

# R.A.R.E

## Rapid Assessment of River Environments



L.J. Dugdale<sup>1&2</sup>, J.Brown<sup>1</sup>, S.N. Lane<sup>2</sup> and A. Maltby<sup>3</sup>

<sup>1</sup> Eden Rivers Trust, Units O&Q, Skirsgill Business Park, Penrith, CA11 0DP

<sup>2</sup> Durham University, Department of Geography, Science Laboratories, South Road, Durham, DH1 3ER

<sup>3</sup> Association of Rivers Trusts, Well House, Cliburn, CA10 3AL



## Abstract

The R.A.R.E project has employed a range of tools based upon technological advancements in remote sensing, aerial photography, Geographical Information Systems (GIS), environmental modelling and ecological surveying to undertake a cost effective and rapid assessment of the River Eden environment. The key output of the project has been a catchment wide database including information on land management, river habitat quality, and in-stream ecology at local, riparian and catchment scales, which can be used by practitioners to pinpoint sources of environmental degradation and target freshwater restoration strategies within the catchment.

The aim of this report is to share information and raise awareness about the various tools and technologies used, providing practical information and advice to other organisations wishing to undertake a similar project. The report should therefore be of interest to any organisation involved in freshwater management who is looking to identify key sources of freshwater degradation at a catchment scale. This may include government and statutory bodies responsible for meeting the requirements of national and EU legislation such as the Water Framework Directive or Habitats Directive, non-governmental bodies such as rivers trusts, wildlife trusts and fisheries trusts who have limited resources and who want to realise maximum cost benefits from their environmental conservation projects, commercial consultants tasked with providing freshwater management advice within restricted timeframes or research institutions investigating the freshwater environment.

Whilst the R.A.R.E project focuses on the River Eden catchment, Northwest, UK, it is a generic strategy and many of the tools are equally applicable to other catchments within the UK and further a field. **However, it is worth noting that the Eden catchment is a rural environment with 90% of the landscape under agricultural production. Hence, the tools presented are primarily targeted at evaluating the impacts of agriculture upon freshwater ecology.**

**Key words:** river basin management, river habitat restoration, aerial photography, diffuse pollution, electrofishing

## Acknowledgements

R.A.R.E is a collaborative project lead by the Eden Rivers Trust and Durham University in partnership with the Environment Agency, and funded by a Rural Regeneration Cumbria grant. Electrofishing surveys undertaken by the Eden Rivers Trust were supported by the Atlantic Salmon Trust, APEM Ltd and English Nature. The SCIMAP framework has been developed as part of a 3 year Natural Environment Research Council (NERC) funded collaboration between Durham and Lancaster Universities in conjunction with the Eden Rivers Trust, Department of Environment, Food and Rural Affairs (DEFRA) and the Environment Agency.

This report is funded by the Association of Rivers Trusts under the EU Interreg IIIC, Union des Terres de Rivieres (U.TdR) project.

## Introduction



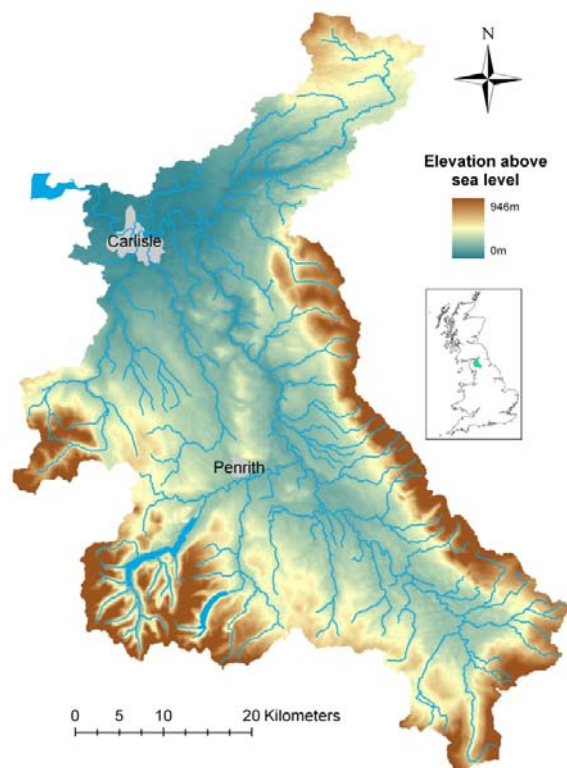
The EU Water Framework Directive states the need to manage land, water and people together in a catchment, placing ecology at the forefront of freshwater management. Habitat degradation due to human activities is frequently cited as the principal cause of freshwater ecological decline. However, whilst the causes of habitat degradation are well understood in general and mitigation techniques known, identifying the exact spatial extent and location of environmental problems at a catchment scale can still prove problematic. Additionally, funding for environmental restoration is often limited making it impossible to tackle every problem within a catchment. Therefore some form of tool for prioritisation must be designed.

