Environmental RTDI Programme 2000–2006

WATER FRAMEWORK DIRECTIVE – A Desk Study to Determine a Methodology for the Monitoring of the 'Morphological Condition' of Irish Rivers (2002-W-DS-9-M1)

Synthesis Report

(Main Report available for download on www.epa.ie/EnvironmentalResearch/ReportsOutputs)

Prepared for the Environmental Protection Agency

by

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1 Introduction

This study was funded by the Environmental Protection Agency (EPA) under contract no. 2002-W-DS-9-M1 of the Environmental Research Technology and Development Initiative (ERTDI) sub-measure of the Productive Sector Operational Programme of the National Development Plan 2000–2006. This ERTDI programme addresses priority areas necessary for the implementation of the Water Framework Directive (WFD) in Ireland.

The WFD establishes a comprehensive basis for the management of water resources in the EU. The priorities of the WFD are to prevent further deterioration of, and to protect and enhance the status of, water resources and to promote sustainable water use based on long-term protection of these resources.

The key objective of the WFD is to attain, or maintain the existing, good status in all unmodified waters by 2015. In the case of surface waters, good status refers to biological, chemical and hydromorphological aspects of water quality. Good status is assigned to situations where conditions show only minor changes compared to the natural state of the waterbody. The assessment of hydromorphological features is a new concept in the context of monitoring aquatic conditions and work is needed to devise a scheme for such an assessment in Irish streams and rivers.

The objective of this desk study is to develop a practical methodology for the assessment of river morphological conditions in Irish rivers, which takes account of the guidance from the WFD implementation activities of the European Commission, national expertise and other forms of international best practice. The analysis undertaken includes a review of 29 different river morphology (habitat) assessment systems and consultations with Irish practitioners in the field.

2 Study Findings

Following the review and consultation process it is recommended that the physical assessment protocol for the assessment of the morphological condition of Irish rivers should be based on the AUSRIVAS Physical Habitat Assessment Protocol (Parsons *et al.*, 2001). The AUSRIVAS Physical Habitat Assessment Protocol is based on the Habitat Predictive Modelling concept of Davies *et al.* (2000). The latter is a physical habitat application of the RIVPACS predictive modelling technique developed by Wright *et al.* (1984) for the biological assessment of stream condition using macroinvertebrates.

In AUSRIVAS, physical, chemical and habitat information is collected from reference sites and used to construct predictive models that are, in turn, used to assess the conditions of test sites. The physical assessment protocol comprises the following major components:

- Reference site selection – to represent 'least impaired' conditions and stratified to cover a range of climatic regions and geomorphological river types.

- Data collection – each reference site is visited and physical, chemical and habitat variables are measured using standardised methods. In the office, a suite of predictor variables is measured using standardised methods.

- Model construction – predictive models are constructed using processes and analyses (see Main Report). In these models, large-scale catchment characteristics (control variables) are used to predict local-scale features (response variables).

- Assessment of test sites – assessment of stream condition involves the collection of local-scale and large-scale physical, chemical and habitat information from test sites. This information is then entered into predictive models and an observed/expected (O/E) ratio is derived by comparing the features expected to occur at a site against the features that were actually observed at a site. The deviation between the two is an indication of physical stream condition.

While the general scientific approach suggested in the AUSRIVAS Physical Assessment Protocol is sound, i.e. the development of predictive or comparative models, it is recommended that modifications are made to improve the collection of control and response variable data in terms of efficiency and accuracy. These modifications should take account of recent technological developments in remote sensing and information technology. Utilising the potential of high-resolution digital aerial photography to acquire physical habitat information and the systematic application of geographical information systems (GIS) to determine first-order control variables are important amendments in this regard.

2.1 Selection of Irish Reference Sites

Reynoldson *et al.* (1997) suggest that the broad geographical limits of a study area be defined. The EU has already undertaken this task with regard to Ireland, recommending that the island of Ireland is contained within a single ecologically significant region. Ireland has been designated as Ecoregion 17 for the purposes of the WFD.

As Ireland, within this general ecological classification, is geographically and geologically quite complex, a further stratification of rivers into functional physical zones based on a number of physical attributes is required. This exercise is likely to generate a reasonable number of hydro-geomorphological river group typologies. For the ecological elements, this has been achieved by the classification of rivers on the basis of a suite of physical parameters (North South Technical Action Group).

Further filtering for reference site selection could be provided by dividing individual rivers into functional physical zones following the scheme proposed by Parsons *et al.* (2001) or as suggested by Rosgen (1994). In the former, four functional zone types are suggested, upper zone A (low energy unconfined), upper zone B (high energy confined), transition zone, and lower zone. These can typically be defined by drawing up long profiles of slope, valley width, planform and channel pattern. There can be a high level of variability and complexity in the arrangement of functional zone types. The four zone types are broadly sequential along the river continuum;

however, the same zone type maybe identified more than once in the same river.

In Ireland, there are approximately 90,000 discrete and identifiable river segments (i.e. confluence to confluence) identified on the 1:50,000 scale maps and therefore 90,000 potential entities to be sampled. It is important to note that, of these 90,000, only a small fraction remain undisturbed by anthropogenic activity, thus necessitating a compromise approach, i.e. identifying river segments that could be considered as being least impacted by man or 'least impaired'.

Human disturbances occurring in and around each functional zone should be examined so that the river segments contained within can be eliminated as potential sources of reference sites. Large catchment-scale disturbances would include changes to land use impacting on the hydrological regime. Most of this exercise could be undertaken in the EPA GIS. Other useful sources of information would include aerial photography and local knowledge. Local-scale or river-scale disturbances can be categorised as activities affecting riparian zone characteristics, channel modification, connectivity to the floodplain, stock access, bank condition and point source impacts.

