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Rapid Assessment of Physical Habitat Sensitivity to Abstraction (RAPHSA)

Science Report - SC020081

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SCHO0508BOAO-E-P

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Science at the Environment Agency

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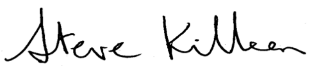

Steve Killeen

Head of Science

Executive summary

Physical habitat is one measure of river ecosystem health that is sensitive to changes in flow or channel geometry. It can be used to assess the impacts on the river ecosystem of changes to the flow regime caused by abstractions, or impoundment or alterations to channel geometry that result from river engineering, such as flood management works. An appropriate flow regime is recognised as an essential supporting element to achieving Good Ecological Status in water bodies, as required under the European Water Framework Directive. In England and Wales, the Environment Agency achieves appropriate flow regimes through the management of abstractions and ensuring sufficient water is released from dams. In addition, the Environment Agency is required to undertake environmental impact assessments of flood defence schemes and other river engineering works.

Physical habitat comprises the physical conditions in a river that determine its suitability for different species and communities, including water depth and velocity. The relationship between physical habitat variables and discharge define the degree to which the physical environment changes as flow varies. How these relationships change with channel geometry provides a measure of the sensitivity of the river to flow change. Physical habitat–flow relationships can be defined for any river reach, but require repeat measurements of hydraulic properties at a range of flows, followed by hydraulic modelling and habitat use data by target species (if the curves are to be related to particular organisms).

The Environment Agency thus requires a set of operational tools that assess physical habitat in a consistent manner regardless of the amount of data available. This paper reports on a study to define a risk-based toolkit for physical habitat assessment. The risk-based approach is a trade-off between avoiding unnecessary work, and the costs of achieving an acceptable level of certainty such that decisions can be made with reasonable confidence. This approach involves starting with simple tools and adopting more complex techniques if necessary; that is, use the simplest approach that gives an acceptable level of confidence, moving to a higher level if the degree of uncertainty is too high. The toolkit was developed through analysis of 66 physical habitat modelling studies across the UK. Each tool requires different input data, thus entailing various levels of investment in field data collection. It is recognised that the results from all tools are uncertain. However, in broad terms, the more data available and the more complex a tool used, the better the understanding, although employing a complex tool does not guarantee less uncertainty.

Acknowledgements

The project team was:

Centre for Ecology and Hydrology: Mike Acreman, Douglas Booker, Tracey Goodwin, Michael Dunbar, Ian Gowing, Andy Young
University of Worcester: Ian Maddock
Utah State University: Thom Hardy
University of Cranfield: Monica Rivas-Casado

Project board Environment Agency members were:

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Contents

Figures

Tables

1 Purpose

Sensitivity to abstraction is a key concept used by the Environment Agency to assess the likely magnitude of change in a river ecosystem when water is abstracted; it is used to help manage water resources, to set abstraction licences and to ensure that water bodies meet the ecological target status required under the Water Framework Directive (WFD). To help define sensitivity to abstraction for rivers in England and Wales, a research project was undertaken between 2002 and 2006 by the Centre for Ecology and Hydrology (CEH), guided by a project board with members from the Environment Agency and CEH. The project investigated the technical feasibility of developing a (suite of) catchment-wide tool(s) to determine the sensitivity of physical habitat to abstraction, thus assisting in setting environmental river flow objectives. The purpose of this document is to provide a summary of the research outcomes, so that Environment Agency staff can recommend how the tools produced might be developed into an operational system. More detailed information on project activities, analysis and results are given in a series of Interim Technical Reports that are listed in Appendix 2.

2 Background

2.1 Introduction

Many abiotic factors influence the health of river ecosystems, including temperature, oxygen, light and flow (discharge, measured in units of volume/time). In terms of flow, all elements of a regime are believed to be important, including floods, average and low flows. However, apart from through dilution effects, flow ($m^3 s^{-1}$) is generally a surrogate variable; it is the water depth and velocity in a river, created by the interaction between flow and channel morphology, that provides physical habitat for river biota. Various researchers have found that the amount of physical habitat was an important determinant of fish and invertebrate abundance.

The direct relationship between physical habitat and flow provides a potential tool for assessing the ecological impact of changing the flow regime of a river. However, assessment of river flow management options often involves assessing scenarios that fall outside the range of observed conditions, thus predictive models are required. The Physical Habitat Simulation (PHABSIM) system was the first model to be widely applied and many models based on a similar concept have been produced, including CASiMIR in Germany, EVHA in France, RHYHABSIM in New Zealand and RSS in Norway. Essentially, these models quantify the relationship between physical habitat for a given site defined in terms of the combination of depth, velocity and substrate/cover at a particular flow. Criticisms of PHABSIM include lack of biological realism and mechanism. Nevertheless, the models have been applied throughout the world, primarily to assess impacts of abstraction or river impoundment. However, the method has also been used to assess the impacts of channel restoration and modification in rural and urban settings. PHABSIM in particular has become a legal requirement for many impact studies in the USA and a standard tool employed by the Environment Agency of England and Wales to define the sensitivity to abstraction, which is required for the development of Catchment Abstraction Management Strategies (CAMS) and assessment of ecological status in the WFD. PHABSIM has also been applied in Scotland and Northern Ireland.

Full habitat modelling is expensive due to the need for extensive collection of field data (including velocities, depths and water surface elevations) at several differing flows and subsequent detailed computer analyses. This has led to demands for a more rapid approach to physical habitat assessment, particularly sensitivity of physical habitat to abstraction. Different methods for defining relationships between physical habitat and flow from simple measurements of river channel dimensions have been developed for rivers in France, the USA and New Zealand.

2.2 RAPHSA project

The Rapid Assessment of Physical Habitat Sensitivity to Abstraction (RAPHSA) project was set up as a collaborative programme between the Centre for Ecology and Hydrology (CEH) and the Environment Agency. RAPHSA has developed some prototype tools that could be used for rapid determination of sensitivity of physical habitat to abstraction on rivers of England and Wales. These tools could assist in setting environmental river flow objectives at different spatial coverages from reach to catchment scale. The project was limited to demonstrating technical feasibility of the tools, with outputs designed to enable the Environment Agency to make a decision as to whether to develop the tools into an operational system.