Traditional attempts at prioritising freshwater management rely heavily on labour, time and cost intensive environmental monitoring e.g. walkover surveys or continuous in-stream water quality monitoring. Funders and managers alike are frequently frustrated by the drain such monitoring and assessment places on resources leaving little left over to achieve tangible results. To be successful at the catchment scale prioritisation tools must instead be practical, cost effective and efficient to apply.



The R.A.R.E project has been successful in utilising a range of such tools which take advantage of technological advancements in remote sensing, aerial photography, Geographical Information Systems (GIS), environmental modelling and ecological assessment. In comparison with traditional methods, these modern tools facilitate catchment wide coverage that is far cheaper and faster to achieve.

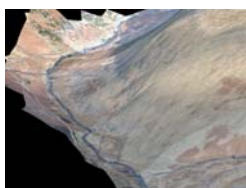
R.A.R.E has been applied to the River Eden catchment, UK. Approximately 2,300 km<sup>2</sup> the Eden is a diverse catchment exhibiting a wide range of physical, ecological and topographic conditions. This diversity makes the Eden an excellent case study as it provides a wide range of environmental conditions within which to rigorously test the prioritisation tools.



*The River Eden catchment*

The sources of environmental degradation can occur at a range of scales including in-stream, riparian and catchment scale processes. No single tool can provide information on all potential sources and impacts. Consequently a range of tools for identifying risks to the freshwater environment have been utilised by R.A.R.E. Each of these tools can be used in isolation to provide specific information or combined to create a more powerful dataset for holistic catchment management.

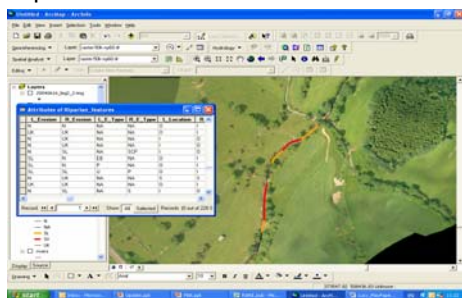
## Geographical Information Systems (GIS)



GIS are powerful computer databases specifically designed to handle, manipulate, visualise and analyse large spatial datasets.

They enable data from a wide variety of sources (e.g. ecological surveys, aerial photographs, and digital maps) to be integrated and analysed within their geographic context, building a holistic catchment picture. GIS forms the basis of the R.A.R.E project and is required for successful implementation of all the tools described below.

At a basic level GIS can generate powerful visualisations of survey results in map or graphical form, an important feature for educating and encouraging co-operation from the local community, land managers, or funders. More experienced analysts can use GIS to perform spatial data analysis, asking simple questions such as: “How many meters of bankside are eroding?” or more complex ones such as “Which pressures are having the greatest impact on fisheries?” GIS can even be used to operate or develop complex environmental models.



A virtual walkover survey can be achieved with GIS and aerial photography.

**Data:** To function a GIS requires data and this must be spatially referenced. Depending on the accuracy required this can easily be achieved by reading co-ordinates of survey sites from a paper map or by using Global Positioning Systems (GPS) in the field. Further baseline datasets which can support and enhance GIS functionality are available from a number of sources in the UK.

- **Ordnance Survey** digital map data ([www.ordnancesurvey.co.uk](http://www.ordnancesurvey.co.uk)) is often the greatest expense in establishing a GIS. However, it is highly beneficial for providing the geographical context and background to other survey datasets. If undertaking projects in collaboration with statutory bodies this can often be supplied freely under sub-license and is worth investigating.



Ordnance Survey Crown copyright ©, Environment Agency, 100026380, 2006.