While the basic approach is one of comparing test sites against reference conditions, the importance of observing the morphological condition of a site over time, as a way of detecting change at that site, is probably of greater analytical importance than the data obtained from the reference site comparison. However, it will take a number of observations for the time series data to be of reasonable usefulness.

The monitoring methodology presented in this report is based on the assumption that, given a specific change in one or more input factors, all channels belonging to the same morphological type will experience similar responses in their diagnostic features. By similar responses, it should be understood that the diagnostic features are expected to have similar trend directions, but this does not imply that the magnitude of the change will be the same.

3 A Methodology for the Assessment of the Morphological Condition of Irish Rivers

An approach to assessing morphological conditions in Irish rivers is illustrated in Fig. 3.1. There are four main action areas recommended. These are the building of the predictive models, data collection, data analysis, and habitat assessment and scoring. As the data collection element is the primary focus of the project most of the recommendations relate to that element.

3.1 Data Collection

The data collection element of the protocol is divided into four activities: (1) the generation of control variables, (2) the measurement of response variables with regard to the recommended surface water quality elements, (3) the construction of the predictive models, and (4) the design of the surveillance and operational monitoring programmes. This section is focussed on two of these elements – identification of methodologies for the generation of appropriate control variables, and the measurement of response variables. Data collection for control and response variables is organised hierarchically into a conceptual framework defining in order of resolution: country, catchment, reach segment scales of reporting (Fig. 3.2).

3.1.1 Control variables

A suite of control variables is listed in Table 3.1. These control variables are generated within the framework of a geographical information system (GIS). This

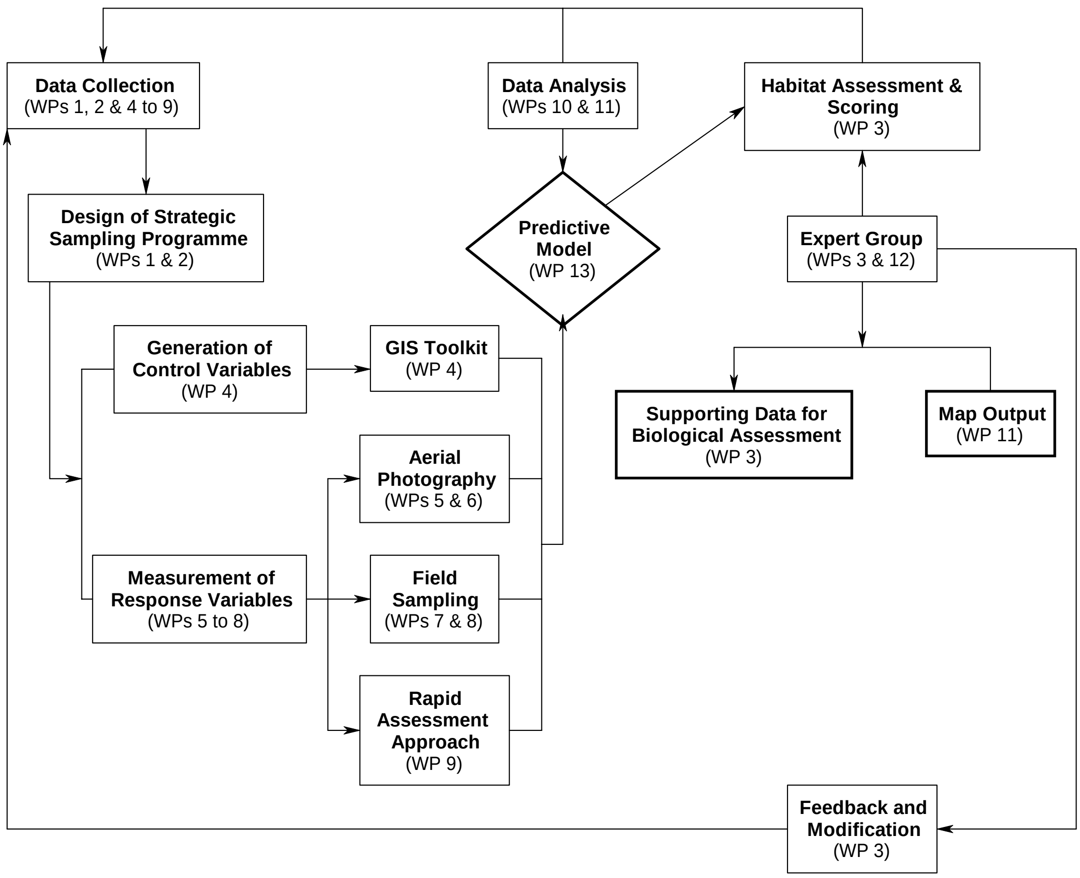

Figure 3.1. Model of proposed Hydromorphological Assessment Methodology for Irish Rivers (see Table 4.3 of the Main Report and Appendix 2 of this report for details of Project Work Packages (WPs 1 to 13)).

