A FRESHWATER MORPHOLOGY PROGRAMME OF MEASURES AND STANDARDS STUDY

Aerial Survey, Feature extraction, typology generation and development of a GIS tool to assist in Irish river and lake morphological assessment

PROJECT REPORT
Submitted to

SHANNON INTERNATIONAL RIVER BASIN DISTRICT

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Executive Summary

This report provides a synthesis of four separate but inter-connected projects that seeks to support the development of a practical approach to freshwater morphological assessment and reporting. The projects were commissioned by Shannon International River Basin District.

Over the last 3 years the requirements for implementation of the Hydromorphological aspects of the WFD have been elucidated at the EU and national levels. Prior to this the requirements for the WFD were unclear and indeed there had been no systematic approach to morphological assessment of rivers and lakes in Ireland. In this regard it is not surprising that some of the emphasis of the projects considered in this report has had to evolve accordingly since inception.

From the outset the scope of the project has emphasised the capture and collation of information that would support morphological assessment – in particular survey methods and the capture and use of remotely sensed aerial imagery. This remains valid, however, in light of the now agreed approach to field survey and monitoring by the EPA and EHS in Ireland the use of such information is now seen more to support and qualify an expert judgement approach rather than attempting to use such information to derive morphological assessment scores for rivers directly from derived metrics. This distinction is important as it has provided a firm perspective on the priorities for further data collection and has allowed the development of a specific analysis and reporting Tool that is anticipated will support the Expert Judgement approach into the future.

The wider Shannon IRBD project has tested field surveying of expert judgement and metric analysis approaches to morphological survey. Irrespective of the approach adopted there is a requirement in both cases to classify the intrinsic nature of a river using a typology system. The premise here is that the impact of pressures on a particular river, the rivers observed deviation from ideal conditions and the likely response to remedial measures are all functions of the river type. Whereas the river type can be observed and recorded during field survey the extent of field survey coverage is likely to remain low for the foreseeable future and there is a requirement to determine the type of all rivers. In this regard a specific project element was included at a later stage that attempts to map typology values using metrics that can be derived by desktop analysis in a GIS.

Additional scope was added to the overall project in 2008 through separate contract.
This has included specific tasks concerning the re-run of a Risk Assessment originally undertaken at Article V stage, an expert report on the value of remote sensing in support of field surveys and on the prioritisation of waterbodies for Measures (Geodata Institute) and the development of a desktop web-map Tool that integrates a wide source of data relevant for hydro-morphological assessment.

The report includes a section on a separate contract with EPA on the hydro-morphological assessment of lakes. This includes the application of the Lake Habitat Survey (LHS) method to 50 lakes in Ireland, a scoping study on the use of GIS and remote sensing to generate lake MImAS scores and recommendations for future monitoring of lakes.

This report is divided into sections that relate to the different projects and their constituent elements. To achieve the combined project goals:

- Aerial imagery has been captured and processed.
- Custom GIS tools for feature extraction were developed.
- A Morphological Assessment System (MAS) was developed to store relevant data.
- Expert reviews of 1) the remote sensing and feature extraction methods developed by the project for morphological assessment or rivers, and 2) approaches for the prioritisation of river waterbodies for measures, are presented.
- A web-map browser facility to assess river morphology at the desktop level, integrate field and desktop derived data in a combined database system, perform risk assessment and generate reports has been developed. This system will be installed at EPA.

In the final section of the report a series of recommendations are provided around the project elements included in the projects.

1.0 Introduction

The Shannon International River Basin District Freshwater Morphology Programme of Measures (POMS) study is testing GIS based approaches to assist in morphological assessment for WFD purposes. This follows a range of earlier trials and tests of field based monitoring techniques (RAT, MIMAS and RHS) and the development of a river typology. The principle is based on the concept of reference condition for hydromorphology, where the river system is in high status, with no significant morphological pressures and with the features present of a particular waterbody typology. Thus, in principle, a bedrock channel will differ from a lowland meandering channel and the morphological features will be sufficiently distinct to allow separation of these types from these input parameters. Modifications alter, to a greater or lesser degree, the features expected within the reach and the degree of modification may be used to assess the departure from high status and to assign a grading of the status. In identifying the nature and scale of the departures from high status (missing or altered features) there is potential to identify the practical morphological measures required to restore or rehabilitate the reaches.

This document reports on the morphology project contract for aerial photography surveys, feature extraction and GIS-based analysis as part of Shannon River Basin District Freshwater Morphology POMS studies. Subsequent projects relating to this core project are also reported on namely the development of a decision support tool, the establishment of nationwide typology and using remotely sensed data to generate lake MImAS parameters to help establish lake classification for hydromorphology.

1.1 Core Contract

Under the core contract there were four main tasks:

- Task A- Aerial Imagery Surveys
- Task B- Feature extraction from aerial imagery to GIS
- Task C- GIS based analysis and morphology metric generation
- Task D- Support to the wider project team

Each of these tasks has been reported on within this document.

1.2 Typology Contract

The Freshwater Morphology POMS study identified a need for a GIS based assignment of a typology system for Irish rivers. Compass Informatics were contracted to generate typology testing and using GIS methods to derive a national typology dataset to assist morphological assessment.

1.3 Decision Support Contract

The final contract in conjunction with the Geodata Institute in Southampton aimed at developing a framework that would examine the feasibility of using remote sensing for morphological assessment and to bring all the created and existing datasets into a common morphological pressures database (MPD). This contract also re-ran a national risk assessment that had previously been done for Article V. The main outputs from this contract are this report, the new national risk assessment and the GIS based morphology tool that uses the MPD.

1.4 Lake Classification for Hydromorphology

Lake habitat surveys have been carried out by the EPA on fifty lakes, this project processed this data and researched and developed a methodology for obtaining LHS (Lake Habitat Survey, Rowan et. al 2006) data from remotely sensed data. The LHS scores were used to generate a lake MImAS result. Using remotely sensed data obtained for one of the fifty lakes a comparison is made between LHS generated and remotely sensed generated MImAS results.

1.5 Document Structure

The aforementioned projects ran in conjunction and had a lot of similar components and therefore this document does not examine each contract separately but combines the three together to create a document that flows from the initial contract through to the final deliverables from the three contracts.

The sections in this document that relate to the various work packages within the contracts can be summarised in table 1.1 the final section (section 11) states the recommendations from the projects.

PROJECT	TASK/WORK PACKAGE	REPORT SECTION(S)
CORE CONTRACT	TASK A	Section 2
	TASK B	Section 3
	TASK C	Section 4
	TASK D	Section 5
DECISION SUPPORT TOOL DEVELOPMENT	WP 1	Section 6
	WP 2	Section 7
	WP 3	Section 8
	WP 4	Section 9
TYPOLOGY		Section 10
LAKE CLASSIFICATION	WP1	Section 11
	WP2	Section 11
	WP3	Section 11
RECCOMMENDATIONS		Section 12

Table 1.1: Document structure

2.0 Core Contract: Task A: Aerial Imagery Surveys

This section outlines work undertaken to develop high resolution integrated aerial images for 45 waterbodies, problems encountered and the processes that were developed to allow the smoothest flow from the capture of data through to the finished geo-rectified imagery.

2.1 Introduction

Within the context of testing of the two field survey protocols RAT (NS-SHARE, 2006) and MImAS (Sniffer, 2006), Compass were commissioned to undertake over-flights to capture aerial images; to mosaic and geo-correct these to provide a referenced image set for the pilot rivers being investigated (Shannon IRBD Freshwater Morphology Study). The approach uses a light aircraft and digital camera setup to create images that can be mosaiced to provide coverage along the waterbody and its floodplain.

For the 45 pilot river waterbodies, images have been captured and initial assessment against the feature lists within both MImAS and RAT has been undertaken. The morphological features that were sought and the initial list of attributes that were investigated for the features were those that were relevant to the MImAS implementation in Scotland and the RAT condition category listing (trialled by EPA and EHS in Ireland) and the typical pressures that mark the departures from high status within given river types.

Features are identified as well as broader scale modifications – such as realignments and channelisation. The nature and extent of the information used within this assessment has also been enhanced by the collection of additional data from historic mapping.

2.1.1 Data Capture

The aerial images were captured using the established Compass GeoFOTO aerial survey system (see Appendix VI) that uses a medium resolution camera mounted in a light aircraft and GPS positioning. Subsequent to field survey the individual images are integrated into river corridor blocks using a process known as geo-rectification. In this project the rectification task was performed by a specialist sub-contractor.

The workflow from initial survey configuration through to the derivation of the geo-rectified image product is shown in the following flowchart (figure 2.1).

Capturing the imagery involved overcoming three main logistical steps:

- The weather was the overriding logistical drawback as optimal conditions were necessary over the target waterbody before image capture could begin. It was often found that on leaving Weston aerodrome in Co. Kildare in blue skies once the target area was reached the cloud level would be too low or that the headwind would be too strong to get good imagery.

- The availability of a plane with a suitably trained pilot for river corridor surveying was also a regularly encountered problem in the early stages of the project.

- Some of the selected rivers are in quite remote areas of Ireland which can lead to an issue of availability of suitable airport locations for potential refuelling.

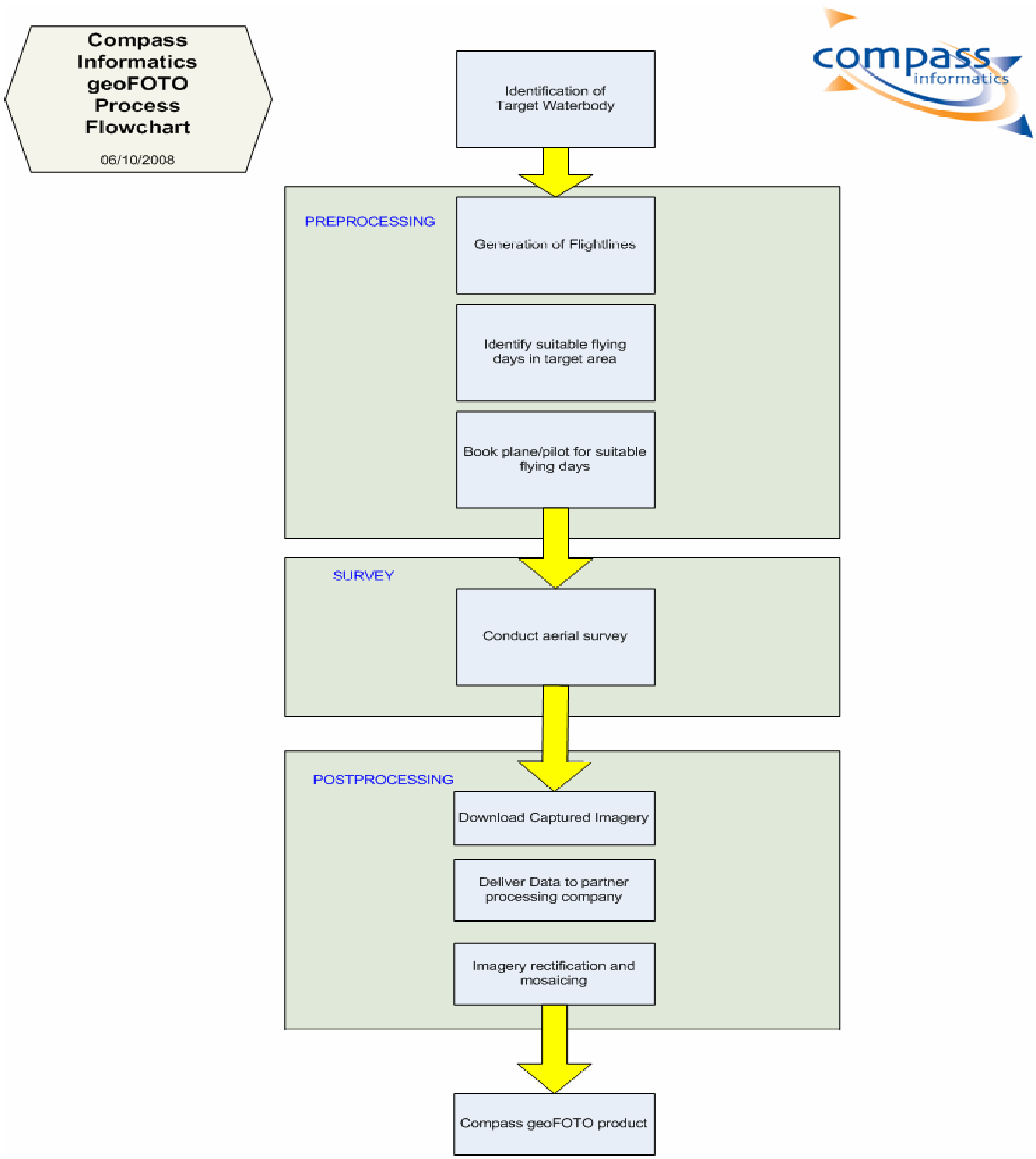


Figure 2.1: Compass geoFOTO workflow diagram

2.2 Comparison of current OSI Imagery and Compass GeoFOTO imagery

Currently the highest resolution imagery widely available in Ireland is supplied by the Ordnance Survey. This OSi imagery is at a resolution of 1 metre, however, and may not reveal adequate detail for the assessment of river channels.

The Compass GeoFOTO system captures higher resolution imagery through specifically commissioned aerial surveys. Imagery captured and processed is typically at a resolution of 15-25cm. Table 2.1 shows the attributes for all the waterbodies captured.

River name	Hydrometric Area	County	Waterbody Code	Waterbody Length	Length of channel imagery
Agivey		Derry	GBNI1NB030301075	14602m	14700m
Blackwater	21: Dunmanus-Bantry-Kenmare	Kerry	SW_21_2203	12068m	12068m
			SW_21_2484	5815m	5815m
			SW_21_1445	2314m	2314m
Blackwater Benburb	03: Bann	Armagh/Tyrone	GBNI1N030307043	7343m	8400m
Bonet	35: Sligo Bay & Drowse	Leitrim	WE_35_3493	7958m	7958m
Breagagh	15: Nore	Kilkenny	SE_15_1269	1316m	2316m
Burrishoole (catchment)	32: Erriff-Clew Bay	Mayo	Various	26512m	26512m
Callan	03: Bann	Armagh	GBNI1NB03037026	18619m	18619m
Castlebar	34: Moy & Killala Bay	Mayo	WE_34_1580	3140m	2645m
Clady	38: Gweebarra-Sheephaven	Donegal	NW_38_4124	7808m	7808m
Claureen	30: Corrib	Mayo	WE_30_2791	2798m	3500m
Cloon	30: Corrib	Mayo	WE_30_1442	1724m	4066m
Dodder	09: Liffey and Dublin Bay	Dublin	EA_09_1656	14755m	6874m
Doughery Inverburn	NA	Antrim	GBNI1NE040404037	6738m	6738m
			GBNI1NE040404040	3988m	3988m
Dromahair	35: Sligo Bay & Drowse	Leitrim	WE_35_274	5648m	6516m
Eask	37: Donegal Bay North	Donegal	NW_37_3087	8469m	8469m
Eglish	37: Donegal Bay North	Donegal	NW_37_411	5507m	5507m
Erne	36: Erne	Leitrim	NW_36_854	10907m	6845m
Faughen claudy	2	Derry	GBNI1NW020204002	1488m	3328m
Fergus	27: Shannon estuary north	Clare	SH_27_1122_1	3645m	3956m

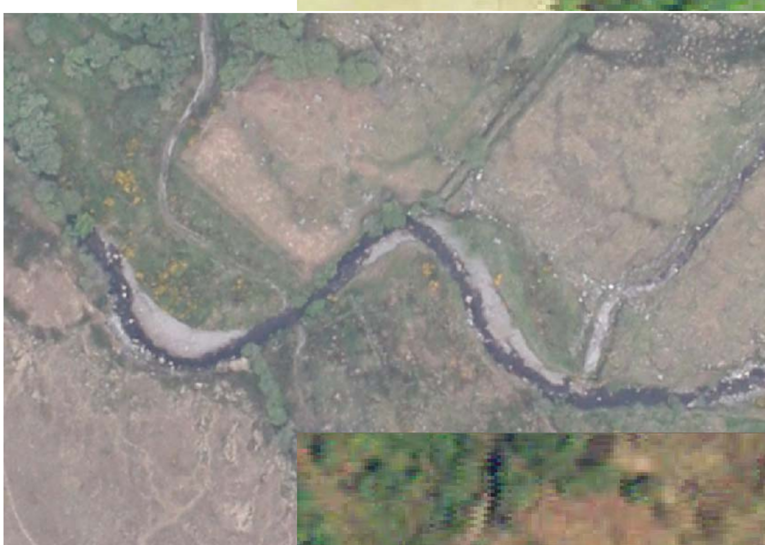
Ferta	22: Laune-Maine-Dingle Bay	Kerry	SW_22_3296	5730m	5730m
Glashoreag	23: Tralee Bay-Feale	Kerry	SH_23_1902	3102m	3279m
Glendavock	32: Erriff-Clew Bay	Mayo	WE_32_809	1347m	3464m
Glenree	34: Moy & Killala Bay	My	WE_34_2868	2337m	2830m
			WE_34_2869	6414m	3280m
Glenscollip	01: Foyle	Tyrone	GBNI1NW010102039	12284m	12284m
Glentornan	38: Gweebarra-Sheephaven	Donegal	38_816	1749m	2929m
Lee	19: Lee, Cork harbour and Youghal Bay	Cork	SW_19_944	3193m	3193m
Liffey	09: Liffey and Dublin Bay	Dublin/Kildare	EA_09_1870	82219m	60017m
Lyracumpane	23: Tralee Bay-Feale	Kerry	SH_23_2832	1274m	1274m
Moy	34: Moy & Killala Bay	Mayo	WE_34_1935	7936m	7936m
			WE_34_2369	4794m	4794m
Muroogh	28: Mal Bay	Clare	SH_28_106	706m	706m
Oboy	39: Oboy	Donegal	NW_39_584	4764m	4764m
Oily	37: Donegal Bay North	Donegal	NW_37_36	4423m	4423m
Owenbrin	30: Corrib	Mayo	WE_30_1063	11678m	11678m
Owenduff	32: Erriff-Clew Bay	Mayo	WE_33_3193	16653m	16653m
Owenglin	32: Erriff-Clew Bay	Galway	WE_32_3028	16720m	13365m
Owroe	21: Dunmanus-Bantry-Kenmare	Kerry	SW_21_5608	6475m	6475m
			SW_21_1565	1586m	1586m
Owveg	23: Tralee Bay-Feale	Kerry	SH_23_1743	6359m	6359m
Pollaphuca	09: Liffey and Dublin Bay	Wicklow			
Recess	31: Galway Bay North	Galway	WE_31_1600	2134m	6060m
Shannon Cappagh	25: Lower Shannon	Galway	SH_25_668	10693m	5607m
Sruffaun	30: Corrib	Galway	WE_30_2681	2782m	2782m
Toon	19: Lee, Cork harbour and Youghal Bay	Cork	SW_19_1236	10689m	10689m
Vartry	10: Ovoca_Vartry	Wicklow	EA_10_1471	10271m	10271m

Table 2.1: The captured waterbodies

Figures 2.1, 2.2 and 2.3 below shows the differences in the level of feature detail between the two sets of imagery. In each instance the higher resolution Compass GeoFOTO imagery is shown as the first image in each pair.

One of the specific project tasks was to compare the two sources of imagery in the context of identifying in-stream and riparian features and condition (section 3).

Figure 2.1: Comparison of imagery at scale of 1:1000



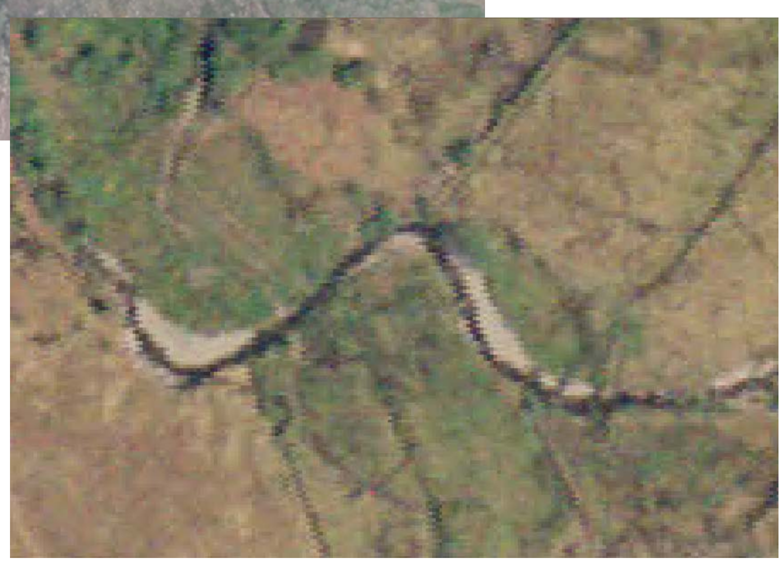


Figure 2.2: Comparison of imagery at scale of 1:1000

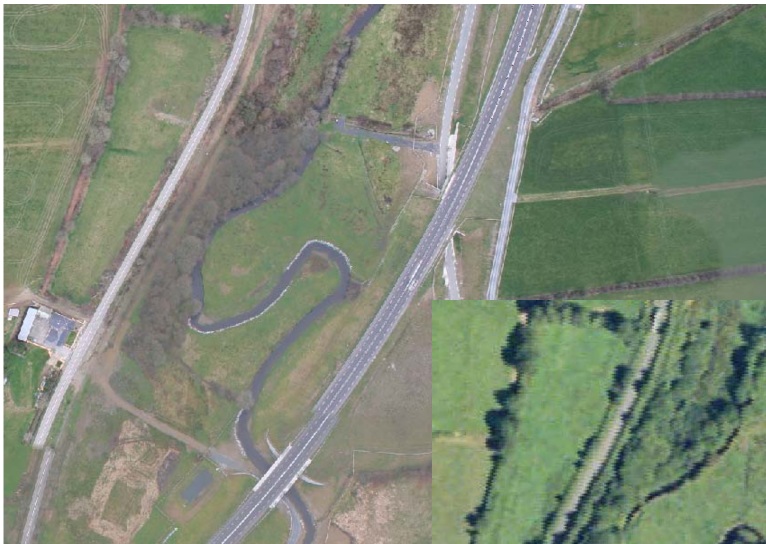


Figure 2.3: *Comparison of imagery at scale of 1:2000*

2.3 Feature extraction methodology

Previously Compass had used remote sensing techniques to extract in-stream habitats from river surveys. Compass had already developed the 'event manager tool' (see section 4.3) to enable users to classify sections of river , road or other linear features by overlaying the lines on images and using visual identification techniques to assign line portions to a series of 'classes' set up in a data dictionary. This tool has been used in this project to overlay the WFD river segment vector dataset onto the river corridor imagery and assign hydro-morphological category values from a customised list to individual sections of a river.

2.4 Established work flow

Through this project Compass Informatics has developed a streamline system for capture and processing of imagery. The cost of image capture and processing is €1850 per ten kilometres of river (correct as of summer 2008). As the camera system has evolved, a camera with a higher megapixel is currently been sought which will allow on the ground resolution of sub 20cm continuously. Further to this, investment in a MEMS orientation sensor has been made which provides data about the pitch, roll and yaw of the plane. This data allows greater accuracy to be achieved when processing the captured imagery.

3.0 Core Contract: Task B: Morphological feature extraction

3.1 Reach identification

Within the operation of the morphological field assessment techniques a typical approach has been to assess modifications and pressures over prescribed reach lengths, typically 500m or forty times channel width multiplier. Whilst this is pragmatic it provides only a fixed length sample 'snapshot' of a longer river. Thus it may not reflect the full extent of the modifications, or the length of the channel within a particular homogeneous typology, or the length over which a typology variable (e.g. slope or sinuosity) can be effectively measured.

Linear referencing (as used in the Event Manager Tool) overcomes these issues if the data are collected in a semi-continuous way, as the features are recorded over the length in which they occur and multiple features can be associated with any length of channel. Assessing what factors are affecting a point or reach on the river is then a database query, which can be visually shown within a GIS application.

Assessing the channel modifications and naturalness requires that the user look both upstream and downstream, and laterally to the floodplain, to assess the lateral and longitudinal connectivity and interruptions to these, as well as the relationships with the catchment scale land use. These factors need to be incorporated within the assessment protocols, to allow the effects of features over longer reaches to be assessed, especially for scale-dependent variables. Within the context of a desktop RAT (dRAT-see section 9.2), which also required a typology assessment the scale dependent variables can also be validated.

The subsequent sections discuss the capture of features from aerial imagery in the pilot waterbodies that have had field surveys using two different assessment protocols (MImAS and RAT).

3.2 Pressures assessment capacity (MImAS)

MImAS is an impact assessment tool to support river engineering regulatory decisions and classification. The term MImAS refers to an overall assessment procedure which includes a field survey to collect pressure data where needed. Both the channel zone and riparian zone are assessed separately in terms of the river's capacity to accept further morphological change[1].

The requirements for feature extraction in MImAS (Table 3.1) are for those that will be incorporated into the Morphological Assessment System (MAS). It should be noted that the list of feature attributes was devised from an ideal, field-based

[1] Lorraine Houston 2007: Freshwater Morphological Assessment in Rivers

assessment and was not based in the first instance on the available data sources and the ability to discriminate and to extract the features. The potential to extract predefined variables from Aerial Photographic Imagery (API) is retro-fitted to a filed based list of features. The following table 3-1 summarises the potential MImAS feature extraction from API, but all of these comments are subject to the presence of overhanging vegetation, that may obscure the features, especially on narrower river systems.

Most activity types recorded in MImAS require variables of use, material, condition, date built and reason built (e.g. Flood alleviation) in addition to the variables measuring feature extent. None of these are discernable from the main Remote Sensing (RS) / secondary sources, although other secondary data sources (engineering records, drainage records) may provide this information. These have been excluded from this table. This leaves simple measures of the features that can often be extracted from the RS data if the feature is discernable, either directly or as a part of the extraction process (via the Event Manager Tool).

Of particular relevance within MImAS is the identification of realignments, where multiple lines of evidence are used. In this instance, the feature is spilt into realignment and partial realignments, recognising that many original realignments will have established a new equilibrium and partially recovered. The extent of this recovery can be judged partially from the historic maps and from API, where irregular channel planform and bank structure are evident. Although the age of the realignments is some guide if continuous maintenance has occurred the reach is unlikely to have recovered. Without knowledge of the sediment regime and the maintenance records of realignments API provides a surrogate basis for judging the extent of recovery.

Within the MImAS recording there is also a need to avoid duplication of features, and this also needs to be incorporated within protocols for capturing features within the Event Manager Tool. A reach that is realigned will, by the nature of the work, also be reprofiled although reprofiling can occur without realignment, so the feature should only be recorded once.

Activity type	**MPD**	**Ability to discriminate from API**
Bridge	Number of Piers	Number of In-Channel Supports evident depending on the nature of the bridge and the flying angle.
	Length of Abutments	Often hidden, but estimateable
Bridging Culvert	Culvert Length	May be interpolated from lack of channel
	Culvert Type	Not discernable
Fords	Length of Ford	Measurable
	Reinforced	Not discernable
Boat slips	Structure Width	Measurable
	Structure Length	Measurable

Activity type	MPD	Ability to discriminate from API
Intakes / Outfalls Pipelines	Length of Channel	Measurable – but scale dependent
Croys / groynes / flow deflectors	Length Of Deflector	Depends on the structure type and flow conditions, Croys are generally evident but in channel bolder placements are not or may be confused with bedrock exposures
Bed reinforcement	Length Of Channel	Measurable
	Material	Not discernable
Realignment / Partial realignment	Length Of The Current Channel	Measurable
	Length Of Original Channel	Measurable from historical mapping
Flood by-pass channel	Channel Length	Measurable
	Catchment Transfer Involved	Not discernable
	Operational Return Period	Not discernable
Dredging	Purpose	Uncertain
	Length Of Channel	Measurable
	Volume Of Material Extracted	Not discernable
	Frequency Of Extraction	Not discernable
Green bank reinforcement	Bank Affected	Discernable
	Length Of Reinforcement	Measurable
Grey bank reinforcement	Bank Affected	Type and length
	Reinforcement Length	Measurable
Bank reprofiling	Two Stage Channel	Discernable
	Bank Affected	Discernable
	Length	Measurable
	Bank Affected	Bank Recorded
Bank top Embankments	Length Of Embankment	Measurable
	Height From Bank-top	Uncertain
	Distance To Embankment	Measurable
Flood walls	Bank Affected	Bank Recorded

Activity type	MPD	Ability to discriminate from API
	Floodwall Length	Measurable
	Height To Wall Top	Uncertain
Set back embankment	Length Of Embankment	Measurable
	Height From Bank-top	Not evident from RS
	Bank Affected	Bank Recorded
	Distance To Embankment	Measurable
Sediment removal	length	Not discernable
Sediment addition / re-introduction	length	Not discernable
Impoundment	Length	Measurable
	Height	Uncertain – extent of impact on flow may be easier to identify
	Pooling	Measurable
	Fish Pass	Uncertain – larger structures only
	Sluice Gate	Uncertain
	Water Level Change	Uncertain
Boulder placements	Number	Generally not discernable from supplied resolution
Riparian vegetation loss	Length (each bank)	Measurable
	Complexity	Discernable
	Continuity	Discernable

Table 3-1 Pressures within MImAS and the potential to identify from API

3.2.1. RAT category assessment capacity

R.A.T is a field technique which assigns a classification for a waterbody based on the departure from reference condition for the channel type. Channel typology influences the attributes assessed in the field. The technique assigns a morphological classification directly related to that of WFD – high, good, moderate, poor and bad[2].

RAT's assessment approach differs from MImAS in that it combines the assessment of natural channel, riparian and floodplain characteristics at the high category end (description of the undisturbed status) as well as the feature based modifications and

[2] Lorraine Houston 2007: Freshwater Morphological Assessment in Rivers

loss of naturalness within lower categories. MImAS records only the morphological features and uses typology to help allocate the 'naturalness' elements. Table 3-2 identifies the ability of API and other secondary data to be used to identify RAT category elements.

RAT category element	Ability to identify from remote sensed (API) and secondary data
Channel morphology and flow type	Channel form naturalness is evident from planform and modifications to channel bankform and cross sections. May be obscured by vegetation cover. Used in combination with historic API or historic mapping provides greater degree of confidence in assignment of class. Past changes evident from artificial cut-off meanders etc. Flow parameters not evident from images or open to misinterpretation, but may indicate flow regulation within the catchment and Upstream or downstream influences of impoundments.
Channel vegetation and debris	Seasonal dependence and subject to any vegetation cutting, but generally summer images. RS data will also indicate modification that may affect channel vegetation (impoundments), Cutting and management is unlikely to be evident from RS data. Debris only evident if large scale LWD.
Substrate diversity and condition	Generally not discriminated, but where bedrock exposures, boulders or bars are evident these are easy to identify. The pool riffle, meandering and anastomosing classes may be more difficult to identify. Dominant substrate may be identifiable but the sediment diversity, used in this attribute, is largely unidentifiable. Discrimination is very flow dependent.
Channel flow status	Subject to flow conditions at the time of flight, but generally not evident from the RS data. Extent of channel covered by flow may be identifiable, but relating this to the channel form will depend on the flow status.
Bank structure and stability and effect of vegetation	Achievable at high resolution imagery, but often obscured by seasonal vegetation cover. Important to distinguish natural channel bank instabilities and irregular banks from those adversely affected by pressures. Interpretation of this feature is also needed in field assessments and will depend on type and location within the system.
Bank and bank-top vegetation	Marginal vegetation and vegetation loss are evident, but does not equate to the RHS (complexity status) well. Generally, evident depending on seasonality. Estimation of threshold values is needed but these features are easier to extract from RS than in the field. Modifications and management of vegetation are typically evident, but the type-specific interpretation is important (e.g. bedrock banks may not support dense vegetation cover typical of other channel types). Riparian semi-natural classes evident. Non-native vegetation generally not identifiable to resolutions provided
Riparian	Feature is easily identified and may be easier to evaluate the extent of the

land use (4 water widths)	class and modification than in the field. Palaeomeanders and recently abandoned meanders evident. If combined with terrain data the extraction of boundary conditions may be improved. Native versus non-native/agricultural use is evident from RS and the proximity of the modifications to the channel are evident.
Floodplain – lateral connectivity	Feature is easily identified and better achieved from RS data than field data Lateral connectivity between channel and its floodplain is a combination of natural factors and modifications, Key natural parameters: Channel dimensions, Floodplain dimensions, Natural floodplain conveyance routes, Channel and floodplain vegetation. Modifications may include: Flow regulation, Lateral and longitudinal barriers to flow (e.g. weirs and embankments), Modification to channel cross section (e.g. dredging), Extent of floodplain development (area, height and type) and non-natural vegetation types, Extent of artificial floodplain drainage channels

Table 3-2 RAT category elements and the use of API to discriminate

It is evident from this qualitative assessment that many of the features collected from RS and secondary data may be a combination of reach-specific and adjacent floodplain parameters and also the upstream and downstream factors that may affect the 'naturalness' within the reach. As with MImAS, not all the features identified in the field can be identified from the API, although some features and appreciation of the reach in the context of connectivity may be better identified from the remote API assessment.

Within this assessment, which has used RS data coincident with RAT/MImAS survey locations from 2007, it is clear that identification of features is dependent on the quality and characteristics of the imagery, particularly the resolution, and seasonality of the coverage. Although the imagery used within the study has been captured from a light aircraft and standard digital camera set-up the images are of high quality. Nevertheless, a higher resolution image would increase the certainty with which certain features are discriminated, in particular the use of blockstone and in-channel features such as bolder placement and weirs are at the edge of the ability to distinguish these feature and tell them from natural bedrock or natural boulders.

3.2.2 Assessment of RAT/MIMAS Freshwater Morphology Study sites

This section takes examples from the POMS field surveys from 2007 where there is coincident API coverage and assesses the ability to discriminate features and assign RAT scores from the interpretation. The samples are taken from those sites where both the RAT and MImAS surveys were conducted in parallel.

Reference No / Name	RAT score	MImAS score	Evaluation
	field	survey	

	score		
C6 Ballylahan Bridge	G	G	Equivalent classes but API identifies extensive riparian and floodplain land use
C5 At Blearmore	M	H	Classifies as good within API, showing signs of floodplain drainage and intensive land use that probably would not assign as High status site
H6 Ballymore Br	G	H	Modification of the riparian and floodplain vegetation, but otherwise classifies as High.
H17 Leixlip Br	P	B	Downstream structure impacts upstream, extensive land use change and intensive land use
H18 Lucan Br	M	B	Extensive modification of floodplain, loss of connectivity both lateral and longitudinal – though with fish pass, but significant ponding and over-widening. Would probably reclassify as poor.
H11 Castlekeely Ford	G	H	Straight section – though natural might imply realignment, but longer reach context indicates a natural morphology. Riparian and floodplain modifications.
H15 Straffan Turning Lr	G	M	Extensive ponding from major weir and 2 bridges, therefore site is unlikely to be good in morphological terms, extensive riparian vegetation loss
B1 Ivy Br Glashoreag	H	H	Lower resolution images makes interpretation more difficult, but riparian and floodplain land use modification
B15 Tullaleague, Owveg	G	G	Confluence confuses the assessment
B2 Owveg Br	H	H	Loss of riparian vegetation is evident, where vegetated bank tops may provide false impression of the extent of riparian vegetation

Table 3-1 Summary of comparison of RAT classes developed from API based assessments (H = high, G= good, M=moderate, P=poor, B=bad). MImAS score is the channel score only. See ***appendix I*** *for images of these reaches.*

The assessment of just these few cases suggests that the scale of modifications within the RAT assessment often focuses on channel morphological features; where riparian land use and vegetation is often heavily modified or where there is little or no riparian buffer zone these factors are not affecting the class. These factors often mark the differences between good and high status between the RAT and MImAS surveys, where surveys have been undertaken on the same reach. This may imply the higher weight given the riparian and floodplain within RAT than within MImAS scoring (although the latter has a separate riparian score).

There is a further:

- need to evaluate more high status and good status sites to understand the spectrum of variation that yields these classes. The extent of riparian and floodplain cover and land use modifications in relation to the good and high morphology class need appraisal.

- Need to provide a 'crib sheet' based training manual for users of RS data to allow both the assignment of typologies and examples of modification classes with corresponding confirmed RAT scores. This could be provided as an online tutorial system for the Event Manager / RAT surface water morphology tools.

3.3 Section summary

Remote sensing in association with other secondary map data and records provides a good basis for consistent assessment of both RAT condition assessment and morphological modification feature extraction. Not all features originally selected for identification in the field survey approaches can be discriminated from RS data, but the data provides a sound basis for initial assessment, with potential to prioritise subsequent field surveys if needed.

Some features are more capable of being discriminated from remote sensed data than they are in the field. Generally, these features are some of the more significant modifications to channel and riparian systems. In particular, channel realignment, loss of riparian vegetation, floodplain and catchment influences are best discriminated from aerial images and historic mapping.

Discrimination of the relevant features for field RAT approach does not rely on an numeric inventory of features and their precise location on the map (as required in MImAS), but rather on the overall expert impressions of the degree of modification and departure from the high status site. Nevertheless, the ability to refer to the identified and collected features helps in that assessment within an initial desk based RAT assessment.

The ability to discriminate features relies heavily on the quality of the imagery available. These quality parameters include the resolution, seasonality of the images and water levels at time of flying. Seasonality is a compromise between the extent of the vegetation cover and the achievable sharpness of the images and light conditions. From the images viewed within this exercise, the early summer images provide a quality of image. Subject to achieving the same resolution, the over-flight using light aircraft is as capable of generating data of the same quality and discriminant ability as a full aerial flight campaign, achieving 25 cm discrimination.
Despite the higher storage and processing volumes a higher resolution image is to be preferred.

4.0 Core Contract: Task C: GIS Based Analysis; utilisation of the Event Manager Tool for river morphology

4.1 Introduction

Under tasks A and B of the core contract high resolution imagery was captured and extractable features were identified. Task C of the contract was initiated to establish a methodology for extracting the features in a logical fashion. The concept of linear referencing was decided upon as a suitable method and a custom GIS tool was deployed to facilitate feature extraction.

4.2 Linear referencing

Linear referencing enables GIS users to create classes for different sections of the same line feature. For example, one river segment may have many different habitat types, such as riffle for the first 100m, deep pool for the next 20m and glide for the last 40m. Use of linear referencing will enable users to symbolise these changes in habitat without splitting the line into multiple lines.

4.3 Deployment of the Event Manager Tool

Compass has developed a tool that allows users to create events by click on the map. The Event Path Maker tool is a custom GIS tool to assign attributes to river paths in a river network or other linear features including roads. It is part of the Compass Informatics Hydro Tools package, a toolset designed to work with national river network datasets. It can be used to assign different attributes to a stretch of river simply by clicking once on where a certain type, for example a geological class, starts upstream, and a second time to show where it finishes downstream. The river segment does not have to be split into constituent pieces – rather the start and end point along the river that mark a particular feature are recorded in a separate database without the need to split the river. This allows the same river to be recorded in any number of different event tables, allowing the mapping or recording of multiple features at any location as determined by the user.

The tool has a number of customisable settings so it can be used for many different data entry scenarios. For example, the tool allows a user to click once on the river network, and then enter a distance value in order to generate a point at a fixed distance upstream or downstream from the first point. This is useful in situations such as following a river network 10 km downstream of a Sewage Pipe as per government Water Regulations.

The tool is known as an event path creator because demarked sections attributed with a particular value by the user are known as linear events in the ArcGIS system (ESRI), and they follow a path on the river network. The tool allows the creation of these *event paths*.

To find out more about the Event Manager Tool see Appendix II.

4.4 Using Event Manager Tool to derive MImAS metrics

Following a review of MImAS field data and the aerial imagery it was clear that the assessment of morphological pressures through floodplain and riparian land-use assessment and identification of engineering features as per MImAS could be undertaken using the aerial imagery. In the first instance a database is set-up within Microsoft access which stores the pre-defined attribute or event tables. These tables contain specific attribute data describing every pressure and/or feature that can be assigned to a river waterbody. A sample of the database detailing the Event Tables is provided below.

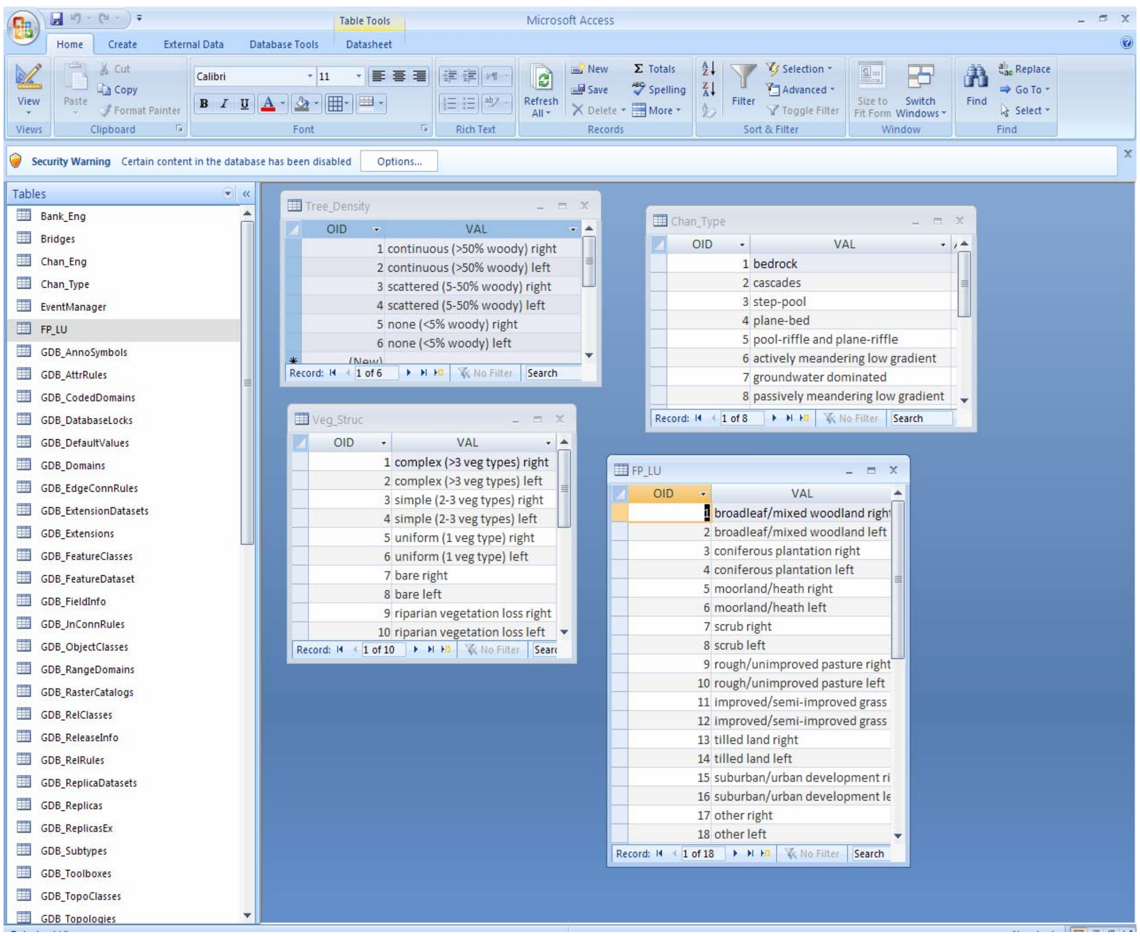


Figure 4.1 Access database detailing tree density, channel type, vegetation structure and floodplain land-use Event Tables

The event tables created within MSAccess are used to assign attributes to the river waterbody based on the pre-defined pressures. The river waterbody is effectively classified into pressures using the Event Manager Tool within ArcMap. The technique used in ArcMap is based on linear referencing which allows the user to select specific lengths of river waterbody to which the attributes are assigned. These new segments of information are stored as Event Layers in the Access database and any number of Event Layers can be created for each river waterbody. The Event Layers can then be mapped in ArcMap.

