RIVPACS AND THE WATER FRAMEWORK DIRECTIVE UNDER CLIMATE CHANGE

Philine zu Ermgassen, NERC Intern to RCEP, Jan-Apr 2009

The Water Framework Directive (WFD) requires member states to collect ecological data and to classify the status of water bodies. The UK has responded by establishing the UK Technical Advisory Group (UKTAG) to develop classification systems to support future monitoring and implementation of the WFD. A key example of such a classification tool is the River InVertebrate Prediction And Classification System (RIVPACS). RIVPACS is designed to determine the ecological status of flowing freshwaters in the UK, through comparing the presence and log abundance of sampled benthic invertebrate families, with the community assemblage[1] predicted under high ecological status[2]. The potential impact of climate change on the efficacy of ecological classification tools, and the resulting implications for compliance with the WFD have not yet been fully resolved. An overview of potential implications of climate change on the functionality of RIVPACS and the associated legal framework are explored in the following report.

WFD under climate change

Ecological classification of water quality provides a holistic and sensitive tool to assess the health of the water body in question. The Water Framework Directive (WFD) requires member states to aim to achieve a “good surface water status” by 2015, and that water bodies should be prevented from deteriorating further. Surface water status is determined ecologically, physicochemically and hydromorphologically. The ecological status is to be determined through classification of a number of biological elements, outlined in **Table 1**.

Good ecological status is defined as water bodies which “deviate only slightly from those normally associated with the surface water body type under undisturbed conditions”. The ecological classification of water bodies is therefore tied to a reference state (i.e. the species composition expected when there is no or little anthropogenic disturbance), although the language of the WFD allows for that baseline to be dynamic, through not strictly defining “undisturbed conditions”. Furthermore, the WFD has a review process built in on a six year cycle, through which reference conditions can be revisited, thus providing a framework for any shifts in ecological concepts to be incorporated into improved management and compliance.

Climate change is currently generally viewed as an anthropogenic stressor. The predicted impacts of climate change on aquatic systems may, therefore, result in a deviation from

[1] Please see the glossary at the end of this report for definitions.

[2] “High ecological status” is a term used within the Water Framework Directive to define water bodies with “... no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions. The values of the biological quality elements for the surface water body reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion. These are the type-specific conditions and communities.” (WFD; Annex V, 1.2)

“undisturbed conditions” and a failure to comply with the WFD (**Table 2**). In light of this, it may be necessary to review the goals of the WFD under climate change to acknowledge that climate change acts on a scale greater than that on which the WFD legislates, such that water bodies impacted by climate change, but not impacted by pollution and habitat alteration could be considered “undisturbed”. The WFD would, therefore, still apply to other stressors which are currently of great concern, such as pollution and habitat alteration. This recommendation would require the current accepted interpretation of the WFD to be challenged in order to incorporate a long term vision of adaptation into the Europe wide interpretation of “undisturbed conditions”.

Rivers	Lakes	Transitional waters	Coastal waters
Macrophytes and phytobenthos Benthic invertebrates (**RIVPACS**) Fish Phytoplankton*	Macrophytes and phytobenthos Benthic invertebrates Fish Phytoplankton	Angiosperms Benthic invertebrates Fish Phytoplankton Macroalgae	Angiosperms Benthic invertebrates Phytoplankton Macroalgae

Table 1. WFD ecological classification requirements. *UK Technical Advisory Group (UKTAG) have stated that it is not reasonable to determine a classification tool for phytoplankton in rivers, given the high turnover of phytoplankton communities in UK rivers and the lack of long term data. Phytoplankton may instead be considered in addition to other measures[3]. See glossary for definitions of terms.

