Report

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Task 3. Typology

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1. Objective

The overall objective of this project is to develop a toolkit consisting of a tiered set of methods to assess the impact of climate change on wetlands and use this to provide a framework for assessing wetland adaptation strategies and assessing whether management options will be sensitive to future climate change. Task 3 of the project is to define a typology. This document describes the typology development.

2. Background

In this task, the consortium team was asked to adapt, add to, or simplify existing typologies to produce an approach that identifies the different aspects of freshwater wetlands that are likely to be sensitive to climate change. Past typologies are based on the notion that hydrology and vegetation are the dominant fundamental characteristics of wetlands that provide the conditions for dependent species. This hypothesis will be tested by assessing the appropriateness of the typologies to other potential criteria for wetland typologies such as archaeology, ecosystem services and landscape location. Appropriate reference will be made to links with the more detailed ‘donor’ typologies. The Steering Group felt that a single generic typology can be developed that is straightforward and simple, yet incorporates the best of several existing wetland classification schemes. The new “wetland sensitivity to climate change” typology will be easy to understand and use, and will be aimed at wetland managers to help direct them towards the most relevant aspects in terms of climate change impacts on hydrology (water quantity) and the implications for ecology and archaeology. Direct effects of climate change, e.g. temperature on vegetation growth are not covered. Water quality issues are only covered in relation to changes in water source, for example where a switch from rainfall to groundwater dominated system which might invoke reduced acidity. Although currently freshwater wetlands can be impacted by saline intrusion and sea-level rise, we are not considering this here. As appropriate, the typology may well be refined in the later stages of the project, paying particular regard to the findings from the case study applications. Where possible the concept of functions and services of wetlands will be incorporated into the typology. To some extent the typology will need to reflect the climate sensitivities we can identify, measure, or have existing knowledge of. For example, we predict that lack of water, through reduced precipitation and/or increased evaporation (due to higher temperatures), will be a major impact. We are highly confident that temperatures will rise, but we are much less confident about future rainfall changes.

3. Review of wetland typologies

The project aims to develop a typology that is useful and accessible and, importantly, captures the main aspects of wetlands that are climate sensitive (*i.e.* to changes in temperature and rainfall). Existing typologies are assessed on these criteria. Where possible significant gaps will be indicated.

All wetlands are unique to some extent. However, broad types reflecting common characteristics can aid assessment and prediction. Existing typologies have been developed for a range of purposes. One of the earliest UK classification schemes was developed by

Goode (1972) for peatlands, or mires, based primarily on topographical setting. It was adopted for the Nature Conservation Review (Ratcliffe, 1977). The main types were:

1. Floodplain mire
2. Soligenous mire
3. Raised mire
4. Basin mire
5. Valley mire
6. Blanket bog
7. Open water transition mire

The classification is simple, but only covers a proportion of UK wetlands and the types included are a mixture of landscape location and hydrological mechanisms.

The International Convention on Wetlands (signed in Ramsar, Iran in 1971) has a globally agreed classification that recognizes 35 types of wetlands (Davis, 1993). However it covers everything from coral reefs, through estuaries to underground lakes in areas of limestone geology. As a result the classification is too broad to be useful at a detailed hydrological level or for UK situations.

The European Nature Information System (EUNIS) provides a classification of European habitats. EUNIS division D is subdivided as follows:

D1	Raised and blanket bogs
D2	Valley mires, nutrient-poor fens and transition mires
D3	Aapa, palsa and polygon mires
D4	Base-rich fens
D5	Sedges and reedbeds
D6	Inland saline and brackish marshes and reedbeds

Wetlands are also covered in EUNIS division C (Inland surface water habitats - rivers and lakes) and other broad habitat types (for example grasslands and woodlands):

EUNIS E3	Seasonally wet and wet grasslands (grassland and tall forb division)
EUNIS F4.1	Wet heath (part of Heath scrub and tundra)
EUNIS F9	Riverine and fen scrub (also part of Heath scrub and tundra)
EUNIS G1.1	Riparian (Salix, Alnus and/or Betula) woodland (with following four types part of the Broadleaved deciduous woodland division G1)
EUNIS G1.2	Fluvial (Fraxinus-Alnus and Quercus-Ulmus-Fraxinus) woodland
EUNIS G1.3	Mediterranean (Populus, Fraxinus and/or Ulmus and related) riparian woodland
EUNIS G1.4	Broadleaved swamp woodland not on acid peat
EUNIS G1.5	Broadleaved swamp woodland on acid peat
EUNIS G4.1	Mixed swamp woodland (i.e. mixed deciduous and coniferous)

A sample of wetland classification schemes that were considered most appropriate to UK conditions, together with the objectives that led to their development, is presented in Table 1. For obvious reasons, botanists tend to use vegetation classifications such as the National Vegetation Classification (NVC; Rodwell, 1991-2000); whilst soil scientists may differentiate between organic soils, such as peat, and mineral soils, such as gleyed soils. Geochemists may classify wetlands according to pH (*e.g.* Ratcliffe, 1977) or nutrient status (*e.g.* Wheeler and Shaw, 1995a), whilst catchment planners may use hydrological functions as a means of classification (*e.g.* Bullock and Acreman, 2003).