Figure 4.2 shows the event manager tool working within the ESRI Arcmap environment. There are two key requirements before creating the linear events, firstly an aerial image mosaic of the river waterbody and secondly a geometric river network which constitutes the river waterbody. The first step in using the event manager tool is to create a new Event Layer. A dialogue box appears and the operator creates the new event layer by giving it a name (event layer friendly name), referencing it to the correct event table (associated values table) and selecting the relevant geometric river network to which that river waterbody belongs (associated network).

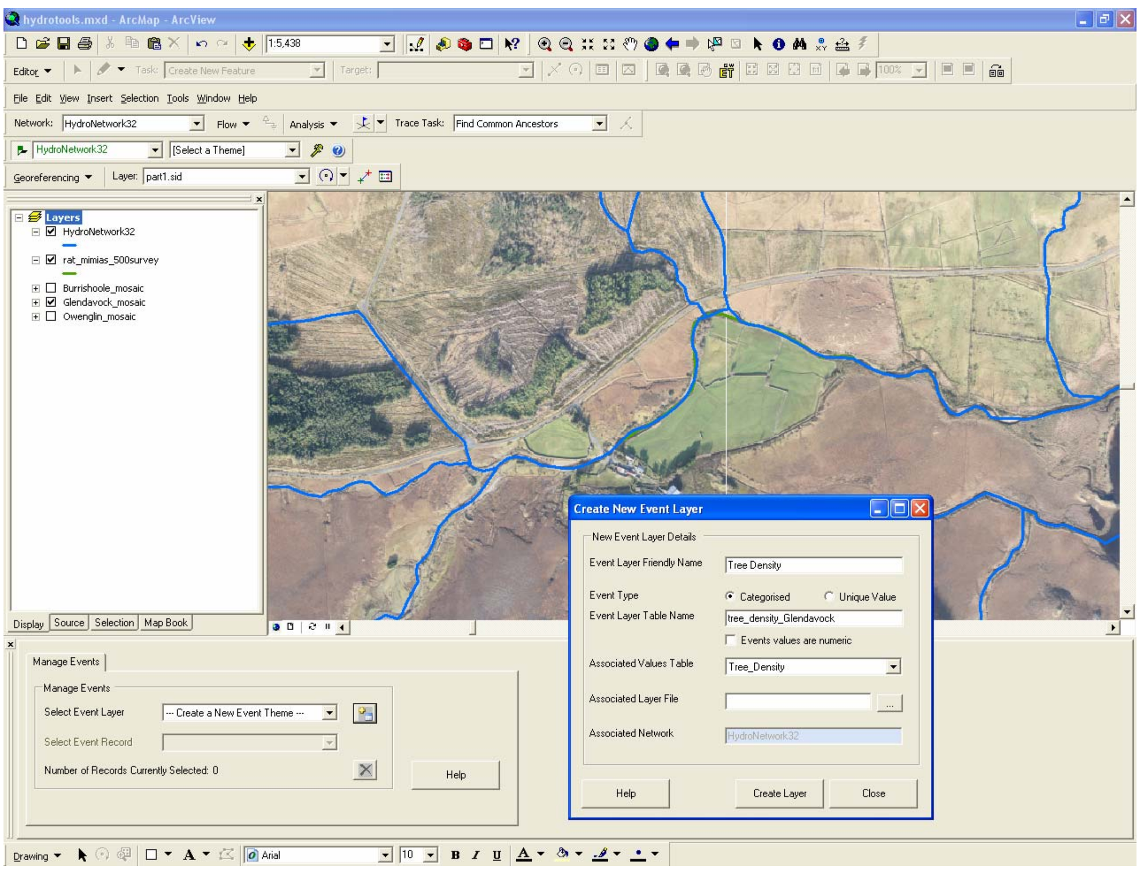


Figure 4.2: The Event Manager Tool in ArcMap

Once the event layer has been created, we can begin assigning attributes to specific segments or river length of the waterbody.

Figure 4.3 illustrates how the tool works. The start point (FMEAS) and end point (TMEAS) of the river segment is recorded to which in the example provided below a tree-density attribute is assigned.

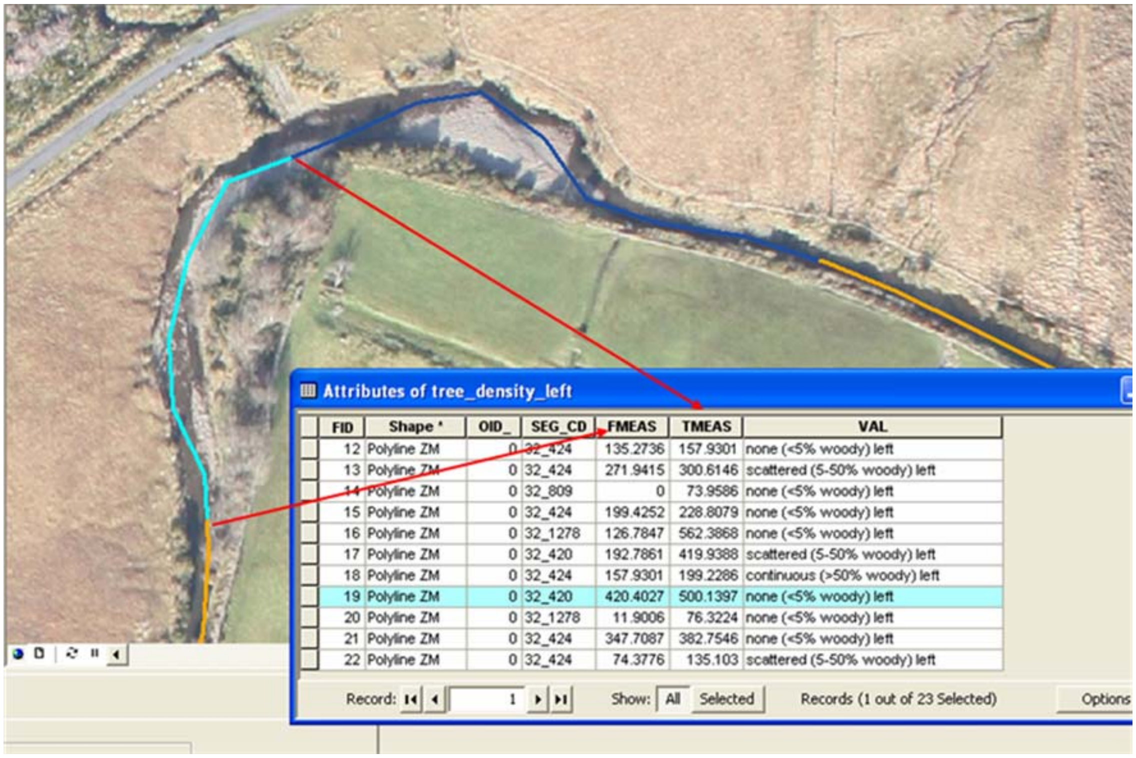


Figure 4.3 Assigning attributes along the river waterbody using the Event Manager Tool

In this way, the complete stretch of river can be cut-up into multiple sections to create a variety of Event Layers.

To allow an assessment of impacts or a river channel's capacity, the MImAS scoring system describes capacity used in terms of a percentage following a 500m morphological pressure assessment survey of the river waterbody in the field;

Capacity Used (%) = Activity Impact Score x Activity Footprint

The Activity Impact Score (pressures score) is calculated as:

Ecological Sensitivity x Morphological Sensitivity x Likelihood of Impact x Zone of Impact

The Activity Impact Score is calculated for each attribute in turn and then averaged for attributes within zones thus providing a score for each activity (or pressure) within each zone.

The activity footprint describes in most cases the length of channel over which the pressures take place. However, for other activities such as riparian vegetation loss, flow deflectors, sediment removal, presence of impoundments and bridges that are not naturally measured in terms of channel length, rules have been devised to determine an activity footprint compatible with the capacity-based scoring system.

Consequently, there are three fundamental problems to generating an overall MImAS score using the aerial imagery in place of fieldwork. Firstly, it was noted earlier that several of the engineering pressures were difficult if not impossible to resolve using aerial imagery alone. Secondly, some features are more easily identifiable on one river waterbody compared to another which creates bias in the scoring system. Finally, the assessment of several of the pressures requires the calculation of an activity footprint which is extremely difficult to determine from an aerial image. For example, while weirs and bridges are clearly visible on the imagery, the height of the weir or number of bridge in-channel supports is needed to require the activity footprint cannot be detected from the aerial photography and hence an appropriate MImAS score cannot be derived.

4.5 Section Summary

The event manager tool is a useful GIS facility that allows metrics, such as required for MImAS, to be calculated. However this tool does not readily record RAT data as this is expert opinion based. Over the course of the projects the emphasis has shifted away from MImAS towards a RAT based approach for assessing river morphology. Due to this shift in morphological assessment Compass has had to change it's approach to custom GIS tools. We quickly realised that the Event Manager could not provide the basis for conducting a remotely sensed RAT and we had to change our tact to reflect the changes in assessment, therefore the idea of a desktop RAT was considered.

Desktop RAT or dRAT quickly became the focus of the end-user morphological assessment GIS tool and this is the approach that has been implemented. MImAS has not been entirely abandoned however and in the latest iteration of the field RAT form some MImAS attributes have been included.

Subsequently the relevant bodies that will make use of these GIS applications now have two tools at their disposal; Event Manager which is MImAS focused and dRAT which supports the RAT survey protocol. This allows flexibility for the future of morphological assessment is Ireland.

-The full installation and users guide can be viewed in Appendix II.

5.0 Core Contract: Task D: Support to the wider project team

5.1 Support to the client team

Throughout the life of these four projects Compass Informatics has given support to the wider project team. This has included provision of GSI metrics prior to field surveys, data processing, presentation of methods and results at workshops and meetings and fostering relationships with interested parties including the EPA, Marine Institute, Central Fisheries Board, Geodata, University of Dundee and RPS.

5.2 Field work support

Field sheets were supplied to the contractors to aid in location of survey sites. For each identified survey site field surveyors were issued with two maps showing the generally location of the site and a more specific zoomed in image of the site. These field maps were supplied in both 2006 and 2007.

Compass Informatics received completed field sheets and undertook the process of recording the data from the field sheets into a digitally spatially correct format. This was done for both RAT and MImAS field surveys. The geographical location of features and pressures had to be identified along the 500m stretches from the supplied field sheets an example of which is shown in figure 5.1.

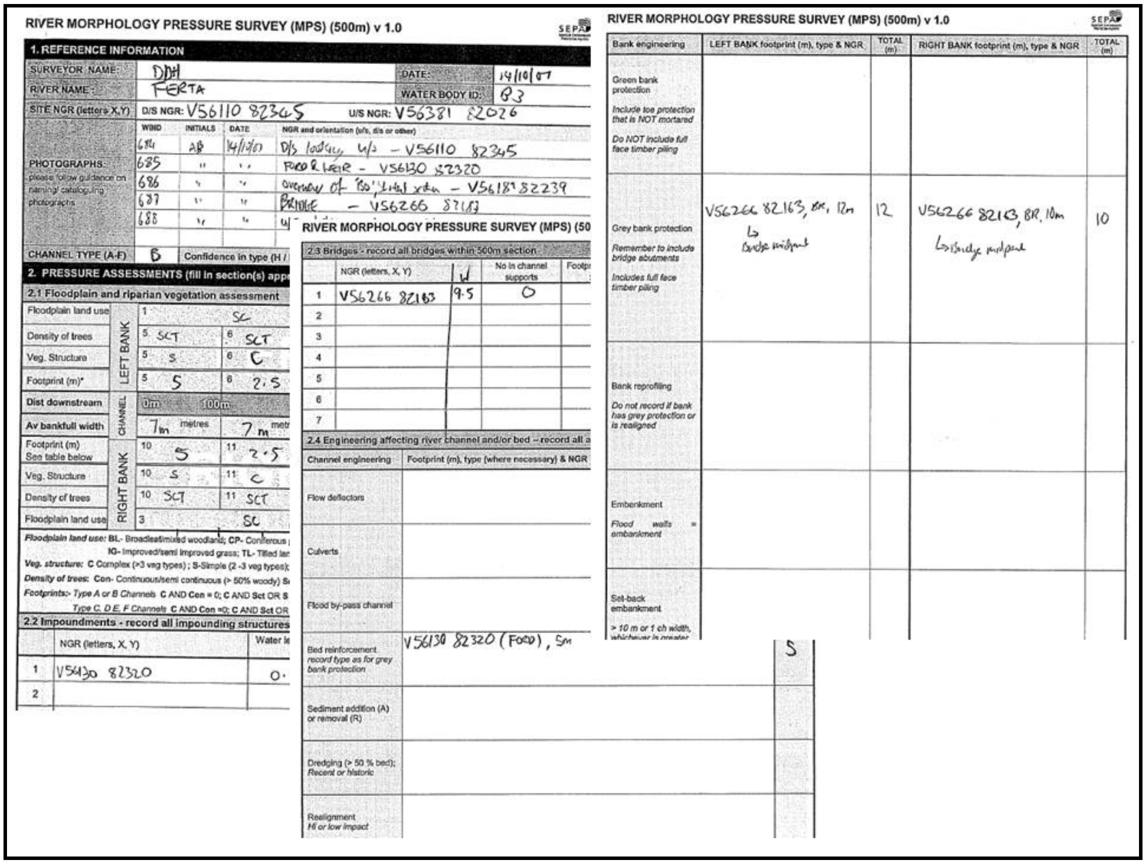


Figure 5.1: Example of a completed field sheet.

6.0 Decision Support Contract: WP 1: Risk Score Assessment Refinement

6.1 Determination of Channelisation Risk Score

The original Article V morphological risk assessment concerning the extent of OPW Drainage works (channelisation and placement of embankments) was been re-run. In this section of the report a synopsis of the GIS method used to calculate the risk score is provided.

The distribution of features is determined from OPW GIS records on the extent of works in Drainage Schemes and Drainage Districts. It is apparent that the original scale of the mapped OPW features is larger than the 1:50,000 scale mapping used to delineate the stream network and river waterbodies. As a consequence the OPW mapping contains more detail and importantly in the aggregate can have a greater length than the river waterbody line mapped at 1:50,000 scale.

The Risk Assessment method is an assessment of the relative proportion, i.e. percentage length, of the waterbody included in OPW works. Because of the different map scales a comparison of relative lengths (waterbody line at scale 1:50,000 vs. OPW works features) could give an erroneous result. To overcome this problem the OPW features were snapped onto the 1:50,000 scale waterbody network in the GIS through a process known as the creation of linear events. This action effectively sub-divides the waterbody feature into sections that lie alongside the OPW features and sections that do not. This preserves the true length of the waterbody feature and supports the risk assessment length comparison methodology.

The risk assessment has been executed in two forms. In the first instance the relative proportion of the waterbody line associated with OPW works was determined. In the second instance all streams (mapped at scale 1:50,000) that occur within the waterbody polygon adjacent to the waterbody line were assessed – thus OPW works on adjacent side tributaries of the waterbody mainstream become included in the assessment.

6.2 Assessment of sites for potential enhancement (fish stocks):

OPW and CFB are undertaking a collaborative programme concerning drainage maintenance and fishery habitat enhancement. Selection of suitable sites for fishery enhancement can in part be determined through GIS analyses. CFB has indicated that habitat enhancement activities would be focussed where conditions are suitable to sustain a productive population. Gradient can be used to indicate reaches with suitable habitat conditions and EPA macro-invertebrate survey scores to determine adequate water quality. In a prescriptive sense suitable reaches should have a gradient in the range 0.2 – 3% and a macro-invertebrate score > 3.

6.2.1 Gradient

Calculation of gradient simply requires information on the elevation at the start and end of the relevant reach and the reach length. Stream reach gradient can be determined within the GIS by reference to Ordnance Survey (OSi) elevation data. For WFD purposes EPA provide a national DTM that has been developed from 1:50,000 scale OSi elevation data.

Unfortunately the margin of error in the OSI elevation data is in the order of > +/- 2 metres. It is not known whether the distribution of the error is random or systematic. If systematic then elevations measured at proximal locations may share a similar error whereby the difference in elevation recorded between the start and end of a reach may be reasonably accurate. A random distribution of the error would give greater inaccuracy in gradient measurement.

The effect of the elevation measurement error in the determination of gradient is reduced as the reach length increases. In the EPA GIS gradient has been calculated as an average value along each 'inter-confluence' river segment. Although variable, a typical GIS river segment length is in the range 750 – 1200 m. Over this distance the gradient calculation may be of reasonable accuracy (+/- 0.2%). However, in reality channel type and form can vary over such a distance and sections of suitable gradient water may not be identified when a whole segment average approach is adopted. Thus it is tempting to determine gradient over shorter reaches although the increasing error in such gradient calculations should not be ignored. As part of the associated river typology project stream gradient has been determined, centred on nodes spaced 100m apart, as averaged values over 200, 300 and 400m sub-reaches. These data have also been assessed as part of the screening process to identify reaches of suitable gradient for CFB habitat enhancement.

6.2.2 Water Quality

The EPA macro-invertebrate Q value score is known to be a good indicator of water quality suitability for fish. The relationship between such Q values and fish stocks has been firmly established in a collaborative research project between CFB and EPA. Q values are measured at some 3500 sites on the national river network but unfortunately the distribution of sites only represents approximately 1/3 of the river network that comprises the WFD river waterbodies. The gaps occur primarily on the smaller channels (typically 2nd and some 3rd stream order).

Given that suitable habitat for fishery enhancement can be found on small channels an attempt has been made to determine indicators of water quality from other sources. In particular the Small Stream Risk Survey (SSRS) undertaken by the RBD projects provides a systematic approach to water quality measurement on many smaller streams. The sites of the SSRS survey have been mapped onto the national river segment dataset to indicate suitable waters (SSRS value > 8) and unsuitable waters (SSRS value <=8).

Although the SSRS survey completes many gaps on the river network where Q values are not recorded by EPA; many gaps remain. A 3rd indicator of water quality has been included in the screening process to help identify conditions where Q value and SSRS fields surveys are not undertaken. This takes the form of a prediction of water quality based on land cover in the upstream catchment area of the streams and has been used as a diffuse pollution test (known as the RD1 test) in the Article V characterisation process. Formally this test is a prediction of the likelihood of achieving a Q value of 4 (Good Status) but low likelihood values can be used as an approximate indicator of Q values <= 3.

6.3 Section Summary

In summary, within the GIS suitable conditions for fish habitat enhancement have been assessed using the following criteria:

Gradient	range 0.2 – 3%
Q value	> 3
SSRS	> 8
RD1	risk score values of 2b and 2a.

7.0 Decision Support Contract:WP 2: Value of Remote Sensing to RAT/Morphological assessment

This section provides an expert review by the GeoData Institute, Southampton, on the potential of the remote sensing techniques deployed by Compass Informatics, described elsewhere in the report, to RAT/Morphological assessment.

7.1 Introduction

This section assesses the role of aerial photographic data and remote sensing to assist in generating MImAS scores, and additionally in generating RAT classes as part of the risk assessment and morphological pressures monitoring. The ability to identify features of morphological pressure from aerial photography and secondary data has been tested within a separate programme within Scotland (GeoData 2005)3 as part of the scoping exercise for the creation of a national pressures database (MPD) programme and as part of the GeoRHS programme (GeoData 2004). These studies evaluated both the features of modification and indicators of naturalness of the channel, riparian area and floodplain. The recommendations for use of RS data (aerial photography) and secondary map and survey records were successfully adopted within Scotland (Sniffer 2006) to provide a comprehensive GIS-based Morphological Pressures Database. A similar approach was also used within the development of the geoRHS GIS application, that tested the use of API in extracting relevant morphological parameters prior to further field-based river reach surveys (GeoData 2004) with the development of GIS/database tools for feature extraction. These are similar approaches to those adopted within the Event Manager Tool. Further Scottish studies (Davids et al 2004)4 also assessed the feasibility to use remote sensed data to assess surface waters and groundwaters, based on a range of map and remote sensed terrain and image products (including Lidar and CASI). These latter products are generally not available in Ireland, but as with the MPD OS MasterMap was an important component, but also used processing of aerial and other sensed images

A key requirement in adopting this approach is the ability to validate the records – that the results of the RS-based process reflect what is on the ground and that the resulting assessments generate equivalent values. This is not to suggest that RS data can capture all the features that a field-based assessment is capable of, but that high influence modifications are captured and that they can be accurately represented. This validation process in Ireland can be assessed both from the results of RAT/MImAS testing records (2007) that record the relevant features (pressures) at a number of 500 m reaches and more broadly, using geomorphological expertise to

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[3] GeoData (2005) Scoping study for the morphological alterations mapping project. Report to SEPA UC0842/1

[4] Davids, C., Gilvear, D. and Tyler, A. (2004_ A feasibility study to assess the usefulness of remote sensed data to assess surface and groundwaters. Report to SEPA, University of Stirling *(undated)*

assess the ability to identify and delineate features extractable directly from aerial photographic interpretation to provide the qualitative RAT based assessment.

Given the appreciation that not all features can be discriminated, it is necessary to identify the features and attributes of these features that can be effectively recorded and the influence of the quality and access to other datasets that may fill gaps. If a national approach is to be adopted based on a RS and GIS record of pressures there is a need to record the quality of the information along a reach (i.e. how much survey has been used and from what date) to ensure that the relative quality of information for any specific reach is interpretable from the GIS.

Remote sensing within the context of channel morphology data extraction has been widely studied but rarely applied in a fully operational context, partially due to the lack of resolution of the aerial images sets in Ireland at suitable resolution and currency and the perception of the data necessary for channel and riparian characterisation.

RS data varies from coarser, satellite based, imagery (e.g. LandSat, SPOT, Quickbird etc) with resolutions of between 30 -5 m resolution to aerial based imagery at resolutions typically down to 25 cms from high resolution aerial photography. Within the context of risk assessment, classification and POMs the task was to evaluate the role that secondary and remote sensed data could play within the identification of departures from WFD quality classes and the nature of the pressures and departures that might feed into the selection of priorities for action based on the characterisation of these departures from good status. This stage assesses the classification of the departures and the WFD rating within RAT and MImAS, the availability and characteristics of RS data, the ability to discriminate relevant parameters for site prioritisation and river channel typological assignment. The assessment of the effectiveness of API within this context needs to evaluate three components, feature identification, feature delimitation and attribute collection.

7.2 RAT and MIMAS characteristics

7.2.1 Introduction

In order to evaluate the capacity of RS data in creating remote measures equivalent to RAT and MIMAS it is necessary to understand the characteristics of these field-based techniques. RAT (Richards et al 2006) and MImAS (Sniffer / SEPA 2007) are two methods of reach-based assessment that have been proposed within the scope of the monitoring and surveillance requirements of the WFD. The former was developed within the scope of the NS SHARE programme as a rapid assessment of the morphological factors considered to affect the biological elements; and the MImAs was developed in Scotland for specific new requirements for regulatory control of channel interventions and developments under the Controlled Activities Regulations.

7.2.2 MImAS

The initial proposal of this project (Work Package 6 Tool Development) was to develop a tool to support MImAS adoption and score calculation within the project. The MImAS tool was developed for regulatory purposes, linked to new Scottish CAR legislation, which requires assessment of capacity of a channel / waterbody to accommodate further engineering without creating a risk of failure in terms of WFD ecological status. It was initially considered that this would also form a suitable approach in Ireland. MImAS takes a mechanistic approach and is information-rich; collecting comprehensive records of sites in terms of modifications calculated through a weighted scoring system. MImAS scoring relies on the knowledge/assignment of the channel typology and the enumeration of modifications in order to calculate the loss of capacity within the system to accept further modifications without lowering the channel and riparian status. This is to some extent a subjective assessment, but one that in Scotland has been tested with expert review. MImAS within Scotland is envisaged as being run in a semi-automated fashion, based of inputs of a morphological pressures database (MPD) and a river channel typology classification, which have been captured for the whole of the Scottish waterbody network. Thus, it is possible to run MImAS on these secondary datasets, as an input to regulatory decision-making, but it is a support tool rather than a decision tool itself. It is important to note within the context of this evaluation that the key inputs to MImAS (typology and the pressures database) have used Scotland-wide aerial photographic coverage and secondary data to develop these inputs.

Neither of the databases (typology and pressures database) required to generate MImAS scores have been comprehensively generated within Ireland and hence the potential to build the capacity linked scores without further fieldwork, API or interpretation is limited in Ireland. It was considered that the RAT method, developed as part of the NSSHARE programme, provided a user-friendly and cost effective method that did not require the degree of morphological training needed by MImAS.

In creating the input variables to the MPD, which predominantly use secondary datasets (OSI Discovery Series mapping, 1:6' historical mapping and OSI 1m resolution aerial images) some features were not identifiable and therefore, at least initially, the MImAS processing relies on assessing capacity without these features. These include features such as sediment additions ands removals, green bank protection, dredging, and boulder placements. Other elements such as flood walls and grey bank protection also proved difficult to collect in a consistent manner, and rule based approaches were included (for example where urban development was based immediately adjacent to the channel bank). In Scotland the OS MasterMap data was used in a topological sense to extract certain modifications (channel riparian vegetation classifications, modified banks etc); these approaches are unlikely to be possible without the appropriate GIS model from Irish national maps.

The incomplete nature of the MPD and quality of the data is an important consideration, as this can affect both the approach to and the values generated by the MImAS calculation. The relative influence of different types of modifications on the capacity calculation needs to be evaluated and the completeness of the information from which the features have been identified needs to be appreciated in running MImAS. Comprehensive field-based assessment of the features is likely to suggest greater modification than where the features are measured from remote or secondary data, where it is harder to discriminate all the features.

The feature list identified for MImAS (Table 7-2) provides a basis for the assessment of the scope for RS imagery to contribute to the morphological assessment. Within MImAS a series of attributes are also captured that attempts to qualify and partially quantify the scale of the impact of the features (e.g. a bridge with no piers within the water have a lower potential impact than one with multiple piers and abutments and bed protection). The footprint calculation in MImAS seeks to draw these multi-dimensional aspects into a single input value for each feature into the MImAS tool calculations. In the same way the relative influence of the feature needs to be assessed in RAT, but in a more qualitative way.

Channel morphology	**Boundary conditions**	**In-channel construction**	**Sediment modifications**
Realignment Partial realignment (partial recovery)	Green bank reinforcement	Bridge	Dredging
Bank re-profiling	Grey bank reinforcement	Bridging Culverts	Sediment removal
Impoundment	Banktop Embankments	Fords	Sediment addition / re-introduction
Bed reinforcement	Setback embankment	Boat slips	
	Flood by-pass channel	Intakes /outfalls / Pipelines	
	Flood walls	Croys / groynes / flow deflectors	
	Riparian vegetation loss	Boulder placements	

Table 7-2 Modification features used within the MImAS Morphological Pressures Database (Scotland)

7.2.3 RAT

Whilst MImAS records the features, their locations and a number of other attributes of the features (e.g. number of piers within the water in a bridge, materials of bank protection etc) the RAT system merely seeks a summation of the views of a surveyor who has sufficient expertise in morphological assessment against narrative descriptions of eight status classes (0-4). These evaluations are based on the contract with the undisturbed situation and the typical pressures that might be anticipated and the impact of these in generating departures from high status. The approach is, as it suggests, descriptive; no records of individual features are made from which to re-run or reassess this score. Whilst this means that it is not possible to revisit the classification, the system is rapid and is seen as being 'fit for purpose' for the surveillance monitoring use to which it is to be put. That does not mean that the RAT approach will be appropriate to fulfil the needs for the regulatory purposes to which MImAS is being put, but at this stage of the assessment process and the application specific needs are better addressed by use of RATS in the field. It is still necessary whether running MImAS or collating a remote RAT score to appreciate the features that one is trying to discriminate from the aerial images.

The RAT assessment procedure has been run in the field within 2006 and 2007, and within the scope of this was the intention to have other preparatory data. The Assessment Procedures (NS SHARE 2005) states that '*depending on the purpose the field survey should be preceded or followed by exhaustive use and interpretation of all available data … including historic maps and aerial photography*'. Thus remote and secondary data was anticipated to help determine the channel types, based on likely channel morphology and features, and to be used as a preliminary assessment of stream condition. In general, the datasets and systems to explore this information have not been available, or not in the comprehensive way envisaged, prior to field assessment.

Whilst the field-based RAT approach does not rely on the identification and enumeration of the specific events or modifications there is an inherent need to make a qualitative judgement in the field of these pressures, their scale relative to the reference (natural) condition and the degree to which they are affecting the reach in question. Thus to some extent the RAT and MImAS approaches are equivalent; both needing to establish the nature and extent of the pressures. In the operational context MImAS relies on the Morphological Assessment System (MAS) and for each pressure type a series of attributes are recorded, although within the scope of MImAS risk assessment only certain parameters are used to calculate the 'footprint' which contributes to the MImAS calculation.

From the perspective of the Article 5 risk assessment for rivers the following list was used to generate the scores:

- channelisation, dredging and river straightening
- flood protection and embankments
- impounding
- water regulation

- intensive land use.

The extended list of characteristic features and the attributes of features within the MImAS and incorporated into the capability of the Event Manager Tool allows for the development of a datasets equivalent to the Morphological Pressures Database used in Scotland. This allows for the effective re-run of the Article 5 based risk assessment, but using additional datasets.

8.0 Decision Support Contract: WP3: Prioritisation of Waterbodies for Measures

This section provides an expert perspective, provided by the GeoData Institute, on the prioritisation of waterbodies for different measures under POMS activities.

8.1 Prioritisation

The results of the RAT / remote RAT assessment and typology assessment provide the inputs to selection of appropriate POMs to address waterbodies at risk of status failures. The problem remains that at the broad level there is often insufficient information to identify priority areas for POMS and to establish a priority of the appropriate specific measures. In studies in the UK the general diffuse agricultural pollution and the hydromorphology are the most significant risks to not meeting the environmental objectives, although it is noted that there is a degree of uncertainty in relation to the risk assessment.

Identifying and prioritising the sites for POMS across the whole waterbody network cannot be achieved through RAT field based assessment, and therefore the role of the risk assessment improvements and secondary data become relevant. The morphological pressures database and the Event Manager Tool allow for the collection and collation of parameters. Additional, secondary field and survey data are relevant to this process, and can be collated within the same linear referenced based approach used within the Event Manager Tool. These records may include the surveys of arterial drainage and the Q scores (from biological monitoring). Combined, these records provide a basis for assessing the departures from good status, the degree of that departure and hence the potential priority for measures. A separate Compass activity to generate the river channel typology allows for the identification to river types, relevant to the selection of the measures that meet the type-specific requirements.

Other factors may moderate both the approach and the priority of the actions, based on the degree to which the measures might be considered effective. A key question is whether measures should move highly degraded sites up status levels or whether the target is those sites at moderate status moving to good. The answer may be dependent on where the sites are within the river system, what the nature of the pressures the departures from naturalness and an assessment of the sustainability of the approaches.

The Freshwater Morphology Workshop April 2008 has defined targets for the prioritisation, which determined an order for response to the risk of failure of standards. The implementation of measures to these priorities is likely to be determined by the site specific data at river, waterbody and catchment scales.

Prioritisation measures:

- Protected area waterbodies
- Achieving favourable conditions (e.g. freshwater pearl mussel areas and siltation impacts)
- Preservation of existing high status
- Preservation of existing good status
- Prevention of deterioration
- Licensing, land use management and morphology mitigation toolkit measures – new activities
- Restoration of good status
- Improvement programmes (application of morphology mitigation toolkit measures) in waterbodies where these measures will be effective – not polluted and suitable for enhancement

From: Objectives and Programmes of Measures: Making Decisions on Measures (Glasgow 2008) [5]

8.2 Principles for establishing actions

From the hydromorphological and ecological status perspective the principle that underlies this approach is that providing the physical processes and environmental parameters characteristic of channel types are achieved, then the niches for habitats and species associated with type-specific channel will also be maintained.

The experience from channel restoration activities is relevant to the POMS, but it is still unclear whether the restoration approaches for morphology have been truly effective in achieving the objective of 'good ecological status' or in the case of HMWB of 'good ecological potential'. The question is whether morphological actions from restoration results in the desired ecological enhancements and hence the suitability of existing approaches to deliver the POMS measures under WFD. Such assessment requires both the morphological and ecological pre and post-intervention monitoring to test the validity of this approach.

The risk assessment under Article 5 and its enhancements indicate the potential of failing to maintain or achieve the ecological status of waterbodies. Identification of

[5] Programmes of Measures and Standards Freshwater Morphology Outcomes Workshop 4th April 2008 Objectives and Programmes of Measures Making Decisions on Measures, Grace Glasgow (2008)

types of pressures (via the Event Manager Tool) that may place a waterbody at risk of failure is a necessary step. The significance of the pressures is evaluated through footprints within MImAS and through classes in RATs. The significance of the pressures is important to judge as impacts may work cumulatively; many small pressures may put the waterbody at risk. The assessment of significance relies on assessing the potential impact on the biological quality elements.

Table 8-3 illustrates the types of pressure, the morphological alterations and impacts on the ecological status that may result. This is not a comprehensive assessment for all pressures, but provides the basis for establishing the relationships between the pressure, its direct impact (morphological alterations) and resulting effect on ecological status. Through this type of impact assessment the approaches to addressing and mitigating these impacts (measures) can be assessed; whether these are direct (causal) or indirect responses (reactive). For example, the increased supply of fine sediments associated with smothering of channel gravels is often treated responsively by direct jetting or raking, rather than addressing the land use change causes.

Pressure	**Morphological alteration**	**Potential impact on good ecological status**
Engineering structure for erosion control or flood defence	Loss of natural bank morphology	Loss of habitat and natural sediment supply
Dredging of sediment shoals	Damage to river bed substrates Release of fines	Disturbance to sedimentary habitat, Loss of invertebrate community / change to composition
Catchment land use change	Changes in sediment loads Changes in regime / stability	Smothering and infiltration of fines

Table 8-3 Types of pressure, the morphological alterations and impacts on the ecological status that may result.

The rationale for POMS is to ensure that through measures waterbodies achieve or remain at 'good ecological status' or 'good ecological potential' as defined within the WFD, where the hydromorphological elements are not defined but are consistent with the values specified for and able to support the biological quality class (by UK TAG 2003). Only at 'high' status are morphological conditions anticipated to be close to Reference Condition that need to be preserved. This implies that even at 'good' and at 'less than good' status the targets set by reference conditions are relevant, and this is the approach taken by RAT in referring the departures of hydromorphological elements from the high ('appears natural') condition category. This is in essence an

assessment of the degree of naturalness of the system and given the use of RAT within Ireland is appropriate to the prioritisation and selection of measures.
The specific 'hydromorphological quality elements' that the WFD where high ecological status implies no or very minor deviation from undisturbed conditions. These are also the elements that are to be addressed by the POMS to aim to achieve the supporting hydromorphological conditions at good and moderate status. Table 8-4 sets out the hydromorphological elements under the WFD.

Hydrological Regime	Continuity	Morphological Elements
Quantity and dynamics of flow Connection to groundwater	Sediment transport Migration of biota – longitudinal connectivity Floodplain connectivity	Channel pattern Width and depth variation Flow velocities Structure and Substrate conditions of the bed Structure and condition of riparian zone

Table 8-4 Hydromorphological elements under the WFD that form targets for Programmes of Measures

The notion is that it is possible to set principles for establishing actions that address departures from the hydromorphological elements where they are not supporting 'good status' or 'good potential':

- Given a particular river channel type (typology) and the known pressures that are affecting a reach (within reach and potentially from upstream and downstream) it is possible to identify appropriate options for type-specific morphological measures. The principle does not go as far as decision-making, but provides support to selection of appropriate options. Actual selection of measures will rely on more site-specific data and no single approach may be effective within a reach, (e.g. green bank protection may need to be combined with re-sectioning and re-profiling within restoration activities).

- Given the ability to effectively map the risk assessment (equivalent to Article 5 assessments), as improved by API data, there is then the potential to identify prioritisation for where the PoMs measure may be best applied. If the details of the pressures are associated with these priority areas it should also be possible to identify the characteristics that need to be modified to reduce the risk (through restoration, rehabilitation, or in some cases by allowing existing natural recovery processes to continue (by accepting longer term targets).

8.3 Feasible measures

8.3.1 Measures Approaches

The classes of measures to achieve the WFD targets are not only direct actions, but a series of complementary regulatory, management and direct actions, that may themselves be classified:

- Basic measures – controls and regulations, licences, prosecutions, alignment of plans with WFD objectives
- Protected areas measures - targets for favourable condition etc
- Supplementary measures - national programmes, grants, stewardships schemes. education/awareness integrated plans / morphology measures toolkit
- Voluntary measures – e.g. rehabilitation projects
- Morphology monitoring programmes

These measures have varied levels of cost, effectiveness and results timescales and do not relate solely to hydromorphological elements. The likelihood of not achieving the targets by using basic measures alone is recognised and supplementary measures are anticipated within the multi-disciplinary and multi-project approach.

The direct POMS measures can be defined by type of action (rehabilitation, natural recovery etc), by the measures themselves (bed raising, riffle emplacement) or by the processes that the measures seek to address (e.g. sediment- related). At the broad scale the class of measure is needed at a waterbody level, at the reach-level the approach needs to be defined more explicitly and ultimately specific measures are needed. The broad scale is needed to help determine the sequence and scales of POMS within a waterbody in order to establish an overview for the network. Once these issues are appreciated it may be possible to assess the sequencing of any actions, e.g. working from upstream to downstream, seasonality of action etc and to evaluate how the individual measures sum to achievement of the good ecological status within the waterbody.

The measures may be applied at different levels within the system (catchment, floodplain and channel). An example of the complementary approaches that the POMs of measures may take in morphological terms is illustrated within Table 8-5 for catchment and channel management of sediments. These illustrate that restoration and channel management activities themselves may be modifications (for example where grade structures are introduced to control erosion or channels are narrowed to re-establish morphological relationships with flow).

Catchment scale sediment controls	**Bed controls** (stop and retain sediment – reduce knick point migration)	**Bank control** (to prevent erosion)	**Features installation** (missing features and geometry
Reduced stocking Drilling to replace ploughing Planting and introducing buffer strips	Sills Grade control structures Check dams	Re-profiling Riparian and bank top buffering Bioengineering	Channel narrowing Installation of riffle / pool sequences Deflectors / groynes

Table 8-5 Examples of morphological measures that may be taken at different points and levels in the catchment / river system

Measures may also be based on two classes:
Maintenance activities
Capital works

Capital works will encompass restoration, rehabilitation and enhancement activities, whilst maintenance and possibly reduced maintenance is more likely to be targeted at assisted natural recovery options.

A similar approach to POMS prioritisation has been developed within the scope of strategic assessment for fluvial audit (within the River Nar and Wensum)6. The principles are illustrated here as they provide a possible framework for implementation within a best practice tools and a decision support system (DSS). The approach to selection is based on collation of morphological pressures and departure from naturalness assessment, the latter based on the understanding of the channel/waterbody typology that can be assessed against reference condition sites and is assumed to be the 'natural' typology of the river – that without modifications. These are the same terms used within the RAT assessment and capable of identification from the results of Event Manager Tool derived datasets and remote RAT assessment.

Channel modification is based on the identification of the specific features / pressures within the system. "Naturalness" and the extent to which the current channel diverges from the natural condition, is an important element of the restoration vision and process as it provides the reference conditions that may form the basis of channel designs, and the baseline against which to monitor the effectives of the restoration. Naturalness is type-specific and therefore appreciation of what constitutes naturalness in different typology classes (via reference condition sites and expert opinion) is an important component in determining the response measures.

[6] GeoData (2005) River Wensum SAC Geomorphological Audit, Report to English Nature. Sear, D.A. Newson, M., Old, J.C. and Hill, C. 2005 Report UC0762/1

The matrix of naturalness and modification allows the categorisation of the status of the channel/waterbody, whether natural, semi-natural, through to recovering, degraded and at the extreme artificial (Table 8-6). These approaches were developed by the project team within the context of Fluvial Audit on the Nar and Wensum and subsequently through the generalised specification for development of measures to achieve favourable condition within protected sites; which have similar objectives to the POMs targets.

	Naturalness					
		Natural	Predominantly natural	Partially natural	Practically Un-natural	Un-Natural
	Unmodified	Natural	Semi-Natural	Damaged	Damaged	Damaged
	Predominantly Unmodified	Semi-Natural	Semi Natural	Damaged	Damaged	Damaged
	Obviously Modified	Recovered	Recovering	Degraded	Degraded	Degraded
	Significantly Modified	Recovered	Recovering	Degraded	Severely Degraded	Severely Degraded
Modification	Severely Modified	Recovered	Recovering	Degraded	Severely Degraded	Artificial

Table 8-6 Classification of reach types arising from the combination of Modification and Naturalness indices.

Evaluating this condition matrix allows the identification of the 'class' of potential measure that may be appropriate to achieve staged improvements or the practicality of achieving these status improvements. Typically, the greater the degree of departure from natural and unmodified status the greater the intervention and costs needed to restore. Table 8-7 sets out the potential management actions relevant to the classification of reach types. There has been no attempt to classify this matrix within the context of the WFD condition status as these relate to morphological elements and are evidence based.

	Natural	Predominantly natural	Partially natural	Practically Un-natural	Un-Natural
Unmodified	Protect Monitor	Protect Monitor	Assist natural Recovery	Restoration	Restoration
Predominantly Unmodified	Protect Monitor	Protect Monitor	Assist natural Recovery	Restoration	Restoration
Obviously Modified	Conserve & Monitor	Assist Natural Recovery	Rehabilitation	Rehabilitation	Enhancement
Significantly Modified	Conserve & Monitor	Assist Natural Recovery	Rehabilitation	Rehabilitation	Enhancement
Severely Modified	Conserve & Monitor	Assist Natural Recovery	Rehabilitation	Rehabilitation	HMWB

Table 8-7 Management action associated with each reach class. (HMWB – Highly Modified Water Body)

These management action approaches provide a basis for also classifying the measures that may deliver the target status. The terminology is described in Table 8-8.

Term	Definition
Restoration	Restoration of channel processes and forms to pre-disturbance conditions.
Rehabilitation	Physical modification to the river form to re-create physical habitats (e.g. re-meandering, riffle installation, bed level raising).
Enhancement	Addition of structural features to improve physical habitat diversity (e.g. narrowing, woody debris).
Protect & monitor	Afford legal protection to the site and monitor for change in status. Given that the site has legal protection (e.g.SSSI/SAC), monitor to ensure that the status is maintained and take action if required.
Assisted natural recovery	Amplification of existing processes to encourage recreation of physical habitats (e.g. encouraging berm formation to narrow channel, removal of bank revetment to create sediment supply).
Conserve	Protect site against further degradation not necessarily with legal statute.

Table 8-8 Definition of terms used in Figure 6.2, typically, implementation costs rise to towards the top of the table

What may be helpful to river managers is a typology of river restoration approaches that provides them with a means of clearly communicating their actions to a wider stakeholder community. **Error! Reference source not found.** below presents some of the typical morphological options in a simple matrix of restoration approaches, additional options might be added to this table, but this forms the basis for the classification. Selection of measures needs to balance a range of other factors (costs, technical feasibility, social and socio-economic factors etc) based on the environmental objectives or alternate objectives where the default objectives cannot apply. The sequence through which these measures would be identified is proposed within

which illustrates the roles of typologies and modifications to prioritise at risk areas, the evaluation of the appropriate classification and management actions feeding into selection of indicative restoration / morphological measures.

Table 8-9 River restoration options.