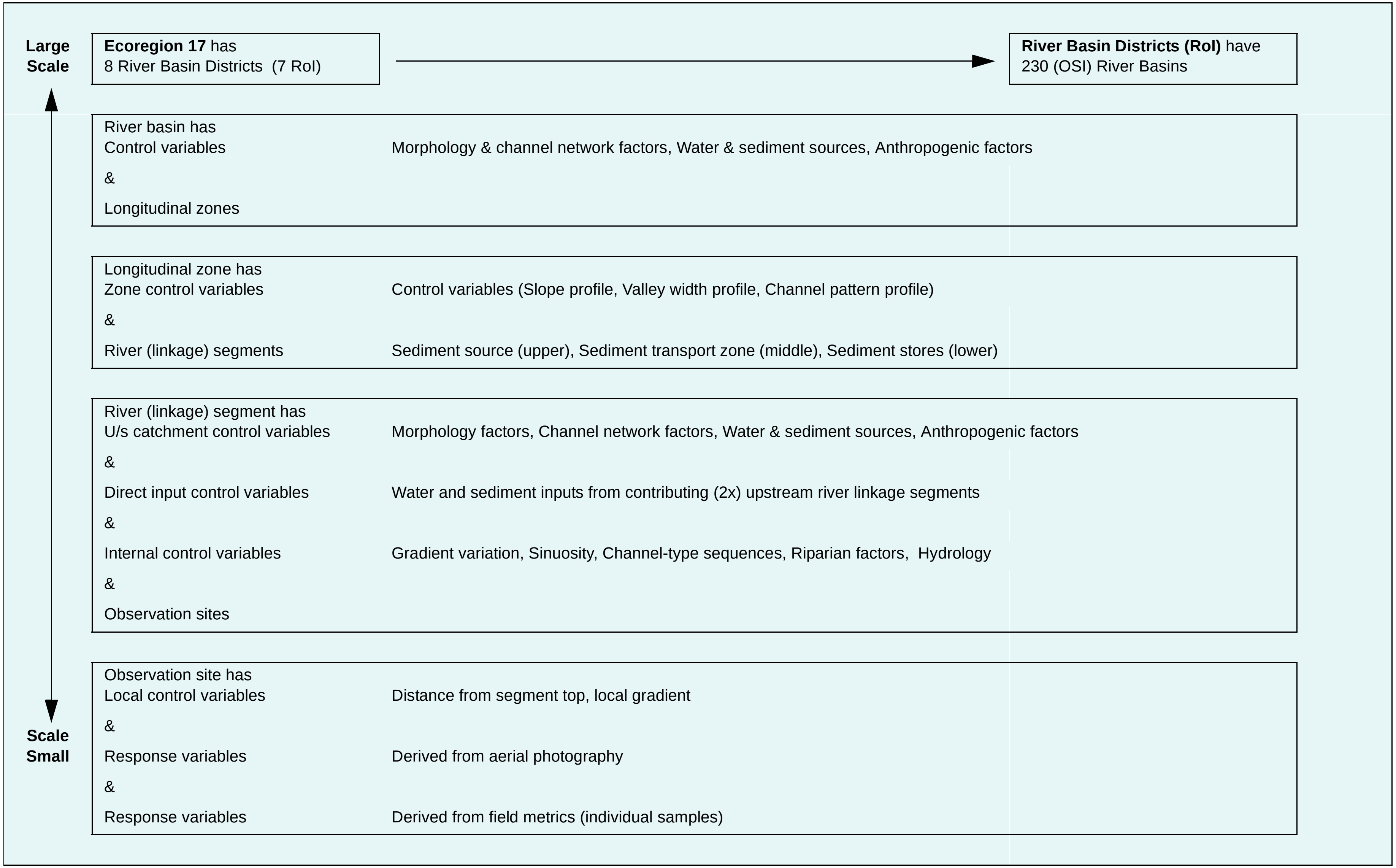

Figure 3.2. Conceptual framework for control and response variable data collection.

Table 3.1. Control variables determined by the hydromorphology GIS toolkit.

Control variable	AUSRIVAS Metric	Field	Definition
Elevation of site	✓	station_z	Site elevation OD m^{-1}
Catchment area	✓	cat_area	Area of site watershed in m^2
Total stream length	✓	uslen	Total stream length (m^{-1}) above site
Stream order		order	Strahler stream order
Link magnitude	✓	shreve	Stream link magnitude
Main channel length	✓	main_len	River channel length from source to site (m^{-1}). Excludes distance across lakes
Sinuosity	✓*	sinuosity	Channel length/downvalley length (where downvalley length = length of a 3-part line approximating the river channel)
Mean gradient of segment	✓	sl_segment	Mean gradient of 'interconfluence' stream segment
Mean stream slope	✓	sl_rivs_me	Main stem gradient/total stream length
Mean gradient of main stem channel		sl_cat_riv	Mean gradient of channel between source and site (elevation difference between source and site/channel length)
Local channel gradient 100 m		sl_us100	Channel gradient – above station – average over 100 m
Local channel gradient 200 m		sl_us200	Channel gradient – above station – average over 200 m
Local channel gradient 300 m		sl_us300	Channel gradient – above station – average over 300 m
Local channel gradient 400 m		sl_us400	Channel gradient – above station – average over 400 m
Local channel gradient 100 m		sl_ds100	Channel gradient – below station – average over 100 m
Catchment altitude	✓	cat_alt	Altitude range in site watershed (watershed maximum Z – Site Z)
Catchment slope	✓*	cat_slope	Mean of watershed slope (where slope is measured as a percentage)
Drainage density	✓	drain_dens	Drainage density of river (sum total drainage length (km^{-1})/watershed area (km^2))
Relief ratio	✓	relief_rat	Catchment altitude/main channel length
Form ratio	✓	form_rat	Watershed area/main channel length^2
Elongation ratio	✓	elong_rat	Diameter of a circle with an area the same as the watershed area divided by the main channel length (((watershed/3.1416)sqrt)×2)/main channel length
Valley shape	✓*	valley_shp	Classification of valley cross-section Broad, Moderate, Steep Symmetrical, Asymmetrical

Table 3.1. *contd.*

Control variable	AUSRIVAS Metric	Field	Definition
R-side 5 m elevation change		Rdist_to_5z	Right side – Distance to 5-m elevation gain
R-side 10 m elevation change		Rdist_to_10z	*Idem* to 10 m
R-side 30 m elevation change		Rdist_to_20z	*Idem* to 20 m
R-side 30 m elevation change		Rdist_to_30z	*Idem* to 30 m
L-side 5 m elevation change		Ldist_to_5z	Left side – Distance to 5-m elevation gain
L-side 10 m elevation change		Ldist_to_10z	*Idem* to 10 m
L-side 20 m elevation change		Ldist_to_20z	*Idem* to 20 m
L-side 30 m elevation change		Ldist_to_30z	*Idem* to 30 m

✓, Metric specified in AUSRIVAS Physical Assessment Protocol.
✓*, AUSRIVAS metric – determined by new algorithm.

comprehensive list includes variables required by the WFD and CEN (2002) together with additional variables utilised in the AUSRIVAS approach. A GIS toolkit developed in this project provides additional functionality for the efficient acquisition of these variables within the GIS. The control variables, e.g. relating to geology and climate, are the major drivers of stream structure and are typified by not being influenced by human activities in the river or in the landscape.