Three hydrological features that have been used in wetland classification are: (1) connectivity with groundwater, (2) connectivity with the downstream channel network and (3) topographical setting. Novitsky (1978) used the first two features to divide wetlands in Wisconsin into four classes:

1. *Surface water depression wetlands* occur where rainfall and flow collect in a depression. Water leaves only by infiltration into the ground or by evaporation / evapotranspiration.
2. *Surface water slope wetlands* occur along the margins of lakes and streams. These wetlands receive water primarily from the lake or river flooding and water can drain back when levels fall.
3. *Groundwater depression wetlands* occur where depressions intercept the water table. These wetlands receive direct precipitation, runoff and groundwater inflow. There is no surface drainage away from the wetlands.
4. *Groundwater slope wetlands* occur where groundwater discharges as springs. Water may flow from the wetland down slope. They occur where geological conditions inhibit downward movement of water.

In their work on hydrological functions of wetlands, Bullock and Acreman (2003) added a fifth class, floodplains, to distinguish between headwater and downstream wetlands and thus include feature (3), topographic setting.

Table 1. Examples of wetland typologies

Authors	Typology name	Objective	Wetland characteristics	Geographical scope
Goode (1972)		Selecting wetland nature reserves	Landscape situation	Peatlands, UK
Novitsky (1978)		Functional analysis	Connectivity with channel and groundwater	Wisconsin, USA
Cowardin *et al* (1979)		Inventory	Associated water body, hydrological regime, substrate type and many others	USA
Lloyd *et al* (1993)		Wetland vulnerability assessment	Hydrological mechanism	East Anglia
Wheeler and Shaw (1995b)		Resource evaluation	Landscape situation	England and Wales
Acreman (2005)		Hydrological impact assessment	Landscape location and water supply mechanism	England and Wales
Wheeler *et al* (2009)	WETMECS	To link hydrology and vegetation	Landscape situation, water supply mechanism, pH, soil fertility	England and Wales
SNIFFER (2009)			Biological and hydrological types	Scotland

Cowardin *et al* (1979) produced a hierarchical system that contains many features and defines five types at system level (including rivers, lakes and marshes), 11 at sub-system level (e.g. perennial, intermittent), 55 at class level (e.g. rock bottom, unconsolidated), and 170 at sub-class level (e.g. broad-leaved plants, needle-leaved plants) resulting in 210,240 possible types given all potential combinations of descriptors. This classification was intended as a general inventory tool and was then used by Adamus and Stockwell (1983) to assess wetlands in terms of hydrological functions, such as flood storage and groundwater recharge. The hierarchical approach provides useful guidance for development of a UK-appropriate typology. However the sub-levels do not relate explicitly to hydrological mechanisms, such as river or groundwater-fed and some classes relate to arid environments not found in the UK.

Lloyd *et al* (1993) produced a classification of East Anglian wetlands according to hydrological mechanism (Figure 1). Three broad types were distinguished:

1. Surface water fed
2. Surface-water and groundwater fed
3. Groundwater fed

Sub-divisions of these three types relate to whether the flow is vertical or lateral and whether the aquifer is unconfined or leaky. The draw-back with this type of classification for impact assessment is that the relative contribution of surface and groundwater is often unknown, which is the very attribute that needs to be defined. Thus the classification can only be done once a good conceptual understanding of the site exists. It does not, therefore, help greatly in the development of a typology suitable for climate impact assessment.

Wetlands occur in many landscape situations, but the common feature is that the substratum is saturated or water-logged for either all or part of the year. Water-logging occurs because the downward movement of water under gravity is impeded either by an impermeable layer or because water is rising from an underlying aquifer. Wheeler and Shaw (1995b) concluded that water-logging results from an interaction between landscape topography and water source and occurs in three main situations:

1. Topogenous wetlands: where water collects on flattish ground or in hollows and wetlands are maintained by retention of precipitation, surface runoff or groundwater.
2. Soligenous wetlands: which occur on sloping ground, where water supply from precipitation, surface runoff or groundwater inflow exceeds the outflow rate.
3. Ombrogenous wetlands: which are more or less exclusively maintained by direct precipitation, but can occur in hollows or on flat or sloping ground.

In Wheeler and Shaw's classification, each of the above three are further sub-divided according to topography and water supply mechanism. The different attributes on which wetland classification can be based should be seen as a series of overlays that are potentially independent of each other.

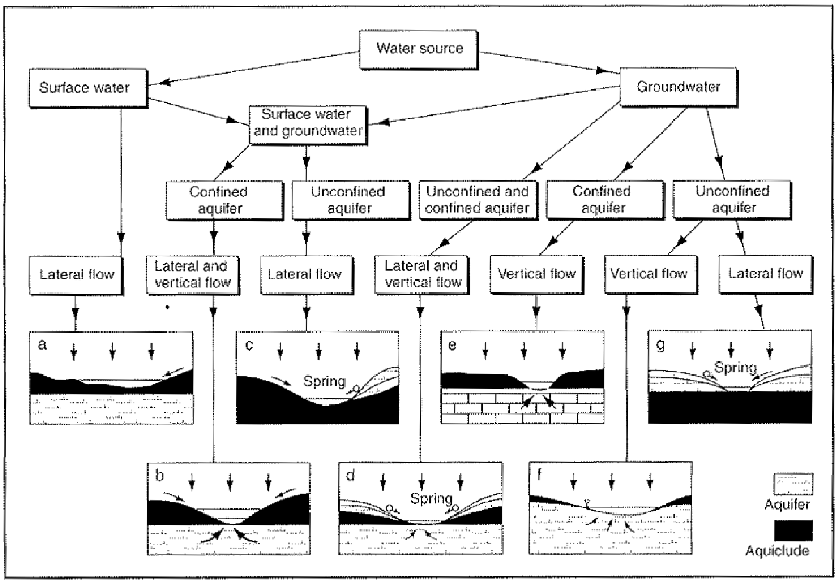


Figure 1. Wetland typology (after Lloyd et al, 1993)

Gilvear and McInnes (1994) identified 12 types of wetland based on possible combinations of hydrological mechanisms (Figure 2). In recognising the importance of landscape location in influencing wetland character, Winter (2000) defined six types of wetlands in the USA: mountainous, plateau and high plain, broad basins of interior drainage, riverine, flat coastal, and hummocky glacial and dune; some of these do not occur in the UK.