	Restoration Class	
	ACTIVE physical creation of forms or removal of structures to improve degraded ecosystems.	**PASSIVE** physical manipulation of flow and sediment transport regime to create physical habitat and to improve degraded ecosystems
Form-mimicry the re-creation of physical habitat features without reference to the processes required to create them	Riffle recreation Re-meandering (on new course) Channel reprofiling e.g. 2-stage channels in channelised reaches Backwater channels creation, channel narrowing, Habitat enhancements / fish shelters	Gravel augmentation which then is moulded by river flows into bed features (riffles) Introduction of woody debris
Process-based the use of physical processes to create degraded physical habitat	Weir removal – restores sediment connectivity and hydraulic gradient Re-occupation of an old channel course Culvert opening Floodplain reconnections + embankment removals, bed raising	Reduction in catchment sediment supply Management of flow regime (flow re-naturalisation) Reduced maintenance regimes – assisted recovery

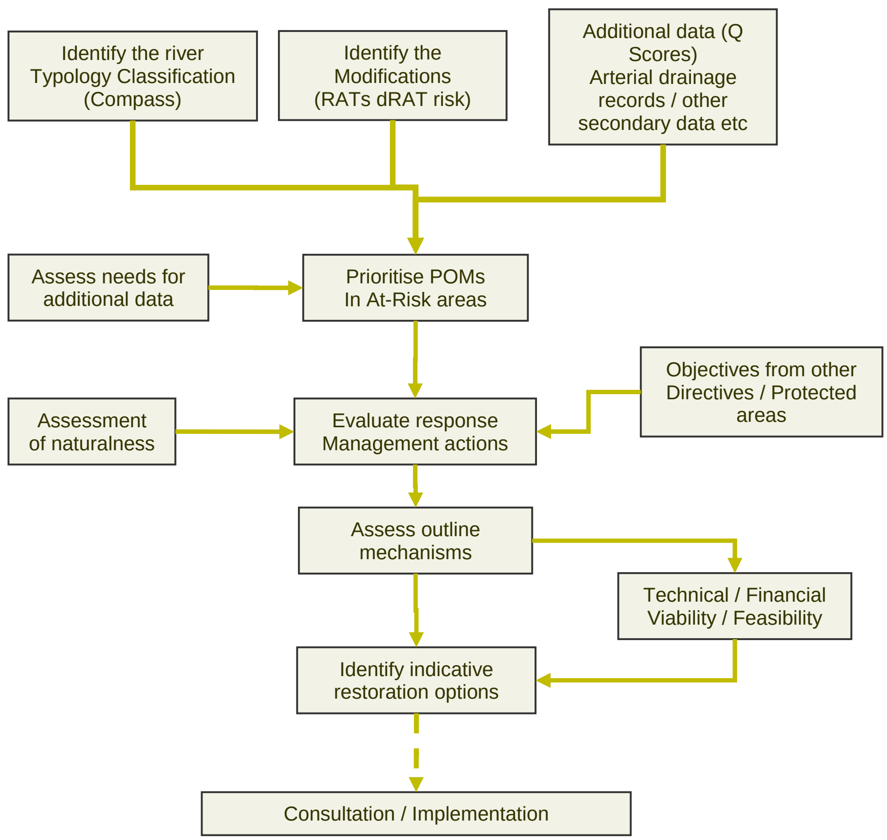

Figure 8-1 Sequence of assessment of morphological measures

There is considerable published advice on restoration techniques and case studies, although as noted the lack of coincident ecological and morphological monitoring reduces the ability for assessment of effectiveness in terms of enhancing ecological status. Hence monitoring the outcomes of programmes of measures both at a scientific levels as well as in condition assessment response will add to the confidence in selecting appropriate measures.

Specific reference should be made to the Guidebook of Applied Fluvial Geomorphology (2004)7 and the River Restoration Centre guidance and advice on appropriate restoration techniques and a reference list of guidance, case studies and site records of restoration programmes. http://www.therrc.co.uk/rrc_references.php

8.3.2 Alternate measures

It is noted within the Programmes of Measures and Standards Freshwater Morphology Outcomes Workshop 4th April 2008 that there are constraints on

[7] SEAR, D.A., NEWSON, M.D. & THORNE, C.R., (2004) Guidebook of Applied Fluvial Geomorphology, Swindon, WRc, 256.

applying POMs within certain classes of Irish river systems. In particular, those channels that have arterial drainage status that are regulated under the Drainage Act 1945. Unless supplementary measures and new legislation were to change this position the hydromorphological measures appropriate to the scale of the significant morphological modifications (dredging and realignment) may not be applicable. These arterial systems exhibit modifications in realignment and reprofiling, floodplain drainage and are associated with intensive floodplain land use. Nevertheless, there is a desire to establish ecological enhancement measures without compromising the arterial drainage standards and ongoing maintenance requirements.

The Channelisation Recovery Assessment report 8 relates to habitat enhancement measures for spawning and creation of habitat for salmonids, practical application and feasibility on rivers subject to arterial drainage schemes. These measures may be seen as surrogates for restoration of natural form and process e.g. secondary meanders within dredged and resectioned areas, introduction of boulders and substrates to increase flow and habitat diversity. This is a different approach to the model taken above and that used within the RAT assessment, that seeks to identify naturalness features and degree of modifications and from this assess the measures to achieve good status based on type-specific naturalness categories. In these instances it will be important to have a classification (potentially via the Event Marker Tool) to identify the reaches where these approaches may be appropriate.

8.3.3 Mapping catchment scale initiatives

Catchment scale influences on the channel system, in terms of sediment inputs and water quality, are also likely to affect the waterbody status. Whilst these are outside the scope of the identification of reach-level features and pressures, the use of aerial photography interpretation offers the opportunity for the identification of the sources of sediment inputs, pathways and land use classes that potentially are indicators of adverse water quality / sediment inputs.

This approach is used within the geomorphological survey approach, Fluvial Audit, which seeks to identify, map and understand the hydrological and geomorphological issues within a river system as a whole. In order to do this it is necessary to identify what Fluvial Audit terms 'potentially destabilising phenomena', those activities that may disrupt natural functioning of the river system – such as unnatural sediment inputs. These data are then used to establish remedial measures based on the understanding of the problems and causal relationships. Typically aerial photography and historic maps are the main sources of secondary information.

In the same way within the scope of the current use of API there is potential to identify land uses and flow paths that are often associated with introduction of sediment inputs (and potentially other water quality factors) that may be adversely affecting the waterbody status. Currently, this is not accommodated within the

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8 ShIRBD Freshwater Morphology POMS Study 2007

recording for the reach within the Event Manager Tool. The nature of the data differs from the feature identification, although there would be potential to enhance the data structure to accommodate this.

8.4 POMs Support Tool

The current Event Manager tool does not support the decision support for the selection of morphological measures, although it does provide the potential inputs to understanding the modifications that might be addressed by POMs. Further enhancement of the tool is necessary to take this next step in using the geodatabase and typology to identify management options. These are likely to be type-specific management options where the database of modifications linked to the database of options and selectable on specific morphological criteria would create a decision support tool.

The POMS Decision support tool (morphology mitigation toolkit) sets out certain objectives for the POMS (Programmes of Measures and Standards Freshwater Morphology Outcomes Workshop 4th April 2008)

- Design with nature
- Engineering and habitat objectives
- Multi-disciplinary approach
- Incorporate mitigation into design
- Post works enhancement

From the hydro-geomorphological perspective these can be re-cast as principles:

1: Restoration of natural functioning / process rates.
2: Restoration of natural processes where these are missing.
3: Restoration of natural form where this has been damaged by past modification since the river is only able to adjust through fine sediment deposition.

It is recognised that not all of these principles will be achievable within POMS and development of a Decision Support Tool needs to recognise certain limitations and constraints, but where the river system and functioning needs to be understood, possibly beyond the level generated by the risk assessment process. The targets for the POMS also need to be understood, whether this is to achieve good status or whether the morphological actions are attempting to achieve pre-disturbance states. Form the POMS perspective the targets are based on the WFD status classes, but actions (especially supporting and voluntary actions) may set different targets.

So within the context of the mapping of features of modification it is necessary to understand the level to which these have affected the capacity to operate specific styles or types of morphological measures (POMS):

- Natural processes may be used to allow natural recovery of channels – subject to appropriate or low maintenance regimes

- River processes may be so modified that they are unable to recreate forms and functions
- River form (cross and long profile) may be relic features where lateral and longitudinal connectivity may be relic and unable to recover to pre-disturbance levels without major intervention
- Catchment-scale processes may affect the ability to achieve the target outcomes

9.0 Decision Support Contract: WP4: GIS Tool Development

9.1 Introduction

Compass Informatics were contracted in association with the GeoData Institute to create a GIS based tool that will enable the end-user to prioritise waterbodies for which morphological measures are required.

The GIS tool will provide a tool that will bring together data from five separate projects each focusing upon various aspects of the Freshwater Morphology study through the Shannon International River Basin District Project. These projects examine areas such as:

1: *Typology (Republic of Ireland and Northern Ireland)*

2: *Feature extraction and Aerial Survey (Shannon IRBD Freshwater Morphology Study).*

3: *Lakes morphology feature extraction (Shannon IRBD Freshwater Morphology Study, in conjunction with University of Dundee)*

4: *Decision support tool (Shannon IRBD Freshwater Morphology Study, in conjunction with GeoData Ltd)*

5: *Artificial barriers (Central Fisheries Board)*

The tool brings together the datasets listed above while also providing the user with a method for recording RAT from the available layers within the GIS a method that is known as desktop RAT (dRAT). The tool draws heavily on existing background mapping including OSI 1:50,000 discovery mapping, OSI Orthophotography, High resolution aerial imagery and OSI First Edition 1:6 inch historical maps.

9.2 Tool Specification

Following an in-depth workshop with the EPA on the 14th of April 2008 and subsequent team meeting on the 16th of April, the decision was made to move forward on the development and deployment of two ArcGIS GIS server tools, with these tools an operator will have the ability to:

- Rerun a risk assessment for a waterbody using the pressure thresholds channelisation and embankment and methods established through the Freshwater Morphology Study as a follow up to the Article 5 risk assessments.
- Conduct a Desktop Rapid Assessment to generate a remote R.A.T score if deemed necessary.

Further to these two tools a GIS desktop application has been developed that will be made available allowing sectioning of a river waterbody into morphological classes. This tool is known as the event manager too and is discussed in more detail in section four.

General Functionality: The tool will allow querying, analysis and reporting functionality on waterbodies for which R.A.T. data is already available.

Rerun risk assessment: The operator will be able to take a waterbody with a risk score and changing the parameters rerun the risk assessment. For example: If a river has an application to be channelised this can be incorporated and a new risk can be generated by applying the channelisation threshold between "at risk" and "not at risk". This will indicate if the proposed activity could cause a risk of deterioration in morphology status.

Desktop R.A.T (dRAT): The operator will be able to conduct a desktop RAT, using aerial imagery and generate a score and subsequent WFD class. The same attributes recorded in the field can be remotely identified. Not all R.A.T attributes will be readily identified due to imagery resolution/availability and limitations of identifying certain features remotely. However, this is similar to the field survey methodology where under certain conditions (e.g. high flows) an incomplete survey will be recorded however a valid R.A.T score can still be generated from this data.

The full specification document can be viewed in Appendix III.

9.2.1 Deployment environment

A technical review meeting was held on the 19th of April 2008 where it was decided that the Environmental Protection Agency (EPA) would be the host for the tool, with this knowledge the tool has been developed to link directly into existing EPA databases and for the tool infrastructure to be built in a manner compatible with the EPA's own IT infrastructure.

9.3 Morphology Assessment Geodatabase Design

The Morphology database has been designed to store datasets which are specific to the Morphology project. Other datasets which are utilised by the application, such as the EPA river network, are stored in existing databases in the EPA. The application will also need to connect to and display data from these existing EPA databases. Designing the database structures in this way avoids duplication of datasets. Ideally, each dataset should reside in only one location.

The Risk Assessment and the dRAT tables are dynamic and are stored as an ESRI object class in the database. Other datasets which are specific to the project are also stored in the morphology assessment system, figure 9.1 shows the database schema that has been developed to for the morphology tool, the schema defines the database structure and the relationships between each of the classes.

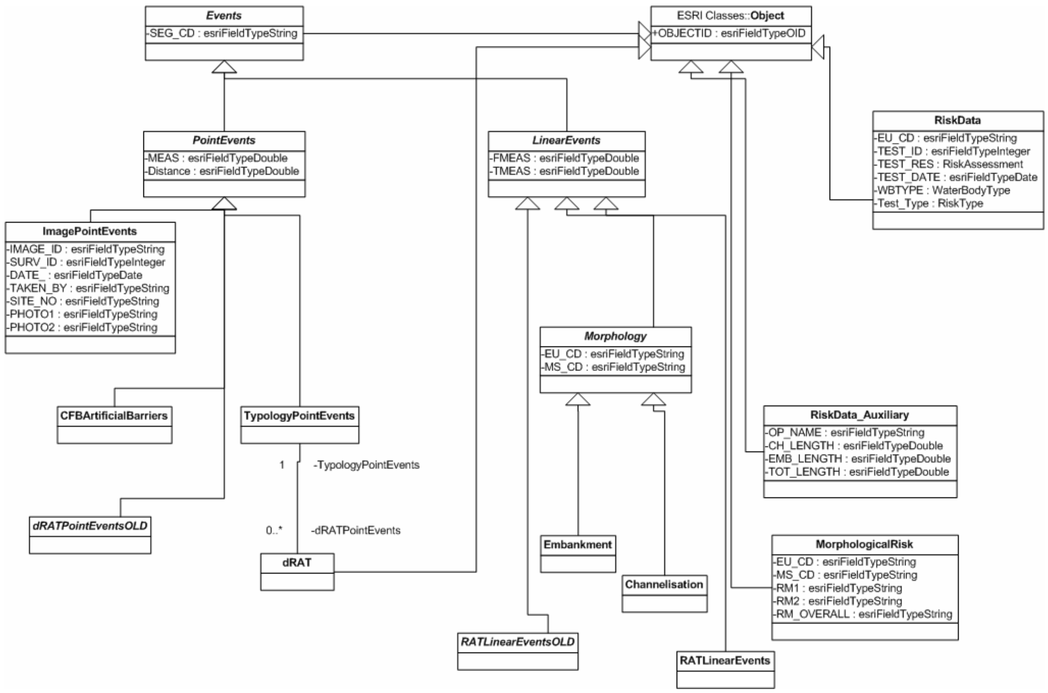


Figure 9.1: Morphology database schema

The schema and the database can be updated as new data becomes available for the existing databases (e.g. the CFB add more barriers) and as more data sources become available.

9.4 Base Datasets

A base dataset is a dataset that is used as a reference whether for locating a user spatially or for performing a dRAT on a section of a river. These datasets are national and are non editable however as more updated versions of these become available these can be implemented into the system. Below is a short description of each of the four base datasets all from the same location:

- Compass Informatics high resolution imagery: This dataset covers 45 river stretches and 3 lakes within Ireland. This data was captured as part of the feature extraction and aerial survey contract.

Figure 9.1: Compass Informatics high resolution imagery

- Ordnance Survey Ireland (OSI) orthophotography: This dataset has been purchased by the EPA and was collated by the OSI in 2005.

Figure 9.2: Ordnance Survey Ireland (OSI) orthophotography

- OSI 1:50,000 Discovery Series: This is the digital format of the OSI's popular national raster dataset. This dataset is fully licensed by the EPA.

Figure 9.3: OSI 1:50,000 Discovery Series

- First Edition 1:6 inch historical mapping (1:10560). This digital dataset was created as part of Compass Informatics project for Duchas (now under Dept of Environment, Heritage and Local Government.

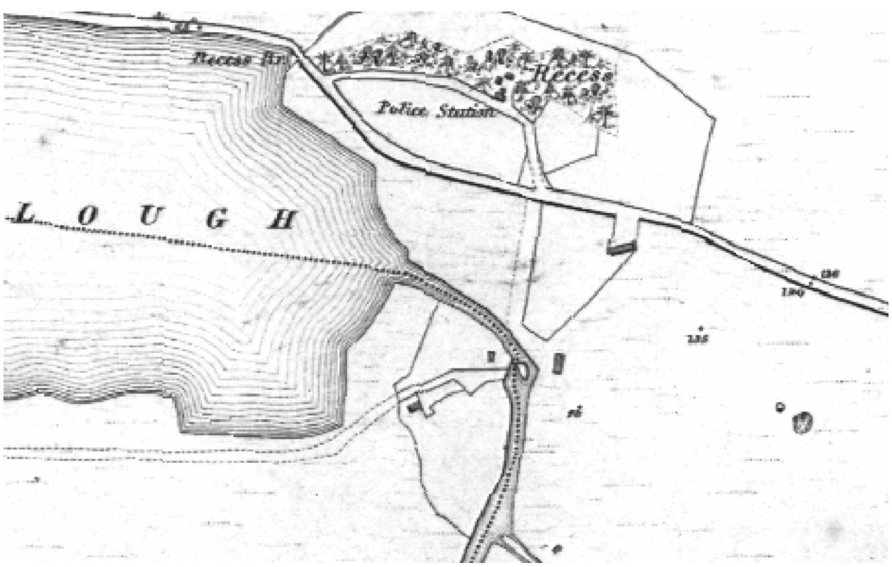


Figure 9.4: First Edition 1:6 inch historical mapping (1:10560)

9.5 Tool User Guide

The Freshwater Morphology Tool is hosted by the EPA and will be used as an intranet GIS tool and parties outside of the EPA should contact the EPA directly to apply for access. A user guide has been created for the tool which explains in full the operation and functionality of the tool, this can be seen in appendix IV.

10.0 Typology Contract

10.1 Introduction

The objective of the project is to apply a river typology classification scheme to Irish rivers based on GIS analysis. The method is based on the analysis of existing datasets and is predicated on theoretical constructs developed by fluvial geo-morphologists, particularly in reports provided by the NS-SHARE RBD project and SEPA in Scotland.

The NS-SHARE report presents a typology scheme based on 7 main channel types with sub-types in certain cases ~ 10 channel types. Each type represents a discernible channel form to a geo-morphological expert and is described by the expected value (or value range) for a series of parameters – slope, sinuosity, confinement, geology, sediment regime and structure.

The application of a river typology scheme in the GIS is constrained by several factors:

- Many of the parameters can only be measured during field survey or perhaps from high resolution aerial photography. The extent of hydro-morphological field survey in Ireland to date is limited and thus several parameters are not available for the GIS analysis. This constrains the ability to apply a complex scheme in the GIS at the current time.

- The channel types recorded in the scheme in reality are not likely to always occur as discrete and clearly defined entities. Rather rivers typically exhibit gradual change in form along their length. Certain types are more typically found in the upper, middle or lower reaches of a river although local variations in geomorphic factors can lead to the short length interspersion of a channel type not generally typical of that locality.

- Typical examples of each channel type can be described by value ranges for the key controlling parameters. However at many locations the channel is likely to exhibit a form that is 'between types' rather than a clear example of a particular type. In these (common) instances the assignment of a channel to a particular type class is somewhat arbitrary. Comparison of field survey assignment of channel type by different observers at the same location often bears this out.

- The scale and resolution of information held in GIS datasets may be too coarse to yield measurements of sufficient accuracy to support the level of analysis required. This potentially applies to all data sources used: - plan form factors sinuosity and confinement; longitudinal factor gradient and site location factors geology and subsoil parent material type.

Through a review of literature and discussion with experts it is apparent that channel type can change over relatively short reaches. Whereas the majority of a river segment or section **may** exhibit a single type, significant changes can occur at local reaches. In this regard it is thought appropriate to measure channel type at closely spaced intervals in an attempt to record local variation. If required it is possible to summarise at a river segment or longer WFD Waterbody level using, for example, a majority or longest continuous section length rule. In this project typology is assessed at 100metre intervals along the river segments held in the EPA WFD GIS river network.

A programme of hydro-morphological river surveying as part of the WFD Surveillance Monitoring has commenced This is being undertaken by EPA staff and uses a common approach agreed with NIEA that has been subject to a successful inter-calibration exercise. The approach is based on a modified version of the NS-SHARE Rapid Assessment Technique (RAT) that importantly now only recognises 4 channel types – Bedrock, Step-Pool/Cascade, Pool-Riffle and Lowland Meandering. These 4 types are to encompass all channel forms found on Irish rivers and *sensu stricto* do not adhere to the original types set out in the NS-SHARE report. Rather they represent a pragmatic approach that recognises the most common channel forms found and avoid the need for laborious field measurement of parameters or advanced fluvial morphology expertise to record.

In following sections of the report the derivation and analysis of metrics in the GIS is described that leads to the assignment of a channel type value at each of the 640,000 nodes along the river network. In practise only 3 of the 4 types can be determined – type 'Bedrock' channels can not be reliably recognised from the available data. The scale of the datasets and the fact that the current '4 fold' scheme does not concur with the original 8-10 fold RAT scheme does not allow the direct use of the value ranges provided in the NS-SHARE report for all of the parameters.

Analysis of the metrics or parameters at each typology node has been performed in an empirical process by comparison with the metrics of nodes at field survey sites where channel type has been assigned by the surveyor. Field surveys data are available for 142 site reaches. The field assessment is made along a section corresponding to 40 times the stream width. In the GIS typology points within 200-250 metres of the recorded survey location are considered to occur within the survey reach.

An attempt was made to predict the channel type at each node on the basis of a formal statistical model based on metrics from the nodes at the field survey. However, analysis of the metrics indicated that this would not be reliable or feasible based on the current data.

The empirical approach attempted to analyse on the basis of all available metrics. However, it was apparent that the only reliable metric was channel gradient – with the best correspondence utilising the gradient measured over the short 200m reach length.

Some 36 of the 575 field survey reach location nodes are excluded as they occur on reaches classified as 'Bedrock' Channels. Of the residue of 539 nodes some 399 were correctly assigned to the field survey typology value based on the 'slope_200m' metric:-

75.6% - Lowland Meandering
73.1% - Pool-Riffle
73.0% - Step-Pool/Cascade

The original GIS metrics and the estimated typology values at all nodes on the river network are included in the Morphology Tool developed for EPA by the project. These estimates can be used to facilitate the use of the 'desktop RAT' or dRAT tool that facilitates a desktop/remote sensing preliminary or proxy assessment of hydro-morphological status.
In addition the Tool allows different users to record their own typology classification of a particular channel reach.

10.2 Creation and Attribution of Typology Points

The following data sources were utilised in the creation of the typology database:

Rivers network	EPA WFD 1:50,000 scale
Bedrock	GSI Rockunits
Subsoils	Teagasc/EPA subsoils
Elevation	EPA 1:50,000 scale Digital Elevation Model (DTM)
Flood Zone	OPW 1:50,000 scale Flood Attenuation Indicator polygons

Typology node points have been placed along each river segment in the EPA WFD river network. The spacing interval is 100 metres and points are not placed within 100m of the start or end of each segment to avoid the placement of points close to confluences. Based on this method some 640,000 points have been inserted into the typology geo-database.

<u>Basic Attributes</u>

ID Codes	The typology points inherit the segment code of the parent river segment Each typology point is uniquely identified in field 'node_cd' with a code that is a concatenation of the river segment code and a counter number (1..n) that starts at the u/s end of the segment, for example segment code 26_3412 and the 3rd node creates the node_cd value of 26_3412_3
Segment attributes	The following descriptor attributes are copied from the parent river segment

- segment gradient
- segment mid point elevation

Typology Attributes

Bedrock — The value of the bedrock code at the node point is copied from the rockunit database (point in polygon analysis).

Subsoil — The value of the subsoil at the node point is copied from the subsoil database (point in polygon analysis). In addition Boolean type fields (Y/N) are populated to indicate whether the subsoil class at the node point is 1) rock or 2) alluvium and whether the subsoil dataset indicates bare rock within 20 metres of the point.

Gradient — In addition to the segment gradient, specific gradient values are determined at the node by reference to the EPA DTM over the following sub-reaches:

- 200 metres
- 300 metres
- 400 metres

The sub-segments of the river segment where the slope measurements are made are based on equal distances above and below the node – i.e. for the slope over 200 metres the analysis is carried out between points that are placed 100m u/s and d/s of the node.

For the slopes over 300 and 400 metres the first and last nodes on the segment are too close to either end of the segment to allow the slope analysis to be based on equal portions above and below the nodes. In these instances, at the first node the slope analysis is from the start of the segment in a downstream direction over 300 or 400 metres. For the end node the analysis is performed over the relevant distance upstream from the end of the segment. Where the river segment is shorter than 200, 300 or 400 metres the slope analysis is performed over the whole length of the segment.

Sinuosity — Sinuosity values are calculated for the complete river segment and over sub-reaches of 200, 300 and 400 metres centred at the node. In each instance sinuosity is determined as the ratio of the minimum (straight line) distance between the end points of the sub-reach or segment and the length of the river channel line between the same points.

Confinement

The confinement of the river channel is an indicator of the cross sectional form of the floor of the river valley – in theory it indicates the extent of the floodplain or absence of true floodplain in certain situations. In the context of the determination of a river typology the confinement indicator is required in a general form to indicate the degree of confinement - low, medium and high.

Confinement is a specific hydro-morphological measure that is not routinely recorded or known for the river channels. However, GIS studies undertaken by the OPW in the context of the Flood Studies Update programme has derived approximate zones of inundation (Flood Attenuation Indicator polygons – FAI) based on topographic analysis (OSI DEM) along river channels. The FAI polygon represents the extent of the floodplain adjacent to the river where the elevation is not greater than 1 metre above the mean bank level of the channel. Through comparison with aerial photography and historic information of floods, OPW has determined that the FAI polygons are an approximate indicator of the 100 year return period flood – i.e. most of the floodplain.

In order to utilise the OPW FAI polygons as an indicator of valley confinement at each node, a cross section GIS data class has been created. This places cross section lines at each typology point that are orthogonal to the direction of the river channel (in turn the direction of the river channel is taken from the 200m sub-reach 'straight line' sections used during the calculation of sinuosity).

The length of each limb (from the left and right banks) is limited to 1000 metres. The length along each limb to the boundary of the FAI polygon on either side of the river segment is recorded. This provides an estimate of the floodplain width and whether this is symmetrical or asymmetrical with regard to current river channel position (Figure 10.1).

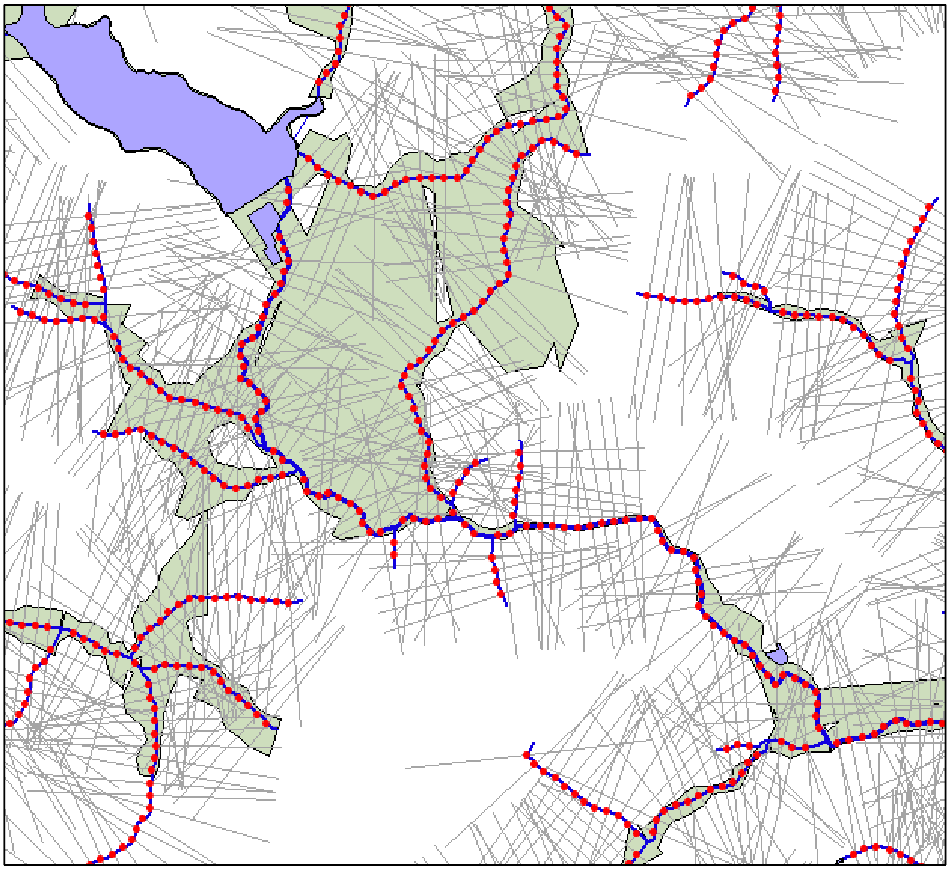


Figure 10.1 Confinement - Cross section lines and Flood Attenuation Indicator (OPW) polygon

10.3 Geodatabase

The datasets derived by the project form a logical extension to the existing EPA WFD data model. The key connection is through the River Segment class which in turn relates to the WFD River Waterbody Class.

In logical form the data are organised as set out below in Figure 10.2. Full detail of the attributes in each dataset is provided in Annex I.

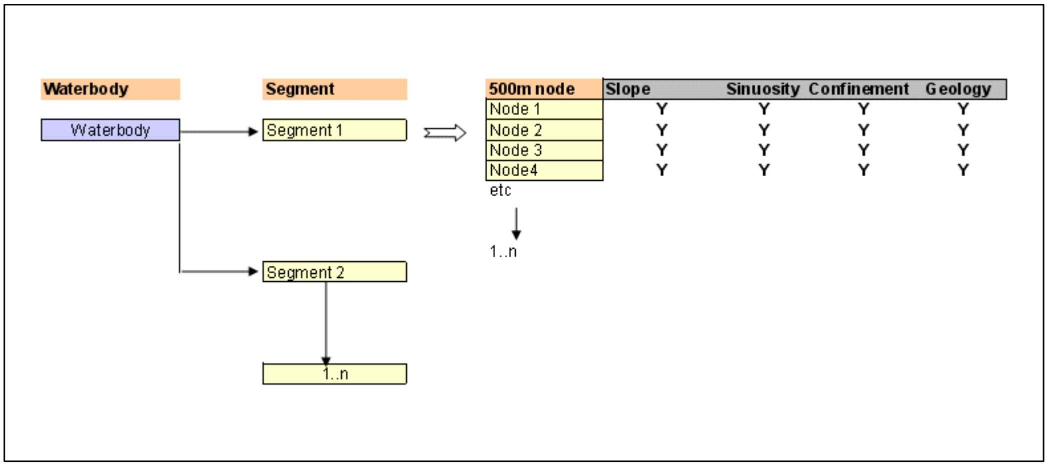


Figure 10.2 Logical model for typology point data classes

10.4 Analysis of Typology metrics and assignment of channel type

The 4 fold channel type scheme adopted by EPA and NIEA for the classification of Irish rivers does not concur exactly with the original NS_SHARE 8-10 fold typology schema. However, in broad terms the geomorphic principles are similar and are set out in Table 1.

Type	Confinement	Sinuosity	Slope	Geology
StepPool / Cascade	High	Low	High	Solid
Riffle & Pool	Low - Mod	Mod	Mod	Drift / Alluvium
Lowland Meander	Low	High	Low	Drift / Alluvium
Bedrock	High	Low	Variable	Solid

Table 10.1 Metric categories for typology assessment

The available metrics for the assessment of channel type are:

Gradient	segment slope, slopes over 200, 300 and 400 metre sub-reaches
Sinuosity	segment sinuosity, sinuosity over 200, 300 and 400 metre sub-reaches
Elevation	mid point elevation of segment
SubSoil	soil parent material classes including tills, alluvium, exposed rock, peats
Confinement	valley floor topography

Based on the fluvial geomorphic principles that underlie the NS_SHARE typology scheme it was hoped that a formal statistical modelling approach could provide the most powerful means to predict the channel type at each typology node based on the metrics determined by the GIS analysis. However, initial exploratory analysis by statisticians indicated that this would not be straightforward and that the metrics derived for each parameter type did not appear to contain an adequate degree of pattern or trending that would yield a robust model based on multivariate analysis.

Consequentially an approach was adopted based on a simplistic empirical analysis of the metrics. To underpin this approach field survey classification of channel types is available for 142 sites. To perform the analysis it is necessary to translate these sites to notional survey reaches that can be mapped onto the sequence of typology points placed along the river segments. Although the upper and lower limits of each survey site reach are not available (and it is recommended that in future that both of these locations are recorded via GPS) approximate survey reaches were determined. On this basis a field survey typology value was obtained for some 575 typology points as set out below. It should be noted that 4 survey sites were classified as 'braided' – this type is not included in the current EPA/NIEA scheme but was included in the first year of survey. These sites have been included in the Lowland Meandering category.

Channel type	**Survey Sites**	**No of Typology Points**
Lowland Meandering	46	201
Pool-Riffle	72	275
Step-Pool/Cascade	16	63
Bedrock	8	36
	142	**575**

The type 'Bedrock' can not be reliably determined from the available data. Available data to indicate exposed bedrock rather than alluvium or other sediments is based on analysis of the EPA/Teagasc subsoils data. These data are provided as polygons covering the whole landscape and are not recorded in the context of in-channel assessment. Only 10 of the 36 'Bedrock' type typology points had a map analysis subsoil type of exposed rock and thus the subsoils data is not considered as a reliable indicator of type 'Bedrock'.

An analysis of the metrics per field survey typology class is provided in Annex II. Analysis of the data would suggest that the Slope and Confinement parameters may provide the greatest degree of distinction between the types i.e. ability to predict type class from the GIS metrics. Median values, however, appear to be less than mean values indicating that the metric values are not normally distributed. Furthermore the standard deviations of the mean values are quite large which suggests that it is not likely that the GIS metrics would reliably group into the typology class types.

In an exploratory manner the GIS metrics were examined for each group of typology points associated with each of the field surveyed types. It was apparent that the Slope metric provided the best means of correctly predicting the field survey type –

and that Slope measured over the short 200 metre reach was slightly more powerful than the Slope averaged over the whole of the river segment.

The ability to correctly predict 'type' on the basis of the Slope_200m metric is summarised in Table 2.

The Slope rule base used is:
Lowland Meandering Slope < 0.3%
Pool-Riffle Slope >= 0.3% - <2%
Step-Pool/Cascade Slope >= 2%

	n		percent	count
Lowland Meandering	201	correct	75.6%	152
		error	24.4%	49
Pool-Riffle	275	correct	73.1%	201
		error	26.9%	74
Step-Pool/Cascade	63	correct	73.0%	46
		error	27.0%	17

Table 10.2 Analysis of Typology classification based on Slope

In each case the slope rule appears to correctly assign ~75% of the typology points to the correct type class recorded during the field survey. It is furthermore relevant to assess the distribution of the errors in the assignment. Table 3 summarises the distribution of the incorrect assignment of type class for each of the 3 types analysed. The mismatch is almost exclusively between adjacent classes in the slope scheme – the likelihood that Lowland Meandering Sites are misclassified as Step-Pool/Cascade and vice versa is very low.

Lowland Meandering	49 errors	Pool-Riffle	48	(98%)
		Step-Pool/Cascade	1	(2%)
Pool-Riffle	74 errors	Lowland Meandering	49	(66%)
		Step-Pool/Cascade	25	(34%)
Step-Pool/Cascade	17 errors	Pool-Riffle	17	(100%)

Table 10.3 Analysis of misclassification of typology

In an attempt to reduce the misclassification the other principal metrics (confinement and sinuosity) were analysed. However, it was not apparent that the introduction of these metrics would provide an improvement as discernible trends were not evident. Sinuosity values could be used to provide a sight improvement between the Pool-Riffle and Cascade Classes although the trend (that sinuosity is greater in Step-

Pool/Cascades than in Pool-Riffle channels) is counter intuitive. On this basis the typology assignment has been based on the Slope metric alone.

The degree of misclassification (approx 25%) is considered to be reasonably small. It is noted that in 4 instances where field survey records, by different assessors, are recorded within 100m of each other that in each case the field survey assignments are different!. However, in each case the disagreement was restricted to 1 class interval. This supports the preconception that field survey assignment of type will not always be consistent. It is likely that this is a consequence of using a discrete classification system to record channel form which is less distinct than the scheme would suggest.

The use of Slope measured over a short reach of 200m rather than Slope averaged over the complete river segment is both more powerful in classification and intuitive. It is known than Slope can vary considerably over short distances (Figure 10.3). Thus the placement of typology 'sampling' points spaced at a small interval 100 metres apart and the measurement of slope at these points averaged over a short distance of 200 metres would appear to comprise the most appropriate strategy in typology assessment in the GIS.

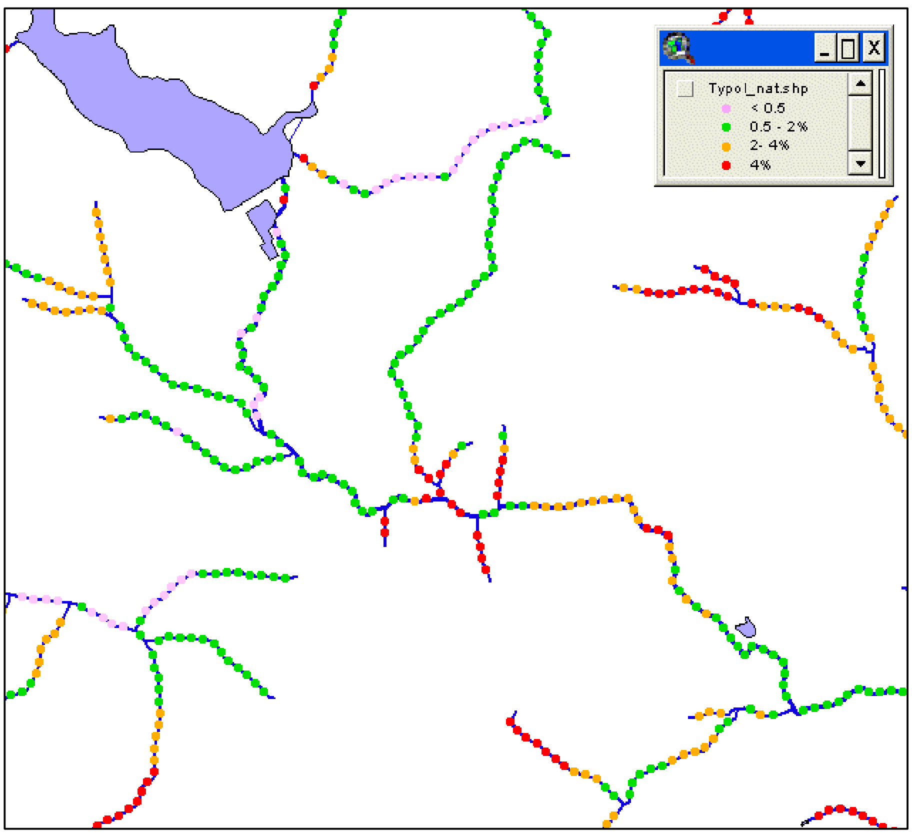


Figure 10.3 Example of Slope variation along a river segment

10.5 Conclusion and Recommendations

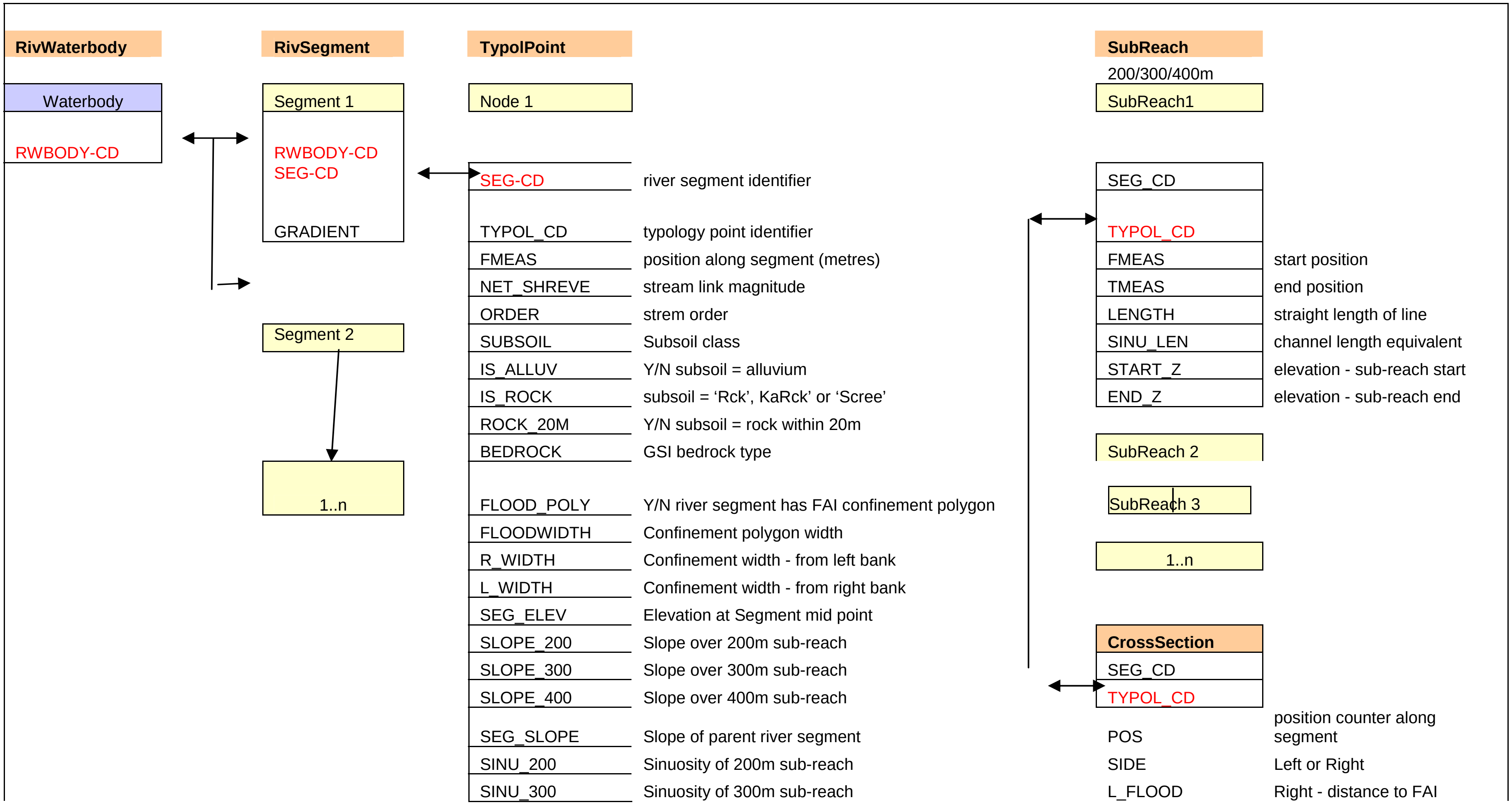
The project has assigned the EPA/NIEA river typology scheme to the river network through the analysis of GIS metrics. Assignment based on Slope measured over a short reach length (200 metre sub-reach) provides the best fit with observed values of typology recorded during field survey. The introduction of further metrics (i.e. sinuosity and confinement) in the analysis appears to add confusion rather than clarification to the classification process.

It is not possible to determine the location of 'Bedrock' type channels from the available data – resolution of in-stream bedrock exposure along channels does not appear to be accurately mapped within the subsoils dataset. In approx 75% of locations, however, where field survey results are available a correct classification has been obtained in the GIS for channel types Lowland Meandering, Pool-Riffle and Step-Pool/Cascade. This degree of correct classification is considered quite good given several factors that may impact on the ability to achieve same:

- limited resolution of the spatial datasets - .e.g. an improved DTM would enable more accurate slope determination and larger scale vector mapping for sinuosity assessment.
- the use of a categorical (4 class) scheme with which each channel must be classified in spite of the fact that river channel form may be more of a continuum and boundaries between classes are less distinct than the scheme may suggest.
- apparent difficulty to achieve consistent assessment of type between field surveyors at certain locations.