3.1.2 GIS toolkit

The EPA has established a GIS system, which, *inter alia*, contains a series of datasets relevant to riverine assessment. Significant elements of this GIS have been developed under individual ERTDI projects in recent years, including the development of a digital terrain model (DTM) and structured datasets on the river and lake network.

The aim of the hydromorphology toolkit is to develop a series of metrics, based on existing GIS data model classes and new factor generation software, which quantify a suite of factors considered to be key control variables in river hydromorphology (Parsons *et al*., 2001). These are largely set out in the AUSRIVAS Physical Assessment Protocol. Specific definitions for most of the factors are set out in the AUSRIVAS protocol. However, in some instances the factors are only described in the AUSRIVAS protocol by a simple term such as “read off a map” and this project has sought to quantify such instances with specific algorithms. Examples of these algorithms include ‘valley shape’, ‘downvalley distance’ and river ‘main stem length’ (pmills@compass.ie). It is proposed that the toolkit be applied to generate hydromorphology factor values at two principal types of locations: (1) existing EPA Biological Monitoring Stations along the river network at which locations type-specific reference conditions are determined, and (2) the outlet points of river sub-systems as defined by confluence points and stream order information.

3.1.3 Response variables

Candidate diagnostic response variables that inform the WFD-recommended river hydromorphology quality elements (QE) are listed in Appendix 1. The response variables are categorised and organised according to three different data collection strategies:

1. Remote sensing – primarily high-resolution aerial photography but also includes collection and analysis of historical aerial photography and could include satellite imagery.

2. Quantitative methods – where entities such as stream cross-section, thalweg (the line defining the lowest points along the length of a river bed), stream bed substrate and riparian condition are directly measured in the field and can also be used to ground truth and verify remote sensed data.

3. Qualitative or semi-quantitative physical habitat assessment methodologies – providing indicators of physical habitat condition and adding value to the existing biological sampling programme.

The high-resolution digital aerial photography will be the primary response variable collection methodology. The main objective of the quantitative measurements taken in the field will be to ground truth and calibrate the photographic data, in addition to the collection of data pertaining to the measurement of parameters, such as fines, residual pool depth and bank stability, that cannot be determined remotely.

3.1.4 Remote sensing

Technological developments in geomatics now provide high-quality, synoptic data over larger spatial scales at relatively low costs in comparison to ground-based measurements. Close-range photogrammetric methods are available for the estimation of water depths, bed morphology and bed material size at the reach scale. It is recommended that a significant proportion of response variables identified in the protocol should be collected using high-resolution aerial photogrammetry (McGinnity *et al*., 1999). A technical overview of digital image capture is presented overleaf.

The imagery can be classified through a number of optional processes: an unsupervised classification, where the software analyses the spectral characteristics of the imagery and highlights spectral classes; supervised classification, where use is made of analyst-entered training areas for identification of similar area through the image; spectral and contextual classifiers, where the contrast of an image section (pixel(s)) is used to classify it according to its most likely feature category, e.g. pool, gravel bank, riparian vegetation. Feature categories can then be exported as vector files for use and analysis in a GIS environment.

It is also recommended that historical aerial photography

Technical Overview of Digital Image Capture

Digital image survey process overview:

The digital aerial image capture and processing require a series of steps to be carried out. These can be summarised as follows:

- Survey planning – area and linear coverage, ground resolution, river segments survey sequencing.
- Survey operations – weather review, system set-up and test, transfer to survey location(s), image capture, imagery in-flight review, imagery archive and transfer to post-processing station.
- Data processing – image locations processing from in-flight GPS records; image selection; image rectification based on in-flight GPS, camera calibration data, aircraft altitude (if available), and ground control points and Digital Elevation Model (if required); image mosaicing export to final image format.
- Image classification – automated and/or manually assisted classification and identification of features from within the digital imagery.

Image system components include:

- High-end professional digital camera with large pixel array for optimal image resolution and image coverage. Suitable cameras include the Fuji FinePix Pro series, Nikon Digital SLR series, and Kodak DCS Pro series.
- GPS capable of per-second output for recording of aircraft/image location.
- Video camera for navigation assistance.
- Laptop computer for software operation and image storage.
- Software for survey planning, camera triggering, real-time image coverage viewing, and post-processing of GPS files and images.
- Power packs for equipment power supply.

Typical image capture recommendations:

Using a professional digital camera of approximately 6 million pixel array size, imagery can be captured at 3,000 feet altitude, yielding imagery with a ground resolution of 20 cm and ground coverage per image of approximately 850 m × 650 m. Given use of suitable software and high-speed computer–camera connections, image overlap of 60% or more can be achieved. This would allow river segments of 750 m length to be covered by three images. However, in practice, additional images will be captured to ensure good coverage over any given segment.

from 1974, 1995 and 2000 be examined and analysed as a means of assessing and measuring change at identified sites, e.g. stream width, etc. Historical aerial photography collected in 1953 (1:25,000 scale) should be analysed as a basis for temporal analyses of habitat change detection – variables of interest include river width, riparian vegetation, etc.

These data will provide an excellent opportunity to examine stream channel evolution and rate change over a number of decades.

Ground-truth data gathered through field surveys have a role in verifying the results of a classification exercise and also in providing data for use in assignment of classification training areas. Such field surveying should avail of Geographical Positioning System (GPS) data logging technologies for spatially accurate and standardised attribution recording.