- **Magic** ([www.magic.gov.uk](http://www.magic.gov.uk)) is a web-based interactive mapping system incorporating a number of baseline datasets including environmental schemes and designations. These can be viewed via the internet without a GIS or downloaded freely to your own system.
- **River Network** centre-lines within Great Britain have been digitised by the Centre for Ecology and Hydrology (CEH) ([www.ceh.ac.uk](http://www.ceh.ac.uk)) from OS 1:50,000 data.
- **EDiNA** (<http://edina.ac.uk/>) provides on-line data sources to education and research institutions including OS digital map data through Digimap, and agricultural census data

A number of different GIS software products are available and selection will depend upon existing resources, operator knowledge, individual requirements and cost. If working as part of a partnership it is recommended that wherever possible all organisations operate the same system for ease of data transfer. The R.A.R.E project primarily used ESRI ArcGIS v.9 ([www.esri.com](http://www.esri.com)) and SAGA GIS freely available at [www.saga-gis.uni-goettingen.de/](http://www.saga-gis.uni-goettingen.de/). A computer with at least 1GB of RAM and plenty of data storage is recommended. At current prices purchasing the hardware and software required to operate a GIS system should be possible for £3,000 - £10,000. However, this is highly dependent upon project scale and the specific capabilities required. If unavailable freely baseline digital map data will add considerably to the above costs.

**For further information on GIS please contact:**

Lucy Dugdale (Scientific Officer): Eden Rivers Trust.  
Tel: 01768866788. E-mail: [lucy@edenriverstrust.org.uk](mailto:lucy@edenriverstrust.org.uk)

## Rapid semi-quantitative electrofishing

Rapid semi-quantitative electrofishing is an innovative technique developed by Crozier and Kennedy, (1994) which can be used to assess the status of juvenile salmonid populations at the catchment scale. Salmonids are considered a key indicator species of freshwater health and ecological condition. As such this technique should be of interest to any organisation wishing to assess the ecological status of its freshwaters or to target fisheries management activities.



*Rapid semi-quantitative electrofishing in action! It only requires two operatives, battery driven backpack equipment and no stop nets. Photo courtesy of A.Tryner and the Countryside Agency.*

The technique has been used by the Eden Rivers Trust (ERT) to undertake catchment wide surveys of Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) (0+) fry since 2002. Specifically targeted at juvenile (riffle) habitat it involves two operatives fishing for a standard period of time (typically 5 minutes) in a downstream direction using backpack electrofishing equipment. Stop nets are not required.

This rapid technique enables wider coverage to be achieved for the same effort and cost as more traditional quantitative survey techniques. 250-350 sites have been surveyed each year giving good coverage of the Eden catchment (approximately 1 site every kilometre). Although semi-quantitative it can be calibrated against quantitative surveys.

Within R.A.R.E. fry are an ideal life stage to use as the project seeks to evaluate the impact of environmental degradation on ecology at discrete locations within the channel network. Fry are the least mobile life stage and it is valid to make the assumption that their population is strongly influenced by local conditions.



*Fry are an excellent indicator of freshwater health.*

The technique is not applicable to assessing parr or adult populations. Instead quantitative surveys using bankside gear in stop netted sections of river can be used. However, the gear is more cumbersome so more accessible sites must be chosen, four operatives are required as opposed to two, and surveys are more time consuming so fewer sites can be conducted in a field season. A new rapid quantitatively based cluster technique is currently being developed by APEM Ltd ([www.apemltd.co.uk](http://www.apemltd.co.uk)) for collecting data on parr populations. This was successfully applied by ERT at 50 sites in 2005.



*Quantitative surveys are more time consuming requiring four operatives, multiple passes, stop nets, and generator driven bankside electrofishing equipment.*

By geo-referencing survey sites using a handheld Global Positioning System (GPS) they can be incorporated within GIS. This enables visual maps to be created and integration of ecological data with habitat information.

## Practical considerations

In England and Wales the Environment Agency operates a national electrofishing programme and may be able to provide data for your area. R.A.R.E incorporated 25 annual monitoring sites and up to 80 rotational sites surveyed by the Environment Agency each year. You should contact your local office for further information. ([www.environment-agency.gov.uk](http://www.environment-agency.gov.uk))

If you are planning to carry out an electrofishing survey yourself you should be aware of the following requirements and considerations:

**Within England and Wales it is an offence to electrofish without an appropriate license from the Environment Agency.**

**Equipment:** Backpack electrofishing equipment can be purchased from Electrocatch International. ([www.btinternet.com/%7Eelectracatch/](http://www.btinternet.com/%7Eelectracatch/)) Other essential equipment may include a 4WD vehicle, nets (both stop nets and catch nets), GPS, buckets, aerators, and waders.