The datasets derived by the project will be included in the Morphology Tool for the EPA. This provides a facility to assign channel type through assessment of remote sensing data and to record further field survey results and provides an integrated environment for the assessment of channel data. Use of the Tool and the availability of improved datasets over time may allow for improvement of typology classification.

Annex I River Typology GeoDatabase



			boundary
SINU_400	Sinuosity of 300m sub-reach	R_FLOOD	Left - distance to FAI boundary
SEG_SINU	Sinuosity of parent river segment	WIDTH	Sum of L_FLOOD and R_FLOOD
IS_SURV	Y/N -site included in existing field survey		
SURV_RAT07	Field Survey site code	CrossSection2	
SURV_TYPE	Field Survey typology class	CrossSection2	
TYPE_CODE	Field Survey class code - LM PR SC B	\	
GIS_TYPE	GIS analysis typology class	1..n	
Node 2			
Node 3			
1..n			

Annex II Analysis of GIS typology metrics per field survey typology classification at 142 survey sites

Attribute	Data source		Bedrock	Step-Pool / Cascade	Pool-Riffle	Lowland Meander
		n = 575	36	63	275	201
is_rock	EPA / Teagasc subsoils	n	10	10	16	5
		%	27.8	15.9	5.8	2.5
is_alluv	EPA / Teagasc subsoils	n	10	23	192	122
		%	27.8	36.5	69.8	60.7
Rock_20m	EPA / Teagasc subsoils	n	16	20	40	12
		%	44.4	31.7	14.5	4.9
Flood width	OPW	mean (metres)	136	145	199	303
		std (metres)	137	154	162	288
		median (metres)	91	90	148	188
Elevation (mid)	EPA DTM	mean (metres)	91	94	76	48
		std (metres)	70	72	53	41
Slope (segment)	EPA DTM	mean (% slope)	1.50	2.00	0.90	0.30
		std (% slope)	1.33	1.38	0.80	0.32
		median (% slope)	1.10	2.00	0.60	0.10
Slope (200m)	EPA DTM	mean (% slope)	1.80	2.80	0.90	0.20
		std (% slope)	2.01	1.71	0.88	0.35
		median (% slope)	2.30	2.30	0.60	0.10

Sinuosity (segment)	EPA	**mean**	1.2	1.21	1.23	1.28
		std	0.03	0.11	0.17	0.29
		median	1.19	1.21	1.21	1.17
Sinuosity (200m)	EPA	**mean**	1.09	1.12	1.09	1.06
		std	0.11	0.14	0.14	0.14
Sinuosity (400m)	EPA	**mean**	1.118	1.16	1.14	1.11
		std	0.085	0.15	0.16	0.16
std = standard deviation						

11.0 Lake Classification for Hydromorphology

11.1 Introduction

Compass Informatics Limited were tasked through the Shannon IRBD to assist the Environmental Protection Agency (EPA) in assessing and processing Lake Habitat Survey (LHS) data and to research and develop a methodology for obtaining LHS data from remotely sensed imagery. This work has been undertaken in collaboration with the Environmental Systems Research Group at the University of Dundee. The LHS scores generated from the imagery will be used to derive a lake MImAS result. The project was broken down into three work packages, the sections below address the outcomes of each work package in turn. This project was carried out alongside the river morphology work and similar methodologies were utilised. The project work will feed into the morphology assessment system discussed in section 9.3

11.2 Project Scope

This project will build towards the EPA's commitment of reporting lake typologies to the European Union under the Water Framework Directive (WFD). LHS surveys were carried out by EPA staff in 2005 for the first time in Ireland and these forms required to be entered into a database so the data are easily accessible. Further to this our project partner Dr John Rowan from the University of Dundee will assist in providing a critique of the LHS protocol.

11.3 Deliverables

The deliverables arising from this project are:

- LHS data processed and entered into a database.
- Inventory of Irish bathymetry sources.
- Scoping study investigating the potential for using GIS and Remote Sensing (RS) to generate lake MImAS scores.
- Final report.

11.4 Work Package 1- LHS Form Evaluation

11.4.1 Introduction

LHS is a field-based assessment protocol developed and tested in recent years (Rowan *et al.,* 2006), which has gained widespread international interest and is currently being extensively used in the UK, Ireland, Poland, France, Serbia and Portugal. It is the only established method recognised within the draft CEN Guidance Standard on lake hydromorphology, which upon completion will be the bench-mark for the physical assessment of lakes throughout the EU. LHS provides the basis for a detailed characterisation of the condition of a lake (structure, composition and diversity of natural habitats and human pressures) and provides the framework data for establishing the linkages between hydromorphological disturbance and ecological impacts. LHS surveys have been undertaken in Ireland by both EPA staff and within the International River Basins as part of the North-South Share agreements also involving EHS Staff from Northern Ireland. Fifty five lakes falling under EPA jurisdiction have now been entered into the LHS database, the latest version of which is held and maintained by the University of Dundee (Rowan 2008a). The quality of the LHS field data collected by EPA surveyors and a summary of the condition of lakes considered using LHS summary metrics are presented in Section 11.6.3.

The original project specification invited the contractors to develop a 'new' rapid assessment version of LHS driven only using map/air photo data. This proposal was motivated by the desire to reduce the time required to undertake the field survey (typically between 2-5 hours depending on lake size) and the aspiration to better exploit existing and new generation high resolution aerial photographs. However it was established that this was an unrealistic goal (at least with the time and resources available in this project) given the complexity of the features and range of assessment scales nested within the LHS habitat characterisation process. It was argued that a more tractable line of enquiry would be to focus attention on the Lake-MImAS decision-support tool (Lake Morphological Impact Assessment System), which is a newly developed pressure-based decision-support tool designed for water body classification and management applications. Lake-MImAS is not considered as a replacement for LHS because its scope is limited to assessing the risk of impairing lake function resulting from pressures without reference to specific hydromorphological attributes or physical habitats. It operates on the principle that the physical response of a water body (or part thereof) to an engineering, or related pressure, is predictable for the type of lake under consideration and further that the ecological response depends on the sensitivity of the aquatic ecosystems in the lake which is also type-specific (Rowan, 2008b).

The input data required to run Lake-MImAS include assigning the lake to a particular lake type within an established typology (primarily based on geology and depth), assessing the extent of existing pressures (representing the existing 'condition' of the lake) and then using the scoring module to calculate the likely further deterioration resulting from new proposals, such as engineering activities.

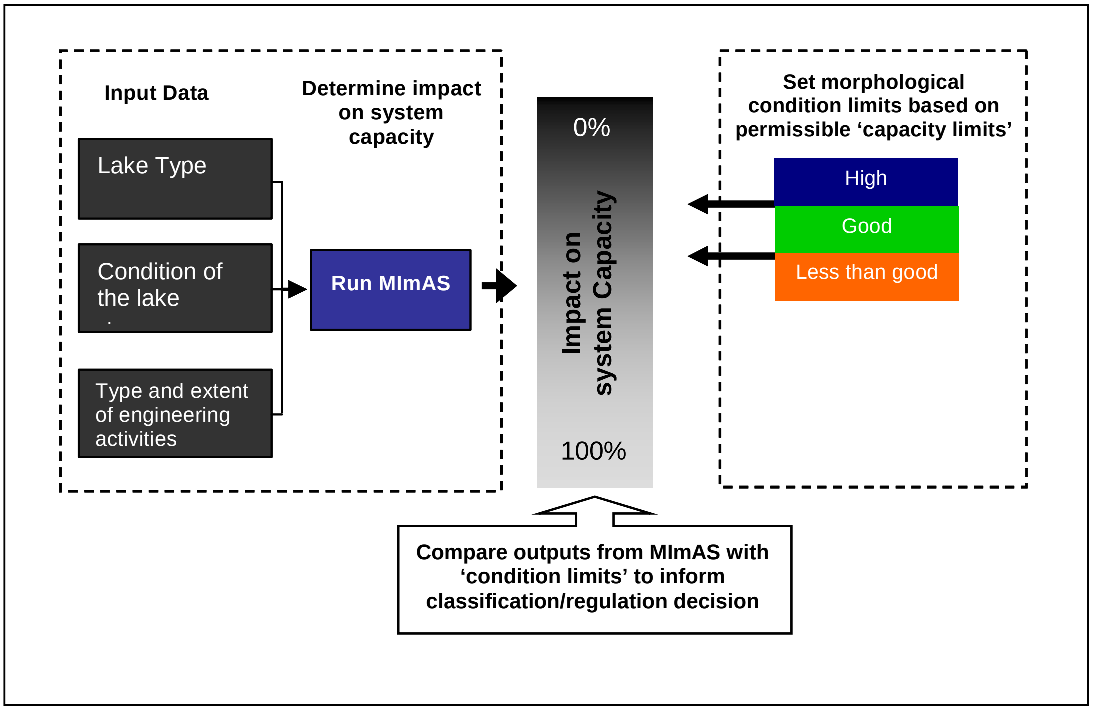


Figure 11.1 Illustration of the elements feeding into the Lake-MImAS 'system capacity' scoring system

A fundamental concept within the MImAS tool is the 'capacity' of different water body types to assimilate some hydromorphological changes before this has a manifest impact on the condition of the system. As system capacity is lost (consumed) it follows that there is an increased likelihood (or risk) that morphological and ecological conditions will degrade. Allied to this is the premise of Morphological Condition Limits (MCLs) which represent thresholds of change beyond which it is understood that ecological and/or morphological conditions could be altered in way that could result in deterioration in status. MCLs provide the basis for water body classification in relation to high ecological status, and beyond that offer scope to characterise the extent of hydromorphological alteration.

Input data to drive the Lake-MImAS tool are automatically generated from the LHS database upon completion of a survey. However where conditions are appropriate (without vegetation obscuring lake shore features) the use of remote sensing data coupled with a GIS system offers the potential to generate much of the required data with a considerably reduced field component (excepting vital field validation as necessary) and the ability to map the location and distribution of pressures within and around the perimeter of a lake. The strengths and limitations of using remote sensing data for application to Lake-MImAS are discussed in Work Package 3.

11.5 Work Package 2- Data Collection and Data Processing

11.5.1 Introduction

Work package two has been implemented to source all relevant data sources relating to lakes. Most of the datasets are held within Compass Informatics own datastores and are regularly maintained, bathymetry is the outstanding dataset. While no new datasets are being created for bathymetry; collation and tracking down of existing bathymetric datasets from myriad of sources was necessary and was undertaken as part of work package 2. This is discussed in more detail in the next section. LHS forms were processed in the University of Dundee under the direction of Dr. John Rowan and these data were used for generate both LHS summary metrics (LHMS and LHQA scores) but also to for Lake-MImAS score generation. To fully assess the potential for generating LHS data from aerial imagery it was decided to capture test lakes to form a test environment. While capture of the imagery was beyond the original scope of the tender it was deemed necessary to fully assess the possibilities for remote sensing in assisting WFD classification of lakes for hydromorphology.

11.5.2 Bathymetry

A review of available bathymetry datasets was carried out as part of this project. This data gathering exercise was initiated by Deirdre Tierney in the EPA by contacting the River Basin Districts and having them report on their bathymetry data. Following on from this the project took on the job of investigating further potential sources of bathymetric data. Two main sources of further bathymetric data have come to light specifically data held by the Central Fisheries Board (CFD) and a similar data gathering project under a North South Share project completed by the University of Dundee.

In total 319 lakes were found to have bathymetry however these data vary greatly in availability and format. Twenty two of the 319 lakes have Lake Habitat Surveys carried out. A full list of the 319 lakes is presented in Appendix IV.

In table 11.1 below there is a list of the 22 lakes where bathymetric data was found to exist. This table also shows were a LHMS score, LHQA and MImAS result have been generated.

Lake Name	Bathymetry	LHMS_score	EPA Code	LHQA	MImAS
Acrow (Lough)		Y		y	p
Acurry (Lough)		Y	EA_07_242	y	p
Anaserd (Lough)		Y	WE_31_211	y	p
Annagh Lough		Y	NW_36_517	y	p
Annaghmakerig Lough		Y		y	p
Ardan Lough		Y	NW_36_432	y	p
Atrain (Lough)		Y	NW_36_618	y	p
Aughrusbeg Lough		Y	WE_32_436	y	p
Ballynakill (Lough)	y	Y	WE_32_479	y	p

Bane (Lough)	y	Y	EA_07_270	y	p
Bunny (Lough)	y	Y	WE_27_114	y	p
Coosan L		Y	SH_26_750c	y	p
Corcaghan Lough		Y	NB_03_71	y	p
Corglass Lough	y	Y	NW_36_655	y	p
Cullaun (Lough)	y	Y	SH_27_115	y	p
Derravaragh (Lough)		y	SH_26_708	y	p
Derrybrick Lough	y	y	NW_36_400	y	p
Doo Lough	y	y	WE_32_463	y	p
Dromore Lough	y	y	SH_27_82	y	p
Drumkeery Lough		y	EA_07_268	y	p
Drumlona L		y	NW_36_525b	y	p
Drumore Lough		y	NW_36_525a	y	p
Emy Lough		y	NB_03_102	y	p
Ennell (Lough)		y	SH_25_188	y	p
Fin Lough	y	y	WE_32_391	y	p
Graney (Lough)	y	y	SH_25_190	y	p
Inchiquin Lough	y	y	SH_27_130	y	p
Inner Lough		n	NW_36_526	n	p
Killinure L		x	SH_26_750d	x	p
Killinure Lough		y	SH_26_750b	y	p
Kinale (Lough)		y	SH_26_678	y	p
Lene	y	y	EA_07_274	y	p
Lickeen Lough	y	y	SH_28_85	y	p
Lower Lough Macnean	y	y		y	y
Macnean Upper (Lough)	y	y	NW_36_673	y	y
Melvin (Lough)	y	y	NW_35_160	y	y
Mill Lough		y	NW_36_336	y	p
More (Lough)		y	WE_31_1113	y	p
Muckanagh Lough	y	y	SH_27_94	y	p
Naglack (Lough)		y		y	p
Nahasleam (Lough)	y	y	WE_31_208	y	p
Oughter (Lough)	y	y	NW_36_657	y	p
Owel (Lough)	y	y	SH_26_608	y	p
Pollacappul Lough		y	WE_32_509a	y	p
Sheelin (Lough)		y	SH_26_709	y	p
Shindilla (Lough)	y	y	WE_31_171	y	p
Skeagh Lough Upper		y	EA_07_267	y	p
Tully (Lough)	y	y	NW_36_561	y	p
White Lough		y	NB_03_86	y	p

Table 11.1: Lakes with known bathymetric values

11.5.3 LHS form processing

A review was undertaken of the Lake Habitat Surveys collected by the EPA largely during the summer field seasons 2006-2007. A total of 48 surveys were supplied to the contractors for entry into the LHS database adding to the seven surveys already stored in the database from NS-Share project work. These forms were analysed from both a quality assurance perspective and in terms of the hydromorphological condition of the loughs as measured by LHS metrics and Lake-MImAS scores.

Data in the field forms were processed entirely by a single experienced database operator based at the University of Dundee and the field forms and data entry were reviewed by Dr John Rowan. A key output from this aspect of the work is therefore a complete database of Irish LHS sites including representative overview and Hab-Plot photographs. During 2008 some significant amendments to the LHS protocol and the associated database were completed with a view to automatic generation of input data for Lake-MImAS. Incorporating the changes to the protocol into the database whilst preserving the integrity of established summary metrics (LHMS and LHQA) and the lake summary report was completed in June 2008 and is called the "LHS Database Version 4" (Rowan, 2008a).

It was apparent during this review that there were a number of issues in terms of the quality of the original survey work, for example there were significant omissions in relation to the basic morphometric data sections (area, depth, altitude, mode of formation and lake type). Of greater importance were the gaps and documented uncertainty on the part of the surveyors regarding engineering interventions and or hydrological control structures at lough flow outlets. This is unquestionably a training issue and indeed EPA field crews undertook a new training and accreditation course on several loughs within the North Western International River Basin in June 2008 which should mitigate many of these issues. It is recommended that all future LHS surveys should be undertaken only by accredited surveyors and that only completed and 'signed-off' surveys should be entered into the database for classification and management applications.

Data entry by an experienced operator took on average 45 minutes per lough, though where there were legibility issues or erroneous codes the time exceeded the hour mark. In terms of completion it is concluded that only 11 of the 48, i.e. less than one in four, field forms submitted by the EPA, provide fully documented entries to all the relevant sections of the survey from which LHMS and LHQA scores (summary metrics of hydromorphological alteration and habitat naturalness/diversity respectively) are calculated. The hydrology section within the form offers the greatest challenge to surveyors and as an illustration of the extent of the uncertainty 22 out of the 48 field forms supplied had incomplete sections in relation to hydrological regime. The outlet geometry has been recognised as one of the key determinants of regime modification but again surveyors either left information on the outlet blank (29 out of 48) or reported it to be 'not visible' in 12 out of 48 cases, meaning the condition of the outlet remains unknown. Because of the importance of hydrological regime alteration to both LHMS and Lake-MImAS scores where such data are incomplete or highly uncertain then this propagates uncertainties into the classification process. The problem is mitigated to some extent because both the LHMS and Lake-MImAS can capture the hydrological regime alteration through proxies such as 'water supply' and 'abstraction' use functions. Moreover as previously stated with better training surveyors both recognise the importance of completing the survey fully and are more confident in tackling potentially complex field evidence at lake outflows.

A summary of the results of the database analysis is shown in Table 11.2, these data were supplied to the EPA for review and consideration in April 2008 and updated by the contractors in August 2008 following the addition of catchment land use data obtained from the CORINE database and as a consequence, three loughs (Anased, Annagh and Aghrusbeg) were downgraded from High Ecological Status (HES) to Good Ecological Status (GES). Some additional examination of the Lough Killinure data qualified the input data and as a result the lough was downgraded from GES to MES. To date no feedback or comment was received from EPA on these data supplied.

Lake name	Pressure	Hydrology	LHS Metrics		MImAS Capacity Loss (%)		Hydromorph. Class
			LHMS	LHQA	Open- water	Shore zone	
ANNAGHMAKERRIG			2	63	0.5	0.5	HES
ARDAN			4	46	0.5	0.8	HES
ATRAIN	Abstraction		8	57	1.1	3.5	HES
BALLYKEERAN-LIH			16	43	1.8	2.5	HES
BUNNY			10	60	2.3	5.1	HES
CORGLASS			2	59	0.3	0.5	HES
CULLAUN			16	58	0.9	1.8	HES
DERRAVARAGH			8	60	0.9	2.3	HES
DERRYBRICK			14	58	0.8	1.5	HES
DROMORE			12	58	0.9	1.8	HES
DRUMKEERY	Abstraction		14	69	1.4	3.5	HES
DRUMLONA			10	39	2	3.1	HES
DRUMORE MN			16	50	1.2	3.1	HES
ENNELL			18	64	1.3	2.5	HES
GRINER			24	49	1.2	3.1	HES
KINALE	Abstraction		10	43	1.4	3.8	HES
NAYRE			10	54	0.6	2.6	HES
MAUMWEE			4	47	0.9	0.8	HES
MILL (CN)	Abstraction		10	74	1.4	4.4	HES
MORE			4	50	0.5	2.6	HES
MUCKANAGH			18	59	0.8	1.6	HES
NAGLACK (MN)			10	45	0.5	0.8	HES
NAHASLEAM			6	65	2.7	3.8	HES
SHEELIN CN			8	69	1.3	2.5	HES
SKALE			12	43	1.3	2.2	HES
UPPER LOUGH SKEAGH			2	58	0.5	0.8	HES
WHITE (1)			16	58	1.3	4.2	HES
ACROW	Abstraction	Regulated	20	48	4.7	6.8	GES
ACURRY	Abstraction		14	59	1.9	5.8	GES
ANASERD	Abstraction		12	69	3	6	HES
ANNAGH	Abstraction		10	66	5	6	HES
AUGHRUSBEG GY	Abstraction		16	32	3	8	HES
BALLYNAKILL	Abstraction		26	48	2.3	5.8	GES
BALLYNAKILL GY	Abstraction		14	33	4.4	5.8	GES
BANE	Abstraction		26	60	2.4	6.3	GES
CARRIGENNCOR			12	67	1.7	7.8	GES
COOSAN-WH			22	39	2	5.3	GES
CORCACHAN	Abstraction	Regulated	24	38	4.4	7.3	GES
FIN (MO)			18	76	4.2	6	GES
GRANEY	Abstraction		12	52	2.2	7.6	GES
INCHIQUIN	Abstraction		22	40	1.8	6.3	GES
LENE	Abstraction		26	70	2.9	8	GES
LICKEEN	Abstraction		18	50	2.2	7.5	GES
OUGHTER (CN)			8	60	2	5.3	GES
OWEL	Abstraction		26	47	2.2	5.4	GES
SALT	Abstraction		14	55	1.6	13.6	GES
SHINDILLA			16	77	2	8.1	GES
TULLY GY	Abstraction		18	38	4.4	5.8	GES
WHITE (2)	Abstraction		24	40	2.1	5.8	GES
DOO (MO)	Abstraction	Regulated	24	44	3	17.6	MES
EMY		Regulated	12	52	4.9	16.4	MES
FERN			18	61	5	22.8	MES
KILLINURE - WH			20	42	3.4	16.5	MES
MUCKNO	Recreation	Regulated	24	65	5.2	19.6	MES
POLLACAPPUL GY			14	56	6	19.9	MES

Table 11.2: LHS and Lake-MImAS summary metrics and provisional water body classification based on survey data used

It is recommended that the EPA reflect carefully on the use of these data considering that some issues have been identified with the application of the LHS survey method. However it is also clear that where surveyors are already on the ground and engaged with other sampling campaigns e.g. in relation to physico-chemical sampling or sampling biological quality elements that the LHS survey generates multi-scalar insights into the diversity, natural composition and modification of the key hydromorphological quality elements. The LHS further provides a rich catalogue of the physical characteristics beyond the pressures used to drive the Lake-MImAS tool such as hard bank engineering giving insight into the structure and condition of riparian vegetation, the range of wetland systems present from reedbeds, to wet woodland and intact hydroseres and also helps identify features of particular conservation interest such as floating vegetation mats. These data provide a vital basis for exploring the still poorly understood linkages between hydromorphological alteration and ecological impact. An example of the output data that are generated from the LHS database along with the use of these input data to the Lake-MImAS tool is shown in figure 11.3

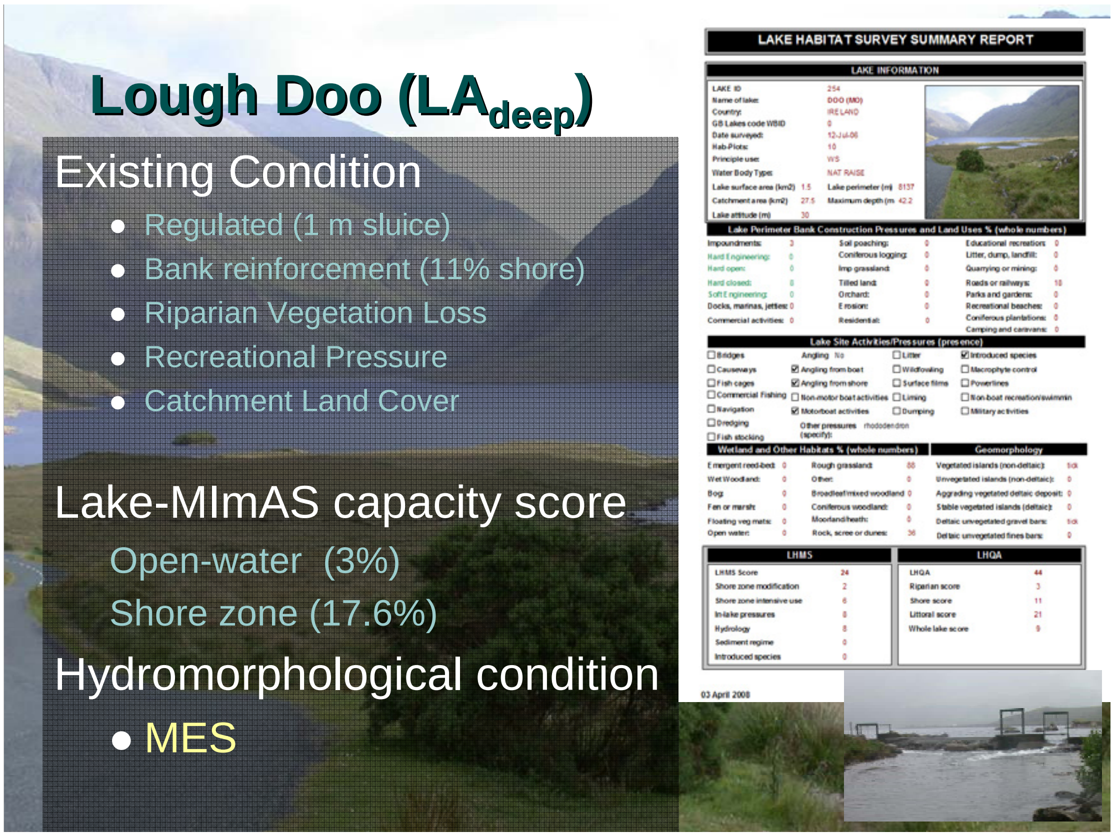


Figure 11.3 Illustration of the lake summary report and the use of LHS data to drive the Lake-MImAS tool and so derived hydromorphological condition.

11.5.4 High resolution imagery data

Although the capture of imagery was not included in the scope of the contract budget it was deemed necessary to capture imagery to properly assess the potential for remotely capturing lake MImAS attributes.

Lough Lene, Lough Killinure and Lough Bane in County Meath were selected for capture because they have known pressures also from a practical point of view these lakes are close to Dublin allowing for the capture of three lakes from one flight.

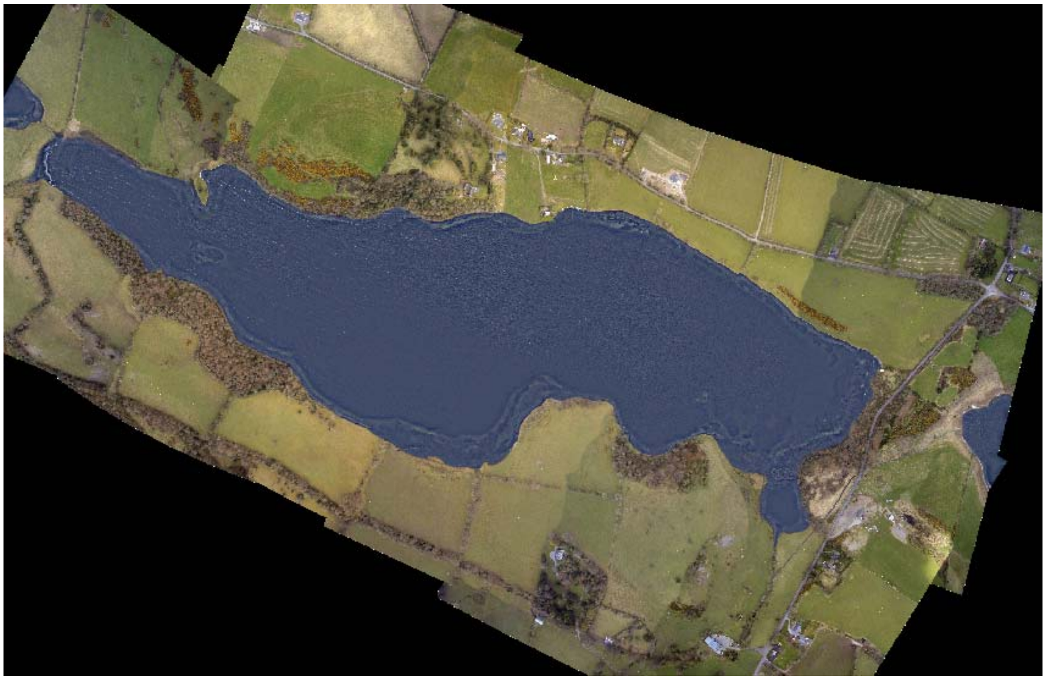


Figure 11.4: High Resolution imagery of Lough Bane

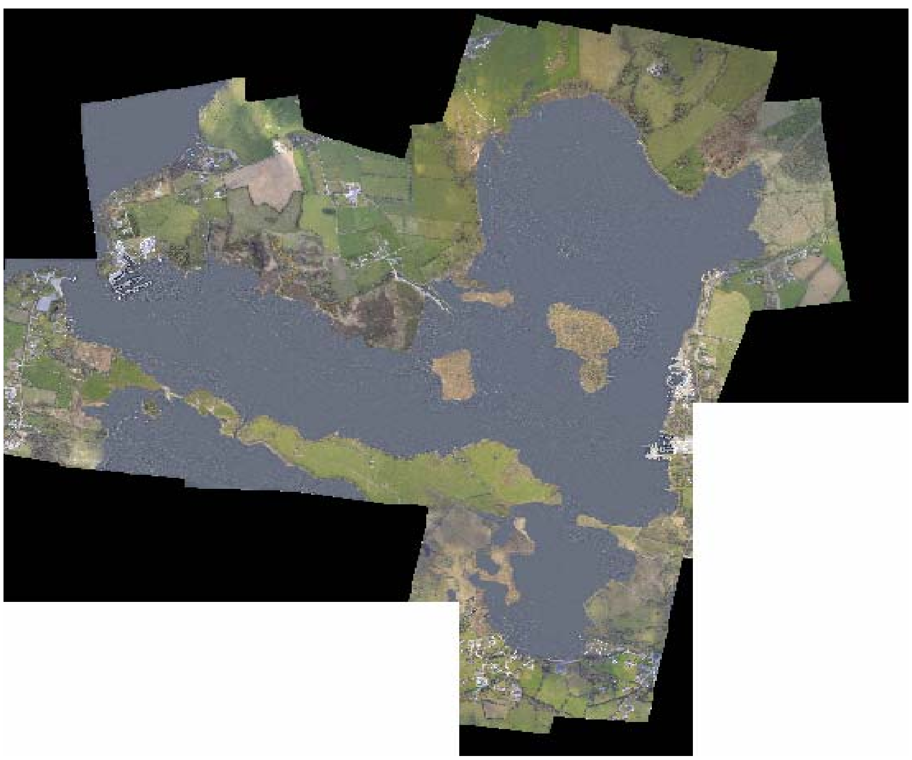


Figure 11.5: High Resolution of Lough Killinure

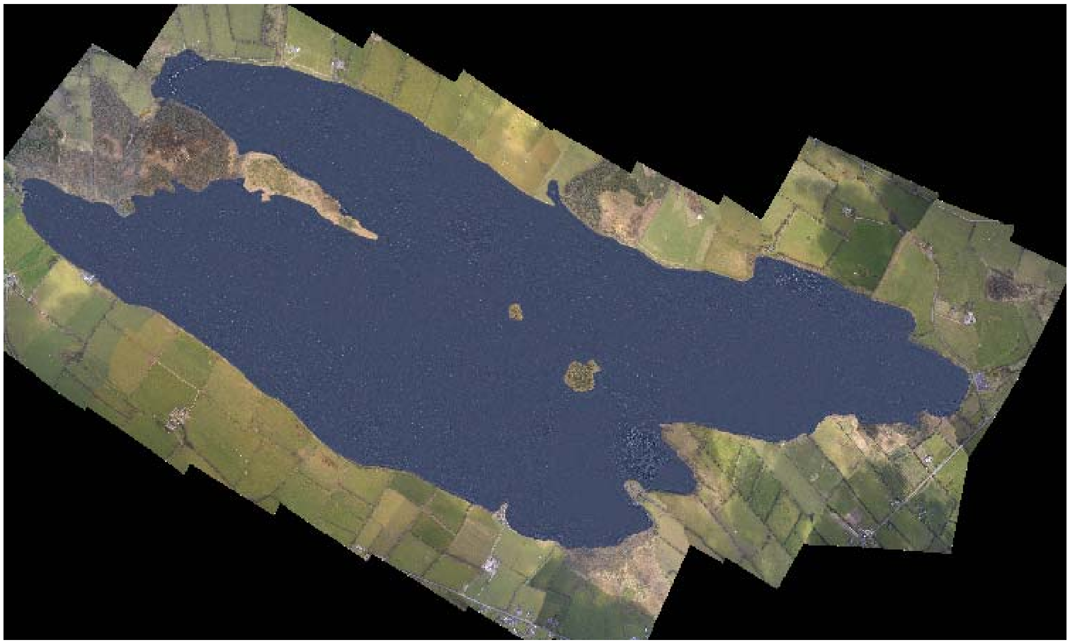


Figure 11.6: High Resolution of Lough Killinure

11.5.5 Other datasets

All other datasets that are relevant are contained within the EPA WFD geodatabase which Compass Informatics has delivered to the GIS section in the EPA headquarters in Johnstown castle, Co.Wexford. As part of an update, historical mapping has been added to the database alongside updating of existing datasets. The aerial imagery captured for this project has also been entered into the WFD geodatabase and this data is visible through the Freshwater Morphology tool. It would be possible to add LHS data and remotely captured linear referenced data to the schema and the database however this is beyond the scope of this current project.

11.6 Work Package 3- Extraction of MImAS metrics from Imagery

11.6.1 Introduction

The overall objective of this activity was to assess the applicability and suitability of remotely sensed data and GIS techniques in generating MImAS scores.

In the first instance, high-resolution aerial imagery was captured and processed by the Compass team for Lake Killinure. Aerial imagery mosaics were constructed for the entire Lake waterbody, the basis from which requisite datasets to meet MImAS requirements were to be generated.

Killinure Lough was chosen as a test site to compare the results obtained from LHS and interpretation of the flown high resolution aerial photographs. With a surface area of 2.65 km^2 Lough Killinure is relatively large lake, but it is fundamental to note that it is essentially a sub-basin of the significantly larger Lough Ree (105 km^2), which is the second largest of the loughs along the Shannon system, and as such its hydrological regime is controlled by the weir and sluice system at the outflow of the main lough (at Athlone). It was suitable for commissioning aerial survey because the size of Killinure was manageable and the heterogeneous shoreline featured a range of hydromorphological pressures.

11.6.2 Feature extraction from imagery-Lake Killinure

Features were extracted using the high resolution imagery and using a custom GIS tool called the Event Path Creator tool (see section 4.3) which was developed for a complimentary river morphology project for Shannon International RBD. This tool utilises a concept known as linear referencing which enables GIS users to create classes for different sections of the same line feature (i.e. the lake shoreline). For example, a shoreline can have many different phases, such as for the first 100m, hard bank engineering then for the next 100m natural riparian vegetation. Use of linear referencing will enable users to symbolise these changes in the shoreline without splitting the line into multiple lines.

11.7 Comparison of LHS field data results with remotely sensed imagery results

11.7.1 LHS Lake Killinure MImAS results

Lake-MImAS results for Killinure were extracted from the field LHS data. It was reported at the time of the LHS field work the water level in the lough was 'exceptionally high' and indeed many of the shoreline features were 'drowned out' meaning that the according to the manual guidance the survey should have been postponed until a later date when the water level had returned to its typical summer range (regulated for navigation on Lough Ree). It was also clear that the surveyors had not appreciated the hydrological dependency of Killinure upon the Ree outflow. This hydrological dependency is recorded within the data as an active water level adjustment score.

Figure 11.7 illustrates the comparison between the shoreline position as recorded in the 1854 in red and the current shoreline position overlain in purple, the modern shoreline demonstrating the extent of the shoreline change and land reclaimed around the perimeter of the lake. The historical maps are an objective alternative and this comparison of early map/contemporary lake is useful for approximately the last 150 years.

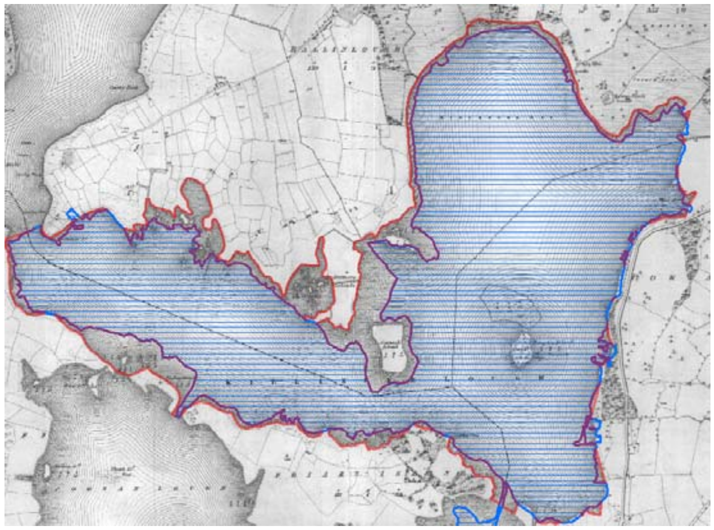


Figure 11.7: Historical and current lake outline

In terms of LHS data used to drive Lake-MImAS it should be recognised that the 2006 LHS field form predated the development of MImAS and consequently not all 19 pressures were recorded prior to the LHS revisions in 2008. Nevertheless the LHS survey data were used to generate a Lake-MImAS score and allowance was made for the passive hydrological regime manipulation associated with the Loch Ree outflow control. The Lake-MImAS capacity scores were 3.4 % and 16.5 % for the open-water and shore zones respectively which exceeds the 15 % MCL for 'good condition' and indicates the lough to have only moderate condition with respect to hydromorphology. Considering the extent of the lake shore developments this seems an entirely reasonable finding.

11.7.2 Lake Killinure remote sensing result

Using the remotely sensed attributes captured using the Event Manager Tool a total of ten input values for lake MImAS were recorded.

For the ten attributes captured they were clearly visible from the aerial imagery the full process for extraction of this data can be seen in appendix V. When these values were entered into the lake MImAS-Tool the lake returned high ecological status for open water/profundal and good ecological status for shorezone.

Figure 11.8 shows the results of the Killinure assessment as inputted into the Lake-MlmAS tool. The Lake-MImAS tool has placeholders for six input lake types, Killinure falls into the high alkaline category and has been assessed within this category.

	Specific Pressures	Entries are primarily entered as percentages (area for areal or length for linear pressures), with the exception of those listed below. For open water, Stage 1 assessments are carried out with respect to a fixed area of 5 ha (equating to a circle centred over the development proposal with diameter 250 m), whilst shorezone activities are expressed as percent of a standard shoreline length of 500 m. Stage 2 assessments are undertaken entire water body area or shoreline perimter length.	P/L-vS	P/L-ShD	MA-vS	MA-ShD	HA/M-vS	HA/M-shD	
Water level control and regulation	Active regulation	Activity Footprint Score	0	0	0	0	0	0	Regulated activity
	Passive outflow control	Activity Footprint Score	0	0	0	0	0	0	Regulated activity
Shore zone alteration	Shore reinforcement (hard bank engineering)	Length	0	0	0	0	0	12.27	Regulated activity
	Shore reinforcement (soft bank engineering)	Length	0	0	0	0	0	4.04	Regulated activity
	Flow/sediment altering structures	Length	0	0	0	0	0	5.1	Regulated activity
	Piled structures	Length	0	0	0	0	0	3.13	Regulated activity
	Outfalls & offtakes	Length	0	0	0	0	0	0	Regulated activity
	Flood embankments	Length	0	0	0	0	0	0	Regulated activity
Within lake structures and alterations	Land claim	Area	0	0	0	0	0	0	Regulated activity
	Dumping	Area	0	0	0	0	0	0.19	Regulated activity
	Sediment extraction	Area	0	0	0	0	0	0.94	Regulated activity
	Causeway	Area	0	0	0	0	0	0	Regulated activity
	Floating/tethered structures	Area	0	0	0	0	0	0	Regulated activity
	Macrophyte manipulation	Area	0	0	0	0	0	0	Regulated activity
	High density moorings	Area	0	0	0	0	0	1.48	Regulated activity
Lakeside pressures	Riparian vegetation loss	Activity Footprint Score	0	0	0	0	0	7	Regulated activity
	Recreational pressures	Activity Footprint Score	0	0	0	0	0	5	Pressure (unregulated)
Catchment alterations	Catchment area impounded	Activity Footprint Score	0	0	0	0	0	0	Pressure (unregulated)
	Intensive catchment land use	Activity Footprint Score	0	0	0	0	0	0	Pressure (unregulated)
	Open water / profundal		0.0% HIGH	0.0% HIGH	0.0% HIGH	0.0% HIGH	0.0% HIGH	1.6% HIGH	
	Shorezone		0.0% HIGH	0.0% HIGH	0.0% HIGH	0.0% HIGH	0.0% HIGH	12.6% GOOD	

NOTE DIFFERENT RULES FOR THE FOLLOWING ENTRIES

1. Active outflow regulation (P-LA & MA)	>0 - 1 m = 2 [3]; >1 - 3 m = 5 [6]; >3 - 5 m = 8 [15]; > 5 m = 18 [20]	For vS lakes, a water level drop of ≤0.5 m = 5 [7]; a drop >0.5 - 1.5 m = 8 [15]; a drop > 1.5 m = 12 [18]
2. Passive outflow regulation (P-LA & MA)	>0 - 1 m = 2 [3]; >1 - 3 m = 4 [8]; >3 - 5 m = 10 [12]; > 5 m = 20 [22]	
	NB values in parentheses [ ] apply to Marl/HA lake types	
3. Recreational pressures	None = 0, minor and local = 2, moderate intensity/extent = 5, intensive/extensive = 10	
4. Catchment area impounded (%)	0 - 1 % = 0, >1 - 5 % = 5, >5 - 20 % = 8, >20 - 50 % = 12, >50 % = 15	
5. Intensive catchment land use (%)	0 - 2 % = 0, >2 - 10 % = 2, >10 - 20 % = 3, >20 - 40 % = 6, >40 % = 12	
6. Riparian vegetation loss	Scores 0 - 17 depending on the extent of the vegetation changes	

Figure 11.8: Remotely sensed attributes inputted into lake MImAS

11.7.3 Comparison

Table 11.3 below shows the inputs from the field survey and from the remote sensing as previously noted the field survey carried out was not carried out fully due to a combination of the hydrological condition during the survey and due to surveyors not having completed appropriate LHS training.

Lake MImAS Entry	From LHS Field Survey	From Remote Sensing
Water level adjustment (active)	2	2
Raising or lowering (passive)	0	0
Bank protection(hard engineering)	6.3	12.3
Bank protection(soft engineering)	0	4.0
Flow/sediment altering structures	6.3	5.1
Piled structures	0	3.1
Outfalls & off-takes	0	0
Flood embankments	0	0
Land claim	0	0
Dumping	0	0.2
Sediment extraction	0	0.9
Causeway	0	0
Floating/tethered structures	0	0
Macrophyte manipulation	0	0
High density moorings	0	1.5
Riparian vegetation loss	0	7
Recreational pressures	10	5
Catchment area impounded	0	0
Intensive catchment land use	2	2

Table 11.3: Comparison of field survey and remotely sensed survey

A lake will generate two scores; one for the pelagic/profundal zone and one for the shorezone, based on this score the lake is given a classification for hydromorphology. Table 11.4 indicates the percentage parameters for each classification.

ZONE	System Capacity Used (%)				
	High (near natural)	**Good (slightly altered)**	**Moderate (moderately Altered)**	**Poor (extensively Altered)**	**Bad (severely altered)**
Pelagic/profundal	5%	15%	30%	<45%	>45%
Shorezone	5%	15%	30%	<45%	>45%

Table 11.4: System capacity classification boundaries for Lake-MImAS tool

Survey	Pelagic/profundal		Shorezone	
LHS MImAS input	3.4%	HES	16.5%	MES
Aerial MImAS input	2.7%	HES	15.4%	MES

Table 11.5: LHS classification V Aerial classification

- Lake Killinure scored High Ecological Status (HES) in the LHS MImAS input and in the Aerial MImAS input.
- Lake Killinure scored Moderate Ecological Status (MES) in LHS MImAS input and in the Aerial MImAS input.