3.1.5 Quantitative field sampling protocols

It is recommended by the project team that a number of strategic field-based response variable measurements (cross-sections, thalweg, sediment core and riparian vegetation) are carried out quantitatively. The variables are listed in Appendix 1. Quantitative methods provide unambiguous measurements and are highly precise (repeatable). They also provide ground truthing for measurements derived from data collected using high-resolution aerial photography.

The USEPA Environmental Monitoring and Assessment Programme (EMAP) field approach to physical habitat characterisation (Kaufmann and Robison, 1998) employs a randomised, systematic design to locate and space habitat observations on stream reaches (lower-scale objective) so as to minimise any bias in placement and positioning of measurements. This allows scaling of the sampling reach length and resolution proportional to stream size. The project team recommends that ground-based photographs should be taken as supporting data and as an aid to interpretation. Central to the overall approach recommended is the use of sub-metre GPS to accurately locate all sampling activities on-site. GPS locations will identify positions for future monitoring activity and will assist in assuring sample repeatability.

3.1.6 Qualitative visual estimation methods

A requirement for a rapid assessment methodology for steam hydromorphology was identified in the EPA terms of reference (EPA, 2002). The visual estimation procedures suggested by the USEPA are attractive in this regard. The qualitative response variables identified by the USEPA Rapid Bioassessment Protocol (Barbour *et al*., 1999) are also included in the AUSRIVAS protocol. However, it is of concern that the measurement of these variables is subjective in interpretation and consequently their lack of precision limits their use in the models suggested in this protocol. Nonetheless, when examined in combination with the quantitative measures of morphological condition, they will represent a valuable source of supporting information.

It is recommended that these qualitative variables be incorporated into the current EPA biological assessment monitoring programme. The data that will originate from this source can be used as a ground truthing and interpretative tool. Refinements to this approach specific to Irish conditions will be required and these will emerge following acquisition and analysis of the initial dataset.

3.1.7 Sampling time and sampling site dimensions

Any time of year is probably suitable for ground-based measurements, as most physical factors do not change across seasons. Although physical habitat can be evaluated during any season, it would be most effective if habitat evaluations were concurrent with biological sampling (Kaufmann *et al*., 1999). It should be noted that collecting habitat data using an aerial photography/ remote sensing survey approach might be more appropriate in early spring prior to leaf growth in the riparian tree canopy. It is critical that repeat sampling be carried out at the same time of year to provide a reasonable background for comparison.

Sampling should also be confined to periods of base flow or low flow conditions and should not follow major flood events. Assessments should be carried out when all features can be described with confidence. The CEN standard (2002) also suggests sampling during low flow periods when vegetation and instream structure can be recorded accurately. It might be argued that most of the changes in channel morphological characteristics in Ireland occur during the wet winter months. During this time period, peak flows commonly match or surpass bankfull conditions. These morphological changes typically extend over the drier summer period. This is a good justification for field data collection during summer low flow conditions. Collecting data during this time of the year also provides other advantages, i.e. minimum disturbance to salmonid spawning habitats and good exposure of stream-bed substrates.

It has been suggested by Parsons *et al.* (2001) that the length of an individual sampling site should be a function of stream size, and is defined as ten times the channel bankfull width. The USEPA (Barbour *et al*., 1999) recommend a sampling site that has a length that is 40 times its low flow wetted width. Field crews measure upstream and downstream distances of 20 times the wetted channel width from pre-determined midpoints to the centre of each 40-channel width field sampling reach. A minimum reach is set at 150 m.

High-resolution aerial photography provides an opportunity to escape the limitations of having to sub-sample a river segment and to collect quantitative data on entire river segments. It is relatively straightforward to photograph a segment (confluence to confluence) in its entirety, possibly 4 or 5 km in length, thus negating the need for sub-sampling. Quantitative measurements of response variables should be extracted from the high-resolution aerial photography within a GIS platform.

The Expert Group should identify cross-sections and field sampling sites from the aerial photograph(s). The photograph(s) should be marked accordingly and used as a reference in the field. In the field, quantitative response variables should be measured as per the locations identified in the photograph(s). The locations of field measurements should be confirmed using sub-metre accuracy GPS.

3.2 Data Analysis

Data analysis for the construction of a predictive model is outside the remit of this project. However, it is difficult to present a methodological protocol without some reference to the data outputs and the utilisation of those outputs to produce an assessment of quality. The project team recommends that specific software should be developed based on the AUSRIVAS approach. Davies (2000), Simpson and Norris (2000) and Kaufmann *et al.* (1999) provide excellent treatises on the construction and application of predictive models for hydrological and ecological assessment of running waters and should be consulted for further explanation.

It will be impossible to interpret the significance, in a habitat quality context, of the measurements and indices derived until baseline and learning datasets have been developed. These datasets will define the methods, which will ultimately become the final methodology. These data will also provide the basis for the re-assessment of actual physical habitat reference conditions, which can be supported by statistical analysis. In accordance with CIS (EU WFD Common Implementation Strategy) Monitoring Guidance, refinement of the methodology will occur on the basis of the process being a 'living' process and eventually the number of variables required may be few if they can reflect change adequately. For example, Wood-Smith and Buffington (1996) found that a three-variable model discriminated disturbed from undisturbed reaches in forest streams in Alaska.

3.3 Hydromorphological (Habitat) Assessment and Scoring

It is recommended that a 'rules constrained' Expert Group should be convened, either within the EPA or selected from specialists working in other state bodies or third-level institutions, to provide HQ (hydromorphological quality) value scores based on assessment of the data elements discussed above to determine the morphological condition. The assessment can be scored and mapped in its own right or can contribute as a supporting element to the assessment and scoring of the ecological quality of a site.

