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Editorial

Synthesis and conclusions to the International Symposium on Ecohydrology, Biotechnology and Engineering: Towards Harmony between the Biogeosphere and Society on the basis of Long-Term Ecosystem Research

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1. Introduction

We live in a period that may eventually be formally designated the Anthropocene (Zalasiewicz et al., 2010), when almost 70% of the Earth's land surface has been converted to agricultural and pastoral ecosystems (anthromes), and the ocean has been significantly changed chemically and through overfishing. It is widely believed that humanity may be exceeding the capacity of Earth to sustain our present population indefinitely (Hughes et al., 2013), not least through high population and degradation of the global environment, aggravated by climate change. It is an ultimate tragedy of the commons (Hardin, 1968). Our future requires a paradigm shift towards more sustainable management of natural resources. The future of nature management depends on changing the way individuals think about the environment and its impact on human well-being, on how decision makers consider and treat environmental values, on how scientists communicate their findings, and whether funds are mobilized to solve environmental problems (Mirtl and Krauze, 2007).

Water has been the key driver of biogeochemical evolution of the biosphere and will continue to be the main limiting factor in achieving sustainable development in many areas of the world. Our existence on Earth inevitably depends on our ability to understand, maintain or restore fundamental long-term climatic, hydrological and ecological processes both locally and globally. Prioritizing short-term management and growth economies, we risk an uncertain future for both human and natural systems (Liu et al., 2007).

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In 1997, the International Hydrological Programme of UNESCO adopted ecohydrology as a foundation of a new scientific approach to integrated water management for sustainability (Zalewski et al., 1997). Ecohydrology, as a management paradigm, extends our perspective from environmental protection and control of environmental hazards towards identification of a hierarchy of natural regulatory processes, with special emphasis on the interplay between water and biota. It embraces our engineering and technological ability to increase efficiency of resource use, prolong the life cycle of products, lower emissions of pollutants to the aquatic system and atmosphere, and most importantly, to take into account the regulatory role of natural ecosystems. It requires socio-ecological research (Redman et al., 2004; Haberl et al., 2006) to define areas of possible augmentation of natural capital, compromise over life style and sustainability, and more sensitive and effective use of engineering in maintaining ecological functions, an essential basis for continuous delivery of ecosystem services. It needs all this to achieve sustainable development, a term that has been increasingly abused, and does not simply mean 'development' *per se*.

Understanding and technology have now progressed enough for an interchange among ecohydrologists, ecologists, hydrologists, hydrobiologists, engineers, and social and economic scientists to contribute to a harmony between the biogeosphere and humanity. Strengthening this communication was one of the goals of the International Symposium on Ecohydrology, Biotechnology & Engineering: Towards the Harmony between Biogeosphere and Society on the basis of Long-Term Ecosystem Research, held in Łódź, Poland, between the 17th and 19th September 2013. It was intended to deepen our understanding of the relationships between environmental and social systems, and help transform them into practical tools for reversing the degradation of the biogeosphere, whilst maintaining reasonably comfortable and thriving human civilisations.

The symposium was organized within the framework of the UN International Year of Water Cooperation 2013 and within the 'Green Future' Programme of the Łódzkie Region, a programme integrating research potential for bioeconomy – intelligent specialization in using biotechnologies for sustainable development and environmental management. It was reinforced by the European Long-Term Ecosystem Research Network (LTER) and its forefront Life+ Project, EnvEurope, both focused on building capacity for long-term socio-ecological research in Europe. It served also as a transdisciplinary, international floor to move forward the conclusions of the 4th International Ecosummit (Columbus, OH, USA, 2012), presented in the "Columbus Declaration: Harmonization of Societal Needs with the EcoSphere in the Anthropocene Era".

The scientific committee of the symposium comprised members from a wide range of disciplines and its programme involved invited and contributed talks and posters, fora, workshop discussions, and field excursions. There were 210 attendees from 31 countries, 95 talks and 50 posters. A general report has been given by Wagner and Zalewski (2013) and an overview of the subject by Zalewski (2014). This account attempts to summarize, in a more interpretative way, the outcome of the scientific discussions and precedes a special issue of Ecohydrology & Hydrobiology (this issue), which has been produced to record some of the findings. Other publications will appear in future issues and elsewhere.