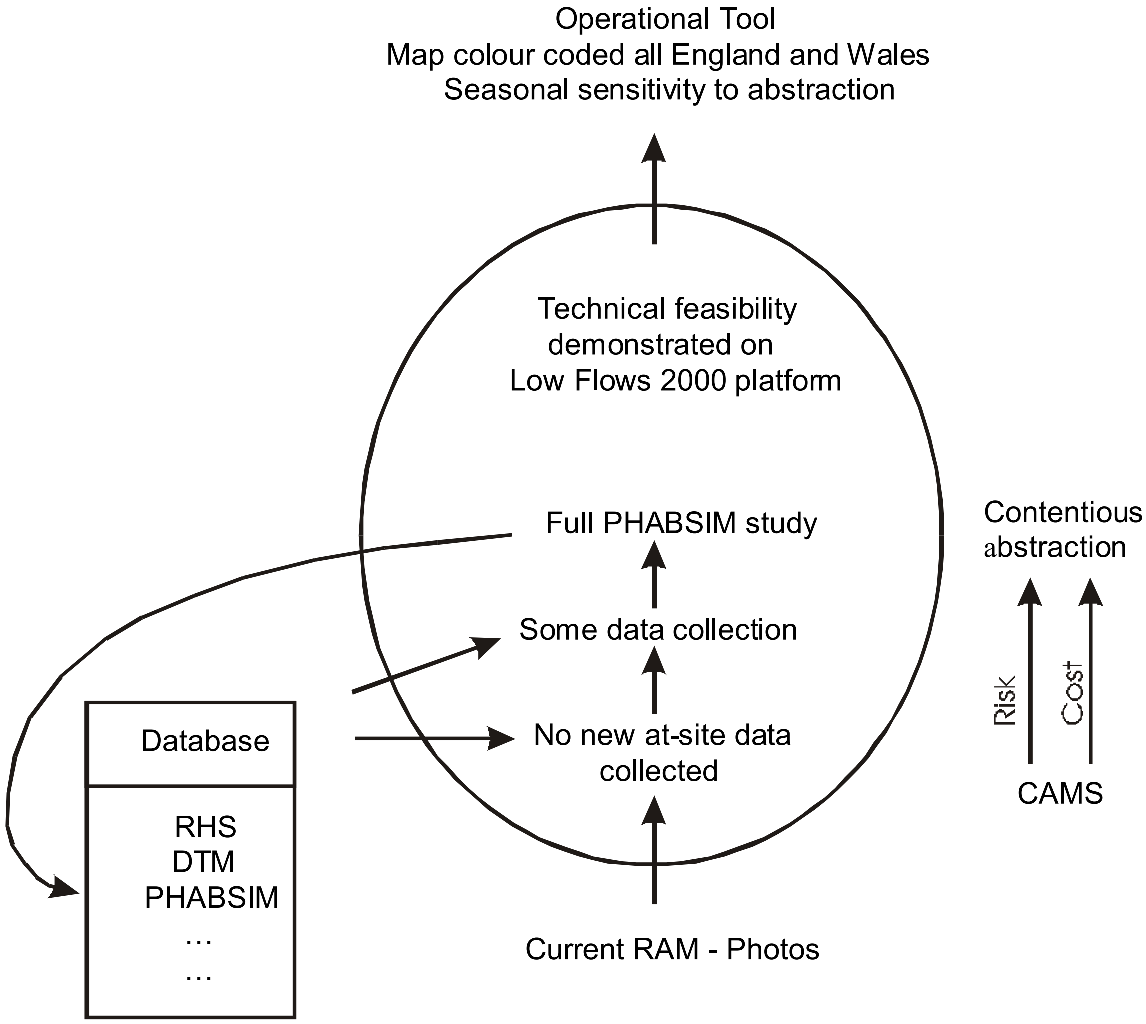

Figure 2.1 Conceptual framework of RAPHSA

The conceptual framework for the project (Figure 2.1) was that the Environment Agency currently has three main tools to assess physical habitat sensitivity to abstraction: PHABSIM, the Resource Assessment and Management (RAM) framework of CAMS and WFD 48. The default approach in the RAM framework classifies the river reach of interest by matching it to photographs of different river types in the RAM manual, and using macrophyte, macroinvertebrate and fish data. A further inexpensive/low confidence tool has recently been developed to define environmental standards for implementing the Water Framework Directive (WFD 48 – Acreman *et al.*, 2006). RAM, WFD 48 and PHABSIM represent extremes of method; PHABSIM is expensive and time consuming to apply, but provides a high confidence method, while WFD 48 and the RAM framework are relatively rapid but the results are more uncertain. RAPHSA has defined new tools – the DRAPHT (Direct Rapid Assessment of

Physical Habitat Toolkit) and the Catchment Habitat Assessment Tool (CHAT). These are consistent with these existing three tools and can make use of other available datasets, such as River Habitat Survey (RHS). The relationship between these tools and gaps filled by RAPHSA are shown in Figure 2.2.

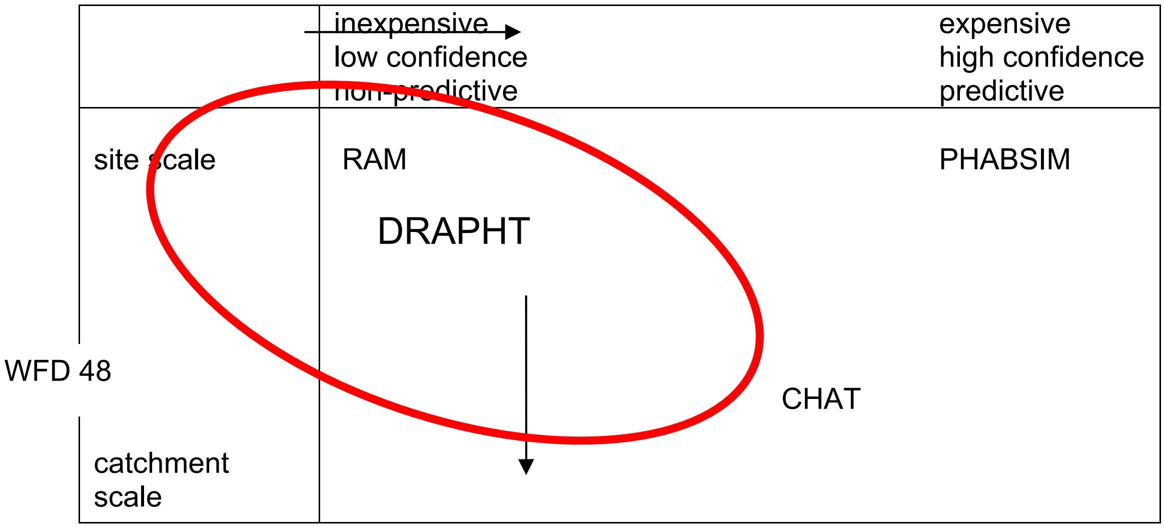

Figure 2.2 Relationship between the RAPHSA toolkit, RAM, CHAT and WFD 48. The red oval shows those tools produced in the RAPHSA project

2.3 Defining sensitivity to abstraction

A main output from PHABSIM is a curvilinear relationship between physical habitat, expressed as weighted usable area (WUA) in m^2 1000 m^{-1} of river, against river flow (Q), in $m^3 s^{-1}$, for particular life stages of target species. The slope of this curve defines the physical habitat sensitivity to change in flow. Figure 2.3a shows a WUA versus Q curve for juvenile salmon on the River Wye at Pant Mawr. Physical habitat is the habitat defined by the hydraulic behaviour of the river; depth and velocity, in the case of this project. Depth and velocity are directly altered by changes to flow. Physical habitat can include other variables such as bed substrate, temperature or cover, but these were not considered in this project. WUA versus Q relationships are specific to individual species/life stages, whose physical habitat requirements are defined by habitat suitability indices (HSIs) for each physical variable. On occasions, it may be more appropriate to define sensitivity to abstraction in a more generic sense in the form of a relationship between wetted bed area, mean depth or mean velocity and Q (Figure 2.3a, c, d). The tools developed in RAPHSA were designed to produce graphs of width, depth, velocity and WUA versus Q.