It is recommended that this Expert Group operate on a basis similar to the National Salmon Commissions Standing Scientific Committee. The group should meet on an annual or on a twice-yearly basis to decide on hydromorphological scores for the sites sampled in the previous sampling season. A pilot study will be essential to initiate and develop processes and procedures which ultimately will deliver a user-friendly methodology. It is recommended that a suitably qualified data analyst be available to assess the data in support of the Expert Group.

The data analysis process undertaken by the Expert Group will involve examination of five discrete pieces of information as derived from the processes shown in the model in Fig. 3.1.

These are:

1. **Control variables** from the GIS as inputs to a prediction process of expected morphological conditions.

2. **Response variables** from high-resolution aerial photography (Figs 3.3 and 3.4).

3. **Qualitative field assessment** carried out by the EPA biological monitoring team using the USEPA Rapid Bioassessment Protocol (Barbour *et al.*, 1999).

4. **Response variables** from quantitative field measurements taken by the hydromorphological monitoring team(s).

5. **Statistical analyses** of expected occurrence of a habitat feature (E) at a site compared with actual observed habitat feature (O) at the site. Probability of

Figure 3.3. Section of digital aerial image showing river habitats. Image resolution is approximately 20 cm.

occurrence is calculated from the occurrence of the habitat feature at reference sites. The difference between the two (O/E ratio) constitutes the indicator of habitat condition at each site.

A core function of the Expert Group will be to select sampling sites/segments and in-site locations for cross-sections and sampling of depths, gravels, etc. Ground truthing will be carried out based on their expert opinion. A colour-coded map should illustrate the distribution of physical habitat quality scores nationally.

It is recognised that the Expert Group's final assessment and scoring is based on professional judgement or 'expert opinion' and is thereby the most subjective phase of the undertaking. It must be remembered, however, that while the final scoring system has a large degree of subjectivity, the data on which the process is based are quantitative and highly empirical. Consequently, there is an in-built safeguard in the system in that the primary quantitative data (which can be stored and retrieved) can be re-analysed and re-scored at some future date if developments occur in statistical or other types of assessment analyses. Consequently, it is envisaged that the scoring system will be subject to constant development and reliability testing.

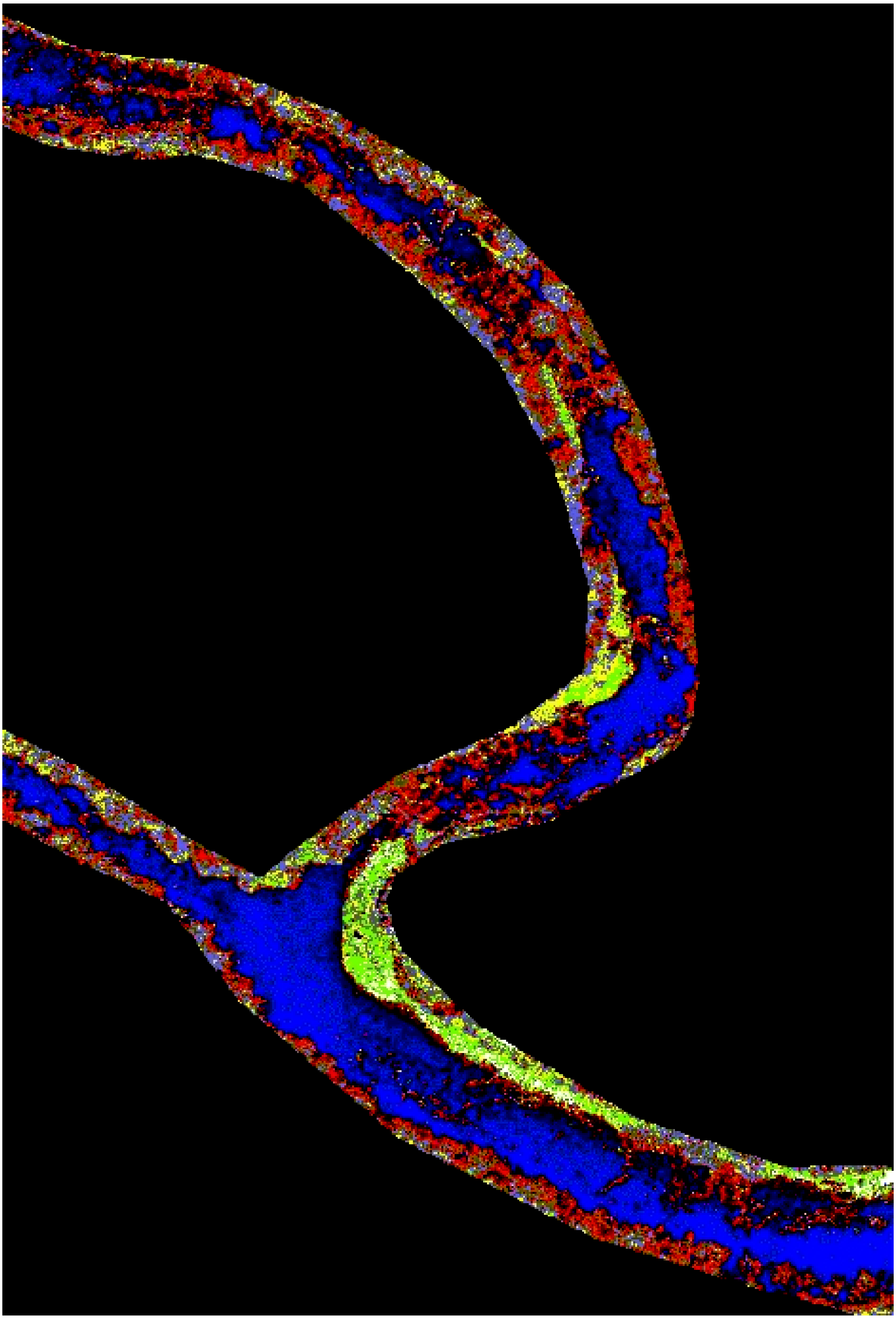

Figure 3.4. Sample classified image showing results of an unsupervised image classification. The next steps in classification include refinement of spectral classes to be identified, use of training areas in classification, and extraction of vector formats for analysis in a GIS.