As part of the development of an approach to hydrological impact assessment, Acreman (2005) and Acreman and Miller (2007) used landscape location (Figure 3) and water transfer mechanisms (Figure 4) as a means of classification, defining flatland (upland and lowland), slope, depression and valley-bottom wetlands as key freshwater types.

Wheeler *et al.* (2009) developed a classification system of 20 WETland water supply MEChanism types (WETMECS) that combine landscape situation, water supply mechanism, hydrotopographical elements, acidity (base-richness) and fertility. A key aim was to identify homogeneous wetland types that are supported by the same hydrological processes and thus broad classes of wetlands that would respond in a similar way to external or internal impacts. However, it was clear from the study that there are several different hydrological mechanisms which can deliver the same National Vegetation Classification (NVC) wetland vegetation community when combined with other variables, such as water quality and soil/geology type.

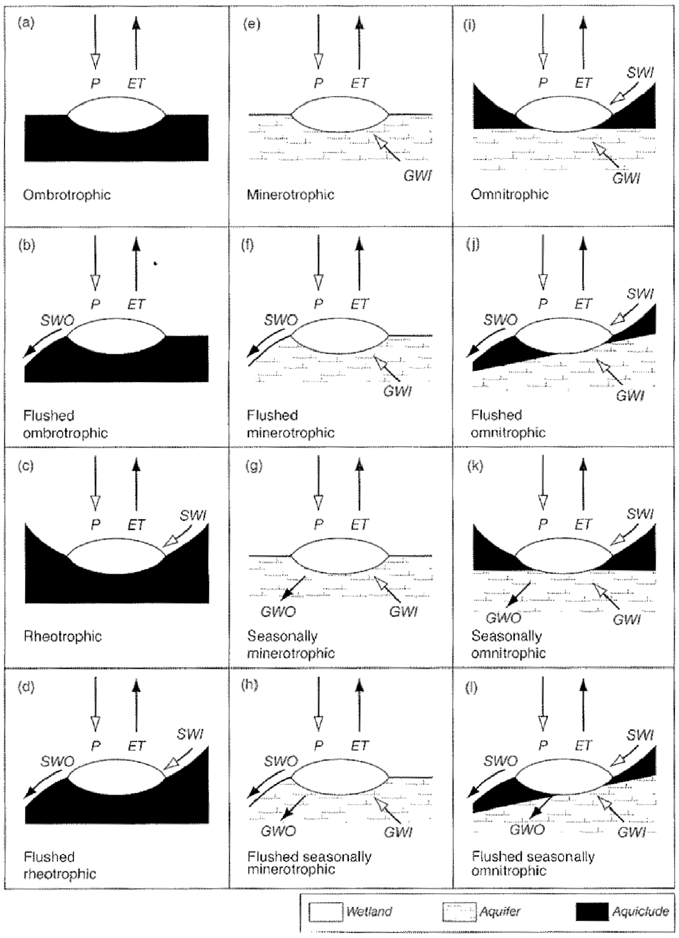


Figure 2. Typology based on water sources and sinks, illustrating the nature of groundwater fluxes (after Gilvear and McInnes, 1994)

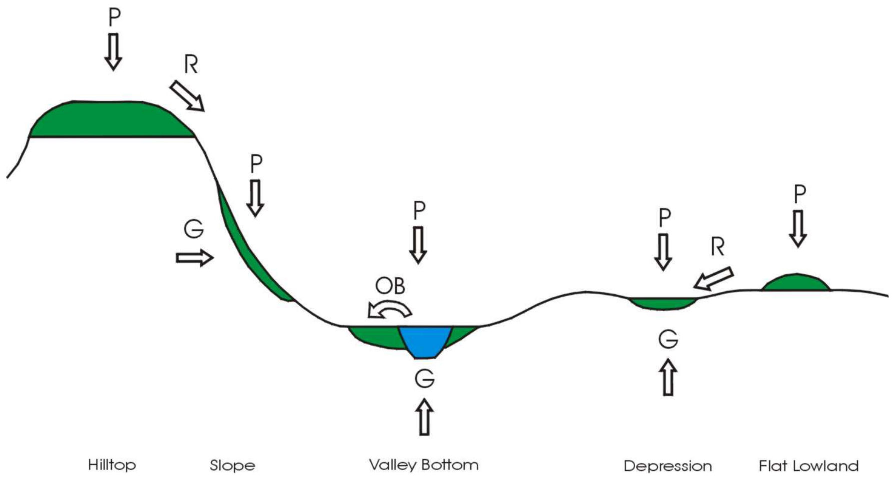


Figure 3. Freshwater wetland types by landscape location and likely dominant mechanisms by which water is transferred into the wetland; where P = precipitation, R = runoff, G= groundwater, OB = over-bank flow (after Acreman, 2005).