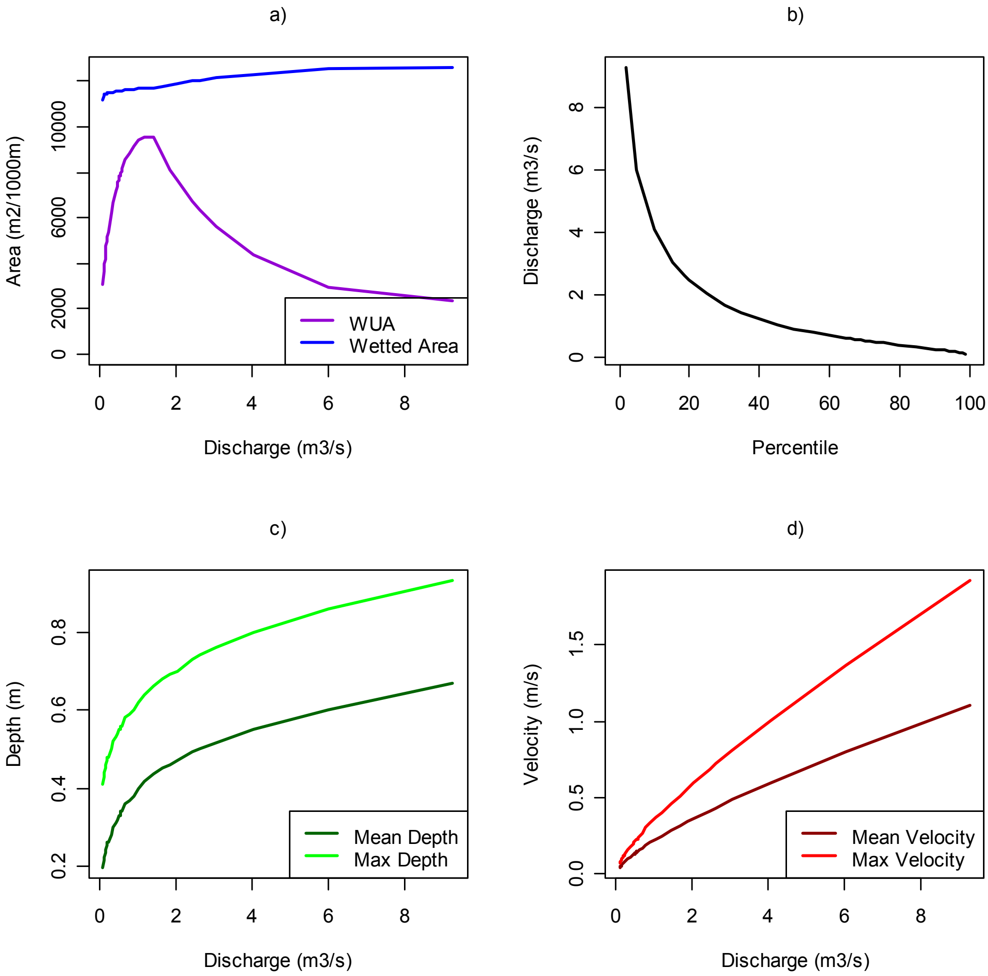

Figure 2.3 WUA and wetted bed area (a), depth (c) and velocity (d) versus Q curves and flow duration curve (b) for River Wye at Mawr

2.4 Database development

The PHABSIM system has been applied to many UK rivers. Most applications have been on physical habitat for fish, although macroinvertebrates and macrophytes have also been studied where they have distinct physical habitat requirements. Most studies have followed national guidelines (Elliott *et al.*, 1996), which include:

(1) definition of river sectors and species/life stage of interest;
(2) specification of habitat suitability indices (HSIs) for the species/life stage;
(3) identification and mapping of habitats that exist within the sectors of interest;
(4) selection of cross-sections which represent replicates of each habitat type;
(5) collection of model calibration data (water surface elevation, depth and velocity) at preferably three different flows;
(6) calibration of hydraulic models;
(7) calculation of physical habitat for the species/life stage of interest for a range of flows, which defines the WUA versus Q curve (Figure 2.3a).

The resulting models also permit calculation the relationship between Q and more basic habitat variables such as wetted bed area (Figure 2.3a), mean depth and mean velocity (Figure 2.3d).

A list of sites in the UK where PHABSIM studies have been undertaken was compiled. Of the 78 sites identified, 12 sites were rejected because data were unobtainable, insufficient data were available to calibrate the hydraulic models or the models would not produce stable results. This left 66 sites, containing a total of 528 cross-sections, for which full PHABSIM models could be defined (Appendix 1).

To standardise the WUA versus Q relationships, flow was recorded in terms of percentiles of a flow duration curve and habitat was plotted as a proportion of total wetted area of river bed at high flow (Q_2). Q_2 was assumed to be broadly equivalent to bankfull flow and can be measured during any site visit. Flow duration curves were based on naturalised daily flows using Low Flows 2000. In total, 41 flows were simulated for each site based on points on the flow duration curve for that site ranging from Q_{99} to Q_2 for each catchment. These flows were defined as being every fifth percentile on the flow duration curve and every percentile for the five percentiles either side of Q_{95} and Q_{70}. Of the 66 sites, natural flow duration curves could not be obtained for two (South Winterbourne, Upper and Lower) as they did not have definable contributing catchment areas (these sites are side channels of the River Frome). These two sites were therefore not included in subsequent catchment-based analysis. Low Flows 2000 and the Flood Estimation Handbook software were used to generate physical catchment characteristics for each site including catchment area, mean annual rainfall, baseflow index and mean catchment slope. Hydraulic modelling of depths and velocities at each site allowed a suite of hydraulic properties to be calculated for each cross-section.

Data on substrate type were available from the various studies. However, these data were collected using a variety of methods and held in different formats. Therefore habitat suitability was assessed based on available depth and velocity only. Substrate is less critical for the juvenile life stage than for others such as spawning and is assumed not to vary with flow in most PHABSIM studies.

2.5 Analytical approach within RAPHSA

The analytical approach adopted for RAPHSA was to investigate how one could determine WUA versus Q curves (and thus sensitivity to flow change at any flow), without undertaking a full data collection, hydraulic and habitat habitat analysis. The initial work of the project focused on trying to define relationships between these curves and the physical characteristics of the catchment upstream of the site. It was envisaged that geology, slope, rainfall, catchment area etc would combine to define the type of river channel, its hydraulic characteristics and habitat structure. This was based on the success of methods relating catchment characteristics to the hydrological regime (Low Flows 2000) and flood frequency behaviour (Flood Estimation Handbook) of UK rivers. The advantage of this approach is that outputs can be derived in the office using existing digital datasets, such as rainfall and topographic maps, and there is no need to visit the site.

Multiple linear regression was used to relate catchment characteristics to parameters defining the form of the WUA versus Q curves. This work had limited success. It is thought that this was because WUA versus Q curves are related to the hydraulic structure of the river reach, as well as its hydrological regime, and few rivers in England and Wales are natural and free from past engineering, such as widening, deepening or straightening.

Better success was achieved by relating parameters of WUA versus Q curves to attributes of the river channel such as width and depth using multiple linear regressions. This was due to the use of actual physical measurements of the site to define the hydraulic behaviour of the reach. The disadvantage is that a visit to the site would need to be made to take these measurements, although width and depth can be measured quite rapidly. The best estimates of WUA versus Q curves came from datasets that included measurements of river velocity, as these were better predictors of hydraulic behaviour. Clearly, taking velocity measurements is more time consuming than recording river width, but the work demonstrated that maximum velocity could be used as a proxy for velocities across a cross-section.

Figure 2.4 shows the performance of the different approaches to estimating WUA versus Q curves for juvenile salmon. It can be seen that the quadratic equations (black line) reproduce the shape of the full PHABSIM data (red line) in most cases. The predictions based on a full site visit where velocity is measured (grey) are closest to the original data. Predictions based on a quick site visit (blue), where only width and depth are measured are next best, while predictions based on catchment variables (green) are the weakest, although they still provide useful estimates.

Overall, the results demonstrate that the more site data that are collected (which requires more investment in time) the better the estimates of the WUA versus Q curves.

WUA versus Q curves are specific to individual species/life stages, so it was decided that the RAPHSA project should also study other more generic (non-species-specific) indices of sensitivity to abstraction, such as graph of wetted bed width (WW), mean depth (D) or mean velocity (V) versus Q. Consequently, the relationships between catchment/site variables and curves for WW versus Q, V versus Q and D versus Q were also investigated. For the analysis of V versus Q and D versus Q it was not necessary to limit the analysis to PHABSIM studies, and data from 97 natural section gauging stations were also used from which measurements of velocity and depth were available.