The actual percentage difference between the two methodologies is quite small indicating a good correlation. This is not enough of a test to determine whether aerial derivation of MImAS data will always mirror field LHS MImAS input however the initial results look promising.

11.8 Conclusion and discussion

From a time perspective to capture Lake-MImAS attributes remotely took approximately half a day for Lake Killinure, if this process was to be done in-situ the process would take more than a day (John Rowan, pers comm.) and this is before the data is entered into a database adding another hour to the processing.

Comparing the LHS input and the Aerial input is hard to do as the LHS input data were problematic both in terms of being from the pre-MImAS 2006 field form and because the survey suffered from high water conditions and was incomplete in places (would not pass current quality assurance targets). A better comparison would have been to repeat the LHS survey for Killinure using the 2008 field protocol and compare the results of this to the aerial survey procedure. These issues notwithstanding, what is clear is that the aerial survey method can generate a very high level of detail and further produces a map capturing the distribution of different pressures. It is felt that the potential for using aerial imagery for lake classification is very high but it is recommended that a fuller programme of trialling and comparative analysis with survey techniques like LHS is needed before the use of aerial imagery could become a standard procedure in lake hydromorphology classification.

12.0 Report Recommendations

12.1 Aerial Imagery Recommendations

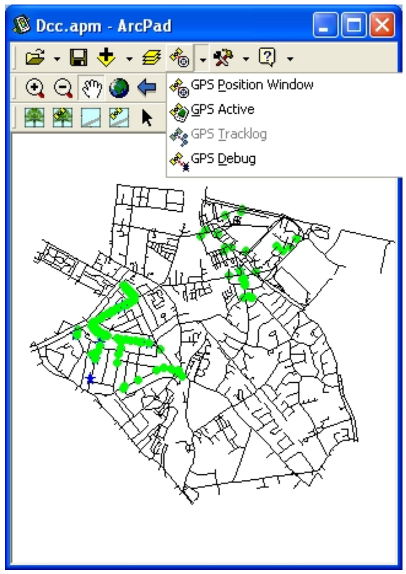
It is considered that high resolution aerial imagery (e.g. Compass GeoFOTO) provides a powerful means to assess morphological condition is support of the RAT 'expert opinion' approach to morphological assessment now adopted in Ireland. (Such imagery is deemed superior to the ubiquitous OSi ortho-photography given its higher resolution although even larger scale imagery would be desirable). The imagery obtained by the project can also be used to assess conditions where surveys are not yet performed – providing a facility to screen other waterbodies or sections of waterbodies not observed during the fixed reach length field surveys. The cost of image capture and processing at ~ €1850 per ten kilometres of river (correct as of summer 2008) is considered cost effective. Thus it is a recommendation of this report that an ongoing image capture programme is established to expand the coverage within the Morphological Assessment System (MAS).

The project has developed methods to extract the extent of features (both natural environment and introduced, i.e. engineered) which in particular provides support to the MImAS type of assessment. Unfortunately not all of morphological feature types identified in MImAS were present in the pilot waterbodies analysed for this project. It is also known that certain features types are obscured from observation on aerial images. However, this project has developed a streamlined system for capture and recording of such features into a database that can be expanded through analysis of further waterbodies. This method can support the MImAS decision support approach to river engineering classification and regulation if required.

12.2 Incorporating captured field data

Currently RAT and LHS scores are recorded by an expert on paper sheets in the field. A lot of time during the analysis phase of this project was spent on digitising the field survey results and obtaining correct spatial positioning. Field data loggers with embedded GPS have been designed for efficient and structured data collection in the field and are recommended in future field surveys. Custom forms allow for easy checkboxes and dropdown lists to be created pre fieldwork (figure 12.1). Digital cameras can also be used – the image taken is tagged within the GPS allowing for the image to have location information. Thus an efficient digital workflow can readily be established.

For example, the MobileMapper CE GPS data logger with ArcPad for data entry has been used by Compass Informatics on numerous projects and is versatile. GPS accuracy is 1m typically which is thought adequate for routine morphological survey. This technology for field data capture has been used on a range of projects including; cycletrack survey in Dublin; tree survey in Dublin City; accessibility study in Fingal, Co Dublin and habitat mapping in Cork, Sligo and Meath.



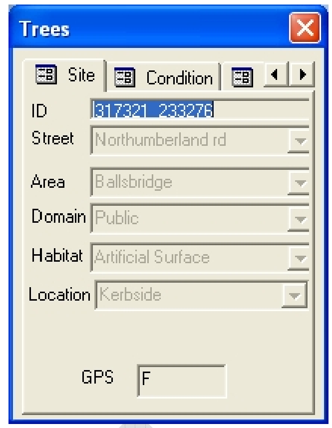


Figure 12.1: Arcpad form and custom attribute capture.

Digital cameras can be used in conjunction with the mobilemapper unit– the camera clock and GPS time can be synchronised and the photo images thereby tagged with positional information.

The overriding advantage of utilising such a data collection system is the saving in postprocessing. Data captured in the field using the data loggers can be loaded directly into the database and displayed within the morphology tool almost immediately.

It is a recommendation of this report that RAT and LHS scores are captured in the field using a GPS/GIS data logger.

12.3 Building upon the Morphology Assessment System

It is the opinion of the project team that the database and the GIS morphology tool that the project has developed can be the starting point for a powerful morphology decision support tool. As the datasets grow and as new datasets are added the potential value of the tool will increase. Expert judgement values (RAT) can be recorded, retrieved and viewed in the context of other datasets particularly imagery. Pseudo RAT surveys (dRAT) can be performed without field survey. Furthermore in the context of potential regulation of engineering activities the morphology pressures database can be expanded. It is thus a recommendation of this report that the MAS be regularly maintained and updated.

12.4 Overarching recommendations

It is recommended that:

1. Remote sensing (RS) and secondary datasets appear to provide a good basis for the targeting of further RAT assessment and the imagery coverage should be expanded. The qualitative assessment used by field RAT, which does not try to record individual features of modification or naturalness, can be complimented by remote assessment as a basis of targeting further assessment needs. Capture of such imagery at ~ €1850 per 10 km is considered cost effective.
2. Aerial imagery based approaches can be used to collect morphological pressures, based on high resolution imagery being available. The extraction of the morphological pressures records from these images can be effectively based on the Event Manager Tool. This approach should be used as a mapping framework into which other records can be incorporated.
3. Historic mapping is an important component of the assessment of large scale morphological change particularly in terms of realignments and partial realignments (those that show recovery) and should be used as a regular component of morphological assessment. The dataset is already available with national coverage for GIS usage. Other secondary datasets will enhance the assessment and can be accommodated within the workflow framework. A mechanism for adding field-based records to update the RS records should be encompassed by the Event Manager Tool. The tool has the capability to record these values but an enhanced protocol would be needed for their capture, potentially with direct field entry systems. Additional utility based records (pipelines, intakes and outfalls) can be added to enhance the pressures records, as was successfully integrated into the Scottish MPD.
4. A mechanism for recording the position of features within and the limits of any selected reach should be adopted. This may be inherent in the Event Manager records if the source of the individual pressures is recorded, but during RAT a specific record of the extent of field surveyed reaches (i.e. assumed highest quality and complete records) should be made.
5. If RS is to be used as the basis for dRAT assessment (i.e. without also undertaking field assessment) there is a need to further validate such an approach with the field-based assessments, i.e. RAT, at trial reaches as it is possible that morphological features included within the RAT field assessment are not visible or discernable from the API. This could give rise to a risk that the status evaluation will not provide the equivalent results or that the thresholds to demarcate between status classes is altered. It is thus proposed that the RS-based determination of RAT scores would be 1) subject

to a field verification trial and 2) augmented by other records held within the database that may help resolve the missing elements of the evaluation.

6. Where assessment of a channel is based on remote sensing data it is also worthwhile to allow the desktop surveyor to assign a RAT river typology class from the remote sensed data. This can then be used to assess the ability to ascribe appropriate channel typologies from RS/secondary data when compared with field data.

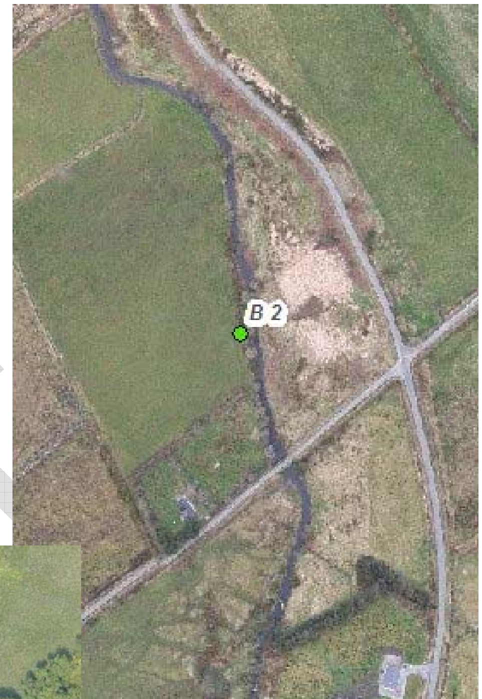
7. The RS data can provide a valuable input into subsequent field surveys, especially in relation to broad scale parameters, such as sinuosity, ponding, riparian vegetation and floodplain characteristics. It is worth establishing the use of RS data in association with field assessments wherever possible and it would be feasible to use the Event Manager Tool in the field – subject to some modifications for suitable devices.

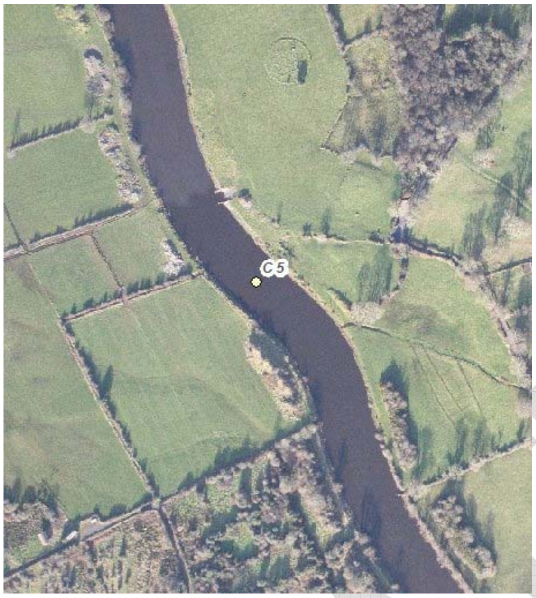
8. Where possible the floodplain and catchment scale influences on the channel and riparian area should be assessed through the use of remote sensing. This will generally provide a good picture of the extent and nature of the floodplain and catchment intensive land use and drainage pattern and may provide insight into the extent of the channel modification (cut-offs, drainage, catchment soil disturbance as sources of in-channel sediments etc). If such records are made they should also be recorded within the geodatabase.

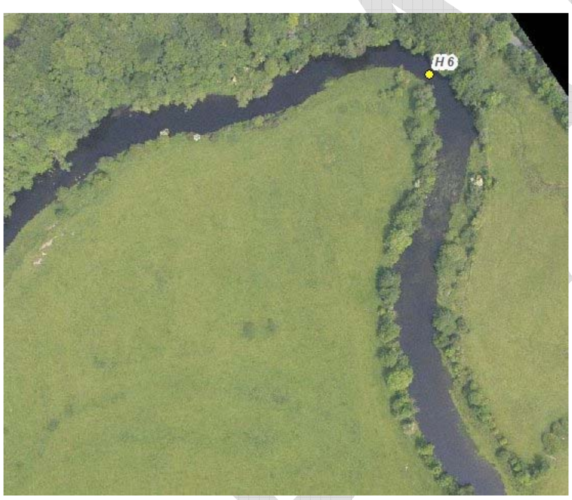
9. Multi-user testing is needed with both the Event Manager Tool and the remote RAT category assessment to ensure that the results are consistent between surveyors/interpreters to maximize the value of remote sensing to freshwater morphological surveying.
10. Additional support and tutorial materials would help to utilise aerial imagery more effectively and consistently. The creation and testing of 'crib-sheet' images of features and their mapping as a field guide would help. This would be of particular importance where a larger morphological field survey team is envisaged.
11. The application of GIS and RS techniques for morphological assessment and recording should be continued and when appropriate new data sources (either RS or from field survey methods) should be incorporated. It is recommended that specialist RS/GIS support to the EPA and RBDs is maintained to ensure the long-term successful development and use of the whole Morphology Decision Support System.

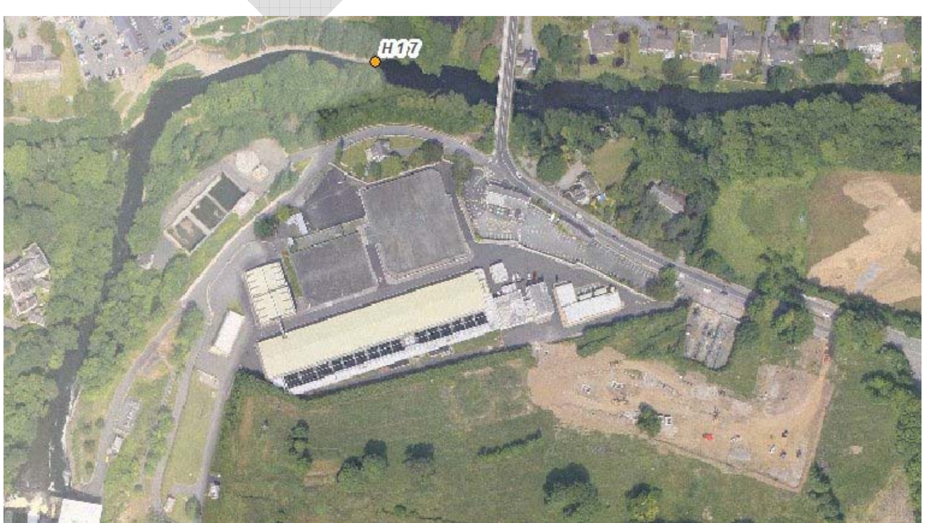
APPENDICES

Appendix I: Supporting images for Table 3-1




C5

H11

H6

B15

H17

Appendix II

1 Event Path Maker: Introduction

Summary
Basic introduction to the Event Path Maker tool, its menus, features, capabilities and most common applications.

1.1 What is Event Path Maker?

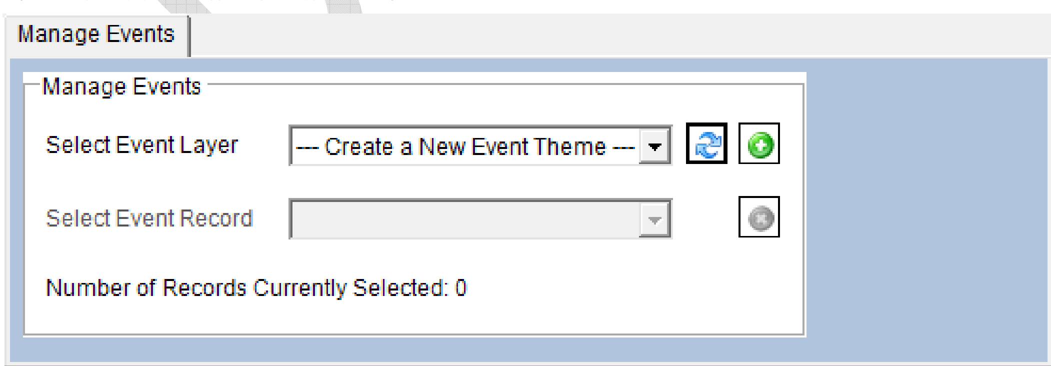
The **Event Path Maker** tool is a custom GIS tool to assign attributes to river paths in a river network. It is part of the *Compass Informatics* **Hydro Tools** package, a toolset designed to work with national river network datasets. It can be used to assign different attributes to a stretch of river simply by clicking once on where a certain type, for example geology, starts upstream, and a second time to show where it finishes downstream.

The tool has a number of customisable settings so it can be used for many different data entry scenarios. For example, the tool allows a user to click once on the river network, and then enter a distance value in order to generate a point at a fixed distance upstream or downstream from the first point. This is useful in situations such as following a river network 10 km downstream of a Sewage Pipe as per government Water Regulations.

The tool is named *Event Path* because newly created segments are called linear events by ESRI, and they follow a path on the river network. The tool allows the creation of these *event paths*.

To install the tool and to resolve common errors, please see the separate **Event Path Maker Errors** page.

1.2 Create New Events Menu



There are two distinct types of events, each handled slightly differently by the syste,. They are:

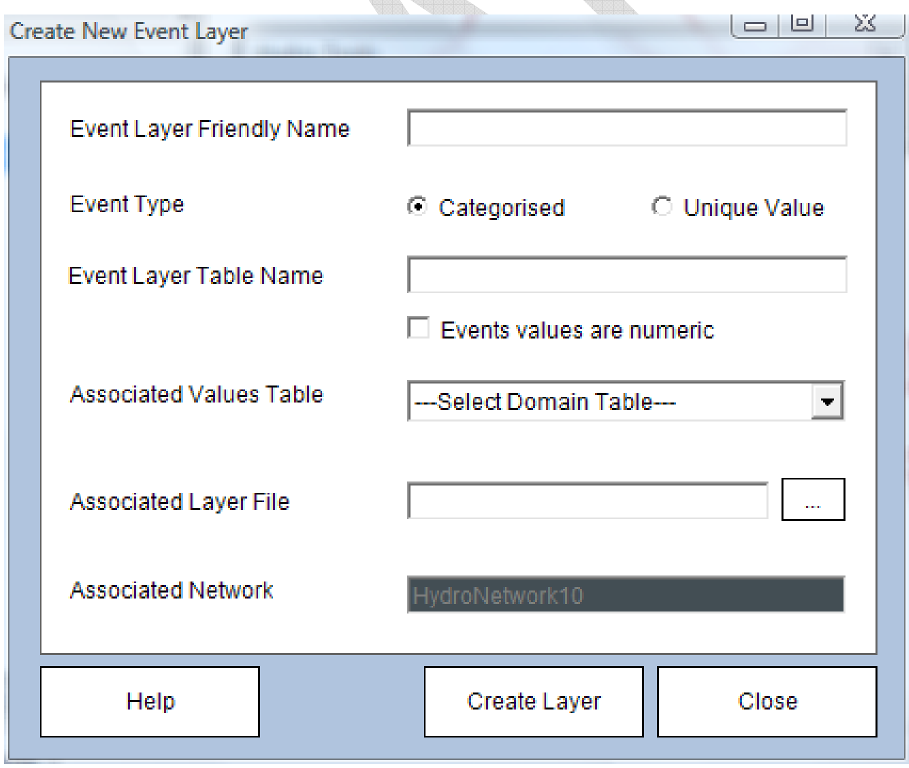
1. **Unique Value Events:** This type of event has a unique attribute for each record. For example EPA Rivers will have a single unique code as their value. No other event record will have the same code, and each code will be entered individually by a user.
2. **Categorised Events:** This type of event layer will have many event records with the same values. For example a geology event layer could have many records with a LIMESTONE value. The user is able to select a value from a list of predefined records, or add a new value to this list if it is not already there.

1.3 Create New Event Path

The custom toolbar integrates into the existing ArcMap interface. It contain three buttons, a *Create New Event Path Layer*, an *Edit Event Paths* button, and a *Select Event Record* button. These are dealt with further in the sections below.

1.3.1 Create Event Path Layer

This button will allow a user to create a new event layer in the Events database. It will only become active when a network has been selected in the Hydro Tools toolbar, and there is a valid Events database set through the Hydro Tools settings. When clicked it will open a dialog similar to the one below:



The dialog will be used to set the following parameters for the new event layer:

- **Event Layer Friendly Name -** this is a user friendly name for the event layer. This name will be used in lists where users can add existing event layers, such as through the Hydro Tools toolbar. For example: Geology
- **Event Type -** choose whether the event type will be *Unique Value* Events or *Categorised* Events. See above for details about these different types.
- **Event Layer Table Name -** the name of the event layer table to be created in the database. This will be the name of table in the personal MS Access geodatabase. For example: GEOLOGY_2008_B
- **Associated Values Table -** the associated domain table containing possible values for events. This table can be selected from any of the existing tables in the Events geodatabase, and should contain all the unique values that can be used for an event record for a Categorised Event layer. If the layer is a Unique Value event type then this field will be disabled.

If the domain table has not been created, a new table name can be entered in the combo box, and then clicking on the button to the right of this text box will create a new empty domain values table. All of these domain tables should be in the same format. This format is yet to be decided upon.

- **Event Values Field Name -** The name of the field that will store the value for an event record, in the newly created events table.
- **Associated Layer File -** The layer file that will be used to symbolise the event layer in ArcMap.
- **Associated Network -** The events will be created for rivers in the network listed here. This value will be taken from the active network set in the Hydro Tools toolbar.

Once these values have been set, a new table is generated based on the Event Layer Table Name, containing TO and FROM fields (named using the general Hydro Settings), and a value field named from the setting in the text box for Event Values Field Name.

1.4 Create & Edit Event Paths

1.4.1 Creating a New *Event Path*

This tool is used to both create new event paths, and edit existing paths in an event layer. To create a new event path the user will go through the following steps:

1. Select a network via the Hydro Tools toolbar. This loads the network into the map.
2. Click on the map to create the first point on the network. By default this is the upstream point.
3. The "Event Path Properties" dialog is opened at this point with the upstream details (x and y coordinates) filled in automatically.
4. If the user does not want to create a point at a fixed distance then they can click a second point on the map.

5. The system finds the path between the two points - if this is possible. If not, both points are removed and the process starts again.

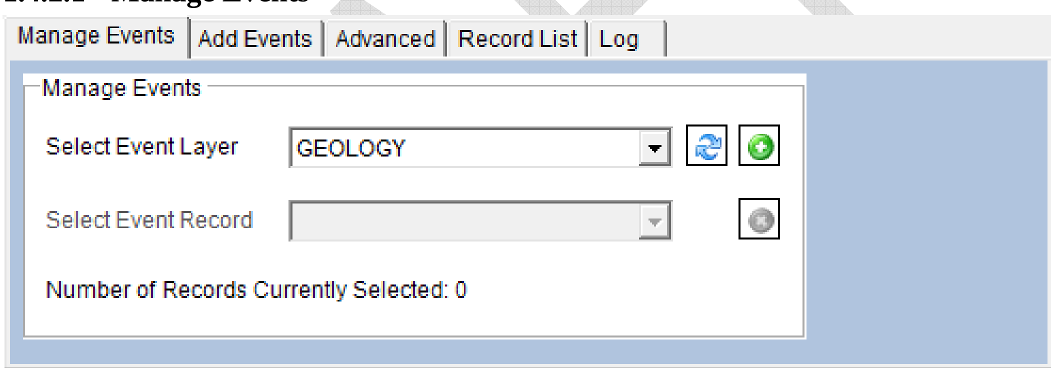
If the user does want to create a second downstream point manually, then after entering the first point they can then enter a distance in the Event Path Properties dialog. This point is then be added to the map automatically.

This does not work for creating a point upstream, as in this case many different paths could be traversed, whereas water only flows in one direction downstream. For creating events a fixed distance upstream the user will have to click two points on the map, and then enter the fixed distance. If the point clicked does not allow the system to work out which upstream branches to take then a warning box will be displayed, and the user will have to create a new second point further upstream

1.4.2 Editing an Existing *Event Path*

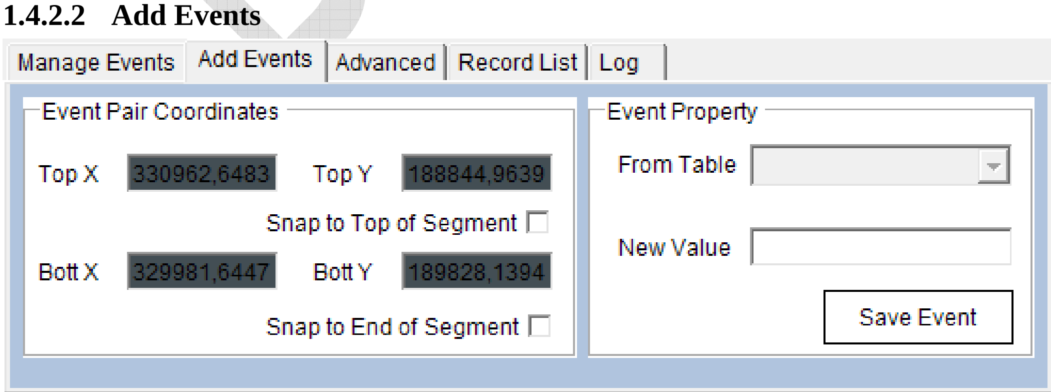
At this stage a variety of other options are available these are all available through the above interface and are as follows:

1.4.2.1 Manage Events



Manage Events --New Record---" will be displayed in the Select Event Record drop down list.

1.4.2.2 Add Events



- Event Pair Coordinates - The coordinates are filled in by the user clicks, or by the system through the fixed distance settings. A number of other options are available to the user. They can snap the upstream point to the top of the segment (rather than creating an event for part of the segment), or snap a downstream point to the end of a segment.

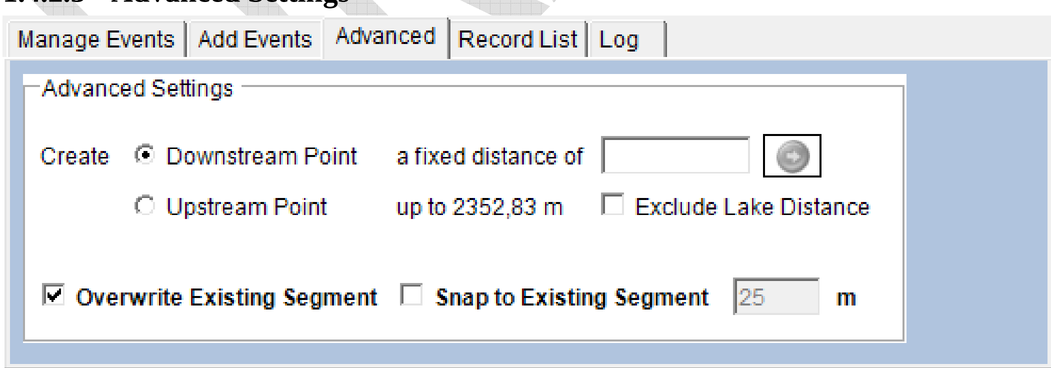
There are also options to handle how events that overlap, or fall within a certain distance of an existing event record will be handled. These work as follows:

If an event record starts within a certain distance of a previously created event on the same segment, then the point can be moved so the event starts from the end of the previous event record and there are no gaps created. For downstream points the point can be moved further along the segment to the start of the next event record. This can be achieved by selecting the Snap to Existing Segment checkbox. This checkbox, and the exclamation icon, will be displayed automatically by the system where relevant.

If an event record overlaps an existing event record then the user has two options. They can either overwrite the existing record, so it becomes smaller, or the current record can finish where the previous event record starts. This can be achieved by selecting the Overwrite Existing Segment checkbox. This checkbox, and the exclamation icon, will be displayed automatically by the system where relevant.

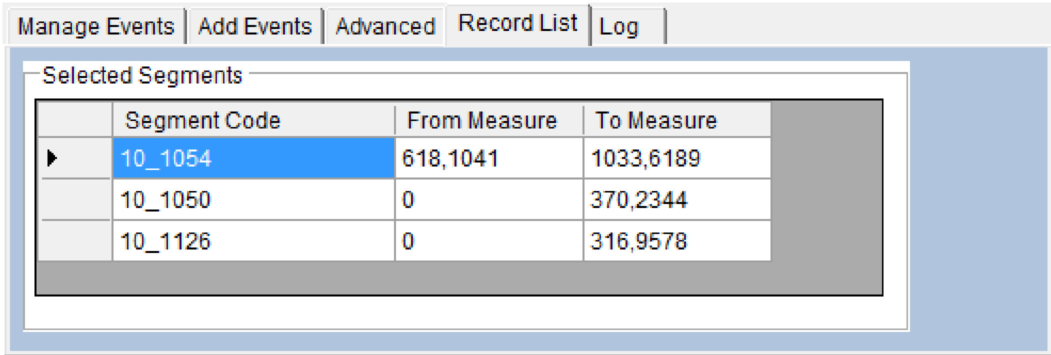
- Event Property - this section of the dialog is where the user sets the value for the event (geology type, EPA river name etc.). The value can be selected from a drop down list (if a Categorised Event), and/or entered in the free text field. If entered in the free text field it can be added by a user to the associated domain table (again only for a Categorised Event). There are a number of checks within the program code to ensure no values are duplicated.

1.4.2.3 Advanced Settings

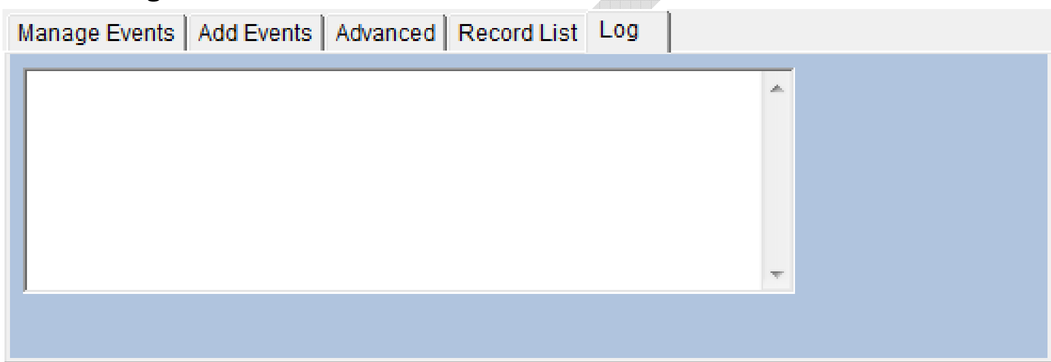


- Update Coordinates see stage 3 for more details. There is an option to exclude distances through lakes - in most cases this will be selected, but for events such as salmon migration it will not.

1.4.2.4 Record List Menu



1.4.2.5 Log Menu



This menu simply lists the most recent changes and updates to the system.

1.5 Saving the event Record

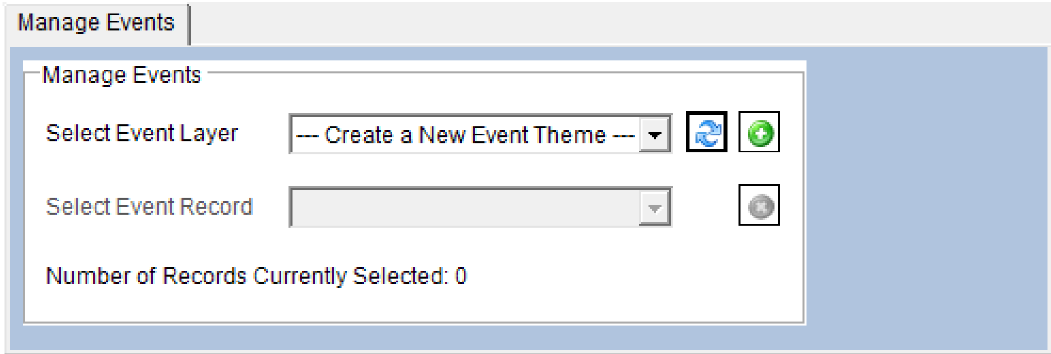
After the properties above have been set the user can save the event record to the database. At this stage the following will occur:

1. The event table will be updated in the events database.
2. The visible event layer will be removed from the map.
3. The updated event table will be rejoined to the relevant river network

These steps will be invisible to the user. The purpose of the above is so the user can instantly see the events they have added or modified in the interface.

To edit an existing event record the user can select an event from the “Select Event Record” drop down list in the above dialog. This will only be useful where there are Unique Events, which can be selected by a unique attribute. As an alternative the user can select an event from the map with the “Event Selection” tool.

2 Unused images...



3 Installation of Event Path Maker

Summary
Additional information on how to resolve common installation problems

3.1 Using Command Line to make Regasm.exe

Using Command Line to make Regasm.exe

3.1.1 Making the Batch (.bat) File

Copy and paste the following three lines of code into a NotePad file, and save with the extention .bat

```
 cd C:\Program Files\Compass Informatics\Event Path Creator\bin
 C:\WINDOWS\Microsoft.NET\Framework\v2.0.50727\Regasm
CompassHydroTools.dll \t CompassHydroTools.tlb
 C:\WINDOWS\Microsoft.NET\Framework\v2.0.50727\Regasm
CompassEventPathMaker.dll \t CompassEventPathMaker.tlb
```

The first line changes the directory (*cd*)

4 Vista-Specific Problems

To run the file, right-click and *Run As...* an **Administrator** (Vista Only)

5 Event Path Maker: Common Errors & Solutions

Summary
Installation errors, problems, permissions and known issues for the GIS additional menu: "Event Path Tool Maker"

The Event Path Maker tool allows certain attributes (soil type, geology etc.) to be attributed to sections of a river path.

5.1 Recommended Minimum Requirements

- A fully licenced version of ArcGIS Desktop 9.2
- Updated to include complete Service Pack 5.2 (SP5.2)

- Windows XP or Vista (see section below for Vista-specific Issues)

ArcGIS 9.2 Service Pack 5 is available to download here:

http://support.esri.com/index.cfm?fa=downloads.patchesServicePacks.listPatches&PID=15

5.2 Installation Steps

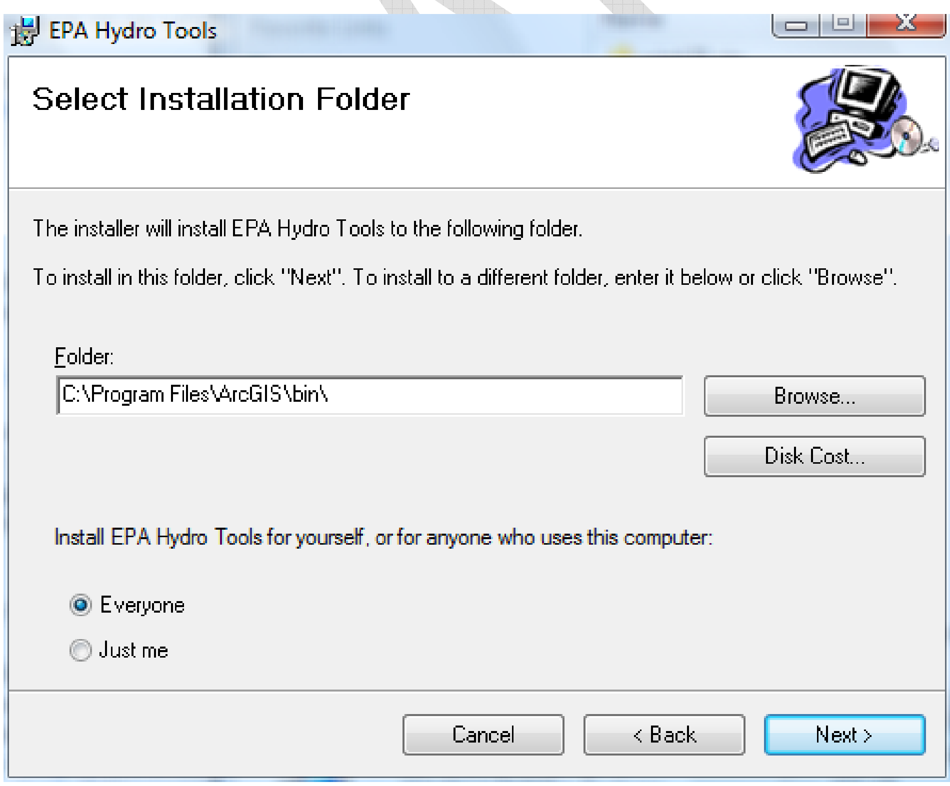
5.2.1 Step 1 - Run EventPathSetup.msi

Run EventPathSetup.msi

Note - You will need to have administrator priviledges to install the software. This may mean you need to right-click and "Run as Administrator...". See the section on Vista-Specific Issues below for further information regarding **User Account Control** related install problems.

5.2.2 Step 2 - Choose install location

Place the app.config file into the folder where EventPathSetup.msi is installed. The default location for this is shown below:



5.2.3 Step 3 - Configure the app.config file

Right-click on the app.config file and "Open with..." Notepad.

```
<?xml version='1.0' encoding='utf-8' ?>
<appSettings>
 <add key='NetworkNamePrefix' value='HydroNetwork'/>
 <add key='SegCodeFieldName' value='SEG_CD'/>
 <add key='RiverLayerFile' value
='C:\Data\AssimilativeCapacity\AC\riverlayerfile.lyr'/>
 <add key='HelpPage' value ='http://www.compass.ie'/>
 <add key='LakeTypeValue' value ='L'/>
 <add key='EventsGDB' value ='C:\Data\events_jean.mdb'/>
 <add key='NetworksGDB' value
='C:\Data\Databases\EPAnetworkZM_v2_working.mdb'/>
 <add key='IgnoredValue' value ='L'/>
 <add key='WaterBodyTypeField' value =''/>
</appSettings>
```

Ensure that the locations and file-names of **EventsGDB** and **NetworksGDB** in particular are correct, including file extentions.

5.2.4 Step 4 - Configure the ArcMap.exe.config file

Right-click to "Open with..." Notepad at the following location: C:\Program Files\ArcGIS\Bin\ArcMap.exe.config

```
<?xml version="1.0" encoding="utf-8" ?>
<configuration>
       <startup>
               <supportedRuntime version="v2.0.50727" />
       </startup>
<appSettings file="C:\Program Files\Compass Informatics\Event Path
Creator\app.config"></appSettings>
</configuration>
```

This file allows the computer to automatically load the additional software when ArcGIS is opened.

5.3 Known Errors & Solutions

5.3.1 Regasm.exe

Issues with the registry file...

5.3.2 Using Command Line to Install

Info on how to use Command Line to help install...

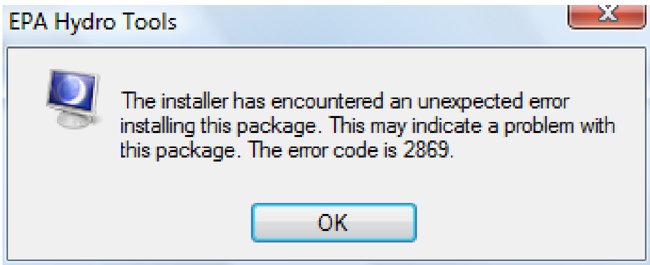
5.3.3 Creating a batch file to help install

Info on how to make a batch (.bat) file to help install...

5.4 Vista-specific Issues

5.4.1 Vista Security Problems: Error 2869

"Error 2869" can be caused by a variety of factors, but is known to occur as a result of **Windows Vista's** *User Account Control* procedures.



The *User Account Control* (UAC) means is an additional security feature of Windows Vista which is designed to prevent unwanted software from installing itself without express permission from the user. This effectively means that an 'Administrator' account remains a non-administrator account, but has the ability to change to one to allow new software to be installed.

Additional information can be found here:

http://blogs.x2line.com/al/archive/2007/07/20/3210.aspx

5.5 Installation Complete

Once the menu is successfully installed, you can view **video tutorials** available **HERE** to become familiar with the new features.

Please update this Wiki with additional issues and solutions using menu options.

Check out the formatting tips on the right for help formatting and making links.

Appendix III

Morphology Tool Specification

Purpose of this Document

The purpose of this document is to fully describe how each function specified in the Requirements Specification will be implemented from a technical perspective. This document will also describe the development environment.

Revision History

Version	Description	Author	Date
1.0	Spec document for SMorrish	AD	280208
1.1	Revision and outline specification	SM	300408
2.0	Outline specification	VK	020508
2.1	Outline specification	VK	060508
2.2	Updated pecification	AD	140508
3.0	Updated with RPS comments	AD	260508
4.0	Updated with RPS comments	AD	270508

Introduction

Overview of Project

Compass Informatics has been tasked to provide a tool that potentially brings together data from five separate projects each focusing upon various aspects of the Freshwater Morphology study through the Shannon International River Basin District Project. These projects examine areas such as:

1: Typology (Republic of Ireland and Northern Ireland)

2: Feature extraction and Aerial Survey (Shannon IRBD Freshwater Morphology Study).

3: Lakes morphology feature extraction (Shannon IRBD Freshwater Morphology Study, in conjunction with University of Dundee

4: Decision support tool (Shannon IRBD Freshwater Morphology Study, in conjunction with GeoData Ltd)

5: The inclusion of data from the Surface water status project (RPS)

Following an in-depth workshop with the EPA on the 14th of April and subsequent team meeting on the 16th of April, the decision was made to move forward on the development and deployment of two ArcGIS GIS server tools, with these tools an operator will have the ability to:

- *Rerun a risk assessment for a waterbody using the pressure thresholds and methods established through the Freshwater Morphology Study as a follow up to the Article 5 risk assessments.*
- *Conduct a Desktop Rapid Assessment to generate a remote R.A.T score if deemed necessary.*

Further to these two tools a GIS desktop application has been developed that will be made available allow sectioning of a river waterbody into morphological classes. This tool is known as the event manager tool, this tool is documented in a separate specification document.

1.11 *General Functionality: The tool will allow querying, analysis and reporting functionality on waterbodies for which R.A.T. data is already available.*

1.12 *Rerun risk assessment: The operator will be able to take a waterbody with a risk score and changing the parameters rerun the risk assessment. For example: If a river has an application to be channelised this can be incorporated and a new risk can be generated by applying the channelisation threshold between "at risk" and "not at risk". This will indicate if the proposed activity could cause a risk of deterioration in morphology status.*

1.13 *Desktop R.A.T (dRAT): The operator will be able to conduct a desktop RAT, using aerial imagery and generate a score and subsequent WFD class. The same attributes recorded in the field can be remotely identified. Not all R.A.T attributes will be readily identified due to imagery resolution/availability and limitations of identifying certain features remotely. However, this is similar to the field survey methodology where under certain conditions (e.g. high flows) an incomplete survey will be recorded however a valid R.A.T score can still be generated from this data.*

Note: dRAT is not a substitute for the field based RAT but more an aid to identify areas where a detailed field RAT should be carried out

Reference Documents

Relevant documentation and reports are outlined below.

- Documentation on the Lake Habitat Survey (LHS) written by Dr. John Rowan, University of Dundee.
- Documentation from SEPA on Morphological Impact Assessment System (MImAS).
- Documentation on river rapid assessment technique (RAT) Functionality Overview and Technical Specification.

Functionality Overview and Technical Specification

Functionality Overview

It is envisaged that the surface water morphology tool will offer the end user a selection of functionality including:

- The facility to browse and query datasets relevant to surface water morphology via a web-mapping interface.
- The facility to locate river waterbodies or survey extents by selecting the feature from a drop down list and zooming to that feature.
- The facility to access various reports relating to morphology assessment including R.A.T scores and field sheets where available, dRAT rscores; WFD Article 5 Risk Assessment Reports and Post Article 5 refined Risk Assessment Reports (where applicable). Other documentation of interest may also be accessed if required.
- The facility to rerun a waterbody morphology risk assessment based on modified channelisation and embankment values.
- The facility to generate a dRAT score (in the absence of a field based RAT score) using aerial imagery (orthophotography or where available, aerial imagery from flight surveys).

In order to achieve the functionality outlined in Section 2.1, the effort required can be broken down into a number of distinct stages (Figure 2.1).