2. Themes of the symposium

The symposium was organized around seven themes, which may be abbreviated to:

1) Integration of environmental knowledge and engineering;
2) Long-term ecological trends and their forecasting;
3) Integrating ecohydrology-based biotechnologies with an engineering approach;
4) Urban ecohydrology;
5) Ecosystem services;
6) Resilience of socio-ecological systems under increasing uncertainty;
7) Modelling, river basin assessment and management.

The attendance at the symposium reflected the breadth of these topics, but there were interesting biases, which reflect the difficulties of changing attitudes and procedures in environmental management. A broad classification of the backgrounds of those giving talks, based on their institutional addresses, suggested that just over half were applied ecologists, about one third hydrologists, and only one sixth engineers and one sixth a mixed group including economists, planners and administrators. This is not unexpected. Environmental management in the past has very much been the province of traditional engineering professions. Their hegemony has been very strong and reflected in substantial achievements in provision of safe drinking water and waste disposal, coupled with extensive river engineering and control schemes, drainage operations and dam building. Engineers have strong professional organizations and in the past have had powerful reinforcement of their approach through its results. Consequently they have traditionally been content within their own organizations.

Traditional engineering schemes have unforeseen drawbacks, however, in interference with more subtle and cryptic, but essential natural systems, and the services they provide such as regulation of atmospheric composition, water storage, chemical processing and regulation of carbon storage in forests and wetlands. Governments have favoured short-term approaches that give obvious and immediate results but do not embrace a long-term ecocentric view. Governments are made up largely of people with professional backgrounds that promote control and exploitation. In recent years 75% of 194 world leaders have come with economic, legal, business, political, engineering and military educations and only one with any sort of environmental qualification (Moss, 2012).

Educational backgrounds strongly influence attitudes and decisions, and electorates also mostly share an approach whose propaganda is that our species is the most important species and one capable of controlling all aspects of the environment to its own ends. Approaches such as ecohydrology, which involve recognition of an equal, or likely much greater, collective role for other species, are relatively new and are contradictory to the

more attractive traditional approach that is self-adulatory for humans and also generates wealth and growth for its more acquisitive citizens. A representation of one sixth for engineers among contributors is thus some cause for optimism, whilst the prominence of ecologists and hydrologists is as expected. Presence of several representatives of governments at regional and national level was encouraging and further development in this research domain should generate their future interest. The relative shortage of policy-makers, economists and planners perhaps reflects a reluctance to abandon familiar and traditional roles among these groups. New attitudes needed for environmental management are not well served by slow and steady processes. They require revolutions in thought that do not come easily to well-established disciplines whose very foundations are being challenged by the global problems we face. Reaction to this plight has frequently been denial and even, where climate change has been concerned, a well-funded and corrupt attempt to discredit data that are now so extensive and critically examined as to be entirely convincing.

The subject areas of the talks and posters at the symposium were extremely varied, and defied simple classification. They embraced, in no particular order, ecological engineering, the development of green economies, climate change, water security, flood risk and modelling, ecosystem services, the government of water regulation, long-term ecosystem and socio-ecological research, water politics and educational programmes. They extended to the genetics and diversity of micro-organisms and their use in technologies for waste treatment, decision making and capacity building in developing countries, eutrophication, lake restoration, and nutrient control. Further, they included river engineering and channel restoration, water management and problems in developing countries, river basin and land management, urban water management, regime shifts in marine systems, acidification, alien species invasions, aridity studies and the role of vegetation in the hydrological cycle. They touched on the Water Framework Directive, ecological theory, thresholds of change and wicked problems, water resources planning, reservoir ecology and planning, drinking water supply, sludge disposal and pollution, the ecology of benthic invertebrates and fish, river flows, the water cycle, and the ecology of vegetation.