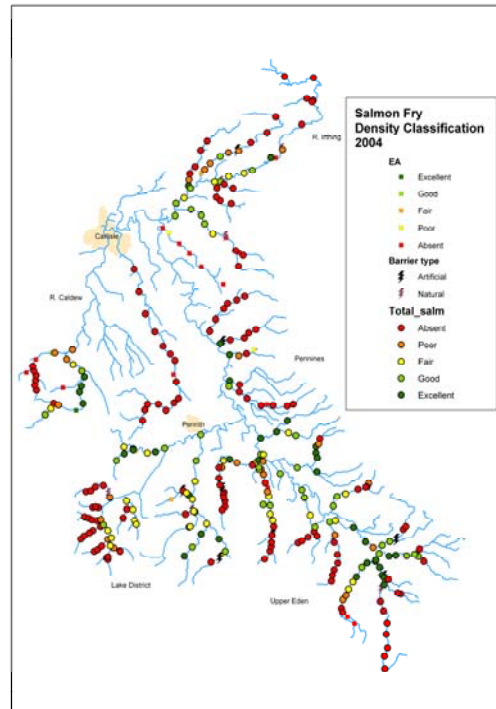
**Staff & Training:** Two operatives are required to carry out a semi-quantitative electrofishing survey. Both should be trained to Environment Agency standards and at least one should be qualified in fish handling and ID. For example at ERT electrofishing is undertaken by a qualified fisheries scientist assisted through the kind help of trained volunteers.



Adult brown trout

**Insurance:** You will need to confirm that your insurance policy covers you, your staff and any volunteers to carry out electrofishing.

**Access:** You must obtain the permission of riparian and fisheries owners before undertaking any survey on their land.



*Excellent catchment coverage is achievable for limited resource in a single field season.*

It is estimated that the costs of undertaking an electrofishing survey in a catchment similar to the Eden would be in the order of £15,000 - £20,000 including start up equipment costs, insurance, staff time (one qualified fisheries scientist), training and travel. Running costs thereafter are estimated to be approximately £5,000 - £10,000 per annum. This is of course highly dependent on project scale. Alternatively, electrofishing services can be provided by a number of commercial aquatic consultants including:

- APEM Ltd: Tel: 0161 226 2922. Web: [www.apemltd.co.uk](http://www.apemltd.co.uk)

**For further information and advice regarding electrofishing please contact:**

Judith Brown (Fisheries Scientist): Eden Rivers Trust. Tel: 01768 866 788 E-mail: [judith@edenriverstrust.org.uk](mailto:judith@edenriverstrust.org.uk)

## Aerial photography

Aerial photography can provide an amazing and rapid insight into the state of rivers and riparian corridors. R.A.R.E integrated aerial photography with GIS to undertake a catchment wide virtual walkover survey, mapping features such as bank erosion, the level of channel cover and shade, riparian vegetation, agricultural stock access and channel substrate. Other potential applications could include:

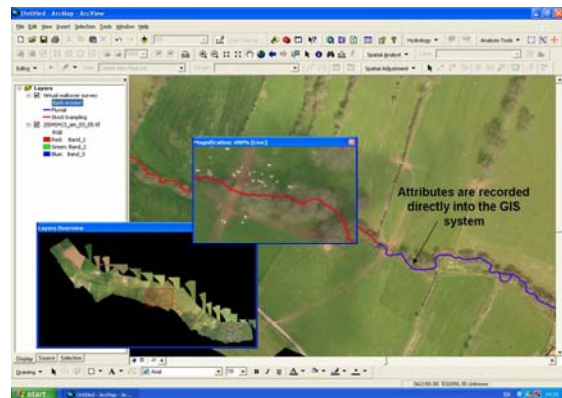
- In-stream analysis of flow type, water depth channel substrate and macrophyte distribution.
- Location and assessment of obstructions to migratory fish such as weirs and dams.

### Why aerial photography not walkover?

- It facilitates rapid coverage of an extensive area. Analysis of the Eden catchment took one interpreter 50 days to complete compared with an estimated 250-500 person days for a walkover equivalent.
- It enables data collection in areas otherwise inaccessible due to access restraints or difficult terrain, thereby providing a continuous data source.
- Sites many kilometres apart can be compared next to each other on the computer screen reducing subjective errors.
- It provides a permanent visual record for monitoring environmental change.
- It provides a powerful visual tool useful for encouraging co-operation from local communities, land owners and funders.



*Birds eye view! Aerial photographs can provide an amazing insight into the riparian corridor rapidly and cost effectively.*



*Individual sites can be evaluated in the geomorphological context of an entire reach or tributary utilising GIS multi-viewer capability at a range of scales.*

Using the latest technology a true colour digital aerial photography survey, yielding 20cm ground resolution data was commissioned as part of the R.A.R.E project and undertaken by Compass Informatics ([www.compass.ie](http://www.compass.ie)).

This was the first time a survey of this type and scale had been undertaken in the UK.