For each WETMEC type, the wetlands are further classified into sub-types according to such characteristics as the strength of spring discharges. Within each sub-type, there are two further categories, which define 'ecological types': base-status (base-rich, sub-neutral and base poor) and fertility (oligotrophic, mesotrophic and eutrophic). The base status category can be determined on site by pH measurements. The fertility category requires phytometric analyses of soil samples. For both these categories, the plant communities present may be used as a surrogate indicator. NVC community types are then related to ecological types. An example (WETMECs 5a and 5b) is given in Figure 5.

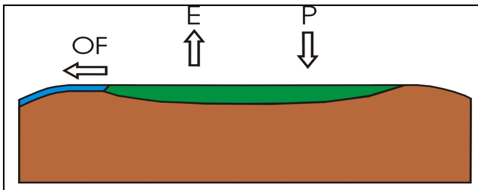
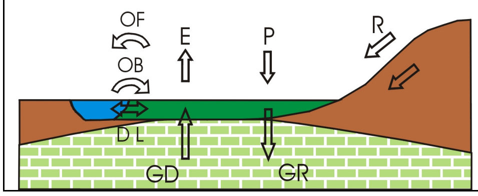
	**Upland flat area wetlands** **Surface water-fed:** Wetland underlain by impermeable strata. Input dominated by precipitation. Output by evaporation and surface outflow. Example: South Pennine Moors.
	**Valley bottom wetland** **Groundwater-fed:** Wetland in direct contact with underlying aquifer. Input dominated by over-bank flow and groundwater discharge, when groundwater table is high, supplemented by runoff and precipitation. Output by groundwater recharge when water table is low, drainage, surface outflow and evaporation. Example: Boxford, Berkshire.

Figure 4. Example wetland types (after Acreman, 2005)

SNIFFER (2009) identified 11 wetland types in Scotland (Table 2), which are a mix of biological and hydrological classes: wet woodland, wet grassland, seepage/flush/spring, fen, swamp, reedbed, wet heath, bog, saltmarsh, dune slacks and Machair.

For climate change studies, where the major impact is through hydrological change, classification needs to incorporate the hydrological regime, either directly, such as through water supply mechanisms, or indirectly such as through landscape location or vegetation type that indicates hydrological mechanism.

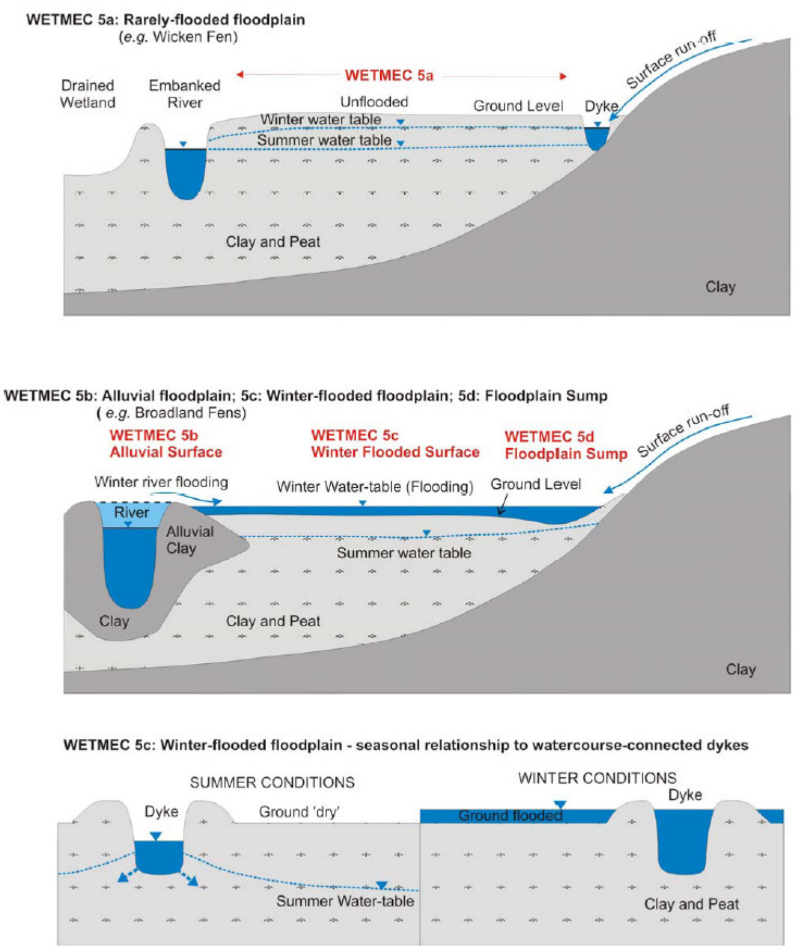


Figure 5. WETMEC 5 a,b & c (after Wheeler et al., 2009)

Table 2. Wetland types for Scotland (after SNIFFER, 2009)

Wetland type	**Wetland sub-type**
1 Wet woodland	1a Bog woodland
	1b Other wet woodland
2 Wet Grassland	2a Marshy grassland
	2b Montane grassland
3 Seepage/ flush/ spring	3a Montane flushes
	3b Tufa-forming spring
	3c Other spring
	3d Seepage/ flush
4 Fen	4 Fen
5 Swamp	5 Swamp
6 Reedbed	6 Reedbed
7 Wet heath	7 Wet heath
8 Bog	8a Peat bog
	8b Quaking bog
9 Saltmarsh	9 Saltmarsh
10 Dune slacks	10 Dune slacks
11 Machair	11 Machair

4. An appropriate typology for assessing climate change impacts

The selection of a typology depends primarily on the purpose of the classification and secondarily on the feasibility of applying it. It has been agreed that this is a hydrological project focusing on the implications for freshwater wetlands of changes in hydrology due to climate change; it does not consider other direct impacts such as CO_2 concentrations or temperature on species. Consequently, the typology needs to focus on the manner in which climate change impacts on wetlands through the hydrological cycle. The classification process involves three main factors (Figure 6):

(1) **Climate change (geographical location)**. The major driving variable is the change in climate itself. Climate models, such as those used within the UK Climate Projections (UKCP09) produce predictions of changes in precipitation, temperature (which influences evaporation) and other meteorological variables for different scenarios. Model results show that these changes vary geographically. It is, for example, widely expected that the greatest changes in the UK will be in the south and east.