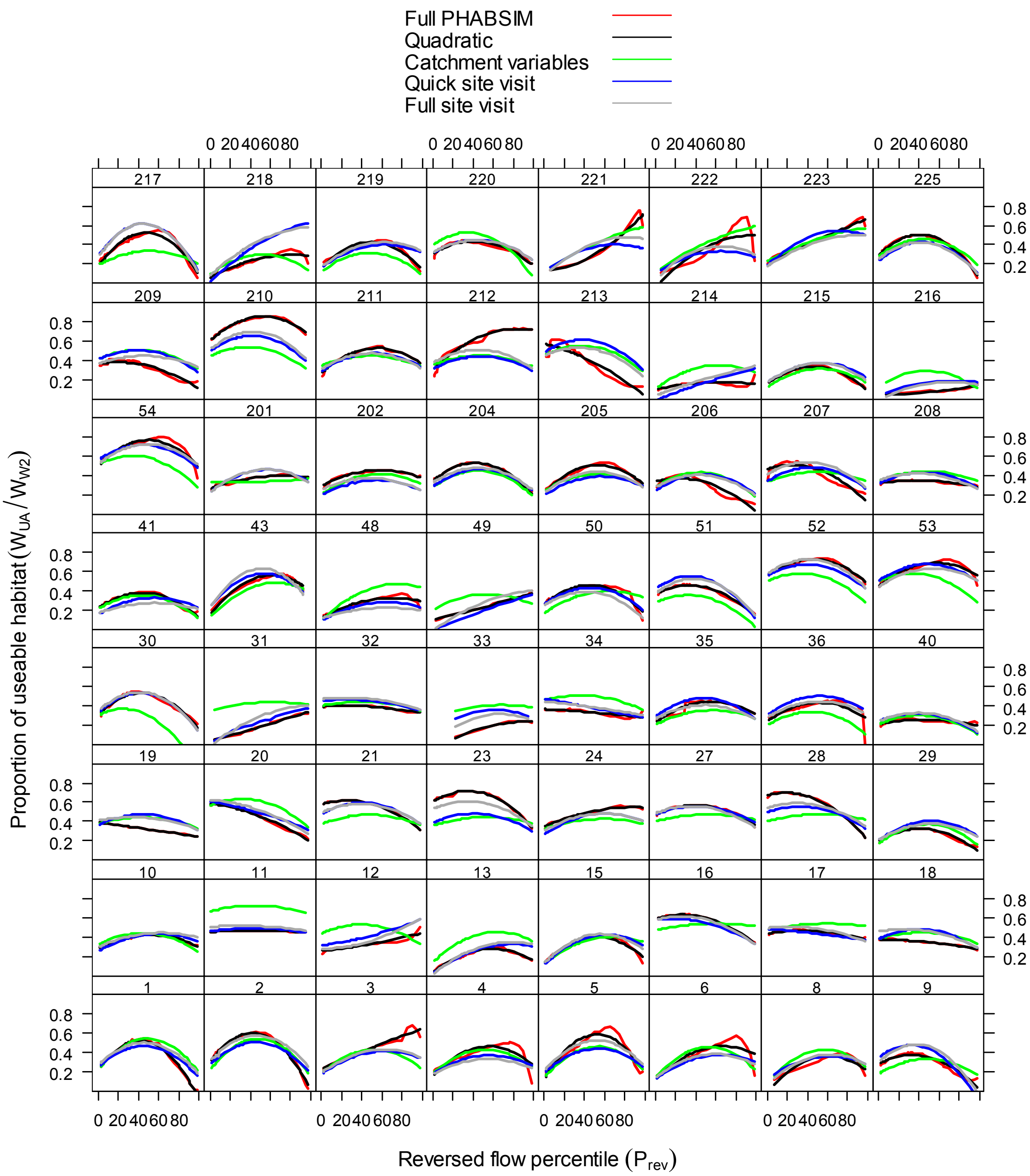

Figure 2.4 WUA versus Q curves (for juvenile salmon) for all RAPHSA sites

3 Understanding the RAPHSA toolkit

3.1 The spatial approach to habitat assessment

In the traditional habitat modelling approach (such as PHABSIM), the first step is to produce a habitat map of the river length of interest, which classifies areas of the river into channel geomorphological units (CGUs) such as riffle, run, glide and pool (Figure 3.1). This is largely a subjective process, relying on visual inspection of the river by an expert. Representative CGUs are then chosen for detailed hydraulic study. Results are scaled-up according to the proportions of those CGU in the river length of interest.

In other approaches, such as MesoCaSiMiR, the user takes some measurements of depth and velocity as part of the mapping procedure. This has two implications (1) the definition of CGUs is more quantitative and objective (2) the measurements can be used directly as inputs to rapid assessment tools, such that mapping becomes a more integrated part of habitat assessment, without the need for further data collection. As part of RAPHSA, a trial of different habitat mapping approaches was undertaken on the River Windrush. It was concluded that habitat mapping combined with taking measurements provided the most robust method, but also required most user input.

The approach taken for RAPHSA is that all tools will have a spatial component; that is, all applications will involve explicit location of observed features and measurement points on a map of the river length of interest. This may be:

(1) an office-based assessment, where data are retrieved from an existing database;
(2) a rapid assessment, where the user walks along the river length of interest and makes some measurements; or
(3) a full habitat model, where a habitat map is produced of the river length of interest to define representative CGUs for detailed hydraulic measurements.

Thus geo-referenced habitat measurement provides the umbrella under which the various RAPHSA tools fit. Geo-referencing is essential because it permits flexible use of the data for different purposes at different times, thus allowing future data collection to build on existing data. This aids the progressive use of wider datasets and more complex tools consistent with the risk-based approach.

As part of RAPHSA, a PhD study was undertaken on the uncertainties associated with different sampling strategies for river morphology and hydraulic variables (Rivas-Casado, 2006). Part of this work also assessed the sensitivity of different CGUs to changes in flow. Key conclusions were that (1) reach lengths of 500 m appear to provide satisfactory data for characterisation of spatial patterns of habitat (2) shallow glides and deep glides were more sensitive to flow change than pools and riffles.

Channel geomorphic unit (CGU)	Brief description
Fall (Fa)	Vertical drops of water over the full span of the channel, commonly found in bedrock and step-pool stream reaches
Cascade (Ca)	Highly turbulent series of short falls and small scour basins, frequently characterised by very large substrate and a stepped profile
Chute (Ch)	Narrow steep slots or slides in bedrock
Rapid (Ra)	Moderately steep channel units with coarse substrate, unlike cascades possess planar profile
Riffle (Ri)	Most common type of turbulent fast water mesohabitat in low gradient alluvial channels. Substrate is finer than other fast turbulent mesohabitats. Less white water, with some substrate breaking the surface
Run (Ru)	Moderately fast and shallow gradient with ripples on the water surface. Deeper than riffles with little, if any, substrate breaking the surface
Glide (Gl)	Smooth 'glass-like' surface, with visible flow movement along the surface. Relatively shallow compared to pools
Pool (Pl)	Relatively deep and slow flowing (compared to glides), with fine substrate. Usually little surface water movement visible
Ponded (Pd)	Water ponded behind an obstruction – weir, sluice or other obstruction
Other (O)	To be used in unusual circumstances where feature does not fit any recognised type

Figure 3.1 List of CGUs and hypothetical example of CGU pattern along part of a river sector. Note all lateral divisions cross the entire channel, and no unit is shorter in length than half the channel width

3.2 Input data and time required for RAPHSA tools

The time taken to use any RAPHSA tool is largely dependent on collection or collation of the data required. It is thus useful to provide a list of data types:

1. Physical catchment data

These are descriptions of the catchment in terms of physical characteristics such as drainage area, slope, altitude, geology or baseflow index calculated from geology.

2. Hydrological catchment data

These are hydrological data integrated for a catchment, including annual rainfall and mean flow.

3. Channel geomorphic unit (CGU)

CGUs are zones of the river, classified according to a typology of hydraulic character (e.g. run, glide, pool, riffle). CGUs are normally recorded on a map by walking the river length. CGUs may be defined by visual inspection or measurements of depth, velocity, surface flow type and substrate type.

4. Site length measurements

These are measurements that can be taken with a tape or wading rod, including river width, water depth or distance across the river of a feature.

5. Site velocity measurements

These are measurements made with a current meter as maximum or mean velocity.

Data may be recorded in two ways:

1. Geo-referenced independent measurements

Geo-referencing involves recording the location of a measurement, such as river water depth (normally a point), in terms of national grid coordinates or relative to a known fixed point.

2. Mapping of homogeneous areas

A map records zones or areas within which characteristics recorded are similar, such as CGUs or surface flow types.