4 Other Considerations

The next stage in the assessment of the morphological condition of Irish rivers is to develop a national baseline. The first priority in the process is to identify, select and sample reference sites for assessment and to follow on with a survey of test sites chosen using a statistically robust strategic sampling plan.

This project identified important datasets from the Office of Public Works (OPW) Drainage Division and from the Geological Survey of Ireland (GSI) that will be useful in describing the physical habitat in systems where these agencies operate. Identification of other useful datasets should be a priority for the next phase of the project.

The project team recommends that, in the early stages of implementation, a comparative approach to field sampling techniques should be adopted, particularly where methodologies differ and different levels of confidence or accuracy about the results are acceptable. For example, substrate characterisation is a specialist field and many different sampling techniques are available. Efficiency and cost are likely to be the main factors governing the choice of method and a rigorous experimental programme will be necessary to determine the most suitable method for reporting purposes.

The use of proxy measurements should be explored. Turbidity has been used to examine sediment loadings and techniques such as dissolved oxygen measurement and ground-penetrating radar (Naden *et al*., 2002) have potential in relation to assessment of river-bed siltation levels. The use of surrogates may provide the opportunity to reduce field sampling time and eliminate some laboratory analyses but parallel studies to compare these techniques with direct measurements will be necessary.

5 Estimate of Resource Implications

Value for money is important in all data collection programmes. Aerial photography offers an excellent data collection potential and will represent a considerable investment in relation to resource characterisation. However, such an investment will provide the opportunity to assess ground conditions relating to many different aspects relevant to the aquatic environment (Appendix 2). Careful planning of this function will be required to maximise all potential benefits from this valuable sampling activity.

Indicative cost and resource implications for the annual delivery of the hydromorphological outputs and analysis are presented in Appendix 2. This includes establishment and working of the Expert Group, generation of a statistically sound sampling programme and a pre-survey control variable dataset, quantitative data collection and generation of outputs for scoring. The estimated total amounts to approximately €750,000 p.a., which comprises 13 different work packages. Year 1 costs will be greatest due to the initial outlay on new processes and procedures. Once a pattern has been established and the process is reviewed a re-evaluation of the logistical and cost implications should be undertaken.

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Appendix 1

Summary of diagnostic or response variable parameters including identification of relevant WFD Quality Element (QE) assignations, principal data acquisition methods and sampling levels. Field data collection methodological codes for each variable where appropriate.

Data acquisition method	Mandatory QE (per WFD)	Recommended QE *CIS recommended QE #CEN requirement	Candidate diagnostic response variables	Sampling level	Methodological code (AS, aerial survey; FS, field survey) details in Main Report
AERIAL PHOTOGRAPHY	**River depth and width variation**	River cross-section analysis*#	1 Active channel width 2 Bankfull width 3 Reach mean widths and variability 4 Thalweg location 5 Bank location (geo-referenced) – bank erosion rates (time series location data)	Entire reach photographed (confluence to confluence – estimated 90,000 discrete river reaches nationally)	Refer to Section 4.2.4.1 in Main Report for discussion on acquisition and data extraction from aerial photographs
		Flow*	(could be undertaken by EPA hydrometric teams)		
		Bank erosion analysis (Ramos, 1996)#	Bank erosion rates (time series location data)		
	Structure and substrate of the river bed	Planform analysis (Ramos, 1996)#	6 Channel morphological types ID and measurement 7 Gravel bar area 8 Per cent (%) channel area in gravel bars 9 Pool area 10 Per cent (%) channel area in pools 11 Pools per channel width 12 Pool/riffle ratio 13 ID individual facie units		
		Particle size* (ground reconnaissance activity)	Surface particle size distribution (remote sensing applications in development – GEOIDE Project Canada)		
		Presence and location of coarse woody debris (CWD)*#	Channel roughness (CWD) – count, size, volume & location determination per channel width		AS
			Channel roughness (other obstructions) – ID, count, size, location, volume per channel width		AS

Appendix 1. ***contd.***

Data acquisition method	Mandatory QE (per WFD)	Recommended QE *CIS recommended QE #CEN requirement	Candidate diagnostic response variables	Sampling level	Methodological code (AS, aerial survey; FS, field survey) details in Main Report
	Structure of the riparian zone	Length/width*#	Riparian – width, length, area		AS
		Species composition*#			
		Continuity/ground cover*#	Riparian – continuity & ground cover		
	Current velocity	Not from aerial survey			
	Channel patterns		Sinuosity		
FIELD SURVEY	**River depth and width variation**	River cross-section analysis*#	1 Channel cross-sections (widths & depths)	Cross-section	FS1– cross-section measurement
			2 Bankfull depth (area below bankfull/bankfull width)	Cross-section	FS1
			3 Channel width/depth ratio	Cross-section	FS1
			4 Bankfull width/depth ratio	Cross-section	FS1
			5 Gravel bar volume (gravel bar height)	Cross-section	FS2 – barring survey
		Flow*#	(could be undertaken by EPA hydrometric teams)		
	Structure and substrate of the river bed	Cross-section*/ Planform analysis#	1 Gravel bar aggradation/ degradation rates (temporal change)	Point	FS2 – barring survey
			2 Riffle substrate depth	Point	FS2 – barring survey
		Long section analysis (Ramos, 1996)#	3 Residual pool depths	Channel unit	FS3
			4 Thalweg profile	Reach	FS4
		Particle size*#	5 Surface particle size characteristics (median size D_{50}, cumulative frequency curves, % fine material)	Cross-section/Point	FS5 – modified pebble count
			6 Embeddedness	Cross-section/Point	FS6 – embeddedness
			7 Sub-surface particle size determination (% fine sediment, median size D_{50}, cumulative frequency curves)	Cross-section	FS7 – McNeil sampler (McNeil & Ahnell, 1964)
			8 Bed critical shear stress	Cross-section	FS8 – Imhoff cone