The data recorded has been used to identify tributaries at severe risk from riparian management pressures such as stock access and to produce catchment maps targeting bankside restoration schemes (e.g. stock exclusion fencing, in-stream cover enhancement and riparian tree management). Ground truthing at over 100 sites reported good agreement between remotely sensed and field data.

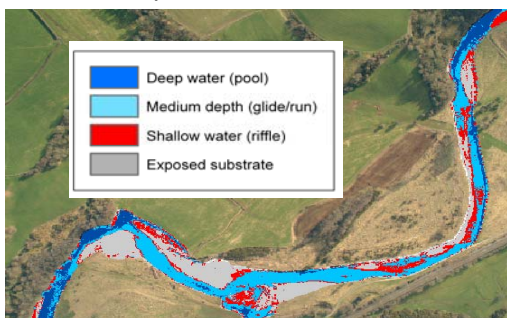
However, aerial photography cannot provide all the details of a walkover survey and in some circumstances traditional techniques may still be preferable. What an aerial survey can do is rapidly highlight reaches where additional, detailed data is required enabling managers to target walkover team resources more cost effectively.

## Practical considerations

It is essential to plan and design any aerial survey carefully to ensure the data collected is appropriate to your needs.

### Image resolution (spatial and spectral)

R.A.R.E found 20cm true colour photography excellent for riparian habitat assessment but less suitable for in-stream analysis. Researchers have used aerial imagery to extract more detailed information (e.g. water depth, flow type and substrate) but this required data of higher spatial and/or spectral resolution. Increasing resolution increases cost and the two must be balanced when designing a survey. As with other technologies potential is advancing whilst cost is reducing all the time and it is always advisable to research the latest developments.



*Automated and detailed in-stream analysis may be possible but success is highly dependent on collecting data of suitable resolution under correct environmental conditions. This requires planning!*

**Environmental conditions:** Ideal flight conditions include a dry period of several days preceding the survey flight ensuring low river flows; and clear visibility with no cloud or high cloud to ensure collection of sharp, clear imagery. The optimum time for image collection will vary according to purpose but important considerations include the effect of leaf foliage on channel visibility and problematic winter conditions such as hard frost cover, restricted flying hours and long shadows resulting from short days and low sun angles.

**Spatial rectification and geo-referencing** of imagery is essential for GIS analysis. This often requires data such as GPS position, ground control points and image orientation to be recorded at the time of survey.

**Ground truthing:** Depending on the purpose of photography ground truthing data may require collection on the same or within a few days of image collection. This is especially important for highly variable factors such as water depth.

**Costs:** for the Eden catchment survey are estimated at £80 per kilometre. However, this is highly variable dependent on location, area, number of flights required, resolution, rectification accuracy and precision.

### UK data sources and providers

Aerial photography with 25cm resolution is available through Getmapping plc ([www1.getmapping.com](http://www1.getmapping.com)). However, this data was not collected for freshwater environmental studies and therefore may fail to meet the requirements above (e.g. low water). However, it could be used to provide general baseline information such as catchment land use.

It is also worth investigating existing data sources in your area such as regulatory bodies, survey companies and military records, particularly if you are only looking for coverage of a small area.

Alternatively a number of consultancies can provide aerial photography services including:

- APEM Ltd:  
Tel: 0161 2262922.  
Web: [www.apemltd.co.uk](http://www.apemltd.co.uk)
- Compass Informatics:  
Tel: +353 1 661 2483.  
Web: [www.compass.ie](http://www.compass.ie)
- Flight Images:  
Tel: 01276 856222.  
Web: [www.flightimages.com](http://www.flightimages.com)



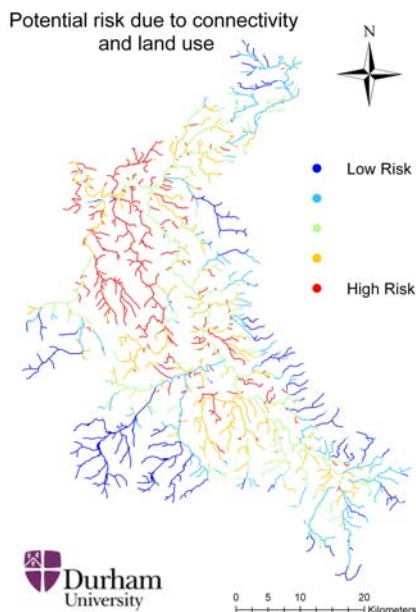
**For further information and advice regarding aerial surveying please contact:**

Lucy Dugdale (Scientific Officer): Eden Rivers Trust Tel: 01768 866 788. E-mail: [lucy@edenriverstrust.org.uk](mailto:lucy@edenriverstrust.org.uk)