3.3 Outputs from RAPHSA tools

All tools can produce graphs depicting flow Q against a range of physical habitat outputs:

- WUA – weighted usable area for a target species based on depth and velocity
- WUAd – weighted usable area for depth for a target species
- WUAv – weighted usable area for velocity for a target species
- WW – wetted river width
- V – mean velocity
- D – mean depth

In all cases but V and D, the primary output graphs have standardised axes; flow is given in terms of the exceedence percentile from the flow duration curve, that is between 0 and 100 (Figure 3.2), and WUA and WW as proportions of WW at Q_2, that is between 0 and 1 (Figure 3.2a). To produce curves with absolute values the graphs must be unstandardised (Figure 3.2b). To unstandarise the habitat axis, all ordinates must be multiplied by river width at Q_2 (bankfull); to unstandarise the flow axis each ordinate must be related to the flow duration curve for the site. For V and D, the flow axes are standardised but the habitat axes are given in real units of depth or velocity.

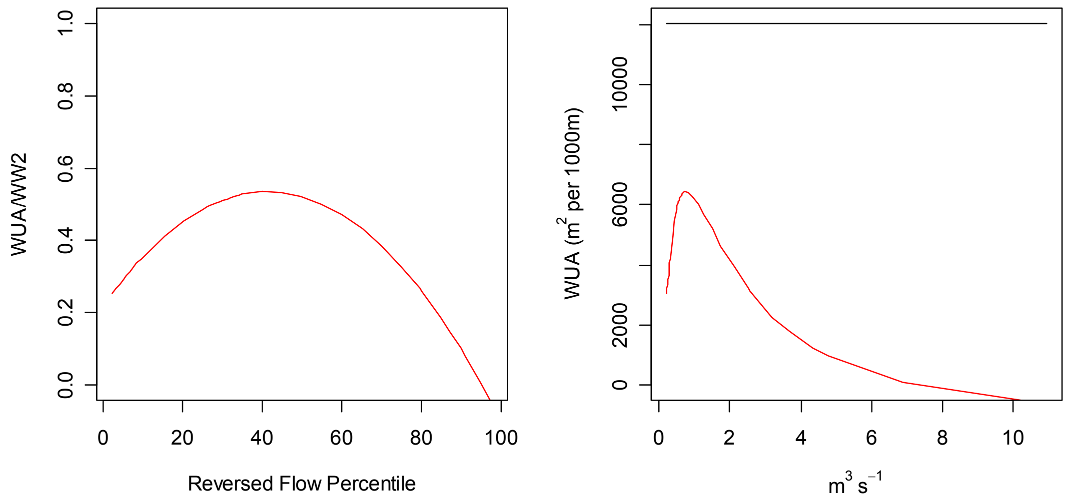

Figure 3.2 WUA versus Q curves: (a) standardised – WUA is shown as a proportion of wetted width at Q_2 and flow is shown as flow exceedence percentile reserved (low flows to the left, high flows to the right); (b) unstandardised the black line shows wetted area at Q_2

3.4 Calculating sensitivity to abstraction

Sensitivity to abstraction is a key concept used by the Environment Agency to assess the likely magnitude of change in a river ecosystem when the flow regime is altered, such as when water is abstracted. The general rule is that the most sensitive rivers should be the most highly protected; thus, less abstraction should be permitted than for low sensitivity rivers. This concept is used to help manage water resources, to set abstraction licences and to ensure that water bodies meet the ecological target status required under the Water Framework Directive.

The slope of any graph produced by RAPHSA indicates the sensitivity to abstraction at that flow. Figure 3.3 shows relationships between flow and WUA for two river reaches. It can be seen that the river reach depicted by the blue curve is sensitive to flow change as the curve is steep (i.e. physical habitat changes significantly with a small change in flow), whereas the river reach depicted by the green curve is less sensitive as the curve is shallower (i.e. physical habitat changes less with change in flow).

The RAPHSA tools produce the curves across the whole flow range. This allows sensitivity to abstraction to be assessed for different flows or flow percentiles, without the need to use any separate look-up tables.

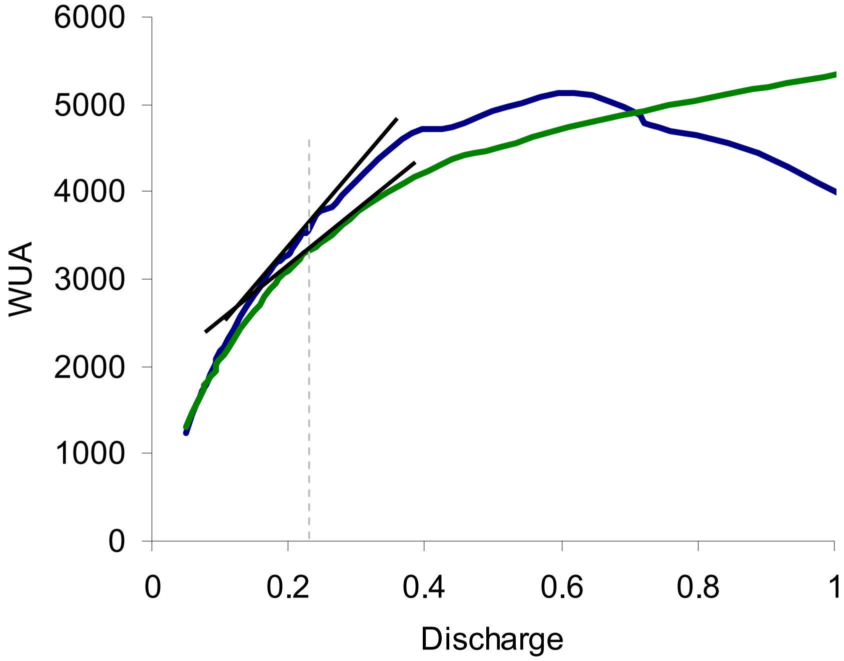

Figure 3.3 Habitat sensitivity to flow change, showing a steeper relationship (upper line) and shallower relationship (lower line) at the same discharge

In numerical terms, sensitivity to abstraction is defined as change in physical habitat score, for example change in WUA (m^2 1000 m) for a given change in flow, Q ($m^3 s^{-1}$):

$$\frac{\delta \text{ WUA}}{\delta \text{ Q}} \qquad [1]$$

To allow easy comparison of different rivers, sensitivity to abstraction can be defined in standardised units, for example WUA/wetted width at Q_2 for a given change in flow percentile, Q ($m^3 s^{-1}$):

$$\frac{\delta \text{ WUA/WW2}}{\delta \text{ \%}} \qquad [2]$$

Since Q_2 is approximately bankfull discharge, WUA/WW2 can be interpreted as the proportion of total channel width (bank to bank) that is suitable for that target species. Equation [2] gives the change in that proportion (e.g. 0.2 to 0.1) for a change in flow % (e.g. Q_{90} to Q_{80}).

The user can employ Equations [1] or [2] to calculate sensitivity to abstraction.

The RAM framework v4considers three environmental weighting bands: low, medium and high sensitivity. Within the RAPHSA dataset, sensitivity to abstraction varies from 0 (at the apex of a curve where there is no change in habitat for change in flow) to X (where the curve is steepest). Figure 3.4 shows the distribution of sensitivity to abstraction at Q_{95} for juvenile salmon for all RAPHSA sites. A figure of 0.01 means that a change in flow of 1% (e.g. Q_{95} to Q_{96}) leads to a change in WUA of 1% of the total wetted area at Q_2. This range of sensitivities can be subdivided into three classes to be consistent with the RAM framework. Table 3.1 gives an example of possible sensitivity to flow change bands for Q_{95}. The RAPHSA user can take the sensitivity to abstraction calculated from Equations [1] or [2] and then use figures such as those in Table 3.1 to classify the change as indicating low, medium or high sensitivity.