The response of water bodies to climate change is likely to be extremely variable and complex, especially with regards to interactions with other stressors. This poses problems in determining which aspects of climate change derived stress should be considered “acceptable” and which should still be guarded against. For example, it may be possible to mitigate through management, some of the negative impacts of climate change directly relating to water quality such as eutrophication (Mooij *et al.* 2005), while other effects, such as increased water temperature, are inevitable and also likely to impact the biotic communities present. Similarly, climate change may act to exacerbate some problems through interacting with other pollution events which are generally considered unacceptable, such as increased heavy metal pollution through sediment runoff during flood events (Longfield & Macklin 1999). Which impacts of climate change should be considered as “disturbance” under the WFD, therefore, needs to be reviewed thoroughly.

The remainder of this report is written based on the assumption that under climate change ecosystems will be dynamic, such that the communities may vary from those present today. It is also assumed that water quality is likely be under threat, and that it would be beneficial for classification tools to be robust in the face of climate change, such that pollution impacts can still be assessed, and therefore effectively legislated.

[3] “Phytoplankton is not explicitly included in the list of quality elements for rivers in Annex V, 1.1.1 but is included as an element in Annex V 1.2.1. It should therefore be possible to use phytoplankton as a separate element, if needed and appropriate, especially in large and low rivers where phytoplankton may be important’ (page 7, Ecostat Guidance (Nov 2003), footnote 3.)” (UKTAG 2005)

Direct effects	**Indirect effects**
Increase in water temperature and potential decrease in dissolved oxygen Increased eutrophication Increase in prevalence of cyanobacterial blooms in slow flowing rivers and lakes Acidification of upland waterways Increase in some invasive species impacts	Changing land use – could impact siltation and nutrient enrichment Increased flooding leading to re-mobilisation of heavy metals in sediment Climate induced migration of new species – could impact community interactions Increased flooding leading to increased siltation

Table 2: An overview of predicted changes to water quality under climate change. The impacts in rivers, lakes and transitional waters are predicted to differ. The above is therefore a simplified set of predictions.

RIVPACS

The River InVertebrate Prediction and Classification System (RIVPACS) is the accepted WFD ecological classification tool for assessing benthic invertebrate communities in flowing freshwaters throughout the UK. RIVPACS is designed to be sensitive to pollution as well as other disturbance, such as habitat alteration.

RIVPACS is a software package originally developed by the Centre of Ecology and Hydrology (CEH) as a tool for assessing water quality in the UK. The RIVPACS model was constructed following analysis of the macroinvertebrate communities at over 600 reference sites (sites of “good” or “high” quality). The model was constructed such that, through entering a number of site specific environmental variables (**Table 3**), the probability of finding certain species (i.e. the community assemblage anticipated under undisturbed conditions) can be predicted. The observed invertebrate fauna (collected through standardised sampling methods) at the site is then compared with what would be “expected” from the RIVPACS model to give an Ecological Quality Ratio (EQR). The EQR is in turn translated into an ecological classification under the WFD. The environmental variables used in the model were selected for their robustness to pollution (Clarke *et al.* 2003). RIVPACS is now built into the River Invertebrate Classification Tool (RICT) for use by the Environment Agency. RICT incorporates RIVPACS alongside other invertebrate bioindicator tools: Acid Water Indicator Community (AWIC), Lotic Index for Flow Evaluation (LIFE), and the Intercalibration Common Metric index (ICMi).

A range of other biological classification tools have been developed within the UK in compliance with the WFD. A non-exhaustive list is outlined in **Annex A**. The extent to which the efficacy of these ecological classification tools will be impacted by climate change varies greatly, as some are sensitive to biological responses which are likely to be considered as disturbance under any climatic regime. For example, in the case of the Macroalgal Blooming Tool (for use in coastal waters), high opportunistic algal mat biomass is a key indicator of a disturbance, and is a very broad indicator of a disturbed ecosystem.

Time invariant map derived variables	Historical data	Data collected at time of sampling, and averaged over recent past
Altitude Latitude Longitude Distance from source Slope	Historical mean air temperature Historical air temperature range Long term discharge (m^3s^{-1})	Stream width Stream depth Substratum composition Alkalinity (mg $l^{-1}CaCO_3$)

Table 3: The environmental factors included in the RIVPACS model.

