ECOHYDROLOGY FOR SUSTAINABLE WETLANDS UNDER GLOBAL CHANGE – DATA, MODELS, MANAGEMENT

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Abstract: Wetlands are the most valuable ecosystems of the world. However, they have been subject to severe threats related to global change, resulting in loss, or serious degradation. Factors impairing wetlands are reviewed. Since climate change may put additional stress on wetlands, brief discussion of climate scenarios is offered. In order to sustain wetlands, it is important to manage them wisely and this can only be achieved if their functioning is well understood – hence results the importance of data, observations, modelling, and theories. The new, interdisciplinary area of ecohydrology, whose classical understanding was restricted to wetlands, is likely to play an essential role in maintaining sustainable wetlands and enhancing valuable ecosystem services.

INTRODUCTION

The title of this contribution contains terms: “ecohydrology” and “sustainable development”, which are not ubiquitously and unanimously accepted and may mean different things to different people. Ecohydrology links ecology, i.e. the science on interrelationships of organisms and their environments, and hydrology, i.e. the science on water cycling (hydrological cycle) in the nature, dealing with properties, distribution, and circulation of water. Alternative perceptions of the compound discipline of ecohydrology are as follows: (1) discipline overlapping the ecology and hydrology; (2) study of ecological impacts on hydrological systems (and the other way round).

Zalewski’s (2002) concept of integration of ecology and hydrology (ecohydrology paradigm) envisages a “Platonian superorganism consisting of a catchment

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(geosphere), water (hydrosphere) and biota (biosphere)", serving reduction "of threats and amplification of chances". Indeed ecohydrology can contribute to alleviation of all three types of water problems – having too much, too little, and too dirty water.

Several earlier uses of the notion of ecohydrology have been restricted to "wet" ecosystems – wetlands, marshes, peatlands, and to aquatic ecosystems. Ingram (1987) studied ecohydrology of peatlands. Wassen & Grootjans (1996) defined ecohydrology as an interdisciplinary approach "for wetland management and restoration". The concept was generalized by Baird & Wilby (1999) who relaxed the constraint of "wet" ecosystems and referred to "plant-water interactions" in any other natural, or managed, ecosystem, including the "dry" ones. However, their definition is still not general enough, as it does not embrace the fauna.

Apart from the notion of ecohydrology, there have been several uses of a term "hydroecology" defined by Baird & Wilby (1999) as the "*study of ecological and hydrological processes in rivers and floodplains*" and by Acreman (2001) as the "*linkage of knowledge from hydrological, hydraulic, geomorphological and biological/ecological sciences to predict the response of freshwater biota and ecosystems to variation of abiotic factors over a range of spatial and temporal scales*". The usage of two different terms: "ecohydrology" or "hydroecology" has been confusing to many people.

Similar problem of competing interpretations occurs with relation to the concept of sustainable development. Although this notion has been in broad use for over 15 years now, there is still no common understanding of the term. Because of the ambiguity, it is not possible to delineate the borders between what is "sustainable" and "non-sustainable". As the notion is amorphous, and its borders are fuzzy, differing interpretations are possible, and manipulations leading to abuse of the notion are not uncommon. Both supporters and opponents of many a project are equipped with the same category of weapon - arguments "enhancing" sustainable development.

Among a large number of existing definitions of sustainable development are the following:

- assuring that the development meets the needs of the present generation without compromising the ability of future generations to assuring their own needs (best known definition, after WCED, 1987);
- improving the quality of human life (attaining non-decreasing human welfare over time) within the carrying capacity of supporting ecosystems (IUCN);
- living on interests from the Earth´s capital, without depleting the capital itself;
- development minimizing probability of future regret for decisions taken today.

Accurate and reliable hydrological information is necessary for water development and management. Without it, uninformed decisions are likely to be made that may lead to unsustainable situations. Therefore, hydrological observations should be recognized as an essential component of sustainable development and management of water resources and a basis for early warnings if sustainable development is threatened. The inadequacy of hydrological networks grows and in many countries; especially in the Third World, the networks are in decline. Even if the data are collected, their availability is often limited. It can be generally stated that hydrological data collection and analysis worldwide are not keeping pace with the actual needs of water development and management.

THREAT TO WETLANDS UNDER GLOBAL CHANGE

Wetlands have suffered onslaughts due to multiple human interventions, extending over millennia. Global change poses direct threat to wetlands: that of loss or degradation.