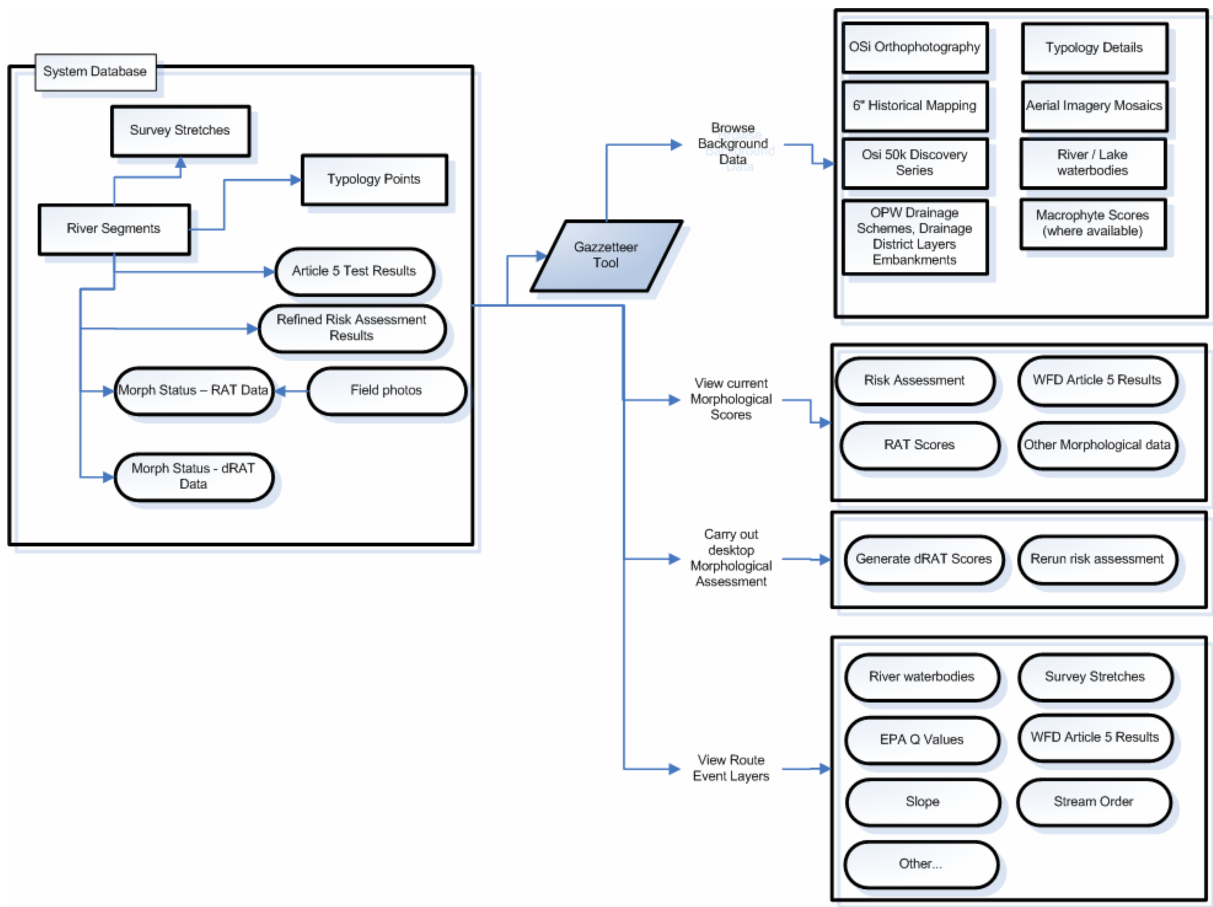


Figure 2.1 Technical overview of the Surface Water Morphology Tool

Development of the System Database: This stage will define and create the schema and database required to store all system data. The existing WFD schema and database will be modified in order to accommodate additional data required for morphology purposes. Tables will be set up to allow for the input of RAT/dRAT or risk assessment results. New event tables will allow for the inclusion of survey extents and new feature classes will allow the input of typology points. Relationships between river features, survey stretches and RAT/dRAT scores will also be included.

Setup of the Web Mapping System, allowing simple Browsing and Querying:

It is proposed that a web mapping system will be developed using an ArcGIS Server platform. This system should allow users to browse and carry out simple identification queries on data relating to surface water morphology.

Proposed datasets to be made available for browsing include but are not limited to:

- OSi Orthophotography
- OSi 50,000 Discovery Series
- 6" Historical Mapping
- River waterbodies/segments
- Lake waterbodies/segments

- Point features with typology details
- Detailed aerial imagery mosaics where available through the Freshwater Morphology Study
- OPW GIS Layers
- Site Photographs where available

These layers, at a national scale, will be available to the user to toggle on or off via the map window Table of Contents.

-Tool Tips will also be set up so that as the cursor passes over a waterbody or typology point the data associated with that feature is displayed.

Incorporate Gazetteer Tool

It is proposed that a Gazetteer-type tool be included in the web mapping system. Primary advantages of this type of tool include increased ease of navigation, application of more in-depth, automated queries and access to linked or externally held information.

Using the gazetteer, the user should be able to select a river/lake waterbody and the system will zoom to the extent of this waterbody. This tool could also allow the user to zoom to the extent of a selected survey. Other options such as zoom to county or catchment area may be included if required.

When the user selects a waterbody using the gazetteer tool, the web map will navigate to the extent of the waterbody and display all relevant layers.

For each selected waterbody, the gazetteer will also offer links to related documentation such as:

- Photos taken by surveyor from point locations shown in the map.
- RAT forms (may be multiple, should be sorted by date, most recent first).
- dRAT forms (may be multiple, should be sorted by date, most recent first).
- Article 5 Risk Assessment details and refined risk assessment details where applicable.
- Other relevant documentation.

RAT, dRAT and Risk Assessment scores will be returned to the user using SQL Server 2005 Reporting Services. Thus allowing dynamic reports to be generated for specific river water bodies.

Rerun Risk Assessment

When a River waterbody is selected using the gazetteer tool or by clicking on the segment, the option to rerun the risk assessment based on known value changes (to either channelisation or embankments) to the waterbody will be available. A form will open showing a list of the parameters available for amendment to recalculate the risk assessment. This will allow the user to quickly determine whether any changes will cause risk of status deterioration of a particular waterbody. The results from the rerun risk assessment will either be saved/discarded or amended.

This data entry will be developed within the .Net 3.5 framework.

Carry out Desktop Rapid Assessment Techniques

When a River waterbody is selected using the gazetteer tool, the option to carry out desktop Rapid Assessment Techniques (dRAT) will be made available to the user. A form will open showing a list of the parameters from the field RAT where a value from 1 to 4 can be entered for each. Once the form is completed, the values can be saved to the system database and a dRAT score can be calculated. Rules can be set to allow the user to include/exclude certain parameters that may not be relevant.

This data entry and updating section will be developed within the .Net 3.5 framework.

View Additional River Data

Additional river information can be visualised using the custom built linear event manager. It is envisaged that this tool would be an administrator tool to be run primarily within the ArcGIS desktop suite. River information of interest to be visualised may include:

- RAT/dRAT scores
- Risk Assessment Scores
- Channel Typology
- EPA Biological Quality values
- Survey stretches
- Slope
- Stream Order

Once linear events for such river data are created, these events can be viewed and queried as layer files on the WebGIS by all users. These layers, if displayed within the web mapping system, would be available to the user to toggle on or off via the map window Table of Contents.

Additional Administrator Functionality

Other tools that may be of use to the administrator of this system might include tools allowing the update of survey reaches or the inclusion of new reaches and tools allowing the addition of new photo sites. It is likely that these tools would be deployed within the desktop GIS environment rather than via ArcGIS Server.

Final Installation Tasks

As part of the final installation and testing of the tool, a phase of user validation and testing can be undertaken. This will provide the end user with an opportunity to go through the system prior to final deployment.

System documentation

Complete system documentation will be provided including all details on the methods adopted and system architecture used.

Required Technology Development Environment

It is proposed that the interface will be developed using an ArcGIS Server platform in conjunction with SQL Server 2005 Reporting Services (SSRS). The development server shall be accessible through secure network protocols and will host the spatial data repository, reporting services and ArcGIS Server mapping interface.

Querying and editing tools will be developed using ArcGIS Server ASP.Net routines. Reporting tools will be developed using SQL Server 2005 Reporting Services (SSRS). These tools will primarily be developed using the ArcGIS Server .Net 3.5 Framework and will support SSRS and alongwith other reporting systems if required.

Test Environments

The development of the RAT/dRAT system will be conducted on a dedicated SQL Data server and ArcGIS Server system. These systems will be made accessible for review through a secure system as development progresses. The primary test interface for users will consist of an ArcGIS Server user interface and linked SSRS. Full functionality will be assured on Microsoft's Internet Explorer v6 & v7. Functionality may be supported in other environments if required.

Error Handling

General errors on the client application will follow web mapping standards regarding accessibility of services, query and redraw errors. Full logging of both access and errors will be maintained and reviewed on the server side applications

Assumptions and Constraints

While the development of the mapping and query tools are fully with in the remit of Arc Server the development of SQL Server reporting services will require the integration of reporting services with the Arc Server instance.

Appendix IV

Morphology Tool User Guide

1.0 General Usage

The tool needs users to be registered before access is granted to the system. This ensures that any edits are logged against a username.

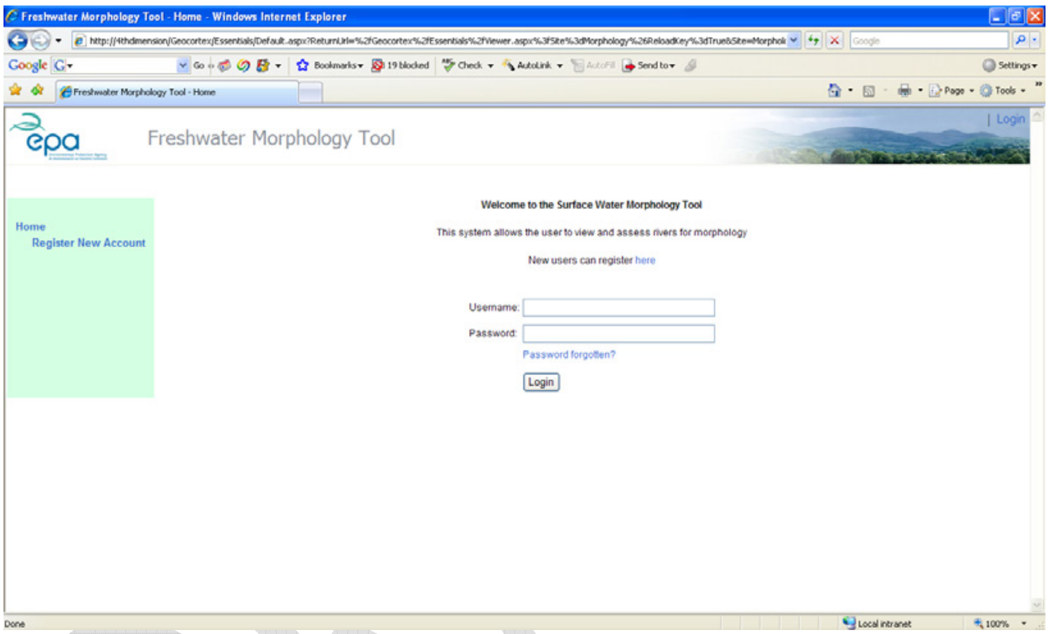


Figure 1: Freshwater Morphology Login page

The user enters their username and password, if this is the users first time they will need to register this can be done by either clicking Register New Account on the righthand side of the screen or by clicking on New users can register here in the centre of the screen.

To register a new account the user will be presented with the following details to fill in:

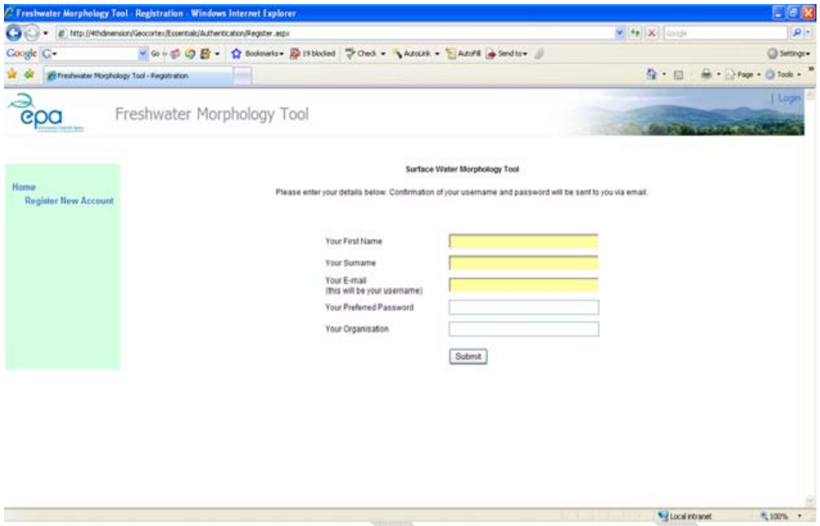
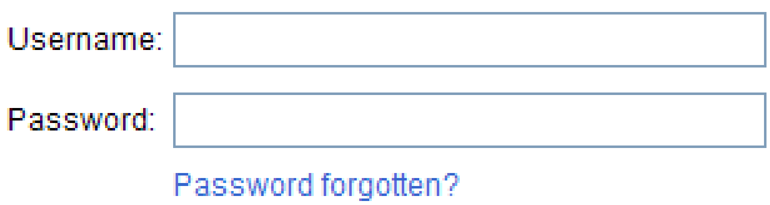


Figure 2: New account registering

The username and password will be sent to the register once they have submitted their details. There is also a facility at the log-on stage to be resent their password in case they have forgotten it:



Once the user has logged in they will be presented with a screen asking them to agree to terms and conditions also the user will be presented with disclaimer text:

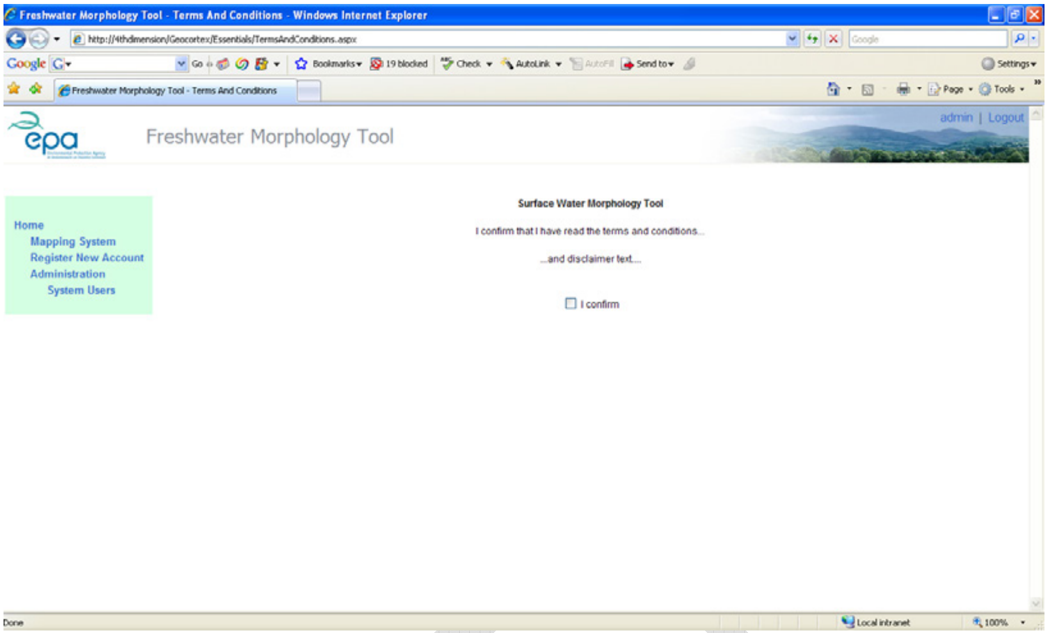


Figure 3: Accepting terms and conditions

Once this box is ticked the user is presented with the opening page for the morphology tool:

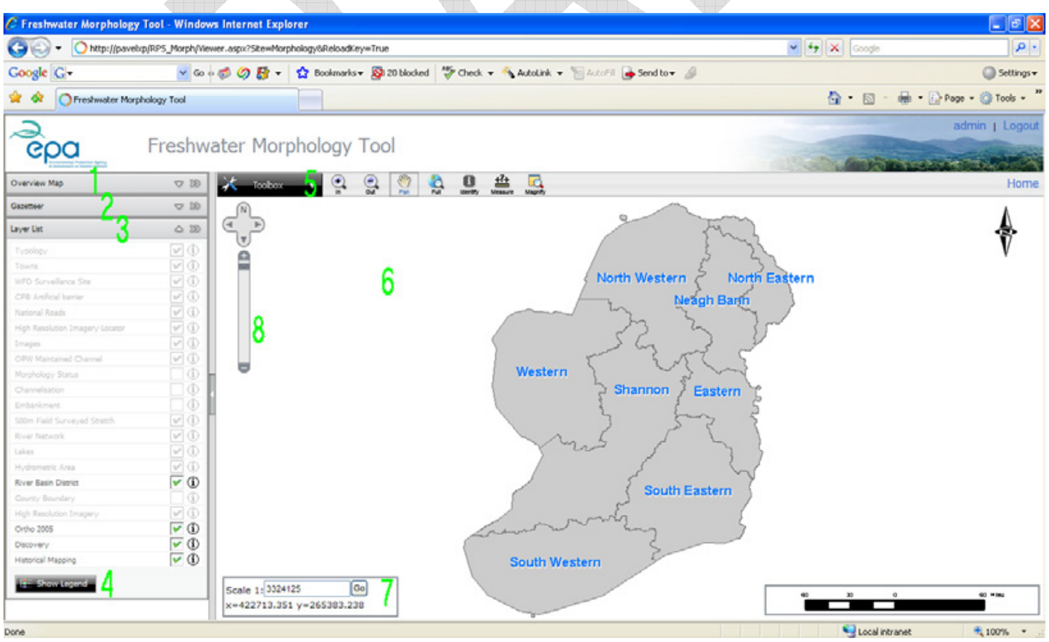


Figure 4: Tool main interface

The system has been broken down into nine separate elements, each will be explained individually, below is a short description of each element:

1: Overview map: Locates the user on a county level.
2: Gazetteer: Brings the user directly to a particular waterbody.
3: Layers List: Lists the elements currently visible in the map window.
4: Show Legend: Shows the symbology for the currently active layers.
5: Toolbox: Custom tools.
6: Map Navigation: Tools to allow the user to move in, out and around the map window.
7: Map Window: Where the layers are viewed.
8: Locational Reference: The user can go to a certain scale while also seeing the X, Y of the cursor.
9: Zoom and Panning tool: Another way for the user to move around the map window.

1: Overview Map:

This allows the user to locate themselves, this is especially useful when you are zoomed right in and are following a river's course. The overview map stays at a static scale of 1: 3,000,000.

To open the overview map click the upside triangle (this is the same for the gazetteer and the layers list), the two icons pointing right will detach the Overview Map which can then be placed and opened anywhere within the screen.

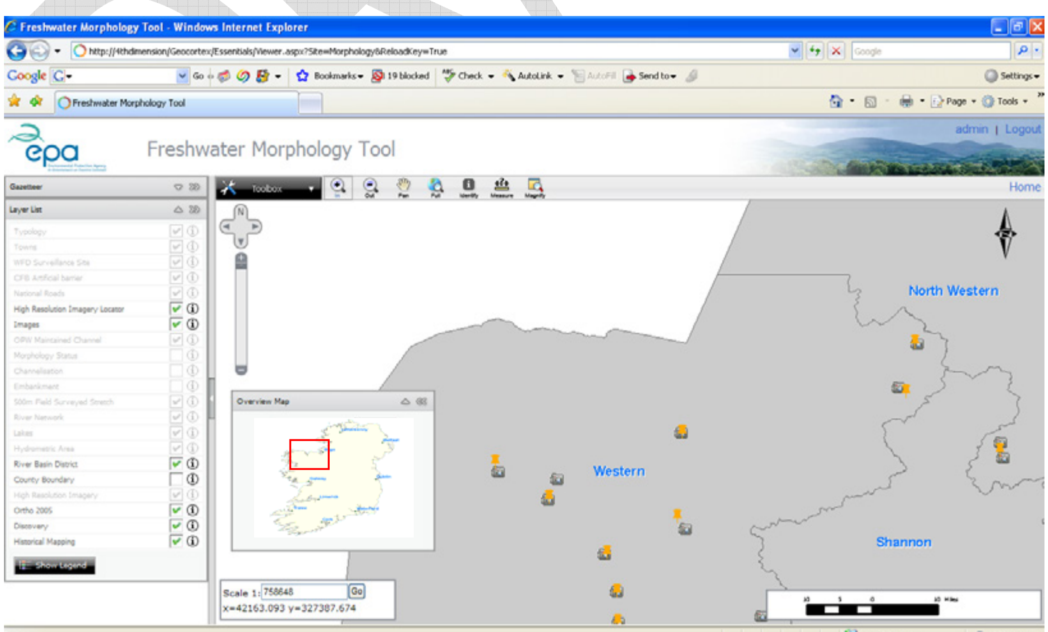


Figure 5: Detached overview map

2: Gazetteer:

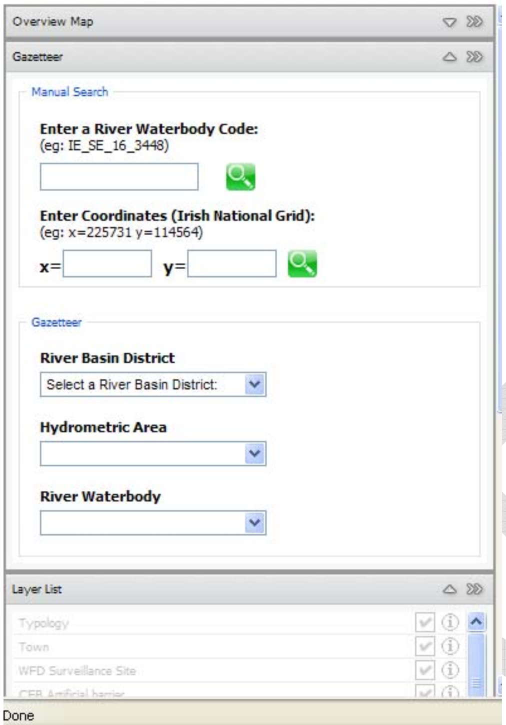


Figure 6: Gazetteer functionality

The Gazetteer has three ways to get the operator to their desired location:

A: The operator can enter the River Waterbody Code directly and by clicking the green icon can zoom directly to the waterbody. An example of the format is given in brackets: the waterbody code must be in this format or an error is returned.
B: The operator can enter the particular grid coordinates they wish to zoom to in the same format as the example given, by clicking the green icon the operator would be brought to this location at a scale of 1: 5000.
C: The operator can get to their waterbody of interest by using three dropdown boxes by first selecting the River Basin District then Hydrometric Area then finally the River Waterbody. There is no need to press any icon as once the River Waterbody is selected the map will automatically zoom to this location.

3: Layers list:

The layers list displays the layers that are currently within the map window. Layers can have four types of settings.

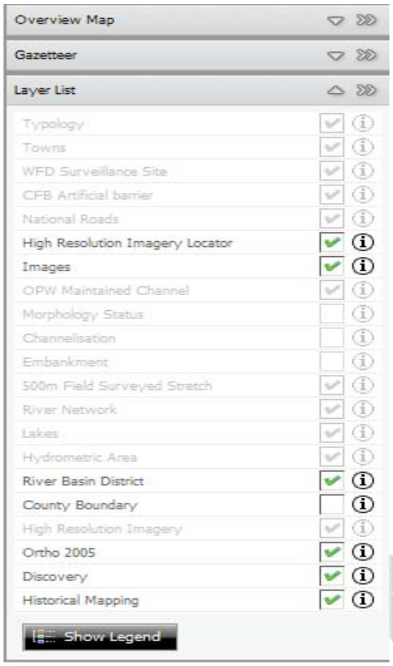


Figure 7: Layers list

A: Greyed out and ticked (eg Typology):
Layer automatically turns on at a certain zoom level.

B: Greyed out and not ticked (eg Channelisation):
Layer is not available at current zoom level and will not automatically come on.

C: Not greyed out and ticked (eg Images)
Layer is currently visible in the map window.

D: Not greyed out and not ticked on (eg County Boundary)
Layer can be viewed at current zoom level but is not currently turned on.

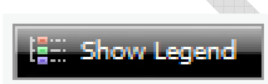
Note: Layers have been set to turn on and off at particular zoom levels this is for application speed and to present a visually less cluttered map. Table 8.1 shows at which zoom levels which layers are visible.

	View Levels			
Data Layer	Out Beyond	In Beyond	Automatically Turns on	Event Layer
River Basin District	NONE	1:750,000	YES	NO
High resolution imagery locator	1:750,000	NONE	YES	NO
Field Imagery	1:750,000	NONE	YES	YES
Hydrometric Area	1:750,000	1:200,000	YES	NO
Town	1:500,000	50,000	YES	NO
National Road	1:500,000	50,000	YES	NO
WFD Surveillance Site	1:350,000	NONE	YES	NO

CFB Artificial barrier	1:350,000	NONE	YES	NO
500m field surveyed stretch	1:200,000	NONE	YES	YES
Lake	1:200,000	1:50,000	YES	NO
County Boundary	NONE	1:50,000	NO	NO
River Network	1:200,000	NONE	YES	NO
Typology	1:10,000	NONE	YES	YES
High resolution imagery	1:10,000	NONE	YES	NO
Historical Mapping	1:25,000	NONE	NO	NO
OPW Maintained Channel	1:200,000	NONE	NO	NO
OSI Orthophotography	1:10,000	NONE	YES	NO
OSI Discovery Mapping	1:50,000	1:10,000	YES	NO
Morphological Status	1:200,000	NONE	NO	NO
Embankment	1:200,000	NONE	NO	YES
Channelisation	1:200,000	NONE	NO	YES

Table 1: Zoom levels for the layers in the morphology tool

4: Show Legend



Clicking this button at the bottom of the layers list will show the symbology for the currently active layers.

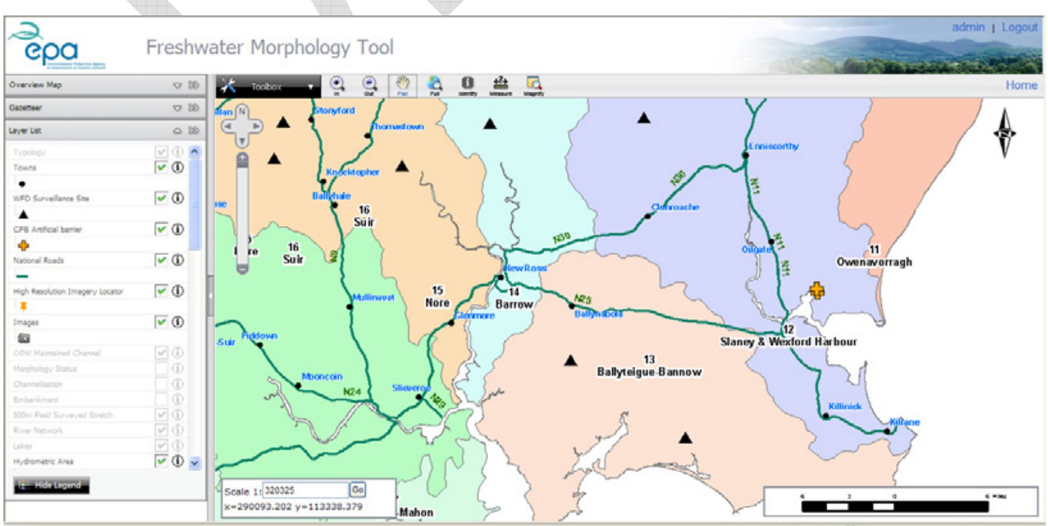


Figure 8: The layers list showing layer symbols

5: Toolbox

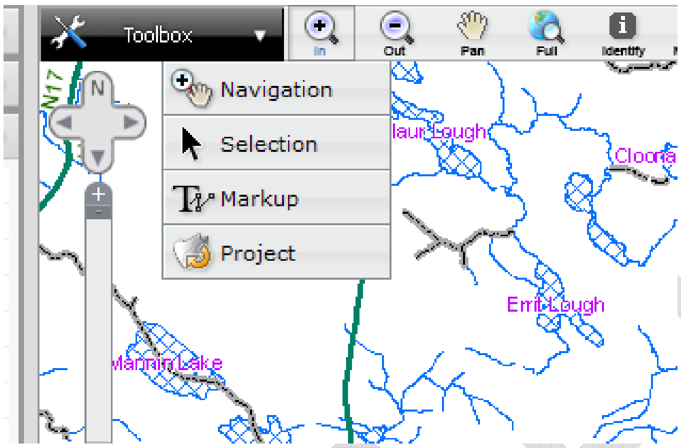
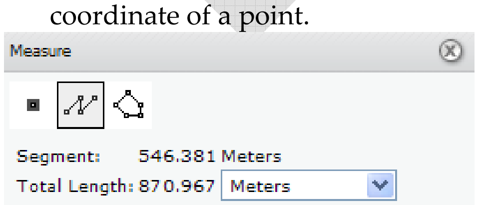


Figure 9: Toolbox options

Under the Toolbox dropdown option there are four available options.

A: Navigation: This is the default option and allows the user to move about the map window the tools have the following functions:

- Zoom in. To do this draw a box by clicking a point dragging and drawing a box and click again.
- Zoom out. Works the same as zooming in.
- Paning. Allows the user to move the map in any direction.
- Full. Clicking this will zoom to all layers.
- Identify. Clicking this icon and clicking on an item in the map window will return the data for the item clicked.
- Measure. The operator can measure either a line, polygon or find out the coordinate of a point.



B: Selection:

This suite of tools allows a user to select one item or multiple items within a layer. The user can select by clicking a point or drawing a polyline, polygon, rectangle, oval or a circle. It is recommended that for ease of use the rectangle is the most user friendly selection tool.

Before an item is selected in the map window the particular layer must be selected in the layers list on the left hand side of the screen. This is done by clicking the information symbol beside the layer:

Once the layer is highlighted this is the selectable layer.

In the example below the operator wanted to know which county hydrometric area 33 (Blackhead-Broadhaven) was in. The operator highlighted the county boundary layer in the layers list then drew a rectangle around the area. The resultant Co. Mayo is hightlighted in the map window and the result is reporting in a selection results dialogue. By clicking on list or table the attributes of the selection are displayed.

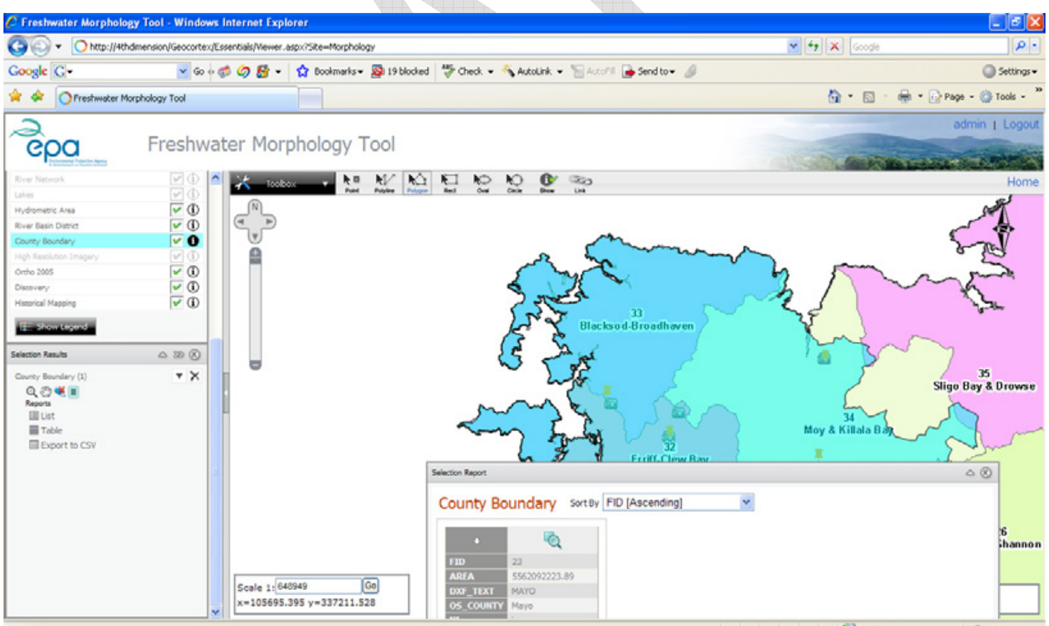
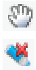


Figure 10: Selecting a county

When you have a selection there are five things the operator can do with the selection:

 Zoom to the selection.

 Pan to the selection.

 Unhighlight or rehighlight the current selection (does not unselect).

Create a selection from the current selection.

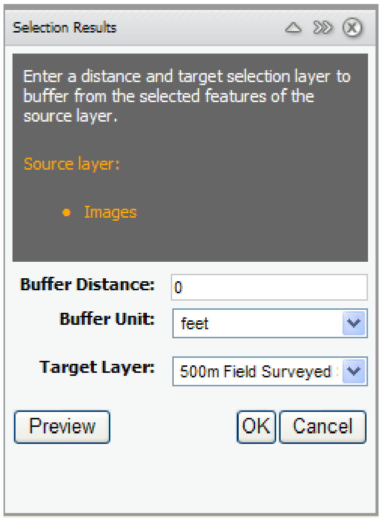


Figure 11: Buffering a selection

This allows the operator to buffer a selected item and select items in another layer or the same layer. This is a very powerful geoprocessing tool, an example of when this tool could be used would be in the following situation:

The user has selected a WFD surveillance site and would like to know where 500m RAT field surveys have been carried out within a 50 kilometer radius of the WFD surveillance site. The user fills in the **Buffer Distance**, **Buffer Unit** and **Target Layer** dialogues, once the user clicks Preview the area from where the selection will be make is highlighted:

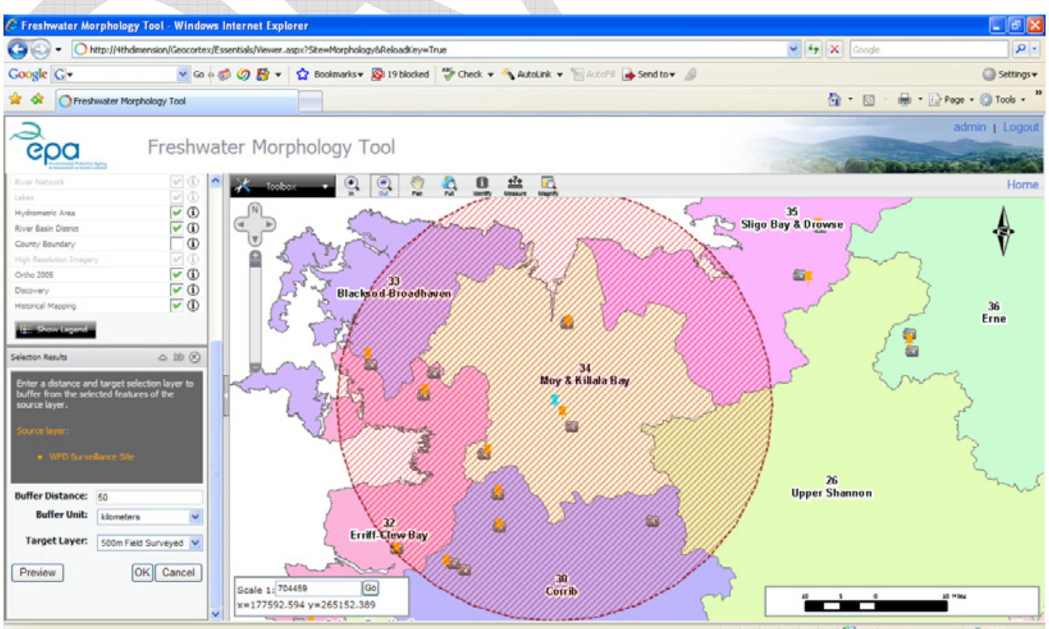


Figure 12: Preview search radius.

Once the operator clicks OK the selection is made and the tabular data is reported in the selection results dialogue:

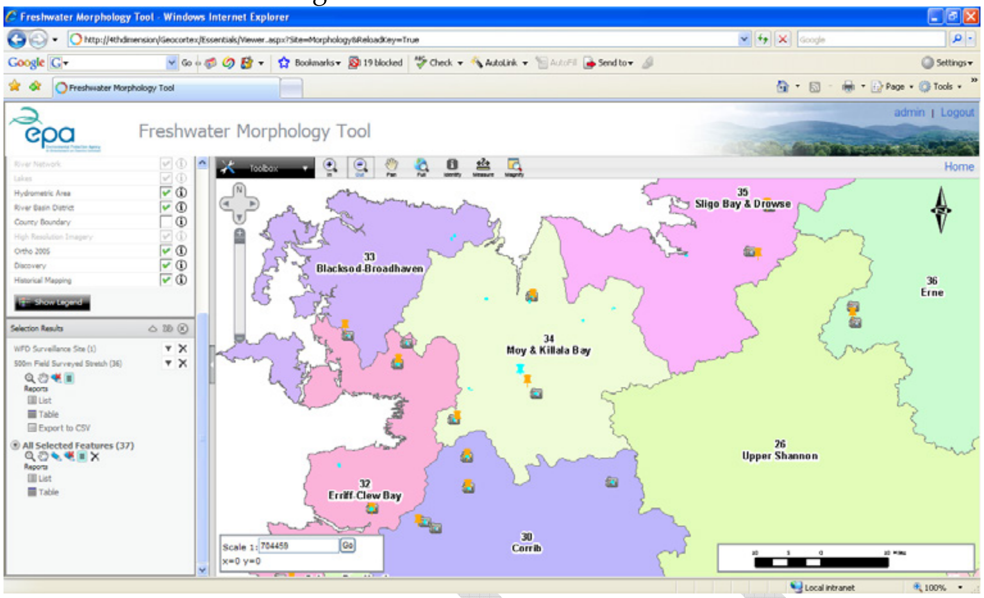
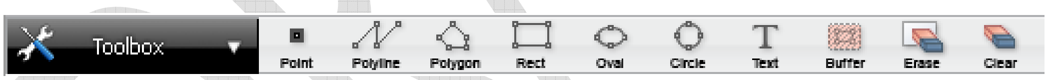


Figure 13: Selection from a selection.

Export to CSV By clicking this icon the data from the selection can be exported to a CSV format, this can then be opened in Microsoft Excel.

C: Mark up



Using the mark up tool it is possible for the operator to draw and annotate directly within the map window.

It is possible to draw points, polylines, polygons, rectangles, ovals, circles and text on top of the map window. In figure 8.18 a polygon with text has been annotated onto the map window. All the annotation parameters can be changed like the colour, size, transparency and angle.

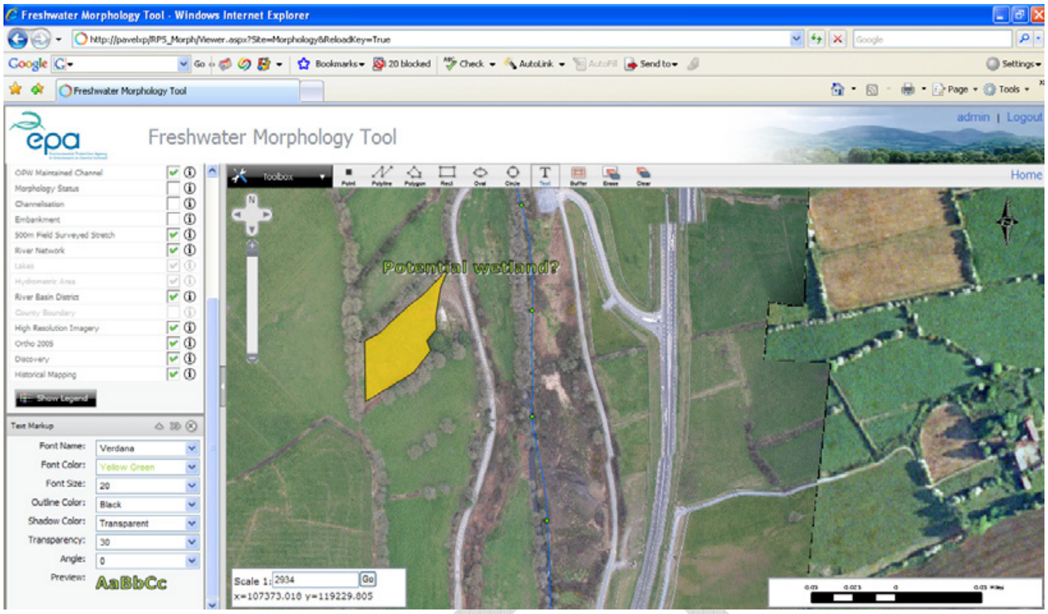


Figure 14: Example of a mark up on the map window

It is also possible to erase and clear the mark ups created using the two tools . Using the buffer tool  the user can create a buffer around a markup. This tool is useful for testing what if scenarios.

For example:

What if a new WFD surveillance site was to be initiated but first the operator wanted to know how many OPW maintained channels would be within 1500m of the proposed new site. The operator could quickly find out and produce something similar to figure 15.

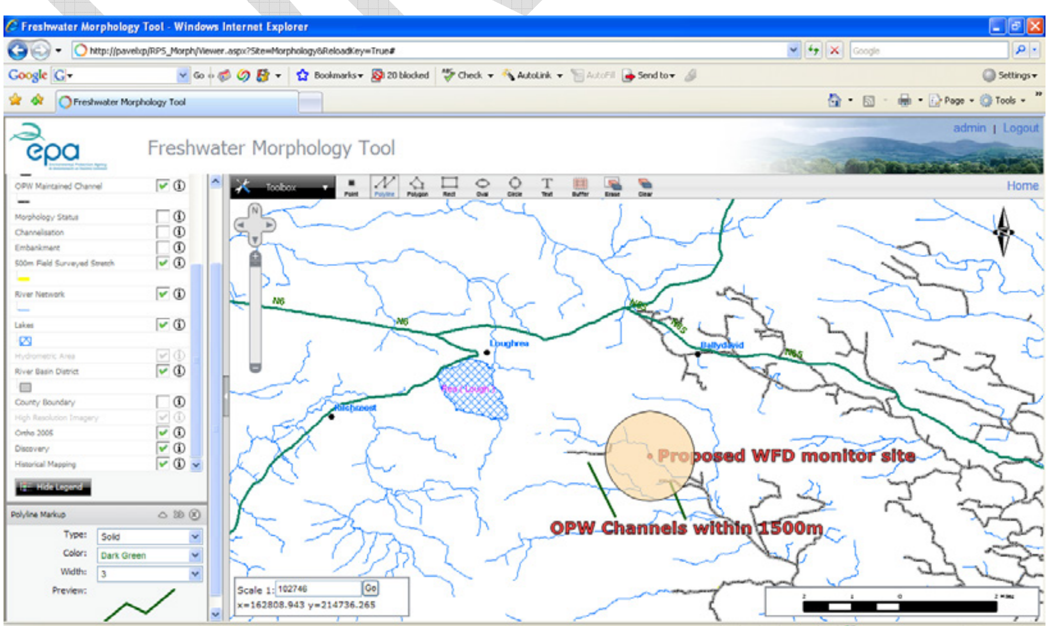
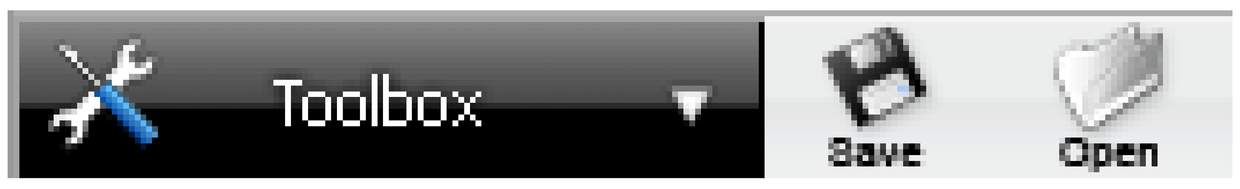


Figure 15: Creating a buffer around a marked up site.