Impacts of climate change and its implications for RIVPACS

It should be noted that the Environment Agency and academics have already begun to consider the implications of climate change on water quality (Wilby *et al.* 2006, Crane *et al.* 2005). There have been a series of meetings to outline the potential impacts and solutions to climate change impacts, both independently and through the Euro-limpacs project (**Box 1** and **Annex B**; in particular section 6). One aim of Euro-limpacs is to identify "how future climate change might influence the attainability of restoration targets" (Euro-limpacs 2009) and to identify indicator species useful in determining the impact of climate change as opposed to traditional land use pressures.

<u>Euro-limpacs</u>

Euro-limpacs is an Integrated Project funded by the EU to examine the implications of global change on Europe's freshwater ecosystems. Euro-limpacs is hosted by University College London (UCL).

The research and horizon scanning incorporated in the Euro-limpacs project are highly relevant to the Commission's study and include "adaptation measures that could be adopted to mitigate the adverse consequences of climate change" and "the implications for policy, especially the implementation of the EU Water Framework and Habitats Directives" (**Annex B**).

Box 1: A brief introduction to the Euro-limpacs project in relation to adaptation.

The degree to which freshwater invertebrate communities are likely to be impacted by higher temperatures is subject to debate. Upland stream invertebrate communities have been shown to be negatively impacted by increased temperatures and by increased acidification, which may in itself also be exacerbated by climate change (Durance & Ormerod 2007). Dr. Terry Langford of Southampton University, who has many years of experience working with invertebrate communities downstream of thermal discharge into rivers has suggested that lowland river communities are likely to be more resilient to climate change, as he has not witnessed significant changes in these communities in the past. Superimposed on this potentially variable response to climate is regional variability in temperature change (Environment Agency 2008). The extent to which the efficacy of RIVPACS is likely to be impacted by climate change may, therefore, be spatially variable.

This uncertainty aside, there is already evidence of climate driven change in distributions of some sensitive and highly mobile taxa e.g. Odonata (Hickling *et al*. 2005; Environment Agency 2008) among others (Walther *et al.* 2002). Nevertheless, climate change is not predicted to be the greatest driver of change in aquatic communities in the future (Sala *et al.* 2000). It is, therefore, important to be able to determine the effects of localised disturbance events, such as pollution and land use change.

Climate change is predicted to impact a range of water quality parameters (**Table 2**) and practically, the ecological response to climate change is likely to be extremely complex. Changing water temperatures will not be the only impact of climate change on water bodies; e.g. flow regimes are likely to change in relation to rainfall (Whitehead *et al.* 2009), and this will similarly have implications for the biotic communities present (and, therefore, on the ecological status in relation to a previous reference state).

RIVPACS, like all current reference state based bioindicator tools, is reliant on the ecosystem in question being viewed as a static equilibrium. The "undisturbed" community can therefore be quantified and, in the case of RIVPACS, predicted. There is, however, acceptance within the field of theoretical ecology that ecosystems are in fact dynamic, may have alternative equilibrium states, and that disturbance may be an important element of the ecosystem itself (Wallington *et al.* 2005). Field observations and practical applications of dynamic equilibrium models are still being investigated and it is, therefore, currently difficult to incorporate this new thinking into management strategies (Wallington *et al.* 2005). The WFD is written such that the concept of a dynamic equilibrium in ecological systems is not legally problematic, as long as Member States have tools which are capable of detecting deviation from "undisturbed conditions".

The ability of RIVPACS to detect a true measure of ecological disturbance under climate change is likely to be impacted primarily by the movement of species. RIVPACS predicts communities based on geographical information (**Table 2**). Therefore as the geographical distribution of species changes, the ability of the model based on the reference data set (collected primarily in the late 1970's) to predict which species to expect, will be diminished. RIVPACS is similarly not able to predict the presence of species which are not well represented in the reference database, such as newly arriving species.