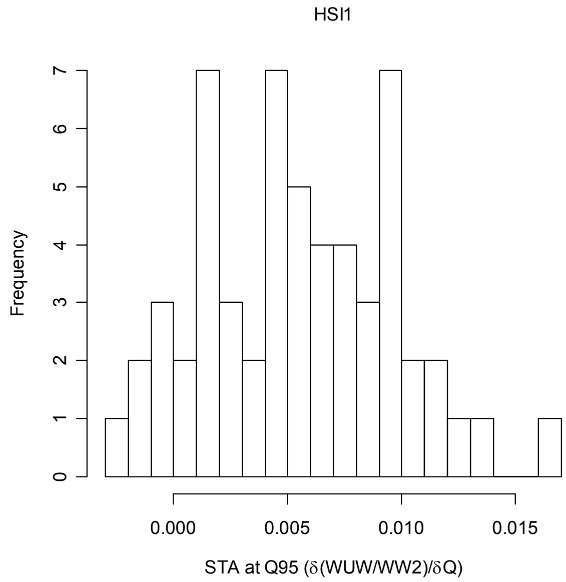

Figure 3.4 Sensitivity to abstraction at Q_{95} for juvenile salmon for all RAPHSA sites

Table 3.1 Sensitivity to flow bands for different curves at Q_{95}

Sensitivity	**WUA/WW2**
Low sensitivity	< 0003
Medium sensitivity	0.003–0.008
High sensitivity	> 0.008

4 The RAPHSA tools

The RAPHSA project has produced two products:

- CHAT, which provides a high confidence tool where there are existing hydraulic models;
- DRAPHT, a toolkit that provides a risk-based approach to rapid physical habitat assessment.

Each tool requires a different level of investments in data collection and analysis and each tool produces results with a different level of confidence. It is this trade-off of resources against uncertainty that largely governs the choice of tool. However, the tools are not intended to be independently exclusive; indeed, the concept of RAPHSA allows information collected for a simple tool to be used later for a more complex tool, thus permitting progressive application of tools.

1. Catchment-scale Habitat Assessment Tool (CHAT)

This stand-alone tool was developed for habitat assessment using hydraulic output data from a separate one-dimensional model output, and software has been written to allow the import of data from the ISIS model. Estimates of physical habitat under different abstraction scenarios are produced for all sections of the river system under study. CHAT was developed initially for catchment-scale application; however, it is equally suitable for application to shorter lengths of river where one-dimensional hydraulic models have been established. The tool was applied on the whole River Itchen catchment (Booker *et al.*, 2004) as part of the Itchen Sustainability Study. The results have a high degree of confidence over an entire catchment and the method is replicable by different users. However, a typical application may take many man-days to apply, in addition to several man-months to produce an appropriate hydraulic model covering the full range of flows. In this tool, habitat mapping at the start of the work would provide an overall picture of the river's CGUs, habitat types and structure, which could help with data collection. However, the tool does not use representative sites or reaches (the whole river system is modelled using a series of cross-sections), thus the habitat map is not used quantitatively, such as for scaling results.

2. Direct Rapid Assessment of Physical Habitat Toolkit (DRAPHT)

DRAPHT contains three tools that differ in their input data requirements.

(i) **DRAPHT$_{CC}$** This tool requires physical catchment characteristics, such as drainage area, average annual rainfall and base flow index. Values for any catchment can be derived from remote sources, such as Low Flows 2000, within a few hours. However, the results have low confidence.

(ii) **DRAPHT$_{TM}$** This tool requires measurements to be taken of the river channel that can be made with a tape measure or wading rod, such as river width or depth. Application requires mapping the river as the user walks the river length of interest and takes measurements at key locations, such as different CGUs. This requires a visit to the river for around 0.5 days per 500 m of river to be assessed. The flow percentile of the discharge at the time of measurement must be known. The results have low–medium confidence.

(iii) **DRAPHT$_{CM}$** This tool requires measurements to be taken of the river channel (as with DRAPHT$_{TM}$) plus velocity measurements with a current meter. Application requires mapping the river as the user walks the river length of interest and takes measurements at key locations, such as different CGUs. This requires a visit to the river for around 1 day per 500 m of river to be assessed. The flow percentile of the discharge at the time of measurement must be known. The results have medium confidence.

For all tools a flow duration curve needs to be estimated using data from a nearby gauging station or Low Flows 2000.

The tools developed under RAPHSA need to be assessed in relation to other existing tools available to the Environment Agency that provide estimates of sensitivity to abstraction.

1. PHABSIM
This is the conventional approach to model physical habitat: undertaking habitat mapping to identify representative reaches, making hydraulic measurements at multiple (preferably at least three) flows and calibrating the PHABSIM models. The different between PHABSIM and CHAT is principally that PHABSIM has its own internal hydraulic models, while CHAT can use hydraulic output from other models.

2. RAM
Application of the full RAM framework requires information on fish, invertebrates and macrophytic vegetation. However, an estimate of physical habitat sensitivity to abstraction can be derived by comparing the river reach to photos of rivers depicting different sensitivity classes.

3. WFD 48 – Environmental standards – water resources
The outputs from this project include a method of classifying river water bodies into classes according to their mean annual rainfall (SAAR), drainage area and baseflow index (BFI), plus look-up tables that give the maximum permitted abstraction from each type depending on the flow.

5 Choosing the right tool for assessing sensitivity to abstraction

One of the major challenges facing the Environment Agency is the need to address a range of issues related to potential impacts of altering the flow regimes of rivers in England and Wales. This includes national reporting for water bodies under the Water Framework Directive, catchment-scale water resources assessment for CAMS and environmental impact assessment of specific abstractions, such as for the Restoring Sustainable Abstractions (RSA) programme.

Undertaking any assessment involves a trade-off between avoiding unnecessary work and the costs of achieving an acceptable level of understanding such that decisions can be made with reasonable confidence. The basic principle is to start with simple approaches and adopt more complex techniques if necessary; that is, use the simplest approach that gives an acceptable level of confidence, moving to a higher level if there is a high degree of uncertainty in the results. Although confidence may increase as model complexity increases, costs and data needs are also likely to increase. DRAPHT is built around this risk-based approach, such that a simple quick tool can be applied and later, if more confidence is required, a more robust version of the same tool or a complementary tool can be applied by collecting more data.

Based on the above, it is concluded that the main criteria for tool selection are minimum staff resources and uncertainty (confidence) in results. The process is described graphically as a flow chart in Figure 5.1. Times are the minimum resources required and for the elements requiring fieldwork time would need to be added for travel, establishing access permissions, bad weather etc.