It is assessed that, worldwide, some half of all wetlands have been lost. In Europe and the USA this percentage is even higher. For example, the states of California and Iowa have already lost 99% of their wetlands.

The history of activities that have caused wetlands impairment contains many elements. A sample, in approximately chronological order, can look as follows: clearance of uplands and conversion of marshlands there to agriculture or to new settlements, deforestation of lowlands and loss of floodplain wetlands, many of which have been converted to extensive agriculture, drying lowland marshes, introduction of water drainage schemes, damming rivers and channelization for water power (mills) and navigation.

There exists an extensive list of activities continuing to impair wetlands (their existence or functioning) at present. A sample embraces: drainage for agriculture and silviculture, urbanization, commercial and residential development, industrial siting, water engineering (damming, river regulation, e.g., strengthening and shortening of rivers, levees for flood control, structures, canals), manipulation with flow regimes, pollution (municipal and industrial sewage, distributed agricultural pollutants, including nutrients and pesticides, waste and dredge disposal, atmospheric deposition, mosquito control), road construction, resource extraction, hunting / fishing, invasion of wetlands by shrubs and trees, introduction of alien (non-native) plants and animals, some of which are aggressive, and highly tolerant.

Wetlands suffer where there is a tough competition for water, leading to excessive withdrawal, groundwater overexploitation, etc. If the dilemma of water allocation reads: water for conservation of wetlands or for sustaining irrigated agriculture, the latter is a clear winner in many developing countries.

Existence of a flood pulse is necessary for vulnerable wildlife, and for economic activities - grazing, fodder. Manipulation with flow regimes (e.g., flow regulation leading to a nearly constant discharge) perturbs the natural annual cycle of flooding and sediment transport necessary for fertility and productivity of soils. Lack of annual flooding pulse, upon which marshes and wetlands relied, has been clearly observed in the dammed Nile. Decrease in the magnitude of seasonal floodings of the Tigris and the Euphrates, during the process of filling reservoirs in Turkey has led to loss of productivity and biodiversity of Mesopotamian marshes.

Wetlands are fragile ecosystems. Van der Kamp *et al*. (1999) discuss an example of drying out of small prairie wetlands in Canada after conversion from cultivation to permanent brome grass (with the environment-friendly purpose of providing improved bird-nesting habitat). Within the area of permanent grass cover, springtime snowmelt runoff essentially ceased. The conclusion from this study is that water balance of prairie wetlands is very sensitive to the land use on the surrounding uplands. (van der Kamp *et al*., 1999)Also climate change may pose threat to wetlands. Findings in climate change impact research indicate that all three problems related to freshwater, i. e. having too little, too much, or too dirty water, can be exacerbated in the warmer world, with obvious implications to sustainable development of wetlands. In particular, the increase in frequency and severity of summer droughts over continental interiors is a threat to wetlands, which may not stand an increasing competition between different economic and environmental water uses.

Figure 1 presents scenarios for changes in mean summer and winter temperature and precipitation for Poland (Parry, 2000). Since regional projections differ considerably between emission scenarios and climate models, it is worthwhile to examine an ensemble of cases. Figure 1 clearly shows that a robust result for all models is – warming both in winter and summer. However, changes in mean seasonal precipitation between different models do considerably differ. All models, except for one run of HadCM2a, project wetter winters, while most models (except for two: CSIRO-GG and CGCM-GG) project drier summers. The drier and hotter summers are likely to generate adverse impacts for wetlands.

Figure 2, obtained within the MICE (Modelling the Impact of Climate Extremes) Project shows changes in the mean July precipitation, between the 30-year interval of 2070-2099 and the standard climate normal period 1961-1990, used as a reference interval. These results a clear divide in the map of summer precipitation: somewhat wetter north of Europe and considerably drier south of Europe.

Indeed, in some recent years (spring drought of 2000 in most of Poland, and summer drought in 1992 and 2003 over much of Europe) may serve as proxies for potentially more frequent and more pronounced summer dryness in continental interiors, as projected in IPCC (2001, 2001a).

Apart from the mean precipitation and the seasonality, significant changes may occur in classes of different intensities. In some areas decrease of precipitation of lower intensities and increase of precipitation of higher intensities can be expected (Fig. 3).