(2) **Catchment response (water source)**. The impacts of climate change will be mediated following precipitation to the movement of water through soils and rocks. For example, small urban rivers will be impacted primarily by changes in intensive local rainstorms (often in the summer), whereas groundwater levels, and in turn groundwater-fed wetlands, will be impacted by changes in winter rainfall (when most recharge occurs). The impacts of climate change on wetland hydrology will therefore be strongly influenced by the water supply mechanisms which are important at a particular site, for example rain-fed, river-fed or groundwater-fed.

(3) **Ecosystem vulnerability (vegetation type)**. The response of the wetland ecosystem to alterations in wetland hydrology will depend on the sensitivity or tolerance of the different components. For example, some vegetation communities may be severely impacted by small changes in water table level or soil moisture, whilst other communities will be able to withstand major changes. Furthermore, birds may be vulnerable to hydrological change in different seasons, whilst archaeological remains may be more susceptible to alterations in any change from permanent saturation to periodic saturation. This element of the typology will depend on the indicator of wetland change or the wetland component of interest.

There may be some feedback on the climate from changes to the wetland ecosystem, such as alterations to evaporation and energy balance as plant communities respond to changing hydrological conditions or changes to greenhouse gas emissions (e.g. CO_2 and methane) as water tables alter.

The typology will thus take the form of a tool to locate a wetland along three axes: geographical location; water source; and vegetation type. Water source and geographical location are to some extent related to landscape location (Figure 3).

The WETMECs typology provides a foundation for two dimensions of the matrix; water supply and vegetation type - for wetlands where the vegetation is the key indicator of change. Wheeler *et al.* (2009) also provide maps of the distribution of examples of WETMECs in England and Wales, which relate to the third dimension of the matrix, the geographical location.

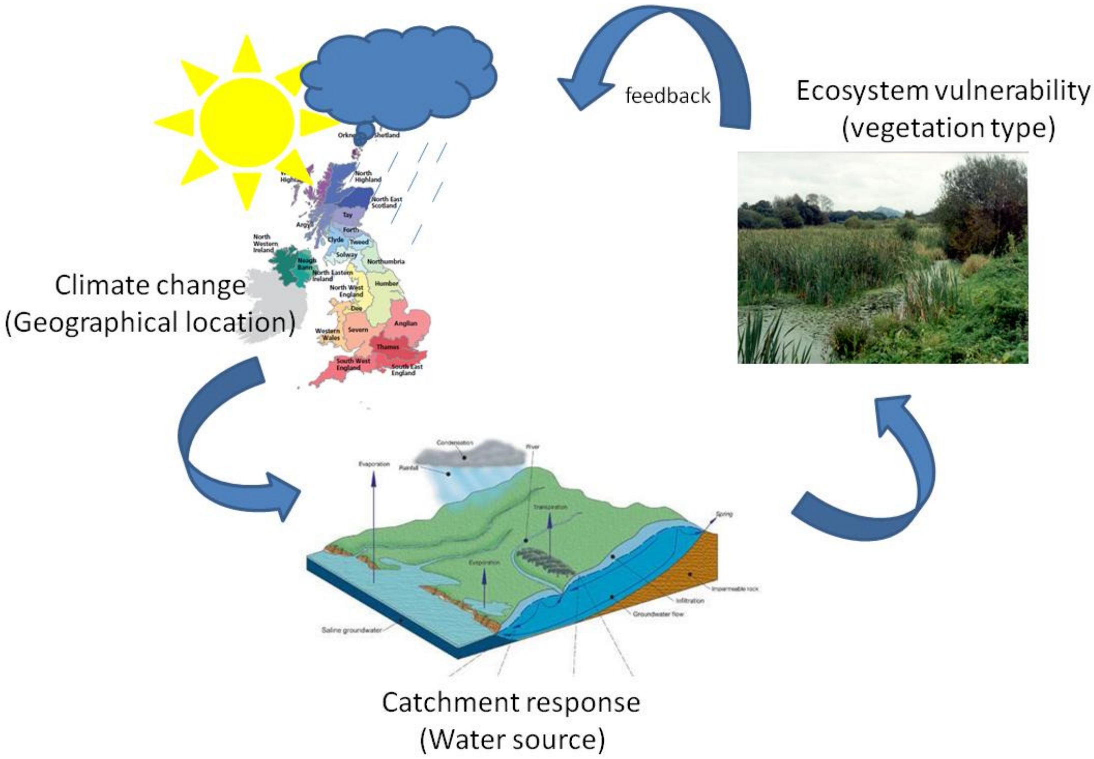


Figure 6. Elements of a typology for assessing climate change impacts on wetlands

The assessment tool-kit to be developed in this project is arranged in three tiers. Tier 1 is a very rapid qualitative tool that relies on simple information, such as geographical location, water source and interest feature (*e.g*. vegetation community). For application of the tool, the WETMEC may not be known, so the method cannot rely on this as prior knowledge. Tier 2 is likely to work on a simple water balance programmed within a spreadsheet; again the WETMEC may not be known. Tier 3 will involve detailed hydrological, hydraulic and distributed groundwater models that are likely to be applied to sites where the WETMEC is known. As a result, the typology cannot rely on site knowledge of WETMECS alone, but requires an alternative pathway to identification of the relevant wetland type.