Potential solutions

a) Sample "new" environmental combinations to expand the parameter space probed by the RIVPACS model.
   As the climate warms it is likely that climates new to the UK will appear, such as warm high altitude sites. There are no equivalent data in the RIVPACS reference data set, and it would therefore not be possible for RIVPACS to predict the expected community under those conditions. It may be possible to sample these "new" conditions as they arrive, thus expanding the reference data set to accommodate them. The difficulties with this approach are related to time scale and the movement of species: It is generally best if sampling is undertaken over a number of years in different sites of the same stream type, such that local and temporal variation can be controlled for. This would not necessarily be possible under this scenario. The data collected may also not represent the community in "equilibrium" (in static equilibrium terms), as species take time to colonise newly evolved habitats. It is

therefore likely that any such sampling would not be representative of the community one might expect to find on a longer time scale.

It may be possible to constrain findings using data from similar sites in Continental Europe. This would need to be explored further, as the suite of species present in the UK is different to that of the continent due to our island status, and therefore the communities may not represent what one would expect to find under similar conditions in the UK.

b) Re-sample reference sites and re-calculate the RIVPACS model.
This is similar to the first suggestion, except that all reference sites are revisited under a warmer climate and the model is recalculated to fit the new reference data set. Similar problems arise here with regards to the non-equilibrium nature of an ecosystem in transition, as ecosystems are liable to be under a climate in transition. There is also the additional concern regarding the time needed and cost of such a venture. This is therefore not a long term solution.

c) Create a climate index equivalent to the Lotic Index for Flow Evaluation (LIFE).
The Lotic Index for Flow Evaluation (LIFE) has been calculated to allow the impact of low flow on freshwater benthic invertebrates to be assessed. The index uses the variable tolerances of species to flow to calculate the impact of flow. It may similarly be possible to determine a climate index by analysing long term data, and data from Continental Europe, to determine which species are sensitive to high temperatures. It would therefore be possible to apportion the degree of change in a community to higher temperatures, and therefore to climate change over other disturbances. This idea has potential in the medium term, while species assemblages are still relatively similar to the RIVPACS reference, but there is a noticeable signal. The index would not allow for RIVPACS to function in unreferenced climate space, but would help to determine the driver behind anomalous classifications, while RIVPACS is still climatically relevant.

It should be noted that these suggestions are the product of generous discussion with Prof. Ralph Clarke, Dr. John Davy-Bower and Dr. Iwan Jones at CEH. This discussion was very preliminary and does not represent the entire range of options. The assessment of these options is similarly not conclusive. Nevertheless it is clear that we should anticipate that communities are likely to be in transition under climate change, and therefore the underlying principle of a static equilibrium in reference state ecological classification tools is fundamentally problematic.

Access to long term data sets is crucial in the development of any such models and indices.

Non-native species under climate change
Climate change is predicted to exacerbate the effects of some invasive species (Mooij *et al.* 2005). This aside, invasive species are already a leading cause of ecological change, particularly in aquatic systems, where their impacts are predicted to be greater that of climate change (Sala *et al.* 2000). The rate of invasion by freshwater non-native species to Britain and Ireland has been increasing (Minchin 2007; Keller *et al.* 2009), and invasion rates are predicted to continue to increase with global trade (Levine & D'Antonio 2003).

Natural range extensions are predicted as a result of climate change. It is therefore very likely that Britain will receive species currently restricted to the continent, through climate facilitated migration. Given the large ecological and economic cost associated with invasive species (Pimentel *et al.* 2001), it is important that future policy regarding climate change distinguishes between potential invasive species and "natural" climate migrant species.

The WFD does not specifically mention non-native or invasive species. The impacts of invasive species are, however, considered to be a form of anthropogenic disturbance. Given the large number of non-native species, it is impractical to assess the impact of each species at every site where they are present. UKTAG have, therefore, drawn up a list of high impact species, the impacts of which feed into the classification of water bodies as illustrated in Figure 1. The list of high impact species is regularly reviewed to incorporate newly arriving species, in fact includes species which have yet to arrive. Climate change is unlikely to affect the efficacy of this system.