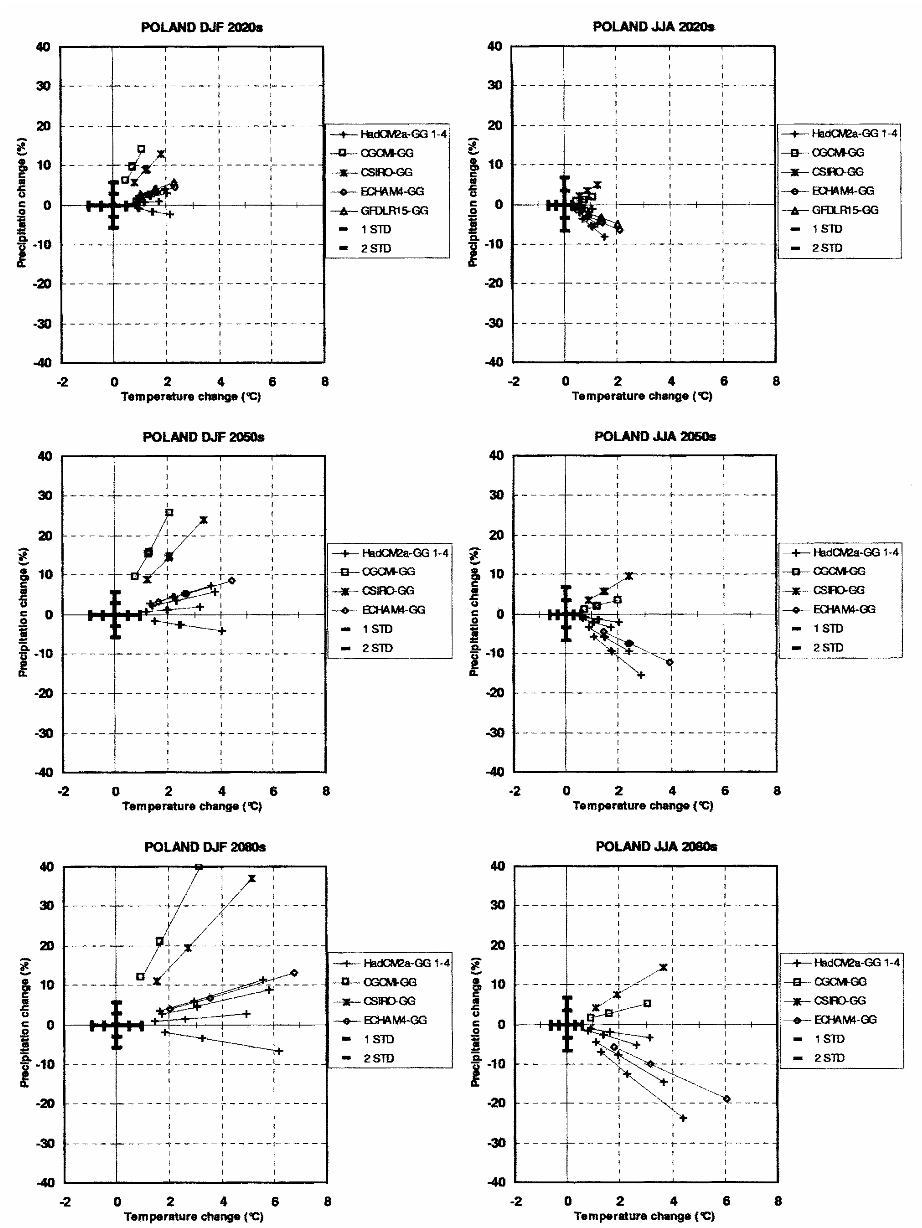

Figure 1 - Scenarios for changes in mean seasonal temperature and precipitation for Poland (from Parry, 2000). The left column refers to winter (DJF = December, January, February), while the right column refers to summer (JJA = June, July, August). The upper, middle, and lower rows refer to time horizons of 2020s, 2050s, and 2080s, respectively. Levels of one and two standard deviations are also marked (crosses passing through the middle of the coordinate system). Symbols linked refer to results of climate models for different emission scenarios.