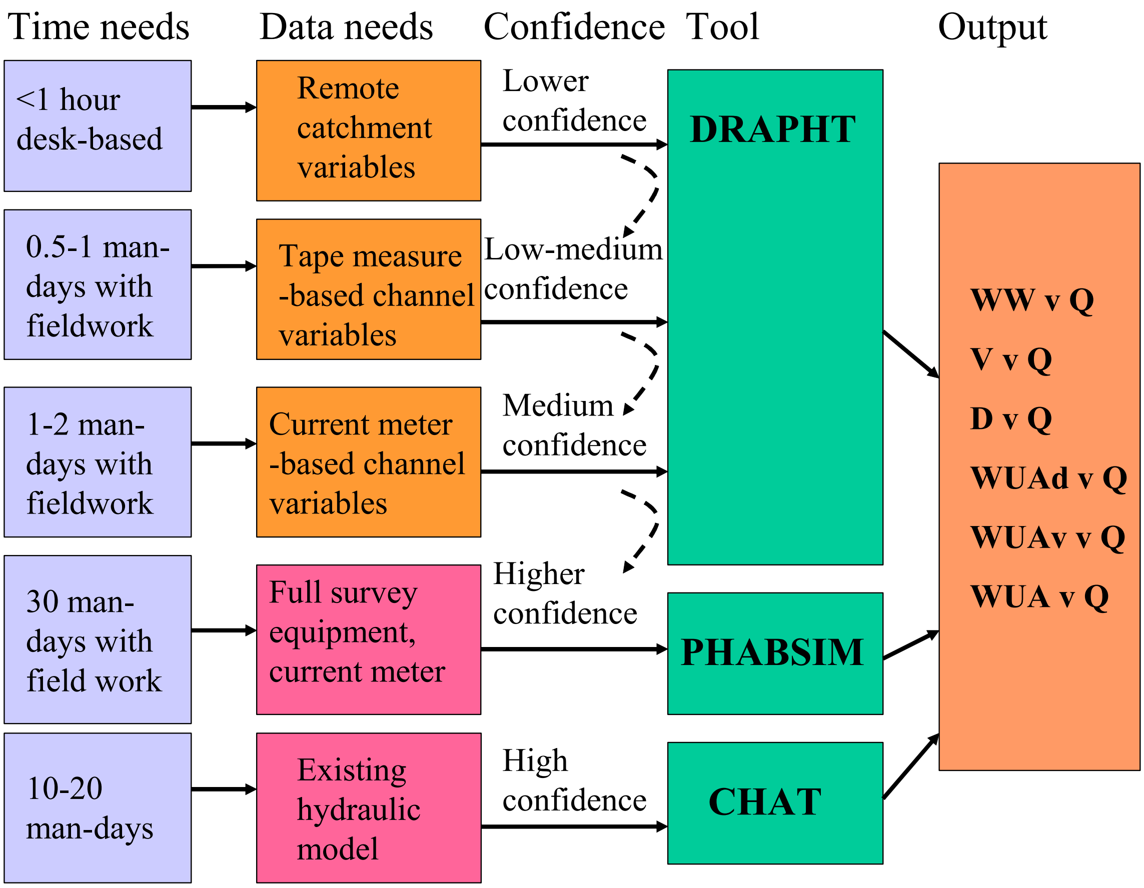

Figure 5.1 RAPHSA flow chart

6 Application of the tools

As discussed above the aim of the RAPHSA project was to test the feasibility of tools for rapid assessment of physical habitat sensitivity to abstraction. Consequently, a fully operational system has not yet been defined. Nevertheless, it is possible to outline how a system could work.

Table 6.1 provides a step-by-step guide to the three tools in DRAPHT. It is noteworthy that steps 1, 2, 4, 5 and 6 are the same in all cases.

Some elements of this step-by-step process may be hidden within the software. For example, it is planned that the user would input data that are available, such as river width from a survey, and the software would calculate the best estimate of the required outputs using the various tools in the toolkit. The precise algorithms used by the toolkit will need to be selected depending on the available data, such as the magnitude of the flow (e.g. Q_{75}, Q_{95}) at the time of the survey.

A key strength of RAPHSA is that, as more studies are undertaken, the results can be added to the database, which reduces the uncertainty in future applications of the toolkit.

Table 6.1 Step-by-step guide to calculating sensitivity to abstraction

	$DRAPHT_{CC}$	**$DRAPHT_{TM}$**	**$DRAPHT_{CM}$**
STEP 1	Identify location of site using Low Flows 2000		
STEP 2	Calculate catchment characteristics and flow duration curve		
STEP 3	Estimate river width, e.g. using large-scale maps or nearest RHS site, if results to be unstandardised	Visit site, walk river length, make rough map of CGUs, take measurements of width, depth etc in each CGU	Visit site, walk river length, make rough map of CGUs, take measurements of width, depth and velocity etc in each CGU
STEP 4	Enter data to DRAPHT		
STEP 5	Specify outputs (e.g. WUA versus Q, WW versus Q) and whether standardised or unstandardised and species of interest for WUA		
STEP 6	Determine sensitivity to abstraction using tables such as Table 3.1		

7 Using RAPHSA to assess changes in channel geometry

As discussed above, the form of the WUA versus Q and other curves is controlled by the hydrological regime, channel hydraulics and habitat preferences of the selected species/life stages. In the above discussion, focus has been on predicting habitat change as flow changes, assuming that hydraulic behaviour of the river and habitat preferences of target species are fixed. In many cases, such as engineering of river channels (widening, deepening, straightening) for flood risk management, the flow regime remains constant, but the channel geometry and hence the river's hydraulic behaviour are altered. The use of PHABSIM for predicting the changes in habitat that would result from proposed channel restoration has been demonstrated on the River Wey in Surrey (Elliott *et al.*, 1999) as shown in Figure 7.1.

Measurements of river depth, width and velocity from design models could be used to provide predictions of likely physical habitat in the resulting river channel for any engineering works. The steps in Table 6.1 would need to be undertaken twice, first for the pre-restoration situation and second for the post-restoration situation (in which proposed channel geometry would be entered at step 3).

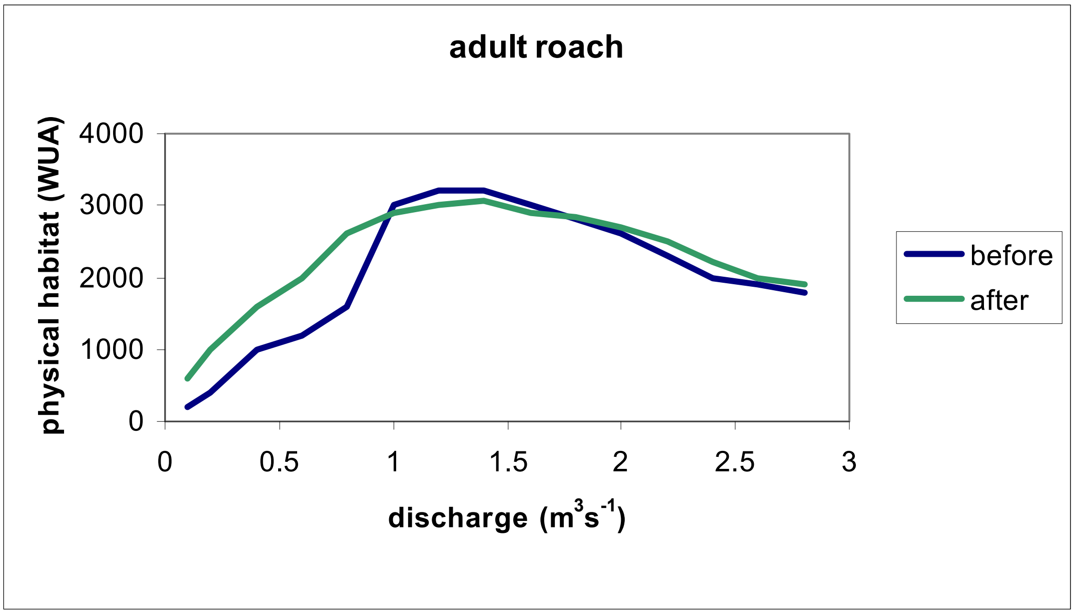

Figure 7.1 Use of WUA versus discharge curves to assess implications of restoration of the River Wey

8 Follow-up research

The main limitation of the RAPHSA outputs is that they are based on a limited set of PHABSIM field sites. As new physical habitat or hydraulic modelling studies are undertaken, their results can be added to the RAPHSA database and the various equations recalculated to improve their confidence and make them applicable over a wider range of river reach types.

The Environment Agency holds a major database of many thousands of gaugings from natural river sections, each of which could be considered to be a one-cross-section hydraulic model. These data need considerable preliminary analysis, such as matching the site grid references to river channels within Low Flows 2000, before they can be included in future RAPHSA studies. Nevertheless, they provide the potential for assessment of the wider applicability of the RAPHSA toolkit, for extended analysis to generate improved tools and as a database for the application of the toolkit to new sites.

Application of RAPHSA ideally requires development of a software package, possibly on a Low Flows 2000 platform. This would enable the end-user to locate the study site on a map, enter data, select the most appropriate tool and obtain the best results.

The DRAPHT_{CC} tool, which is based on physical catchment characteristics, could be used to produce maps of England and Wales where river reaches are colour coded according to sensitivity to abstraction, although this would be of low confidence. This would enable reaches of highest and lowest sensitivity to abstraction to be defined, which would be valuable for water resources management.