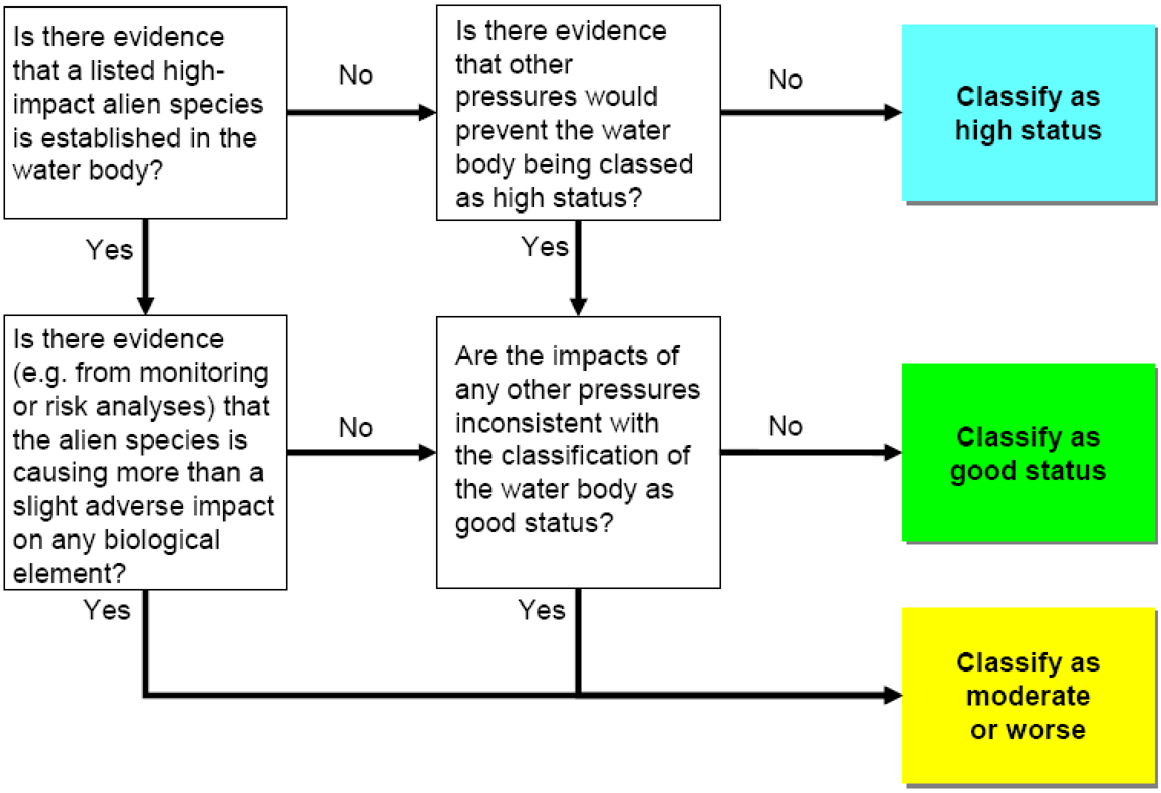

Figure 1: Outline of recommended procedure for taking into account the impact of alien species in classification decisions. From: UK Technical Advisory Group Recommendations on Surface Water Classification Schemes for the purposes of the Water Framework Directive December 2007 (alien species list updated – Oct 2008 and Nov 2008).

References

Clarke, R.T., Wright, J.F., & Furse, M.T., (2003) RIVPACS models for predicting the expected macroinvertebrate fauna and assessing the ecological quality of rivers. *Ecological Modelling* 160, 219-233

Crane, M., Whitehouse, P., Comber, S., Ellis, J. & Wilby, R. L. (2005) Climate change influences on environmental and human health chemical standards. *Human and Ecological Risk Assessment* **11**, 289–318.