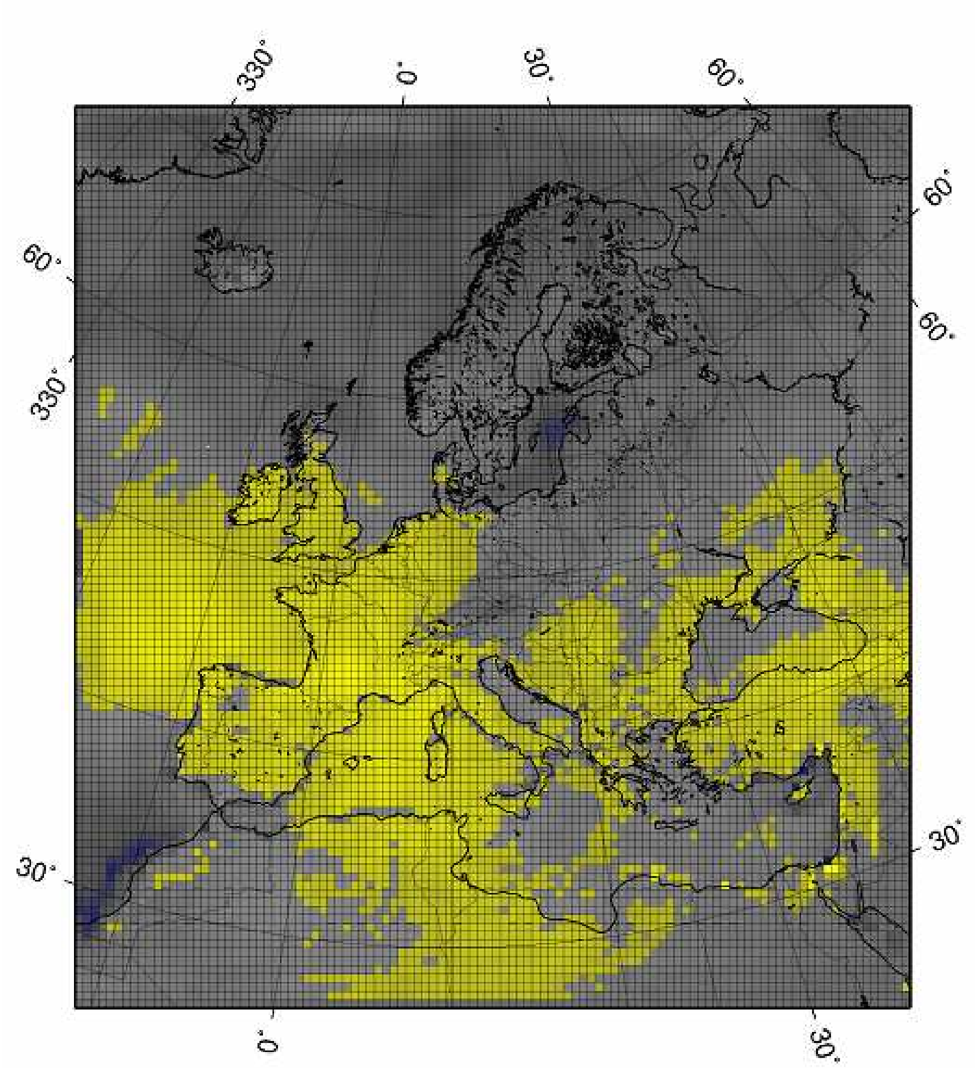

Figure 2 - Changes in the mean June precipitation between the time horizon 2070-2099 and 1961-1990, using HadRM3 results, A2 scenario. The map has been produced within the MICE Project. Legend: light – significant drying, dark – significant wetting, grey insignificant changes.