D: Project



The morphology tool has a function where a project can be saved by clicking . For example once the internet browser was closed after doing the analysis featured in figure 9.19 all of the annotation would be lost. Using the project tools the operator can save their work locally on their computer. The file format is .gep and this can be reopened at any stage in the future by clicking the open file icon  .

6: Map Window

This is the body of the screen where the map and associated data is displayed. There are two elements in this screen that have no interaction.

The north arrow in the top right of the screen and the scale in the bottom right are both uneditable. However the scale dynamically changes depending on the zoom level.

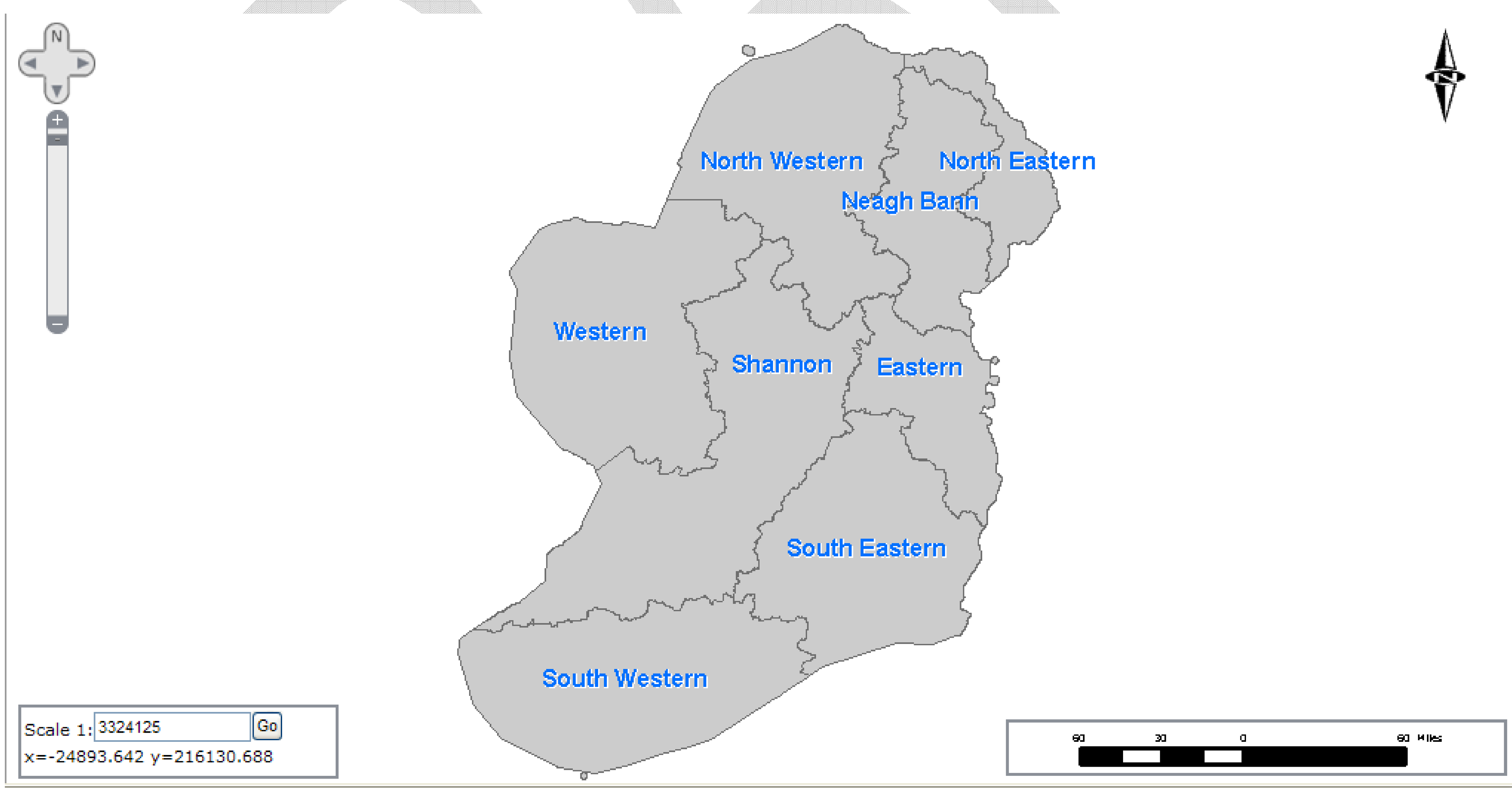
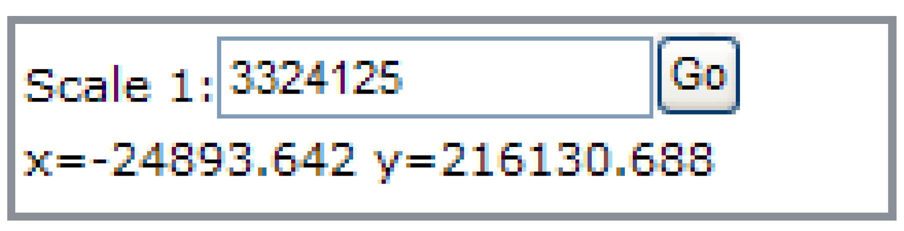


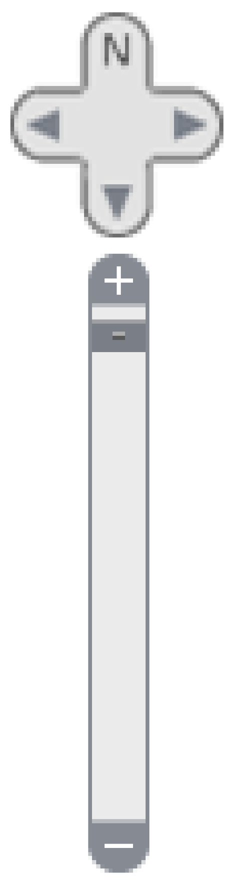
Figure 16: Map Window

7: Map Window Scale



This dialogue box shows the current map scale. It is possible to zoom to a different scale by typing the desired scale in the box and clicking the go box. This dialogue also shows the current X,Y coordinates of the cursor on the screen.

8: Zoom and pan tool.



This tool is another way for the user to zoom and pan around the map. By dragging the paddle between the plus and minus signs the map will zoom in and out. By clicking the N symbol or either of the arrows on the other three compass points the map window will pan in that direction.

2.0 Performing a desktop RAT (dRAT)

The freshwater morphology tool has the capacity for the user to perform a desktop Rapid Assessment Technique (RAT) at any location along the country's river networks. It is hoped that the ability to perform a dRAT will help locate potentially poor morphological sections of river and may require field visits. Fieldwork can be an expensive process and the length of river channel that can be surveyed in a day is determined by numerous factors but typically is on the order of a few kilometres a day. The advantages of assessing a river remotely are numerous:

- No travel time
- Secondary information readily available (eg Historical mapping)
- A whole river system could potentially be looked at in one day
- Cost saving
- Broader picture can be built up (ie Riparian and floodplain can also be assessed)

There are disadvantages aswell however:

- Lack of suitable imagery
- Not all field RAT attributes can be readily assessed

The tool has been set up to have as much flexibility as possibility. To perform a desktop RAT the user first selects one of the typology points that are located every 100m along the national river network.

Figure 17: Potential dRAT site

Before the operator even starts to perform a dRAT they know two things about the river channel firstly by looking at the layers they know it is an OPW maintained channel and by toggling on/off the historical mapping they know that this is the rivers natural course.

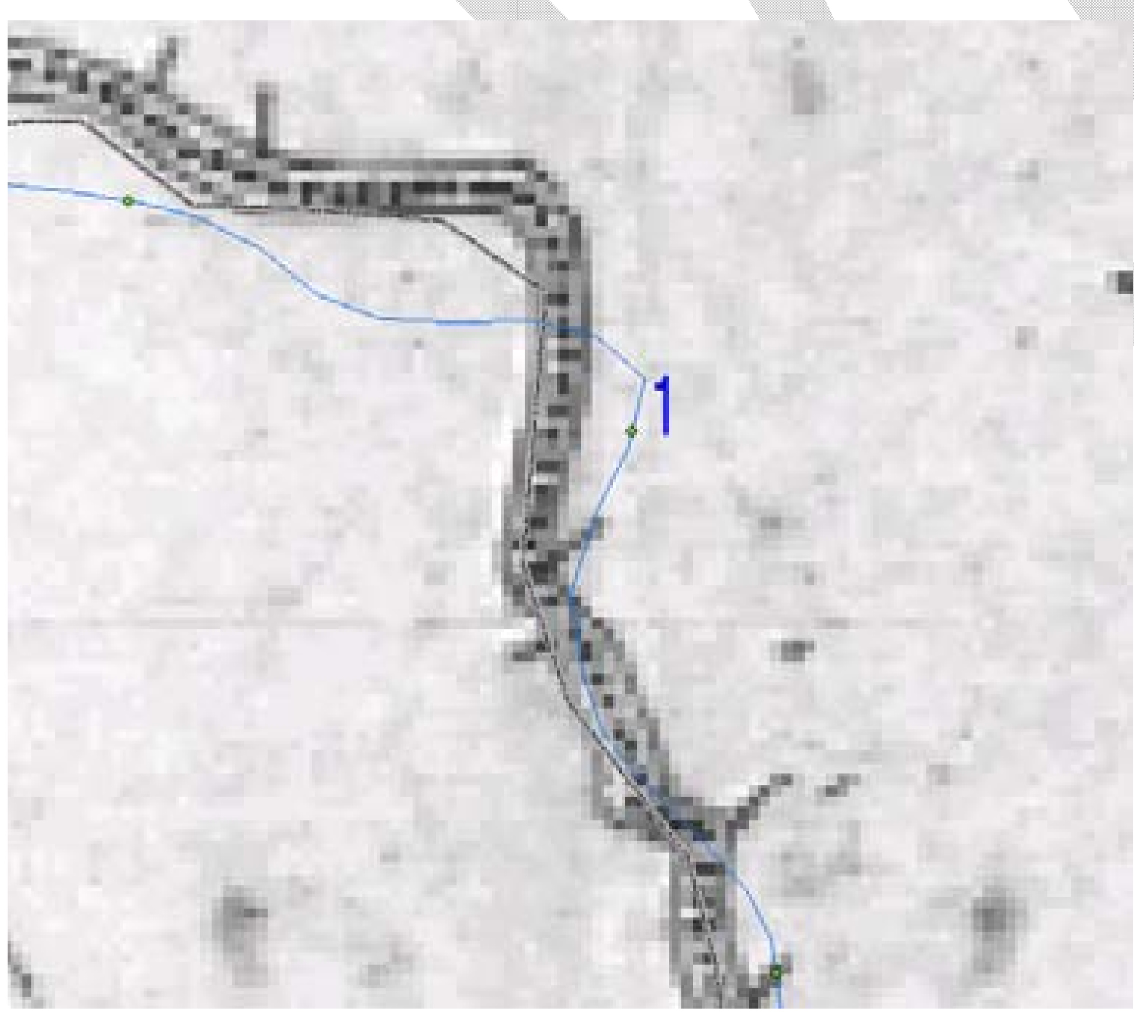


Figure 18: Historical context

The user selects the point by using the identify button under the selection toolbox. Once the user clicks the typology point they are given the option to perform a dRAT or to view a dRAT previously performed at the point.

When the operator chooses to perform a dRAT they are presented with the following dialogue:

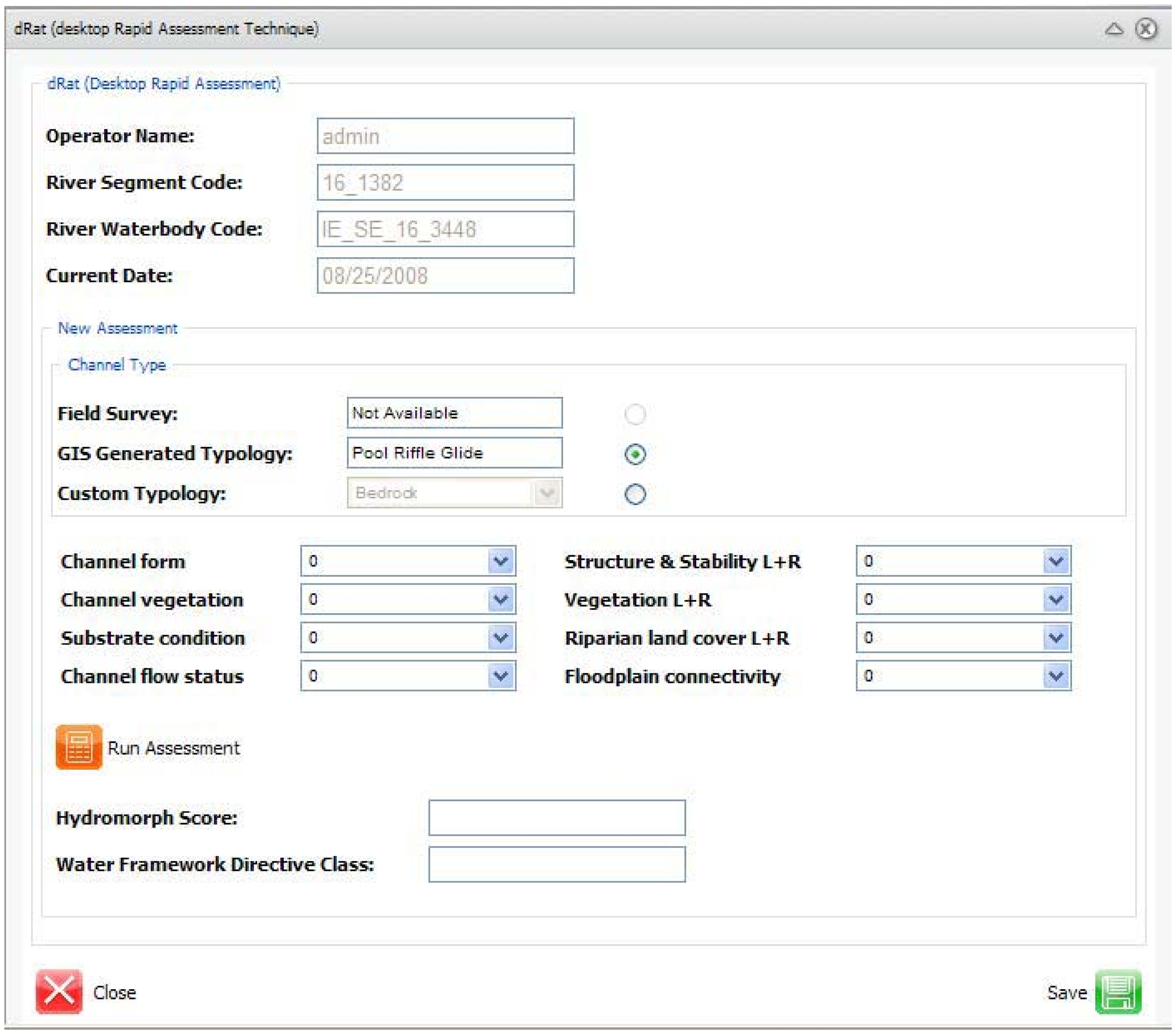
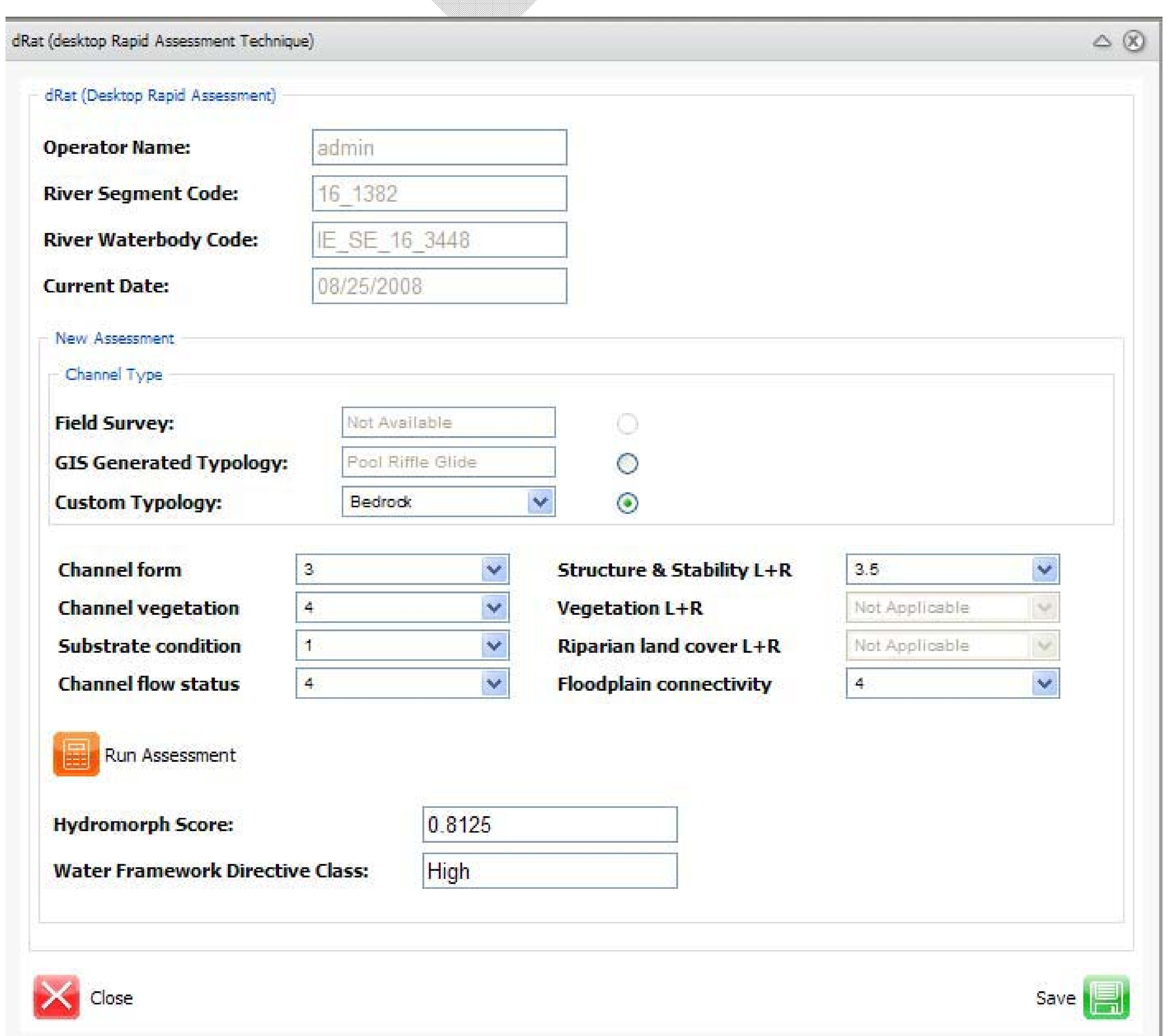


Figure 19: dRAT dialogue box

Under channel type if a field survey has been conducted at the point the typology will be picked up, if this type is unavailable the GIS generated typology is defaulted to *(see section 5)* however the user has the ability to assign their own custom typology to the point if they do not agree with this.
In the example in figure 9.24 the operator has chosen a custom typology of Bedrock (note that Vegetation L+R and Riparian land cover L+R are greyed out not applicable similar to the fieldsheet).

Channel form, channel vegetation, substrate condition and channel flow status are all given a value of 0,1,2,3 or 4.
Structure & stability L+R, Vegetation L+R, Riparian land cover L+R and Floodplain connectivity can all be given a score of 0, 0.5, 1, 1.5, 2, 2.5, 3, 3.5 or 4



Once the parameters have been entered the user clicks Run Assessment and a Hydromorph Score and a WFD class is assigned based on the inputs.

The user can then either close the dialogue box (without saving their inputs) or the user can click save and will be available for viewing by other morphology tool users.

Points that already have an existing dRAT have symbology showing that a dRAT has been done at that point. This data can be reported back by clicking the dRAT History button after querying the point. All previous dRAT's done will be displayed.

Figure 20: Carrying out a dRAT

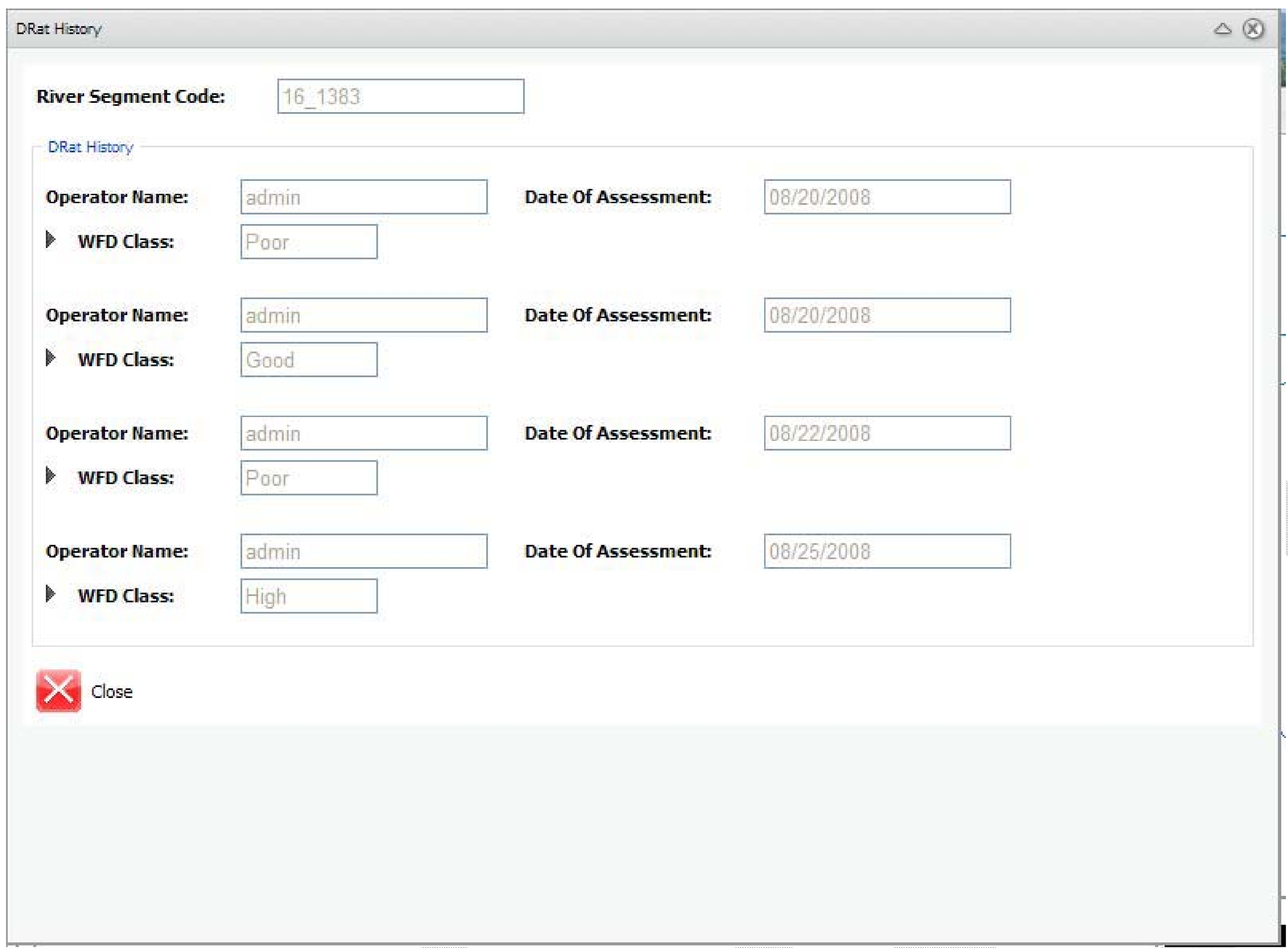


Figure 21: dRAT history report

3.0 Rerunning a Risk Score

The morphology tool has the ability to rerun a morphology risk assessment for any waterbody in the country. To do this the operator selects the identify icon and clicks on any waterbody in the country. The attributes of the waterbody will be displayed along with two options: 1: To view the risk assessment history of the waterbody and 2: To recalculate the risk score based on new parameters.

1: Risk assessment history report

The history report (see figure 9.26) has three sections at the top in yellow is the current risk assessment performed in 2008. In green directly below is the risk assessment completed in 2005 as part of Article 5 reporting. Values below this are operator recalculated risk scores. When an operator recalculates a risk score for a waterbody this score does not become the current risk score.

To find out more detailed information about the risk assessments done on the waterbody click on the black triangle immediately to the left of the Risk Score text:

Risk Score:

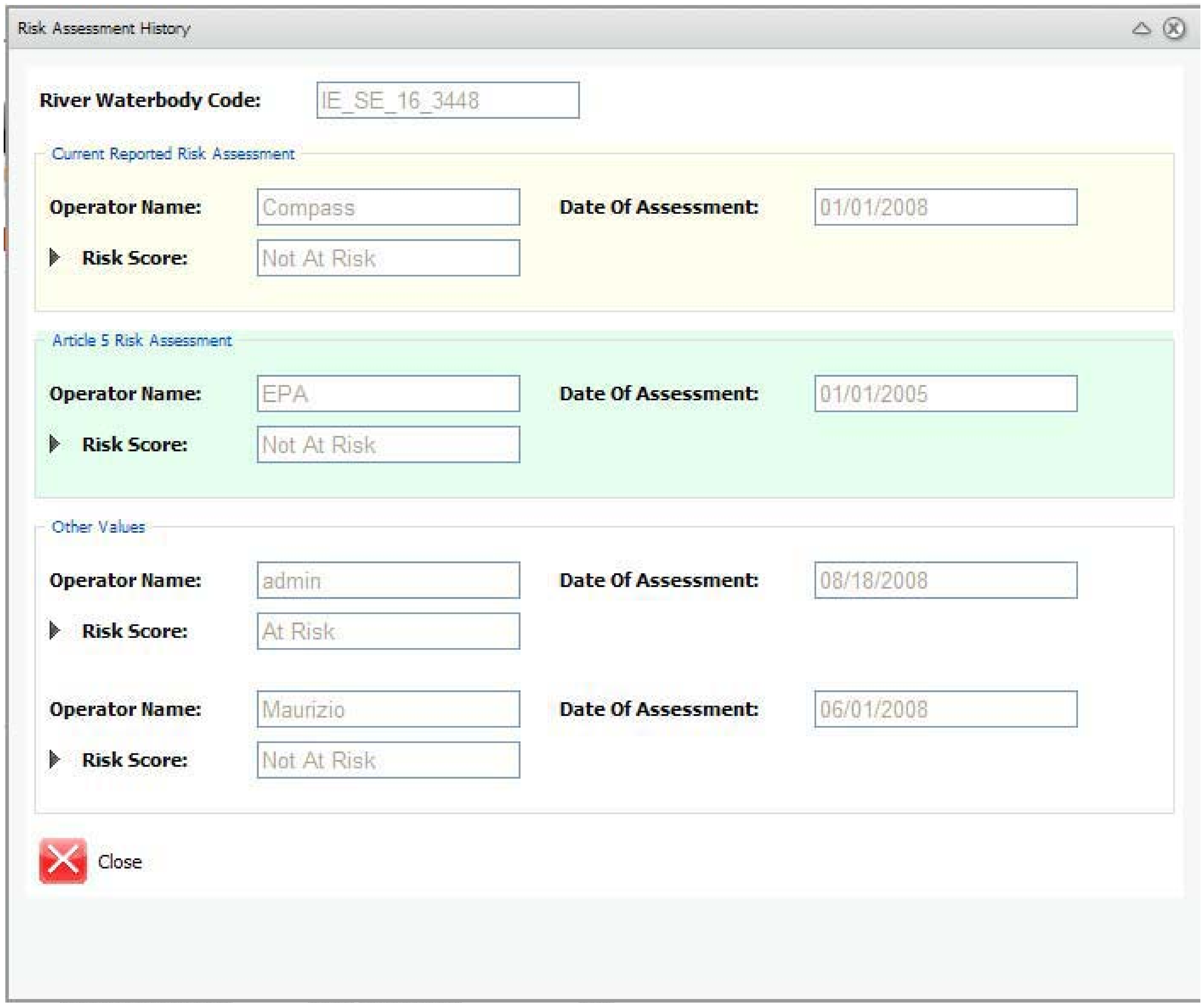


Figure 22: Risk assessment history report

To recalculate a risk score click the identify icon click the desired waterbody then select Calculate Risk Score.

In the dialogue that opens (figure 22) it is possible to enter new values for embankments and channelisation. The current scores are also presented, as a percentage of the waterbody and as a value. If either embankment or channelisation go over their respective thresholds (15% and 50%) then the waterbody is deemed to be at risk. The operator only has to enter the total length of embankment/channelisation as a new value (the percentage is automatically calculated) and click recalculate risk score to see what effects addition or removal of embankments/channels would have. In the example below an additional 25m of embankment has been added but 200m of channelisation has been removed however the addition of embankment pushes embankment past it's threshold causing the waterbody to be considered At Risk.

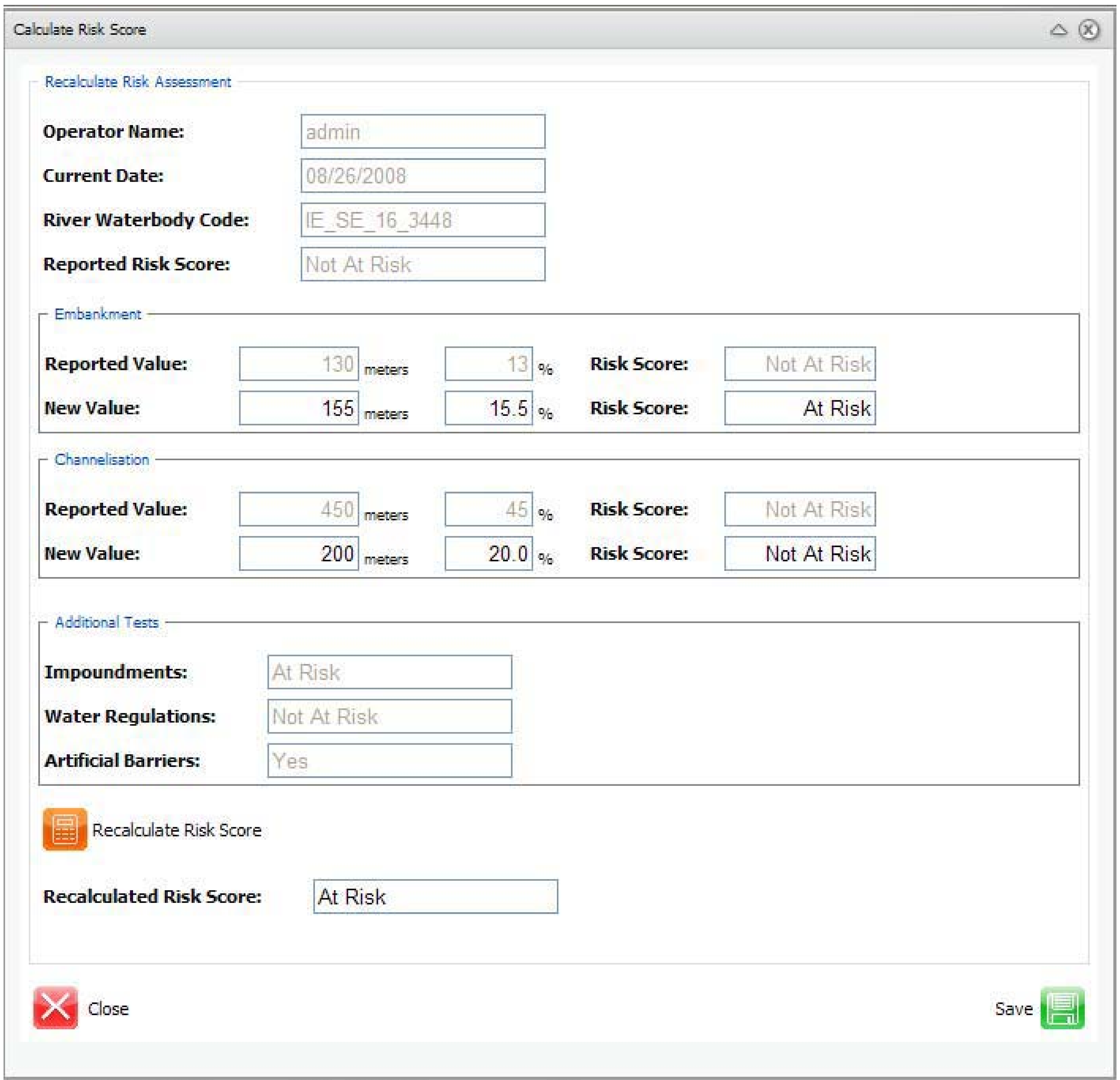


Figure 23: Recalculate risk score

Additional tests are reported:

- Impoundments and Water Regulations are reported but they do not affect the risk score.
- Artificial barriers: It is reported if the waterbody is upstream of an artificial barrier.

It is possible to save the risk score or to close without saving. If the risk score is saved then the operators recalculations will be visible to all other users of the system.

Appendix V

Lake Hydromorphology

Riparian Vegetation Loss – Footprint 7 for Killinure assessment

The land use and alteration of the Riparian zone around the lake shore can be assessed using the high the high resolution aerial imagery. This allows the assessment of the percentage of each land type area for the Riparian zone to give a good indication of the activity footprint for the lake.

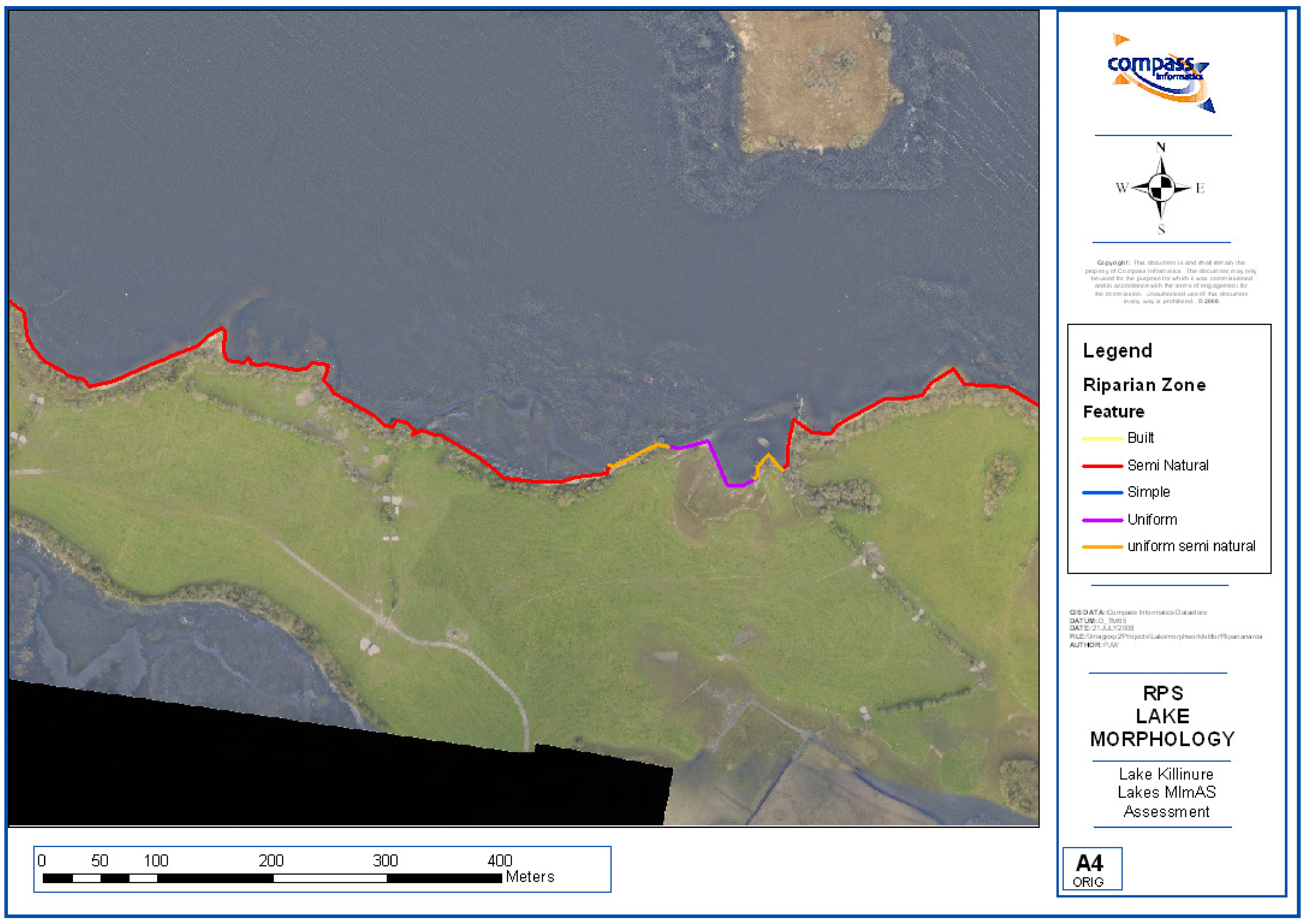


Figure 1: Area of Killinure coast line assessed for Riparian Zone

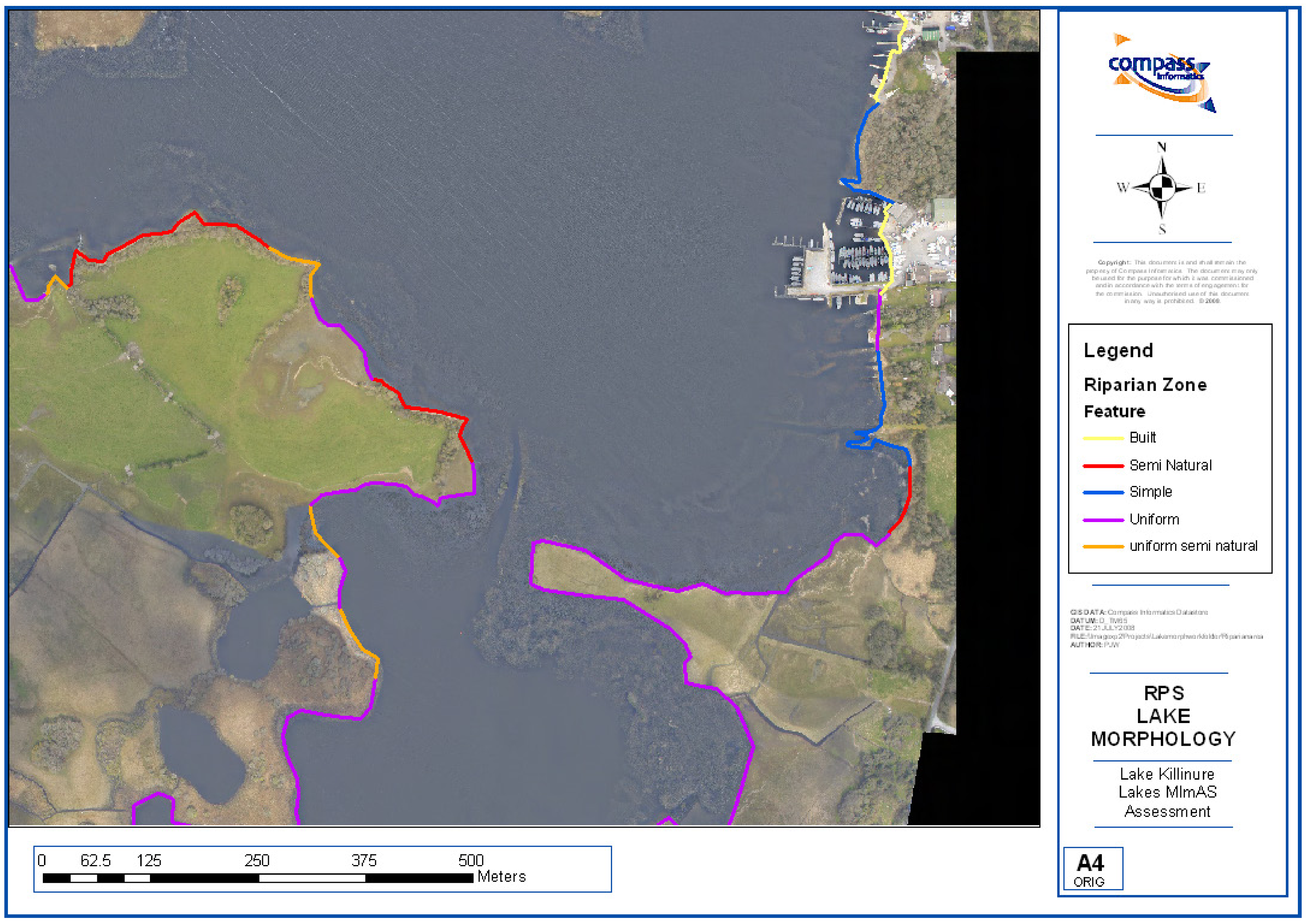


Figure 2: Area of Killinure coast line assessed for Riparian Zone

Shore reinforcement – Hard bank engineering. 12.27% for Killinure assessment.

The areas of hard engineering can be assessed using the high resolution aerial photography to a very good extent. Most of these shoreline areas can be discerned from above quite clearly allowing the digitization of these areas for the length to be assessed and then a percentage of this to be calculated relevant to the overall length of the perimeter of the lake.

Figure 3: Area of Killinure coast line assessed for Hard bank engineering

Shore reinforcement – Soft bank reinforcement. 4.04% for Killinure assessment

The assessment is the same approach as that for hard bank engineering using the high resolution aerial photography. The areas of soft bank reinforcement are not as easily resolved discerned from the aerial imagery but some reasonable indications can be discerned.