Appendix 1. *contd.*

Data acquisition method	Mandatory QE (per WFD)	Recommended QE *CIS recommended QE #CEN requirement	Candidate diagnostic response variables	Sampling level	Methodological code (AS, aerial survey; FS, field survey) details in Main Report
			9 Riffle stability index	Cross-section	FS9 – Shovel (Schuett Hames *et al*., 1996)
		Presence and location of CWD*# (primarily derived from aerial photography but periodic ground truthing may be necessary)	10 Bank stability index	Reach	FS10 (Gordon *et al*., 1992)
			11 Characterisation of CWD	Reach	FS11 – Riffle Stability Index (Kappesser, 1993) FS12 (Bank Stability Index – Fitzpatrick *et al*., 1998) FS13 (Ramos, 1996)
	Structure of the riparian zone	Length/width*# (derived from aerial photography) Species composition*# Continuity/ground cover*#	12 Riparian – species composition/ground cover – ground truthing		FS14
	Current velocity	(could be undertaken by EPA hydrometric teams)	Only certain points could be sampled+		
	Channel patterns	(aerial photography function)			
GROUND-BASED PHOTOGRAPHY (FIELD SURVEY)					FS14
GROUND RECONNAISSANCE (RAPID)					FS15 – USEPA Rapid Bioassessment Protocol

+Current velocity only available at flow measurement point. These are selected to provide good cross-sectional data and not for representativeness of long section. Velocity may be required at a number of points.
The majority of data requirements under the CEN *A Guidance Standard for Assessing the Hydromorphological Features of Rivers* are satisfied using the proposed methodology and collection of the different response variable data. Several CEN 'Assessment categories' and 'Generic features' requirements, including longitudinal section, channel vegetation, discharge regime (abstractions, etc.), longitudinal continuity (presence of barriers), floodplain characteristics and lateral connectivity can be derived from within the project, principally from aerial photography or will be collected by biological sampling teams (e.g. macrophyte sampling).

Appendix 2

Hydromorphology of Rivers – Logistical and resource implications for delivery of work packages required for initial reporting and scoring for the Water Framework Directive in Ireland based on the methodology presented in this report.

Functional input	Work Package	Methodology	Deliverable (output)	Timetable/ duration	Man days/annum	Cost €	Synergies	Linkage to
Statistical design and analysis	WP 1 – Design of strategic sampling programme – A – Reference sites	Statistically based desk study	Identify reference sites; sampling plan	Year 1	60; once-off	20 K		Expert Group Data capture
Statistical design and analysis of hydromorphological requirements	WP 2 – Design of strategic sampling programme – B – Monitoring programme	Statistically based desk study	Inter-annual sampling programme	Year 1	60; once-off	20 K		Expert Group Data capture
Expert Group	WP 3 – Hydromorphology Expert Group	Secretariat; Consensus; Integration of datasets	Within-site sampling location selection; assessment and scoring; system feedback and modification; input to ecological assessment	Quarterly	100 days Secretariat 60 days Expert Group	50 K		All levels
GIS activity	WP 4 – GIS management for hydromorphological project; generate control variable output	GIS toolkit	90,000 sites (a) GIS managment (b) 30 GIS control variable outputs	Year 1	60	20 K		Expert Group Surveyors
Sampling/ processing	WP 5 – Aerial photography programme – data capture	High-resolution aerial photography toolkit	Raw imagery (500 sites/ annum)	Annual programme		15 K	<u>Complementary activities</u> • Risk assessment • Targeting measures • Identification of pollution problems • Farmyard surveys • Remote sensing of lakes • Mapping barriers/river continuity	Image data processors

Appendix 2. ***contd.***

Functional input	Work Package	Methodology	Deliverable (output)	Timetable/ duration	Man days/ annum	Cost €	Synergies	Linkage to
Sampling/ processing	WP 6 – Aerial photography programme – data processing	ER Mapper	Processed and catalogued imagery (500 sites/annum)	Annual programme		150 K	Risk assessment; Pollution monitoring	Field survey teams Expert Group
Sampling/ processing	WP 7 – Quantitative field sampling (response variable) programme – (reference sites)	As proposed	Data to generate 20 variables from 250 to 500 reference sites to be sampled	Year 1	500; once-off	200 K	Two teams; interaction with hydrology/ hydrometric teams	Statistical work packages
Sampling/ processing	WP 8 – Quantitative field sampling (response variable) programme – monitoring programme	As proposed	Data to generate 20 variables from 100 monitoring sites to be sampled/annum	Annual programme	200	80 K		
Sampling/ processing	WP 9 – Field sampling programme (response variables) – USEPA rapid assessment	USEPA	10 variables; 1000 habitat quality assessments/annum	Annual programme		70 K	To be carried out by existing EPA biologist with additional support; useful support information	Expert Group
Statistical design and analysis	WP 10 – Data analysis – model building based on reference site data	AUSRIVAS	Model	Once-off?		25 K		Expert Group
Statistical design and analysis	WP 11 – Data analysis – comparison with reference site database	AUSRIVAS	Model Map outputs	Annual programme		25 K		Expert Group
Statistical design and analysis/ Expert Group	WP 12 – Ecological Quality Rating (EQR) – classification	Statistical analysis – bootstrapping		Annual programme		25 K		Expert Group
Training	WP 13 – Training programme – (a) new methodology (b) USEPA rapid assessment			Ongoing		15 K		
TOTAL						**715 K**		