Figure 7 shows conceptually the 3-dimensional matrix that permits classification of wetlands according to the principal three elements (geographical location, water source and interest feature) or by WETMEC. This concept has to be refined slightly to include ecosystem elements other than vegetation, e.g. birds, archaeological remains or functions.

Application of the typology involves:

(1) Identifying the geographical location from Figure 8 and review of UKCP09 projections to quantify the changes in climate for the climate change scenarios (i.e. time slice, emission scenario, probability) of interest;
(2) Defining the water source in broad terms, e.g. whether rain-fed, river-fed or groundwater-fed;
(3) Specifying the interest features (e.g. vegetation community) of the ecosystem.

With a few exceptions (such as some rain-fed wetlands), no wetland is likely to be unambiguously classified into one single cell of the matrix, because most wetlands have more than one water source and more than one vegetation type (thus more than one WETMEC).

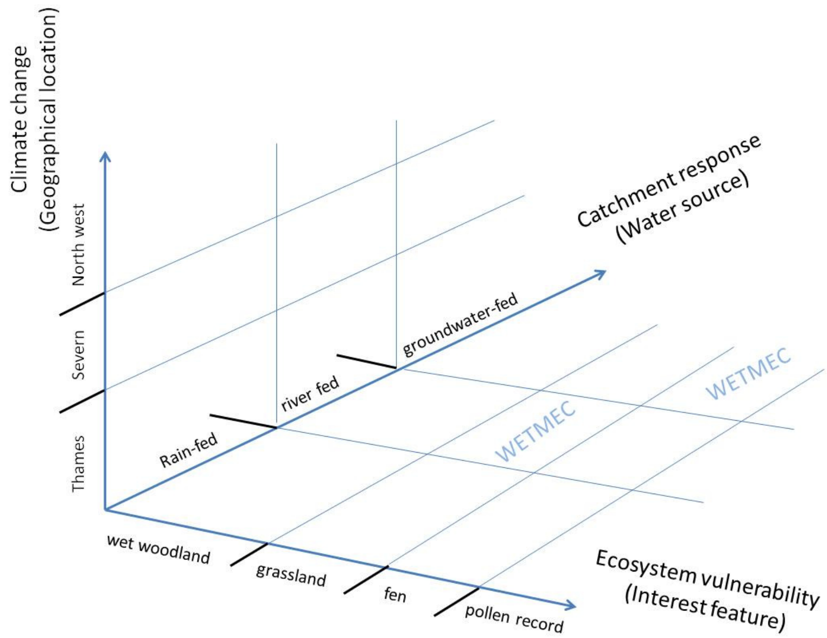


Figure 7. Partial/conceptual image of the wetland typology 3-dimensional matrix

Figure 8. UKCIP climate change regions of the UK (based on WFD basins)[1]

[1] © Crown Copyright 2009. The UK Climate Projections (UKCP09) have been made available by the Department for Environment, Food and Rural Affairs (Defra) and the Department of Climate Change (DECC) under licence from the Met Office, UK Climate Impacts Programme, British Atmospheric Data Centre, Newcastle University, University of East Anglia, Environment Agency, Tyndall Centre and Proudman Oceanographic Laboratory. These organisations give no warranties, express or implied,