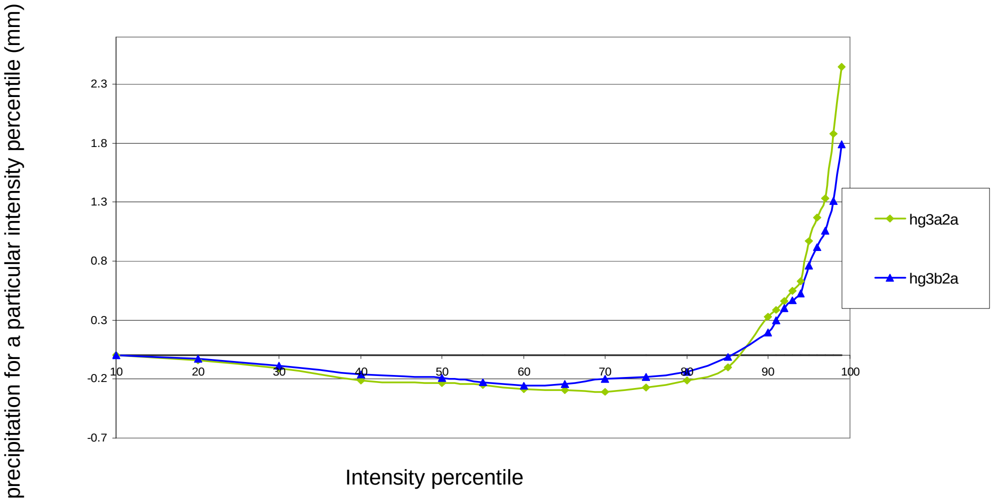

Figure 3 - Changes of daily precipitation in different intensity classes, the percentiles for the Poznań grid of HadRCM3 (2070-2099 vs 1961-1990). This result has been produced within the MICE Project.

DATA, MODELS AND MANAGEMENT ISSUES

Having mentioned the inadequacy of data acquisition worldwide, it is fair to state that monitoring wetlands is by order of magnitude more difficult than in most other environments, due to a numner of complicating factors as, for instance, difficult access in sparsely populated areas (for maintenance, or reading). Hence progress attainable by remote sensing e.g. altimetry is of considerable interest and importance for monitoring wetlands. Long time series of records documenting change in wetlands are very rare. Typically, observation campaigns have commenced relatively recently.

Measuring wetlands embraces multiple characteristics – water levels and flows, areal extent and changes in wetland boundaries; vegetation distribution: changes in occurrence of particular (indicator, protected, or rare) species, biodiversity, or in the distribution of various plant communities; seasonality (stage and flow), water budgets, and hydrochemistry (salinity, heavy metals), changes in the rates of buildup of organic material and sediment or in erosion. The wealth of wetlands monitoring issues refers also to isotopes, tracking source of water (surface water or groundwater?) and residence time. Frequency of measurement can be highly demanding for water budget and hydrochemistry, with initial measurements taken weekly to monthly (more frequently in times of rapid change such as spring thaw) until important times and parameters have been identified. Very valuable are comparison studies of airborne photos, maps, charts and results of field surveys undertaken at different times.

A successful, and well-auguring, example of remotely-sensed altimetry is the determination of satellite-derived wet ditch width (well correlated with ditch water level), at Elmley Marshes, UK, using an automatic water-level recorder (Al-Khudairy *et al*., 2001)

Modelling wetlands is a challenging and difficult field of research. The general aim of modelling of wetland system is to examine changes in some parameters resulting from changes in other parameters. The traditional input–output formulation of the hydrological model, with input being inflow (flow in upstream terminating cross-section), and output being outflow (flow in downstream terminating cross-section) leads already to considerable difficulties. Due to complicated, and changing, topography and morphology of the flat terrain, hydrodynamic modeling (2D rather than 1D) poses surmountable difficulties.

However, in order to answer ecohydrological questions, it is necessary to consider the interdisciplinary framework embracing, in addition to water, also such components as: food (nutrients) - vegetation – fish – benthic microalgae - rooted macrophytes – shelter – shading – food source – inhibition – ion and gas exchange.

The impacts of the flood pulse in the river-floodplain system and related processes, can be also a subject to modeling. The existence of a flood pulse is necessary for succeeding floodplain/wetland habitat complexity, diversity of aquatic life, organic matter storage and breakdown. Flood season and dry season control the timing and the performance of the river-floodplain nutrient transfer, growth of flora, plankton, fish spawning, fish growth, vegetation regeneration, floodplain desiccation). Natural flow variability is indeed essential to biota and ecosystem processes, dependent on transport rates, silt, organic matter, vegetation and spawning pattern.

A special kind of wetland modeling refers to economic evaluation of wetland ecosystem services. Ecosystems provide essential goods and services for life support systems and wetlands play a particular role in this process. Among goods and services provided by wetlands are: food, materials, recreation, peat (energy), flood control, groundwater recharge, biomass production, water quality improvement (harnessed also in man-constructed wetlands), biodiversity.