## SCIMAP (The Sensitive Catchment Integrated Modelling Platform)

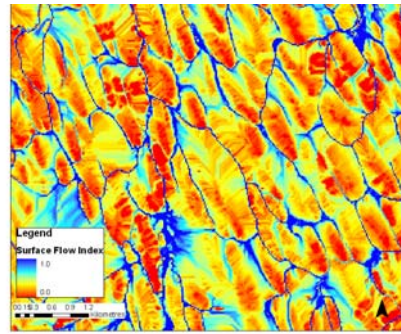
SCIMAP is an innovative framework for the analysis of diffuse pollution risk within river catchments. Presently developed for analysis of fine sediment delivery risk, SCIMAP is currently being developed for other contaminants such as phosphates and nitrates. It should be of interest to any organisation looking to identify critical diffuse pollution sources and delivery pathways that threaten water quality and freshwater ecology and who want to target land management advice within agricultural catchments. The tool works by:

- (1) Assessing the risk of pollution generation at a location e.g. from intensive fertiliser application based on readily available land cover data.
- (2) Most importantly the model identifies which sources are most likely to deliver pollution to the channel based on their likelihood of connection to the channel network by surface flow pathways during a storm event (the hydrological connectivity risk or surface flow index).
- (3) In-stream risk is then calculated by integrating risk from all sources contributing to that point.



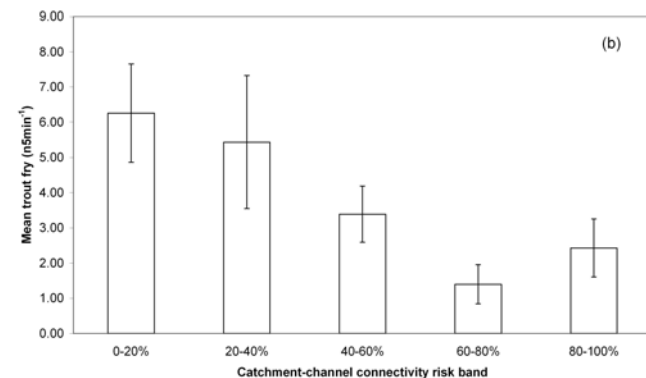
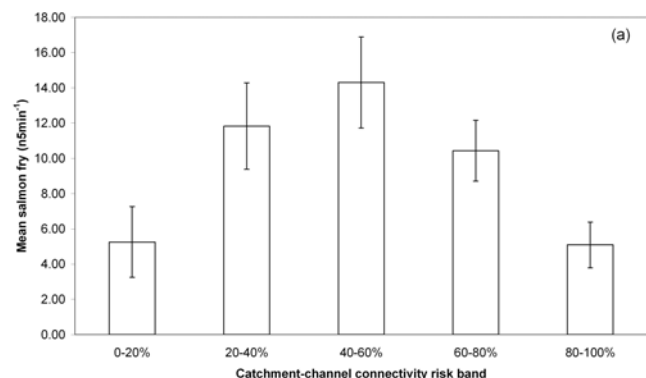
Catchment risk maps are produced identifying which tributaries are at greatest risk from diffuse pollution.

By mapping critical pollution sources and identifying relevant delivery pathways it is possible to target land based restoration strategies such as buffer zones which aim to break connections and reduce pollution delivery to sensitive water bodies.



The surface flow index is determined using a high resolution digital terrain model (DTM) and GIS based hydrological analysis.

The SCIMAP framework has been used within R.A.R.E for the River Eden catchment. Validation of risk maps using water quality analysis, gravel siltation mapping and salmonid data has proved highly successful and the tool is currently being used to target sub-catchments, farms and even fields for land management, buffer zone, nutrient budgeting and soil conservation advice.



A significant relationship has been found between the mean number of fry caught in 5 minutes of semi-quantitative electrofishing and the risk of catchment-channel connectivity: (a) salmon fry; (b) trout fry.