The DRAPHT tools could be used to predict velocity–discharge relationships for macroinvertebrate monitoring sites, providing a link between channel form and biotic response to flow. It is logical that the response of the macroinvertebrate community at a site to flow should be conditioned by the channel form and hence the hydraulic geometry; this has been confirmed in recent work for the Environment Agency at a limited number of sites (Dunbar *et al*., 2006).

More explicit links between RAPHSA tools and other datasets could be developed, such as river topography in digital terrain models, River Habitat Survey (RHS) data and aerial photographs.

A useful follow-up project would be to re-visit all the sites in the RAPHSA database to classify them according to degree of habitat modification (perhaps using RHS criteria). This would permit analysis of why WUA versus Q curves might deviate from estimates produced from catchment characteristics (DRAPHT_{CC} tool).

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List of abbreviations

CAMS	Catchment Abstraction Management Strategy
CEH	Centre for Ecology and Hydrology
CGU	Channel geomorphic unit
CHAT	Catchment Habitat Assessment Tool
DRAPHT	Direct Rapid Assessment of Physical Habitat Toolkit
HSI	Habitat suitability index
PHABSIM	Physical Habitat Simulation
Q	River flow (discharge) measured in units of volume / time
RAM	Resource Assessment and Management
RAPHSA	Rapid Assessment of Physical Habitat Sensitivity to Abstraction
RHS	River Habitat Survey
WFD	Water Framework Directive
WUA	Weighted usable area of physical habitat, in units of m^2/1000m
WW	Wetted width

Appendix 1: RAPHSA sites

Table A.1 RAPHSA site details

Site number	River name	Site name	Number of cross-sections	Number of calibration flows	Easting	Northing
1	Tame	Highly modified	4	3	40290	29270
2	Tame	Less modified	5	4	40300	29250
3	Rea	Concrete lined	5	4	40630	28350
4	Rea	Gabion lined	5	4	40610	28290
5	Cole	Modified	4	3	41750	28760
6	Cole	Restored	5	3	41720	28790
8	Exe	Warren Farm	10	3	27920	14060
9	Hodder	Hodder Bank	6	3	36550	44870
10	Gwash	Belmesthorpe	13	2	50410	31050
11	Itchen	u/s of Highbridge	10	2	44670	12130
12	Lambourn	Hunt's Green	12	3	44350	17010
13	Lymington	u/s of Balmerlawn	12	3	43020	10330
15	Wye	Pant Mawr	12	3	28470	28230
16	Wey	Pre-restoration	12	2	48500	14710
17	Wey	Post-restoration	14	3	48500	14710
18	Wylye	Chitterne Brook lower	5	3	39710	13980
19	Wylye	Chitterne Brook upper	6	3	39730	14104
20	Wylye	Stockton/Glebe Farm	11	3	39850	13840
21	Wylye	Longbridge Deverill	9	2	38738	14332
23	Wylye	Upper Wylye (lower site)	3	3	38640	13910
24	Wylye	Upper Wylye (middle site)	9	3	38460	13720
27	Allen	Upper	11	3	40070	10800
28	Allen	Lower	7	3	40030	10750
29	Bray	Leehamford	12	3	26780	13990
30	Barle	Perry Weir	9	3	29307	12546
31	Piddle	Upper	12	3	37450	9500
32	Piddle	Lower/Briantspuddle	9	3	38230	9330
33	Piddle	Devils Brook	10	2	37790	9900
34	Piddle	Higher Hyde	11	4	38596	9117
35	Walkham	Ward Bridge	10	4	25440	7230
36	Senni	Abersenni	12	3	29300	22680
37	South Winterbourne	Lower site	7	3	37250	8970
38	South Winterbourne	Upper site	4	3	37236	89740
40	Carron	New Kelso	10	3	19420	84280
41	Ordie Burn	East Mains	8	3	30820	73250
43	Kells Water	Shoptown	8	3	NI	
48	Tavy	Nat Tor (1A)	8	3	25460	8220
49	Tavy	Hill Bridge (1B)	3	3	25330	8040
50	Tavy	Horndon Bridge (2)	12	3	25220	7950
51	Tavy	Brook Mill (3)	10	3	24750	7250
52	Kennet	Axford (upstream)	10	3	42360	16980
53	Kennet	Axford (downstream)	15	3	42390	16990
54	Kennet	Ramsbury	10	3	42720	17140
201	Babingley	Site G	5	3	57040	32550
202	Glen (West)	Creeton	5	3	50150	31960
204	Glen (West)	Shillingthorpe	5	3	50560	31125
205	Glen (East)	Edenham	5	3	50630	32230

206	Glen (East)	Braceborough	5	3	50810	31350
207	Wissey	Bodney Bridge	7	3	58285	29884
208	Wissey	Chalk Hill Farm	7	3	58400	29770
209	Wissey	Didlington Gravel	5	3	58020	29460
210	Wissey	Didlington Sand	7	3	57880	29530
211	Wissey	Langford Gravel	7	3	58400	29670
212	Wissey	Langford Sand	7	3	58380	29640
213	Wissey	Northwold	7	3	57560	29780
214	Upper Derwent	River Ashop/River Alport	6	3	41490	38920
215	Upper Derwent	River Noe	6	3	41550	38650
216	Upper Derwent	Jaggers Clough	6	3	41610	38650
217	Upper Derwent	River Derwent	6	3	41970	38460
218	Upper Severn	Dolwen	10	3	29920	28515
219	Churnet	d/s Tittesworth Reservoir	9	5	39935	35860
220	Ure	d/s Kilgram Bridge	8	3	41940	48560
221	Pant/Blackwater	Great Sampford (site 1)	5	3	56470	23500
222	Pant/Blackwater	Little Sampford (site 2)	6	3	56550	23385
223	Pant/Blackwater	Kelvedon (site 4)	4	3	57945	22425
225	Tywi	Rhandirmwyn	10	3	27780	24355

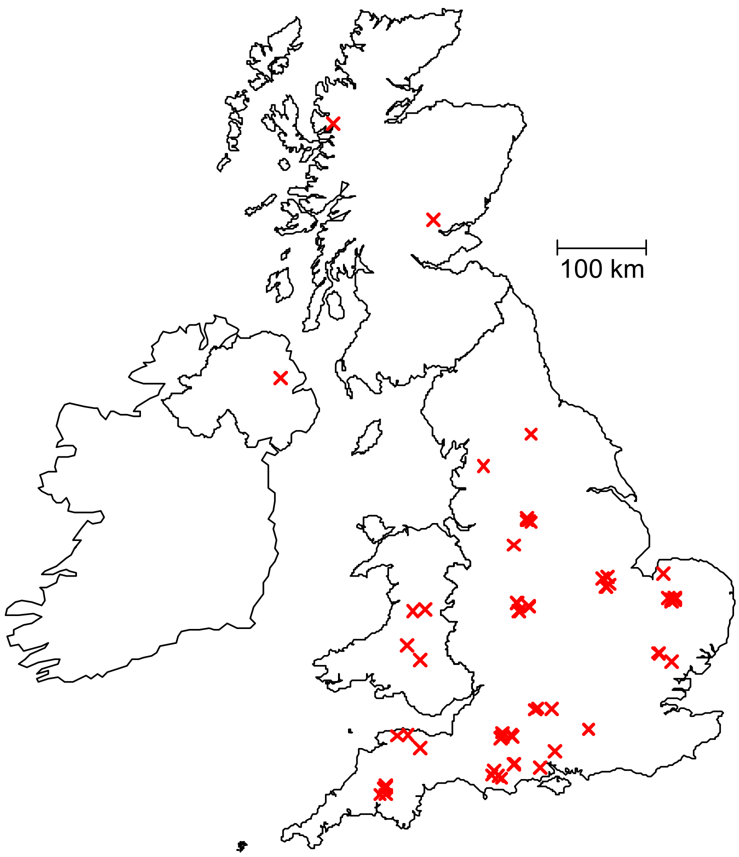

Figure A.1 RAPHSA database sites

Appendix 2: RAPHSA reports

Scientific papers

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