0.33	0.47	0.52	0.61	0.38
Flow and sediment manipulation, submerged – low impact	0.20	0.13	0.17	0.20	0.23	0.16
Shoreline reinforcement, hard engineering – high impact	0.38	0.26	0.30	0.33	0.38	0.23
Shoreline reinforcement, hard engineering – low impact	0.06	0.06	0.06	0.06	0.06	0.06
Shoreline reinforcement, soft engineering – high impact	0.34	0.19	0.19	0.31	0.22	0.16
Shoreline reinforcement, soft engineering – low impact	0.13	0.06	0.06	0.13	0.06	0.00
Flood defence embankment – high impact	0.06	0.06	0.06	0.06	0.06	0.00
Flood defence embankment – low impact	0.00	0.00	0.00	0.00	0.00	0.00
Piled structures – high impact	0.56	0.30	0.40	0.52	0.52	0.28
Piled structures – low impact	0.19	0.08	0.11	0.19	0.16	0.09
Tidal devices – high impact	0.31	0.06	0.27	0.28	0.31	0.22
Tidal devices – low impact	0.13	0.03	0.13	0.13	0.13	0.13
Other seabed uses	0.16	0.06	0.13	0.13	0.16	0.09

Table 29 Summary of impact ratings for morphological alterations- Subtidal zone

Activity	Hydrodynamics	Intertidal	Subtidal
Land Claim - Low Impact	1	1	1
Land Claim - High Impact	2	2	2
Historic Tidal channel realignment (high)	1	1	1
Historic Tidal channel realignment (low)	1	1.5	1
Recent Tidal channel realignment (high)	1.5	1.5	1.5
Recent Tidal channel realignment (low)	1	1.5	1
Dredging - High Impact	1	2	2
Dredging - Low Impact	1	1	1
HV cable and pipelines (high)	1	1	1
HV cable and pipelines (low)	1	1	1
Sea disposal of dredgings (high)	1	1.5	1.5
Sea disposal of dredgings (low)	1	1.5	1.5
Impoundments (high)	2	2	2
Impoundments (low)	1.5	1.5	1
Barrages (high)	2	2	2
Barrages (low)	1.5	1.5	1
Flow & sediment manipulation- submerged (high)	1.5	1.5	1.5
Flow & sediment manipulation- submerged (low)	1	1	1
Shoreline reinforcement - hard engineering (high)	1.5	1.5	1.5
Shoreline reinforcement - hard engineering (low)	1	1	1
Shoreline reinforcement - soft engineering (high)	1	1.5	1
Shoreline reinforcement - soft engineering (low)	1	1	1
Flood defence embankment (high)	1.5	1.5	1
Flood defence embankment (low)	1	1	1
Piled Structures (high)	1.5	1.5	1.5
Piled Structures (low)	1	1	1
Tidal devices (high)	1	1	1
Tidal devices (low)	1	1	1
Other Sea-bed Uses	1	1	1

Table 30 Summary of zones of impact. 1 - impacts likely to be localised and unlikely to extend beyond the local vicinity of the activity; 1.5 - non-local impacts may occur and may propagate upstream and downstream through the system; 2 - non-local impacts likely to occur and impacts likely to propagate upstream and downstream through the system.