## Practical considerations

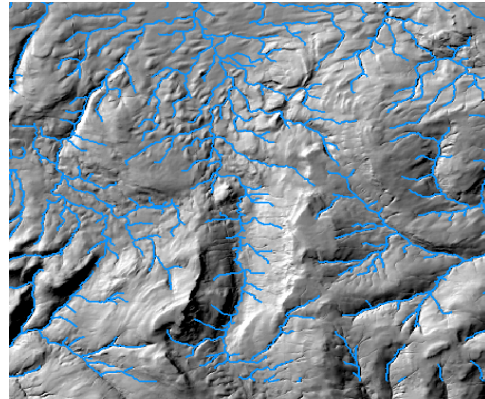
A high resolution **Digital Terrain Model (DTM)** is required to model surface flow pathways and calculate hydrological connectivity risk. R.A.R.E used Intermap's state-of-the-art NEXTMap Britain 5m resolution DTM ([www.intermap.com](http://www.intermap.com)) Available nationally and for many other regions worldwide, it can currently be purchased at a commercial rate of £10.50 per km<sup>2</sup> for areas of 1,001-10,000 km<sup>2</sup>, but significant discounts down to £1 per km<sup>2</sup> may be available for educational or charitable organisations. Alternatively, for bona fide research projects the data may be available from the NERC Earth Observation Data Centre ([www.neodc.rl.ac.uk](http://www.neodc.rl.ac.uk)) without charge. Other high resolution topographic data could also be used such as LiDAR. Several aerial photography systems can also now generate high resolution DTMs.

**Land cover data:** R.A.R.E used the Centre for Ecology and Hydrology's Landcover Map 2000 which is generated from satellite data. See [www.ceh.ac.uk/](http://www.ceh.ac.uk/) for further details. At current prices a 10,000 km<sup>2</sup> area costs £4.5k, £3.5k, or £1.5k depending on whether the data is for commercial, non-commercial or academic purposes respectively. Alternatively, classified aerial photography or agricultural census data could also be used.

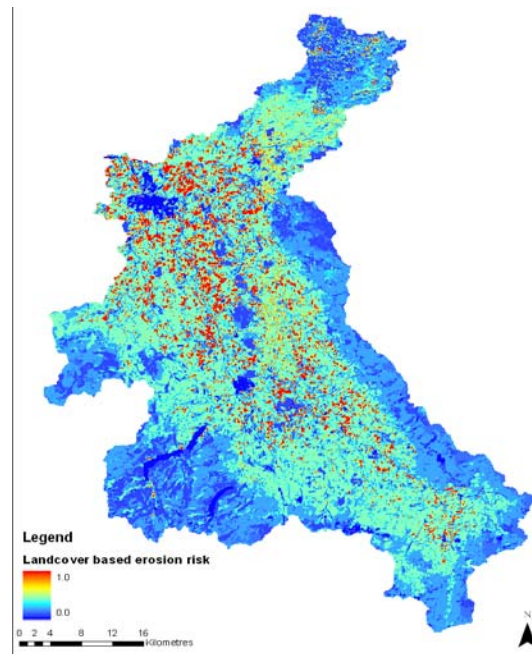
**Rainfall data:** The UK Climate Impacts Programme (UKCIP) 1961-1990 GIS compatible 5km baseline dataset available from the Met Office ([www.met-office.gov.uk](http://www.met-office.gov.uk)) or interpolated long-term average raingauge data available from the Environment Agency are both suitable.

If undertaking projects in collaboration with the statutory bodies it may be possible for much of this data to be supplied freely under sub-license and this is worth investigating.

**SAGA GIS** is also required to operate the model and this is freely available at [www.saga-gis.uni-goettingen.de/](http://www.saga-gis.uni-goettingen.de/).



The NEXTMap Britain DTM provides a detailed model of the catchment's surface by recording elevation readings every 5m.



CEH Landcover Map2000 classified according to the risk of soil erosion.

The SCIMAP framework is being developed as part of a 3 year NERC funded research collaboration between Durham and Lancaster Universities in conjunction with DEFRA and the Environment Agency. SCIMAP software may be available to other rivers trusts through contact with Professor Stuart Lane at the e-mail address below.

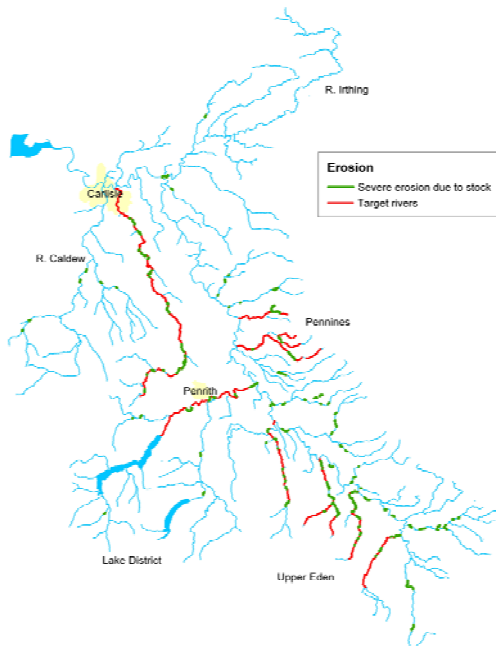
**Further information can be found at:**

[www.scimap.org.uk](http://www.scimap.org.uk) or by contacting: Prof. Stuart Lane [s.n.lane@durham.ac.uk](mailto:s.n.lane@durham.ac.uk) or Prof. Louise Heathwaite [louise.heathwaite@lancs.ac.uk](mailto:louise.heathwaite@lancs.ac.uk).