5. Using the typology for assessing climate change impacts

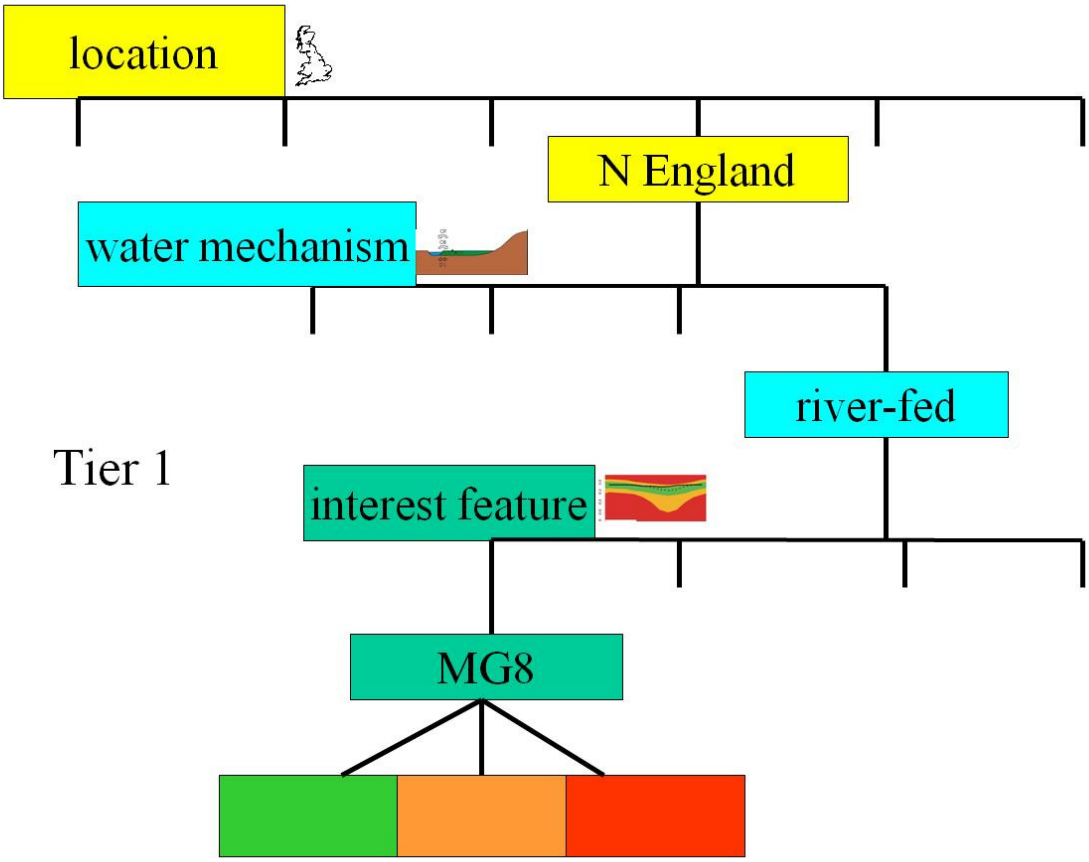


Figure 9. Tier 1 tool framework

Figure 9 shows the framework for tier 1. It is anticipated that this would be delivered as a tool on the CEH web site and so available publically. It would take the form of a series of drop-down menus that lead the user through each of the step depicted in Figure 9: location, water mechanism and interest feature. A list of interest features and metrics is given below.

Hydrological metrics
Minimum water level (mean annual* and period of record**)
Maximum water level (mean annual and period of record)
Number of months with positive or neutral water balance (mean annual and period of record)
Gross annual water balance (rainfall-evaporation) (mean annual and period of record)

Eco-related hydrological metrics
Spring (May) water level
Late summer (August) water level (mean annual and period of record)

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as to the accuracy of the UKCP09 and do not accept any liability for loss or damage, which may arise from reliance upon the UKCP09 and any use of the UKCP09 is undertaken entirely at the users risk.

NVC community metrics

Months in different bands on water requirements diagrams (mean annual and period of record)

Rain-fed:	12 river basin regions 7 NVC types (M16, M21, *MG4 (Types B and K)*, *MG13 (Types H and L*), *M24*)
River-fed:	17 representative catchments covering 12 river basin regions 7 NVC types (MG8, S4, *MG4 (Types B and K)*, *MG13 (Types H and L*), *S24*)
Groundwater-fed:	30 representative aquifer points 4 NVC types (M13, W5, *M24*, *S24*)

Bird metrics

Number of months in breeding season April to July with surface water (mean annual and period of record)

Number of months in wintering season November to March without surface water (mean annual and period of record)

Historical environment metrics

Number of months per year with soil saturation (below gwl, ignoring capillary fringe) at 50 cm below surface (mean annual and period of record)

Number of months per year with soil saturation (below gwl, ignoring capillary fringe) at 100 cm below surface (mean annual and period of record)

<u>Notes on metrics</u>

* Mean annual values over the simulated 30 year time period e.g. mean of the annual minima. These give an indication of long-term sustainability under a changing climate

** The maximum/minimum value for the 30 year time period i.e highest and lowest records. These indicate the effect of extreme events (floods/droughts) under a changing climate

[By comparing these two metrics for the baseline and future emissions scenario, it will be possible to contrast the effect of short term climatic variability versus that of long term climate change].

Final outputs

The final output of tier 1 will be the likelihood (expressed as a percentage) that the interest feature will largely un-impacted (green box), moderately impacted (amber box) or heavily impacted (red box). The percentage will be calculated from the number scenario runs (of the 10,000) that fall into different categories. For example, Figure 10 shows a histogram of 10,000 scenario outputs where number of months where precipitation exceeds evaporation is used as a hydrological generic ‘interest feature’. Purely for illustrative purposes, thresholds of 7 and 7.5 months have been used to mark the boundaries of un-impacted/moderately impacted and moderately impacted/heavily impacted. The areas of the different colours of the histogram show that, in this case, moderate impact is most likely.

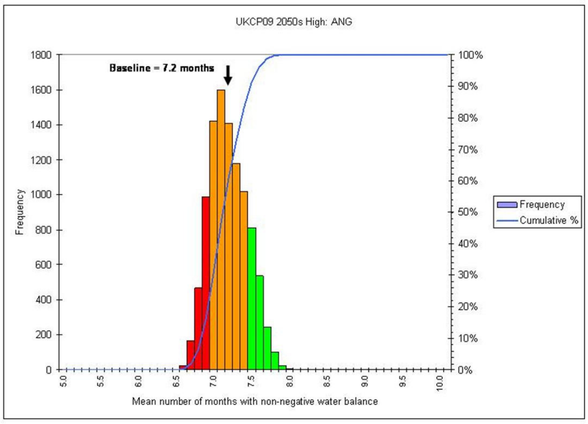

Figure 10. Final output of tier 1 tool – likelihood of impact of climate change

Figures 11 and 12 show schematic diagrams of the tier 2 and tier 3 tools. As discussed above, Tier 2 is likely to work on a simple water balance programmed within a spreadsheet. However, the inputs required for river–fed and groundwater-fed wetlands will require the user to input river flow data and/or groundwater level data both for the baseline period and for climate change scenarios – these will not be part of the spreadsheet. Many rainfall-runoff models are available to derive river flow sequences. For production of the tier 1 model, river flow and groundwater level data will be generated by a separate project that CEH has with the Environment Agency. It is not clear at this time what the IPR status is of these models.