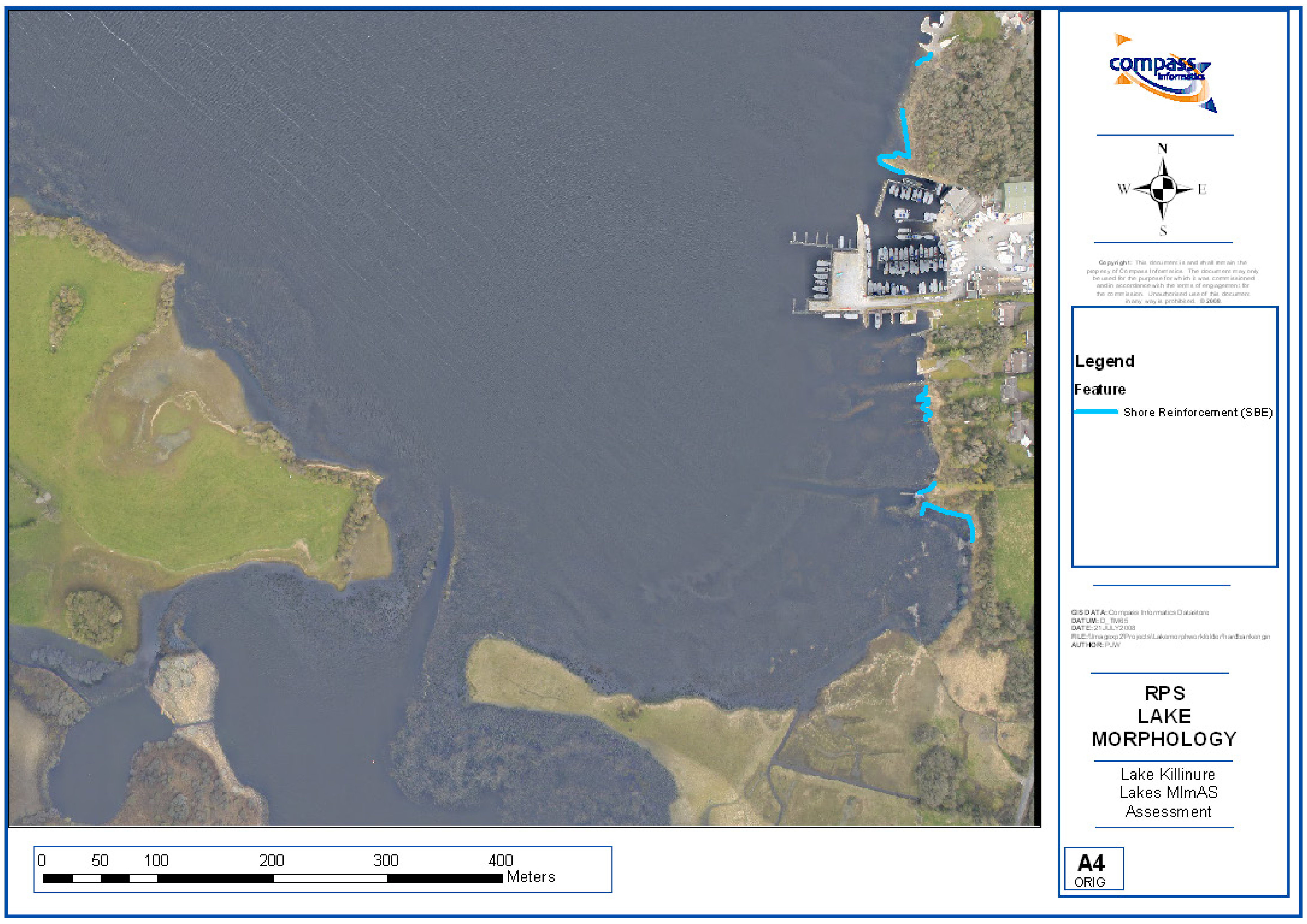


Figure 4.4: Area of Killinure coast line assessed for Soft bank engineering

Flood Embankments - None of these features where discerned from the aerial imagery for Killinure although in other lake studies certain types of these features could be assessed using RS/GIS techniques.

Causeway - Causeways can be easily discerned from the high resolution aerial imagery. There assessment is based on there projection out into the lake as a percentage of the perimeter of the lake. In the case of Killinure the causeway in the area assessed divides the assessed area from another lake area rather than projecting into the lake.

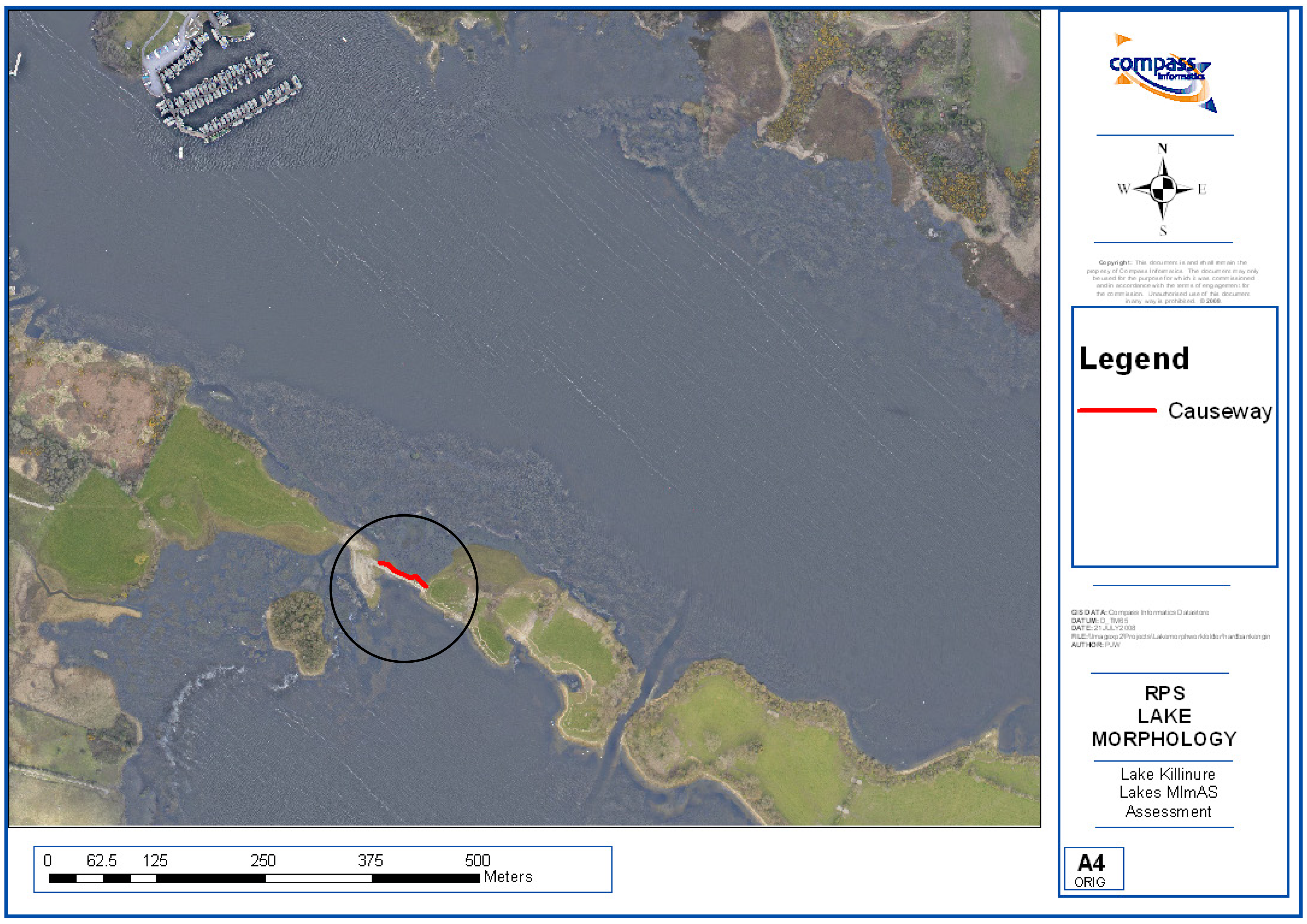


Figure 4.5: Area of Killinure coast line showing causeway

Flow and Sediment Control Structures – 5.1% for Killinure assessment
These structures can be assessed using the high resolution aerial photography to digitise lines representing the projection of the structures into the lake. The overall length is then found as a percentage of the perimeter of the lake. Some supplementation by fieldwork might be required for confirmation but in general the RS/GIS approach can give a good measurement of the features.

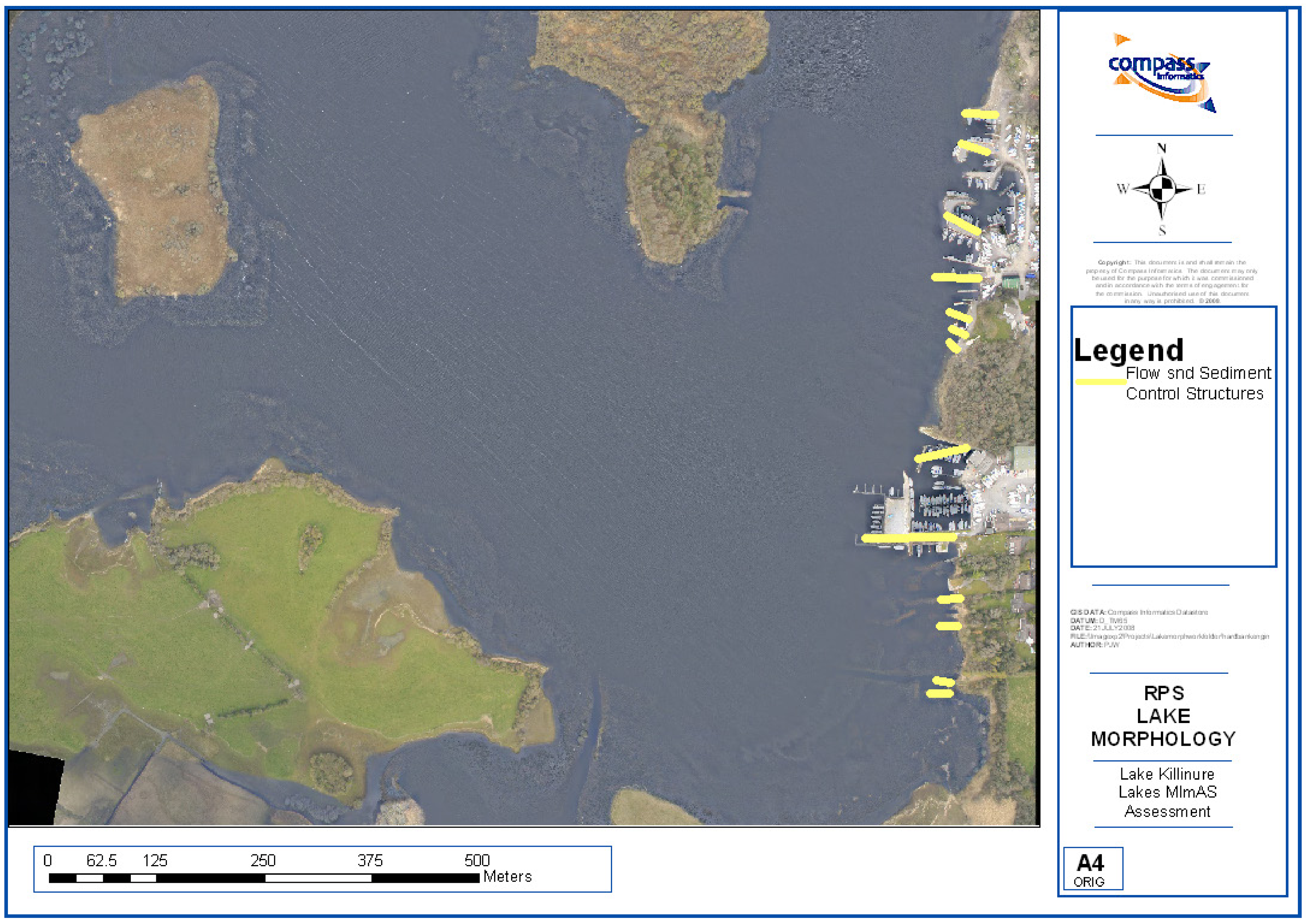


Figure 4.6 Area of Killinure coast line showing flow and sediment control structures

Piled Structures – 3.31% for Killinure assessment

These structures are assessed using the same method as the flow and sediment control structures. The high resolution aerial photography shows these structures very clearly and they are assessed very well using this method.

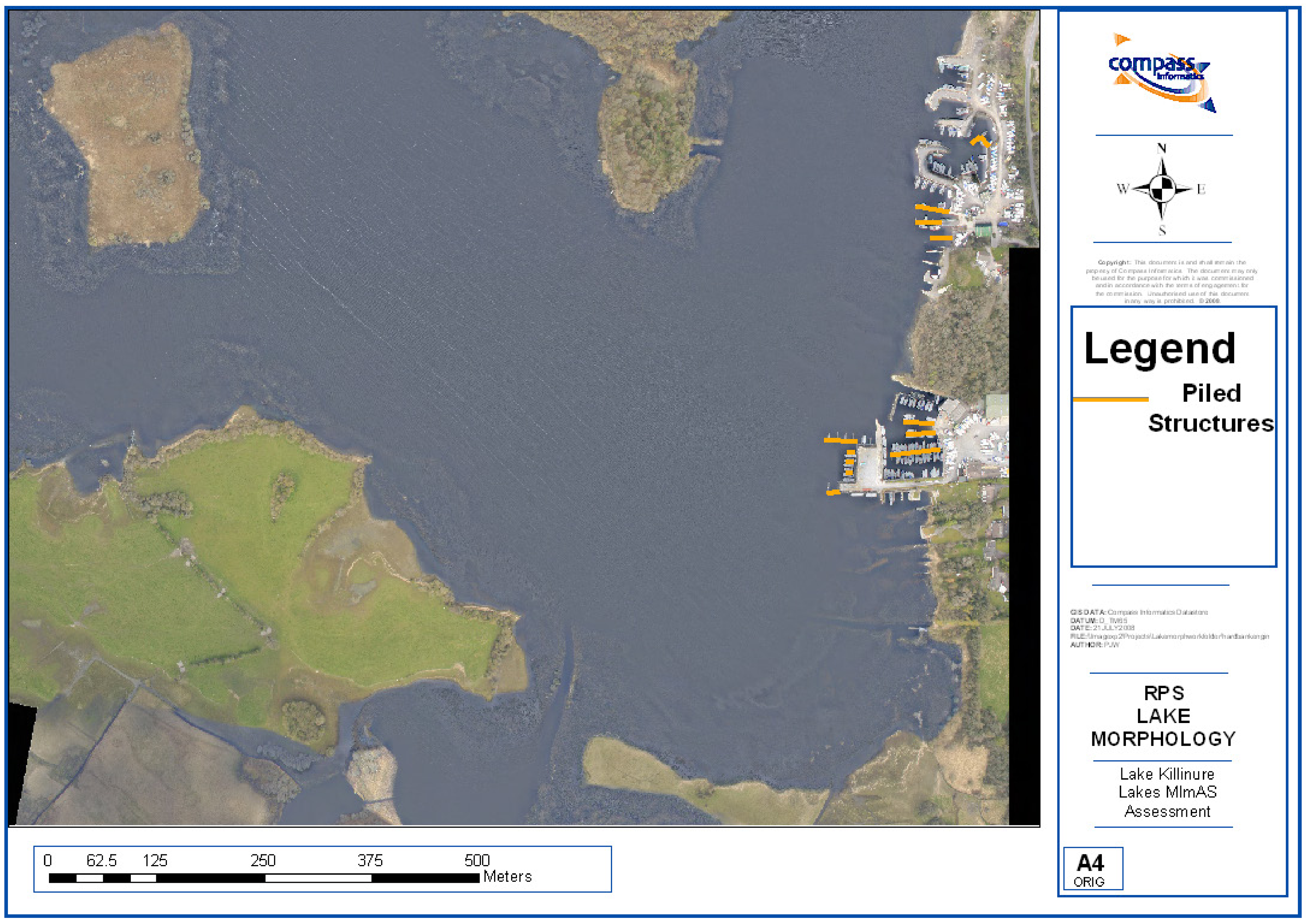


Figure 4.7 Area of Killinure coast line showing piled structures

Moorings (High Density) – 1.48% for Killinure assesment
High density moorings can be assessed using the high resolution aerial imagery. This is done by digitising a polygon to assess the area of the mooring and calculating the total area of moorings as a percentage of the overall lake area.

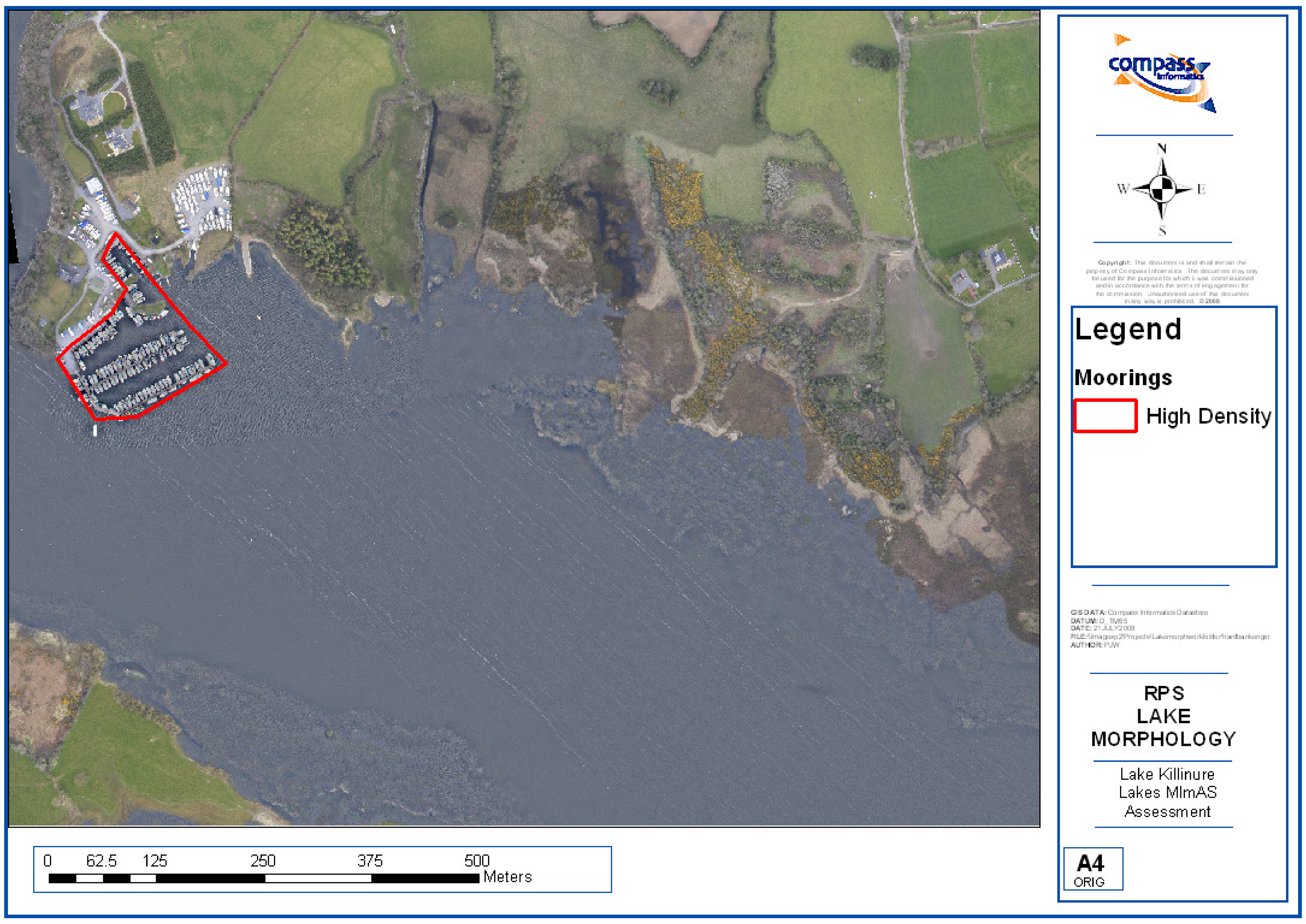


Figure 4.8: Area of Killinure coast line showing area of high density mooring

Outfalls and off-takes - None of these features where discerned from the aerial imagery for Killinure although in other lake studies certain types of these features could be assessed using RS/GIS techniques.

Sediment extraction – 0.94% for Killinure assessment
For Killinure areas of sediment extraction can be assessed using the aerial photography and polygons created to measure the area. From the this the area as a percentage of the overall area is calculated. For deeper lakes and other areas within the lake supplementation with field work might be needed

Figure 4.9: Area of Killinure coast line showing areas of sediment extraction

Dumping – 0.19% for Killinure assessment
Areas of dumping are assessed in the same way as the sediment extraction based on area of dumping as a percentage of the overall lake area. For Killinure various areas of dumping can be discerned from the aerial imagery but supplementation by fieldwork would be needed.

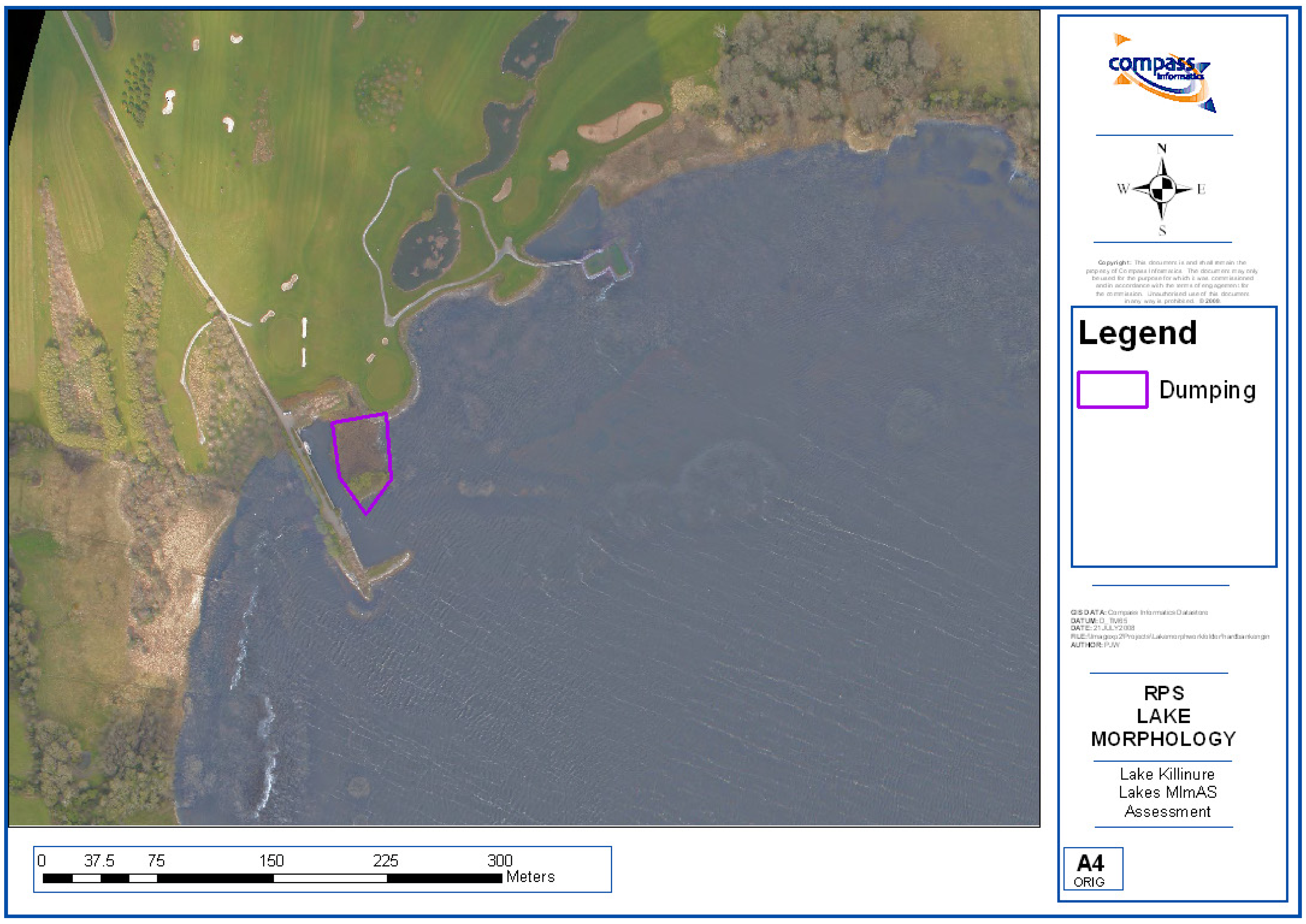


Figure 4.10: Area of Killinure coast line showing area of sediment dumping

Aquaculture – None of these features where discerned from the aerial imagery for Killinure although in other lake studies certain types of these features could be assessed using RS/GIS techniques.

Shore-based recreation – This will have to be assessed by other means than RS/GIS.

Boat Traffic and water sports – Activity footprint 5 for Killinure assessment
An indication of the level can be discerned from the aerial imagery but fieldwork would be required.

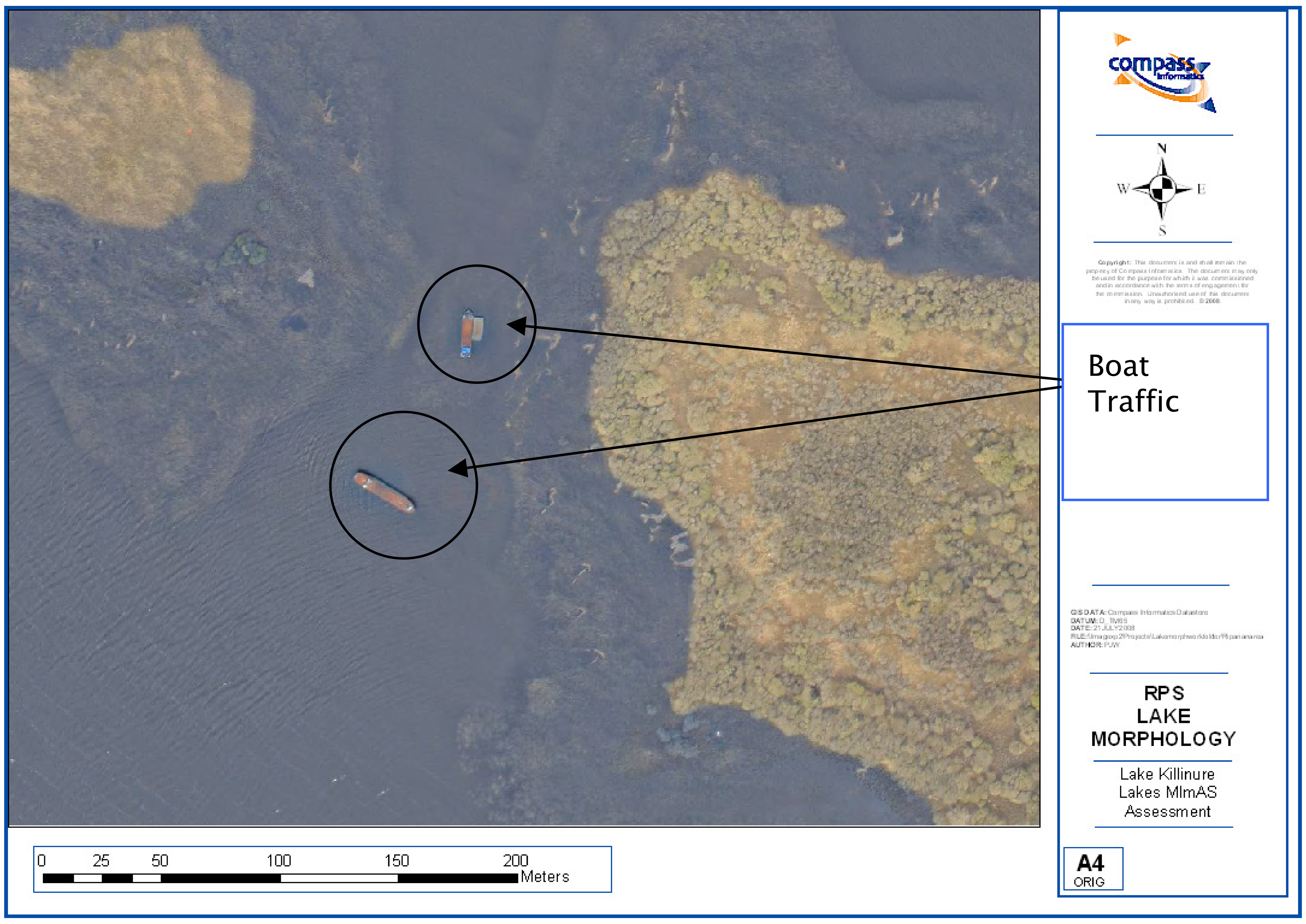


Figure 4.11: Area of Killinure showing indicators of boat traffic

Appendix VI:
Lake Hydromorphology
Complete list of Lakes with Bathymetric Data

Data Source	Lake Name	Data format
A. Wemaere (PHD)	Atedaun	unknown
A. Wemaere (PHD)	Ballyallia	unknown
A. Wemaere (PHD)	Ballybeg	unknown
A. Wemaere (PHD)	Burke	unknown
A. Wemaere (PHD)	Cloonmackan	unknown
A. Wemaere (PHD)	Cloonsnaghta	unknown
A. Wemaere (PHD)	Cullaunyheeda	unknown
A. Wemaere (PHD)	Doon North	unknown
A. Wemaere (PHD)	Gortglass	unknown
A. Wemaere (PHD)	Inchichronan	unknown
A. Wemaere (PHD)	Killone	unknown
A. Wemaere (PHD)	Knockalough	unknown
A. Wemaere (PHD)	Knockerra	unknown
A. Wemaere (PHD)	Muckanagh	unknown
A. Wemaere (PHD)	Naminna	unknown
Allott, 1986	Black	Various
CFB	Aderry	Excel: easting, northing, z
CFB	Akibbon	Excel: easting, northing, z
CFB	Altan	Excel: easting, northing, z
CFB	Altercan	Excel: easting, northing, z
CFB	Anna	Excel: easting, northing, z
CFB	Anure	Excel: easting, northing, z
CFB	Auva	Excel: easting, northing, z
CFB	Avehy	Excel: easting, northing, z
CFB	Bawn	Excel: easting, northing, z
CFB	Columbkille	Excel: easting, northing, z
CFB	Corglass	Excel: easting, northing, z
CFB	Derg	Excel: easting, northing, z
CFB	Derrybrick	Excel: easting, northing, z
CFB	Dunlewy	Excel: easting, northing, z
CFB	Dunragh	Excel: easting, northing, z
CFB	Eske	Excel: easting, northing, z
CFB	Glen	Excel: easting, northing, z
CFB	Gortnawinny	Excel: easting, northing, z
CFB	Mardal	Excel: easting, northing, z
CFB	Meela	Excel: easting, northing, z
CFB	Naback	Excel: easting, northing, z
CFB	New	Excel: easting, northing, z
CFB	Sessiagh	Excel: easting, northing, z
CFB	Shivnagh	Excel: easting, northing, z
CFB	Toome	Excel: easting, northing, z
CFB	Town	Excel: easting, northing, z

CFB	Waskel	Excel: easting, northing, z
COMPASS	Ballycullinan	ESRI grid
COMPASS	Ballyquirke	ESRI grid
COMPASS	Bray Lower	ESRI grid
COMPASS	Bunny	ESRI grid
COMPASS	Caragh	ESRI grid
COMPASS	Cullaun	ESRI grid
COMPASS	Dan	ESRI grid
COMPASS	Doolough	ESRI grid
COMPASS	Dromore	ESRI grid
COMPASS	Easky	ESRI grid
COMPASS	Egish	ESRI grid
COMPASS	Feeagh	ESRI grid
COMPASS	Gara lower (S)	ESRI grid
COMPASS	Gowna	ESRI grid
COMPASS	Graney	ESRI grid
COMPASS	Inchiquin	ESRI grid
COMPASS	Leane	ESRI grid
COMPASS	Lene	ESRI grid
COMPASS	Lettercraffroe	ESRI grid
COMPASS	Lickeen	ESRI grid
COMPASS	Maumwee	ESRI grid
COMPASS	Moher	ESRI grid
COMPASS	Muckno	ESRI grid
COMPASS	Muckross	ESRI grid
COMPASS	Mullagh	ESRI grid
COMPASS	Oughter	ESRI grid
COMPASS	Owel	ESRI grid
COMPASS	Pollaphuca	ESRI grid
COMPASS	Ramor	ESRI grid
COMPASS	Rea	ESRI grid
COMPASS	Talt	ESRI grid
Fishcounter	Acoose	unknown
Fishcounter	Callow Lake	unknown
Fishcounter	Cloonaghlin	unknown
Fishcounter	Cloone	unknown
Fishcounter	Coomsaharn	unknown
Fishcounter	Coumshingaun	unknown
Fishcounter	Currane	unknown
Fishcounter	Cutra	unknown
Fishcounter	Inchiquin 2	unknown
INSIGHT	Annaghmore	unknown
INSIGHT	Arderry	unknown
INSIGHT	Ballynakill	unknown
INSIGHT	Bane	unknown
INSIGHT	Barfinnihy	unknown
INSIGHT	Barra	unknown
INSIGHT	Crans	unknown

INSIGHT	Dunglow	unknown
INSIGHT	Fad (East)	unknown
INSIGHT	Fee	unknown
INSIGHT	Keel (Rosses)	unknown
INSIGHT	Kiltooris	unknown
INSIGHT	Kindrum	unknown
INSIGHT	Kylemore	unknown
INSIGHT	Nahasleam	unknown
INSIGHT	Nambrackkeagh	unknown
INSIGHT	Naminn	unknown
INSIGHT	O'Flynn	unknown
INSIGHT	Oorid	unknown
INSIGHT	Shindilla	unknown
INSIGHT	Sillan	unknown
INSIGHT	Tay	unknown
INSIGHT	Upper	unknown
INSIGHT	Veagh	unknown
Seymore, 1939	Bray Upper	Various
Seymore, 1939	Glendalough Upper	Various
SWRBD	Adoolig	GRID and csv
SWRBD	Allua	GRID and csv
SWRBD	Anscaul	GRID and csv
SWRBD	Auger	GRID and csv
SWRBD	Ballin	GRID and csv
SWRBD	Ballintleave	GRID and csv
SWRBD	Barley	GRID and csv
SWRBD	Beg	GRID and csv
SWRBD	Bhearna_n_g	GRID and csv
SWRBD	Black	GRID and csv
SWRBD	Bofinna	GRID and csv
SWRBD	Brin	GRID and csv
SWRBD	Callee	GRID and csv
SWRBD	Cappanalea	GRID and csv
SWRBD	Cloan	GRID and csv
SWRBD	Clogher_E	GRID and csv
SWRBD	Clogher_W	GRID and csv
SWRBD	Cloonee_Middle	GRID and csv
SWRBD	Cloonee_Upper	GRID and csv
SWRBD	Commeathcun	GRID and csv
SWRBD	Commeeneragh	GRID and csv
SWRBD	Coolkellure	GRID and csv
SWRBD	Coomaglaslaw	GRID and csv
SWRBD	Coomavanniha	GRID and csv
SWRBD	Coomclogheran	GRID and csv
SWRBD	Coomloughra	GRID and csv
SWRBD	Coomnacronia	GRID and csv
SWRBD	Coomrooanig	GRID and csv
SWRBD	Crohane	GRID and csv

SWRBD	Cummeenapeast	GRID and csv
SWRBD	Cummeenduff	GRID and csv
SWRBD	Cummenadilur	GRID and csv
SWRBD	Cummer	GRID and csv
SWRBD	Cummernamuck	GRID and csv
SWRBD	Curraghlicky	GRID and csv
SWRBD	Curraghmore	GRID and csv
SWRBD	Derreenadarod	GRID and csv
SWRBD	Derriana	GRID and csv
SWRBD	Devil's Punchbowl	GRID and csv
SWRBD	Doo	GRID and csv
SWRBD	Dromtine	GRID and csv
SWRBD	Duff	GRID and csv
SWRBD	Eagher	GRID and csv
SWRBD	Eagles	GRID and csv
SWRBD	Eirk	GRID and csv
SWRBD	Erhohgh	GRID and csv
SWRBD	Fadda	GRID and csv
SWRBD	Garagarry	GRID and csv
SWRBD	Glanmore	GRID and csv
SWRBD	Glannafreagha	GRID and csv
SWRBD	Glas	GRID and csv
SWRBD	Glenbeg	GRID and csv
SWRBD	Glenkeel	GRID and csv
SWRBD	Gouragh	GRID and csv
SWRBD	Gowlan	GRID and csv
SWRBD	Guitane	GRID and csv
SWRBD	Iskanamacteery	GRID and csv
SWRBD	Isknaghiny	GRID and csv
SWRBD	Long_Range	GRID and csv
SWRBD	Looscaunagh	GRID and csv
SWRBD	Managh	GRID and csv
SWRBD	Moredoolig	GRID and csv
SWRBD	Mount_Eagle	GRID and csv
SWRBD	Nakirka	GRID and csv
SWRBD	Nambrackdar_N	GRID and csv
SWRBD	Nambrackdar_S	GRID and csv
SWRBD	Namona	GRID and csv
SWRBD	Napeasta	GRID and csv
SWRBD	Reagh	GRID and csv
SWRBD	Reagh_W	GRID and csv
SWRBD	Shanoge	GRID and csv
SWRBD	Skeagh	GRID and csv
SWRBD	Slievenashask	GRID and csv
SWRBD	Tooreen	GRID and csv
SWRBD	Tooreenbog	GRID and csv
Toner, 1979	Key	Various
WRBD_NW	Acorry	Surfer

WRBD_NW	Acorrymore	Surfer
WRBD_NW	Anarry	Surfer
WRBD_NW	Ard	Surfer
WRBD_NW	Arkedy	Surfer
WRBD_NW	Ballinlough	Surfer
WRBD_NW	Belhavel	Surfer
WRBD_NW	Bellanascarrow	Surfer
WRBD_NW	Caheer	Surfer
WRBD_NW	Callow_Lower	Surfer
WRBD_NW	Callow_Upper	Surfer
WRBD_NW	Carrowlustia	Surfer
WRBD_NW	Carrowmore	Surfer
WRBD_NW	Clogher	Surfer
WRBD_NW	Corryloughaphuil_Lower	Surfer
WRBD_NW	Corryloughaphuil_Upper	Surfer
WRBD_NW	Cregganmore	Surfer
WRBD_NW	Cross	Surfer
WRBD_NW	Dahybaun	Surfer
WRBD_NW	Dargan	Surfer
WRBD_NW	Doo	Surfer
WRBD_NW	Doobehy	Surfer
WRBD_NW	Easky	Surfer
WRBD_NW	Glenade	Surfer
WRBD_NW	Glencar	Surfer
WRBD_NW	Holan	Surfer
WRBD_NW	Islandeady	Surfer
WRBD_NW	Labe	Surfer
WRBD_NW	Lannagh_Lower	Surfer
WRBD_NW	Lannagh_Upper	Surfer
WRBD_NW	Nacapduff	Surfer
WRBD_NW	Scardaun	Surfer
WRBD_NW	Talt	Surfer
WRBD_NW	Templehouse	Surfer
WRBD_NW	Tullyvellia	Surfer
WRBD_NW	Washpool	Surfer
WRBD_WRFB	Adooraun	Surfer
WRBD_WRFB	Adrehid	Surfer
WRBD_WRFB	Agraffard	Surfer
WRBD_WRFB	Aille	Surfer
WRBD_WRFB	Alligan	Surfer
WRBD_WRFB	An Damba	Surfer
WRBD_WRFB	Anillaun	Surfer
WRBD_WRFB	Athola	Surfer
WRBD_WRFB	Athry	Surfer
WRBD_WRFB	Aughawoolia	Surfer
WRBD_WRFB	Aunfree	Surfer
WRBD_WRFB	Aunierin	Surfer
WRBD_WRFB	Avally	Surfer

WRBD_WRFB	Awillia	Surfer
WRBD_WRFB	Ballinafad	Surfer
WRBD_WRFB	Ballybwee	Surfer
WRBD_WRFB	Barrowen	Surfer
WRBD_WRFB	Beaghcauneen	Surfer
WRBD_WRFB	Bola	Surfer
WRBD_WRFB	Boliska	Surfer
WRBD_WRFB	Bollard	Surfer
WRBD_WRFB	Cam South	Surfer
WRBD_WRFB	Cam South	Surfer
WRBD_WRFB	Camus	Surfer
WRBD_WRFB	Chluain Toipin	Surfer
WRBD_WRFB	Chluain Toipin East	Surfer
WRBD_WRFB	Clogherkinnalocha	Surfer
WRBD_WRFB	Cloonagat	Surfer
WRBD_WRFB	Conga	Surfer
WRBD_WRFB	Coolagh	Surfer
WRBD_WRFB	Courhoor	Surfer
WRBD_WRFB	Curreel	Surfer
WRBD_WRFB	Derreen	Surfer
WRBD_WRFB	Derrew	Surfer
WRBD_WRFB	Derrycunlagh	Surfer
WRBD_WRFB	Derrycunlaghbeg	Surfer
WRBD_WRFB	Derrylea	Surfer
WRBD_WRFB	Doonloughan	Surfer
WRBD_WRFB	Enask	Surfer
WRBD_WRFB	Fadda	Surfer
WRBD_WRFB	Fin	Surfer
WRBD_WRFB	Halfcarton	Surfer
WRBD_WRFB	Illauntrasna	Surfer
WRBD_WRFB	Inverbeg	Surfer
WRBD_WRFB	Invermore	Surfer
WRBD_WRFB	Keamnacully	Surfer
WRBD_WRFB	Kiltullagh	Surfer
WRBD_WRFB	Knappaghbeg	Surfer
WRBD_WRFB	Knocka	Surfer
WRBD_WRFB	Knockaunawaddy	Surfer
WRBD_WRFB	Leacrach	Surfer
WRBD_WRFB	Lee	Surfer
WRBD_WRFB	Lehanagh	Surfer
WRBD_WRFB	Lettercraffroe	Surfer
WRBD_WRFB	Lough Fauwna	Surfer
WRBD_WRFB	Loughaphreaghaun	Surfer
WRBD_WRFB	Loughaunalyer	Surfer
WRBD_WRFB	Loughaunarow	Surfer
WRBD_WRFB	Loughaunbeg	Surfer
WRBD_WRFB	Loughaunillaunmore	Surfer
WRBD_WRFB	Loughaunore	Surfer

WRBD_WRFB	Loughaunwillan	Surfer
WRBD_WRFB	Loughyvangan	Surfer
WRBD_WRFB	Maumeen	Surfer
WRBD_WRFB	Maumwee	Surfer
WRBD_WRFB	Moher	Surfer
WRBD_WRFB	Muck	Surfer
WRBD_WRFB	Aconeera	Surfer
WRBD_WRFB	Na Cuige Rua	Surfer
WRBD_WRFB	Na gCaor	Surfer
WRBD_WRFB	Nabrucka	Surfer
WRBD_WRFB	Nacarrigeen	Surfer
WRBD_WRFB	Nacorrossaunbeg	Surfer
WRBD_WRFB	Nafurnace	Surfer
WRBD_WRFB	Nahaltora	Surfer
WRBD_WRFB	Nahasleam	Surfer
WRBD_WRFB	Nahillion	Surfer
WRBD_WRFB	Nambrackeagh	Surfer
WRBD_WRFB	Nambrackmore	Surfer
WRBD_WRFB	Nambrackmore East	Surfer
WRBD_WRFB	Nanaugh	Surfer
WRBD_WRFB	nArd Doiriu	Surfer
WRBD_WRFB	Naskeha	Surfer
WRBD_WRFB	Necorrussaun	Surfer
WRBD_WRFB	Nuala	Surfer
WRBD_WRFB	Rusheenduff	Surfer
WRBD_WRFB	Shannagreena	Surfer
WRBD_WRFB	Shliabh	Surfer
WRBD_WRFB	Tawnagh	Surfer
WRBD_WRFB	Tawnyard	Surfer
WRBD_WRFB	Thulaigh	Surfer
WRBD_WRFB	Truska	Surfer
WRBD_WRFB	Tullaghalaher	Surfer
WRBD_WRFB	Tully	Surfer
WRBD_WRFB	Tult East	Surfer
WRBD_WRFB	Uggabeg	Surfer
WRBD_WRFB	Uggamore	Surfer
WRBD_WRFB	Usk	Surfer

Appendix VII

Compass GeoFOTO

A Canon EOS-5D digital camera (13MP, 24mm lens) is used to capture aerial imagery, typically between 2500' and 3500' AGL together with nominal GPS scene centres. Imagery is collected along track with 60% to 80% overlap and across track 30% to 60%. These are collected over preplanned survey rivers. For postprocessing it is necessary to always have forward and sideward overlap to be able to generate a seamless river image. After the flights we are left with a GPS tracklog, an image taken every two seconds and an ESRI shapefile. The shapefile records image names and lat/long/altitude for each Attached is a zip (FTP listed below) containing test images, gps file and associated ESRI shape file (dbf can be opened in MS Excel) together with a camera calibration file for the EOS-5D.

The ESRI shape file (dbf) has a record for each one of the images, listing nominal Lat/Lon/Alt for scene centres, aircraft heading image name etc.
From these data inputs Compass' image processing partners output a seamless mosaic, which is radiometrically balanced and georectied to Irish National Grid projection with a typical resolution of 15-25cm.