## Case study: The Eden catchment

Eden Rivers Trust (ERT) is a registered charity involved in protecting and promoting the flora and fauna of the River Eden. It was identified by ERT and their partners that delivering a catchment wide restoration programme would require prioritisation of management actions if limited funds were to achieve maximum environmental benefits.

All the tools described have been applied to the Eden catchment within a GIS framework creating a catchment wide database with information on salmonid status, land management, diffuse pollution risk and riparian habitat pressures. The project has been successful at identifying risks to the catchment's freshwaters and the results are being used to target conservation efforts.



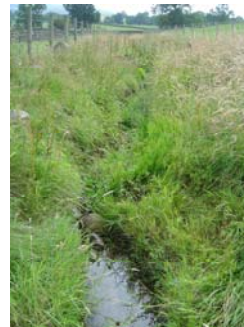
Catchment wide maps locating pressures such as agricultural stock damage have been used to target riparian management e.g. stock exclusion fencing.

Most significantly the database has been analysed to identify factors that help explain salmonid performance and that are critical to the catchment's freshwater health.



SCIMAP risk maps have been used to identify sub-catchments and farms for detailed land management advice such as nutrient budgeting and soil conservation plans.

Land management and catchment-channel hydrological connectivity have been found to be particularly significant, together with the provision of in-stream cover in sensitive juvenile trout streams and the removal of impassable barriers. The database is currently being used to develop a programme of restoration works based upon a sub-catchment approach.



Even tiny tributaries can be very important to trout productivity. Here riparian fencing has encouraged more cover and the results are impressive with an excellent trout fry catch during electrofishing.



Impassable barriers fragment habitat, obstruct migration and prevent re-colonisation of species after pollution events. Here a fish pass has been installed to reconnect and open up valuable habitat.

Total costs of applying the R.A.R.E methodology (including development cost) to the Eden catchment are estimated to be in the order of £125,000. However, costs on transfer to other catchments will be highly dependent upon the tools selected, catchment size, location, existing data sources, and partnerships formed.

## Useful references

Brown, J, Hendry, K. and Maltby, A. 2006. Examining the effect of large scale flooding on salmonid populations using semi-quantitative electrofishing surveys. (Draft). Available from [judith@edenriverstrust.org.uk](mailto:judith@edenriverstrust.org.uk)

Carbonneau, P.E., Lane, S.N. and Bergeron, N.E. 2004. Catchment-scale mapping of surface grain size in gravel-bed rivers using airborne digital imagery. *Water Resources Research*, **40**, 1343-1397.

Crozier, W.W. and Kennedy, G.J.A. 1994. Application of semi-quantitative electrofishing to juvenile salmonid stock surveys. *Journal of Fish Biology*, **45**, 159-164.

Dugdale, L.J., Lane, S.N., Brown, J., Burt, T.P. and Maltby, A. 2006. Salmonids and scales: investigating the impact of land management upon salmonid populations within a hierarchical framework through the use of remote sensing and GIS. *Proceedings of British Hydrological Society Ninth National Hydrology Symposium*, **9**, 27-35.

Dugdale, L.J., Lane, S.N. and Maltby, A. 2006. Achieving a rapid assessment of the river environment: what can remote sensing do to help? *Proceedings of the Institute of Fisheries Management Annual Conference 2005*, 154-173.

Lane, S.N., Brookes, C.J., Heathwaite, A.L. and Reaney, S.M. 2006. Surveillant science: Challenges for the management of rural environments emerging from the new generation diffuse pollution models. *Journal of Agricultural Economics*, **57**, 239-257.

Marcus, W.A., Legleiter, C.J., Aspinall, R.J., Boardman, J.W. and Crabtree, R.L. 2003. High spatial resolution hyperspectral mapping of in-stream habitats, depths and woody debris in mountain streams. *Geomorphology*, **55**, 363-380.



This report is published by the Eden Rivers Trust, Units O&Q, Skirsgill Business Park, Penrith, CA11 0DP. Telephone: 01768 866 788. Web: [www.edenriverstrust.org.uk](http://www.edenriverstrust.org.uk)