Costanza *et al.* (1997) attached monetary values to ecosystem services and evaluated ecosystem functions in economic terms on a global scale. Wetlands were found to be most valuable ecosystems of all. The average annual value of ecosystem services of freshwater wetlands was estimated by Costanza *et al.* (1997) at the level of 19 580 USD per hectare (in 1994 USD). Accordingly, the total value of services of freshwater wetlands, covering the area of 165 million ha, was assessed as 3.231 trillion USD. The calculations by Costanza *et al.* (1997) clearly illustrate the multitude of benefits related to ecosystem services (Table 1). The list of services provided by wetlands is long: gas regulation, disturbance regulation, water regulation, water supply, water treatment, habitat/refugia, food production, raw materials, recreation, and cultural services (Costanza *et al.*, 1997). One of the most valuable services was the disturbance regulation, therein flood alleviation, by reducing the peak discharge and increasing the time to peak (7240 USD/ha). Apart from disturbance regulation, the most valuable among services are: water supply (7600 USD/ha), water treatment (1659 USD/ha) and cultural services (1781 USD/ha).

Table 1. Specification of value of ecosystem services provided by global freshwater wetlands, in 1994 USD

Service	Value in USD per ha per year
Gas regulation	265
Disturbance regulation	7240
Water regulation	30
Water supply	7600
Water treatment	1659
Habitat/refugia	439
Flood production	47
Raw materials	49
Recreation	491
Cultural	1781

The wise (sustainable) use of wetlands for the benefit of humankind in a way is compatible with the maintenance of the natural properties of the ecosystem, according to the "Nature knows best" principle.
The necessity of sustainable development of wetlands has gained high international visibility and profile. The international Convention on Wetlands, signed in Ramsar, Iran, in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources as a contribution towards achieving sustainable development throughout the world. There are presently 136 Contracting Parties to the Convention. A large number (1284) of wetland sites, totaling 108.9 million hectares have been included in the Ramsar List of Wetlands of International Importance (… of significant value … for humanity as a whole), see www.ramsar.org. The List embraces eight complexes from Poland: Biebrza National Park, Słowiński National Park, Słońsk Reserve, Seven-Islands Lake, Stawy Milickie Nature Reserve (Milicz fishponds), Świdwie Lake, Karaś Lake, and Łuknajno Lake.
Another study of the socio-economics of wetlands has been reported in a study jointly conducted by the Wetlands International (NGO) and Dutch RIZA (for a report, see www.wetlands.org). This study aimed at valuing wetlands, in both monetary, and non-monetary terms. The analysis included, for example, nomadic groups in Sahelian Africa, whose culture is based on the seasonal inundation of wetlands. The problems in analysis result of the lack of market and no clear ownership of wetlands and their resources.
Among the three flood preparedness options: protect, accommodate, and retreat, the third one is particularly advantageous to wetlands. After the 1993 flood in the Midwest USA, federally and state-funded projects were established to buy land and properties in flood-prone locations from willing sellers. In such areas wetland

restoration takes place. In several countries of Europe, e. g. in Germany and France, naturalization of rivers gains momentum. It leads to re-creating water storage in wetlands and natural depressions. It is also worth noting the man-created ("constructed") wetlands for distributed pollution control, which are getting increasing popularity in many countries.

Service provided by wetlands for climate protection is very important. The wetlands can act as a carbon sink, storing organic carbon in waterlogged sediments. Even slowly growing peatlands may sequester carbon at the rate between 0.5 and 0.7 tonnes/ha/yr. However, wetlands can also be a carbon source, when carbon is released via degassing during decay processes, or after drainage and cutting, as a result of oxidation or burning. Globally, peatlands have shifted over the past two centuries from sinks to sources of carbon, largely because of human exploitation. Models of future climate change suggest that widespread thawing of permafrost peatlands due to climate warming, is likely to lead to further emissions of greenhouse gases such as methane, thus possibly contributing to further warming in a positive feedback effect.

CONCLUSIONS

Wetlands, the most valuable ecosystems of the world, have been subject to severe threats related to global change. Many of wetlands worldwide have been already lost, or seriously degraded. In order to sustain wetlands, it is important to manage them wisely and this can only be achieved if their functioning is well understood. Hence follows the importance of data, observations, modelling, and theories. It can be claimed that the new, interdisciplinary area of ecohydrology, linking ecology and hydrology, whose classical understanding was restricted to wetlands, may play an essential role in maintaining sustainable wetlands and their many valuable ecosystem services, under continuing global change.

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