The tier 2 tool models currently have the following parameters

Rain-fed wetlands
Precipitation time series, evaporation time series
Specific yield of wetland soil
Maximum water table level before runoff is generated
Maximum water table level before evaporation extinction depths begins
Minimum water table level at which evaporation is zero

River-fed wetlands
River flow time series
Stage-discharge relationship parameters (x 3)
Hydraulic conductivity of wetland soil
Depth of wetland below bank or embankment

Tier 3 will involve detailed hydrological, hydraulic and distributed groundwater models, where considerable data collection and pre-processing will be required.

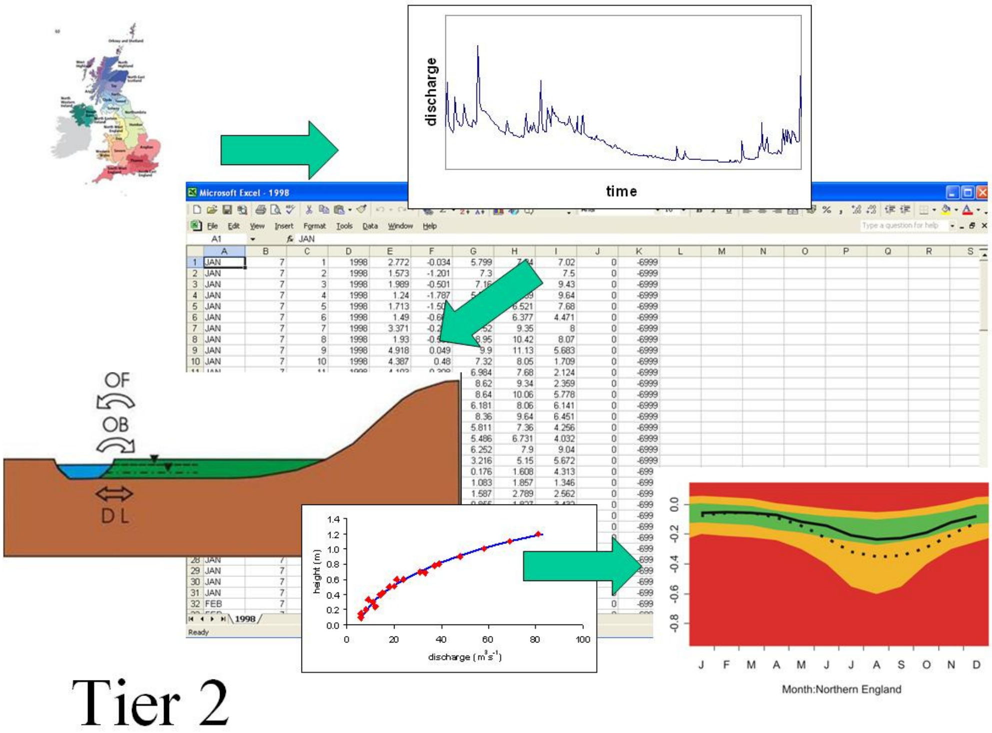

Figure 11. Tier 2 tool framework

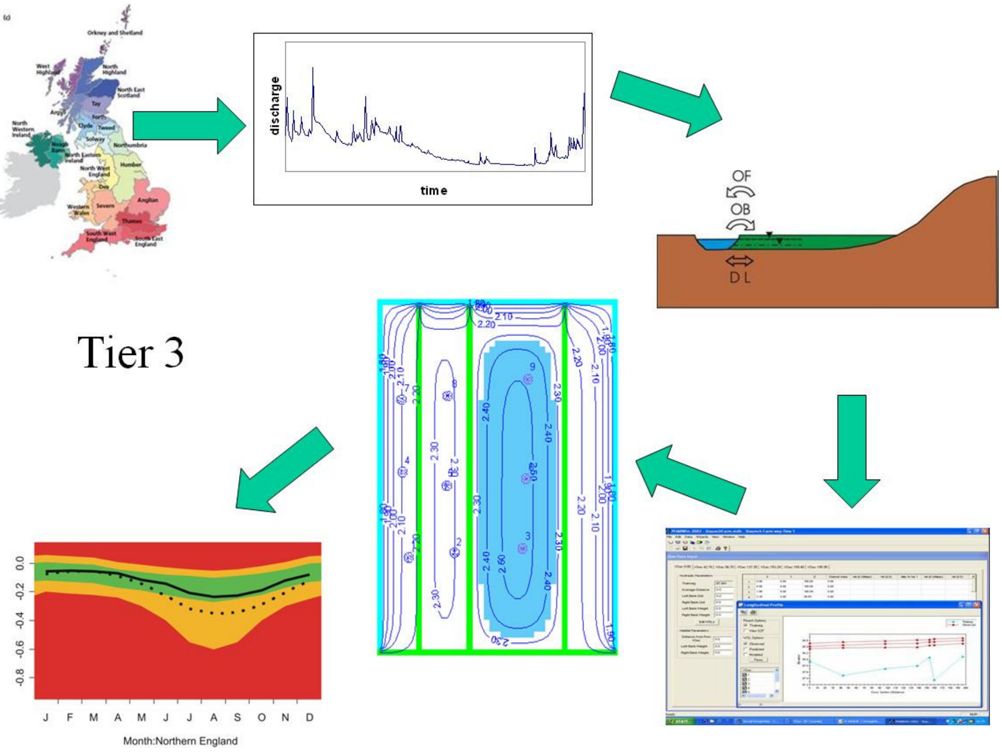

Figure 12. Tier 3 tool framework

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