Durance, I. & Ormerod, S. J. (2007) Climate change effects on upland stream invertebrates over a 25 year period. *Global Change Biology* **13**, 942-957

Environment Agency (2008) Surface Water Temperature Archive for freshwater and estuarine sites. Draft Science Report – SC070035.

Euro-limpacs. Last updated 10.03.09. http://www.eurolimpacs.ucl.ac.uk/index.php/content/view/31/29/ (accessed on 16.03.09)

Hickling R., Roy, D.B., Hill, J.K., & Thomas, C.D. (2005) A northward shift of range margins in British Odonata. *Global Change Biology* **11**, 502-506

Keller, R.P., zu Ermgassen, P.S.E., & Aldridge, D.C. (2009) Vectors and timing of freshwater invasions in Great Britain. *Conservation Biology* in press

Levine, J.M. & D'Antonio, C.M., (2003) Forecasting Biological Invasions with Increasing International Trade. *Conservation Biology* **17**, 322-326(5)

Longfield, S. A. & Macklin, M. G. (1999) The influence of recent environmental change on flooding and sediment fluxes in the Yorkshire Ouse basin. *Hydrological Processes* **13**, 1051–1066

Minchin, D. (2007) A checklist of alien and cryptogenic aquatic species in Ireland. *Aquatic Invasions* 2, 341-366

Mooij, W.M., Hülsmann, S., De Senerpont Domis, L.N., Nolet, B.A., Bodelier, P.L.E., Boers, P.C.M., Dionisio Pires, L.M., Gons, H.J., Ibelings, B.W., Noordhuis, R., Portielje, R., Wolfstein, K. & Lammens, E.H.R.R. (2005) The impact of climate change on lakes in the Netherlands: a review *Aquatic Ecology* **39**, 381-400

Pimentel, D., S. McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L.,Zern, J, Aquino, T., & Tsomondo, T. (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems & Environment* **84**, 1-20

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M., & Wall, D.H. (2000) Global Biodiversity Scenarios for the Year 2100. *Science* 287: 1770-1774

UKTAG (2005) 11k)(i) Progress report: development of UK classification tools (v1.08.05)

Wallington T.J., Hobbs, R.J. & Moore, S.A. (2005) Implications of current ecological thinking for biodiversity conservation: a review of the salient issues. *Ecology and Society* **10**, 15-30

Walther G-.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.-M., Hoegh-Guldberg, O. & Bairlein, F. (2002) Ecological responses to recent climate. *Nature* **416**, 389-395

Whitehead, P.G., Wilby, R.L., Battarbee, R., Kernan, M. & Wade, A. (2009) A review of the potential impacts of climate change on surface water quality. *Hydrological Sciences Journal* **54**, 1-24

Wilby, R. L., Orr, H. G., Hedger, M., Forrow, D. & Blackmore, M. (2006) Risks posed by climate change to delivery of Water Framework Directive objectives. *Environment International* **32**, 1043–1055

Glossary of terms

Angiosperm – Refers to flowering plants.
Benthic invertebrate – Refers to animals with no internal skeleton that live on the bottom of water bodies and among aquatic plants.
Community assemblage – Refers to the populations of organisms in a given water body.
Macrophyte – Refers to large vascular plants.
Odonata – Refers to the order of insects which includes dragonflies and damselflies.
Phytobenthos – Refers to algae found on the river bed or lake bottom. WFD classification tools are based on benthic diatoms alone.
UKTAG – "The WFD-UKTAG is the United Kingdom Technical Advisory Group (UKTAG) supporting the implementation of the European Community (EC) Water Framework Directive (Directive 2000/60/EC). It is a partnership of the UK environment and conservation agencies. It also includes partners from the Republic of Ireland. UKTAG was established in 2001 to provide coordinated advice on technical aspects of the implementation of the Water Framework Directive (WFD)." Reference: http://www.wfduk.org/ UKTAG webpage (accessed 24.03.09)