The topics reflected, of course, the backgrounds of the participants and overall the traditions of their disciplines. Truly integrative studies were very scarce, and even rarer were approaches that really did embrace an equal partnership at the interface between human control and natural ecosystem requirements. However, cases of integrating ecohydrology, biotechnologies and engineering were introduced to the participants during the technical trips and accompanying lectures. Nevertheless, most of our environmental restoration activities remain at a small scale and the difficulties of breaking out of traditional moulds remain prominent. There was a willingness at the symposium to see different aspects of the problem, and no shortage of new philosophies that are needed to drive changes that ecologists, at least, see as essential, but we are still only on the threshold of action. One strength of the backgrounds of biologists is that they can acknowledge our species as an invasive, scheming and clever ape (Rowlands, 2008) and recognize a context that cannot allow these traits to dominate without their leading to its own demise or even extinction. But biologists bear also the human weakness of enjoying the power that these traits give in determining, at least in the short-term, a comfortable life-style. Parallel, but different conflicts exist in all other professional groups. Our problem is probably not in the technology of putting into place new systems but in overcoming the mental attitudes that currently are resisting them.

3. Summary of the sessions

The chairpersons of the Symposium sessions summarized some general thoughts arising from the papers delivered, and the editors of this special issue have likewise commented on its contents in an attempt to see more deeply the state of ecohydrology and its influence.

Session 1, led by Johannes Cullmann, and later co-chaired by Jun Xia and Giuseppe Arduino, concerned the central theme of attempting to integrate environmental knowledge and engineering, a difficult task because of the very different starting positions of the two professions. It illustrated some of the difficulties. The hydrological, eutrophication and pollution problems currently being experienced are very varied and, in many papers, there was a useful description of them, particularly in developing countries, but solutions remain some distance away. In Poland, some ingenious ways of using simple engineering to obviate nutrient problems were described and form the basis of Gołdyn et al. (2014). There were also useful indications that land management is becoming increasingly recognized as a source of the diffuse nutrients that are assuming greater importance now that the technologies for removing nutrients at wastewater treatment works have been steadily improved and more widely implemented. The role of vegetation in determining run off was shown to be particularly important in arid regions. River engineering is becoming more sensitive, but the deep conflict between flood control and reestablishing major functions of floodplains remains elusive where there are major building developments on floodplains or even any intensification of agriculture. However there is growing realization of the need to create migration corridors for fish and the lowering of existing dams where this is feasible. A great deal of experience in monitoring rivers, before and after physical restoration of some previous features such as meanders, was reported.

Session 2, co-chaired by Alessandra Pugnetti and Michael Mirtl, concerned long-term ecological trends. The LTER Europe network covers 24 countries and emphasises standardization of infrastructure and data, and capacity building in terms of expertise. It is focused especially on ecosystem processes that show subtle, chronic changes (e.g. triggered by climate change), or those involving rare, episodic, and/or complex events. In this respect LTER-Europe contributes to better understanding of the complexity of natural ecosystems and coupled socio-ecological systems.

Especially where changes are occurring that are small but continuous, long-term data can give perspectives that short-term measurements cannot. There is no doubt that such data are essential, especially where interpretation of climate change is concerned. Temperature increases may be relatively small and detectable only in long-term data sets, but they represent a colossal amount of energy newly retained in the biosphere. One problem is that trends in one variable are often masked by changes in others. In lakes, eutrophication tends to have been increasing at the same time as changes in temperature and the two trends may reinforce one another (Moss et al., 2011). An example came from studies of changes in population of a sensitive cold-water fish, the vendace (Godlewska et al., 2014).

Many countries have now established sites where long-term data are being gathered in a standard way. It is regrettable that this had not begun some decades ago, but papers in this session showed the value of such data as we have in, for example, following improvements in pH due to the severe acidification of the late twentieth century and of the impact on vegetation of increased nitrogen loadings from fossil fuel combustion and intensive agriculture. Long-term monitoring illuminates change and can be used to reinforce the need for policy moves to remove the causes of the changes. It provides solid and incontrovertible data.

Biotechnology (Session 3, led by Ryszard Chróst and Robert Pietrowsky) covered a wide range of areas but originated as a way of using organisms in environment protection, to carry out industrial processes, to provide particular chemicals or to establish biological detection methods for pollutants or human diseases. Its meaning has now been widened into embracing microorganisms (bacteria, algae, fungi, protozoons) and plants for converting various forms of matter and regulating water and nutrient pathways at the scale of ecosystems and entire catchments. Knowledge of bacterial communities in natural waters is still at an early stage (Lewicka-Rataj et al., 2014). Molecular methods provide ways of detecting hitherto unrecognized and potentially hazardous strains of bacteria and cyanobacteria in drinking water reservoirs. Uses of bacterial systems in the treatment of petrochemical wastes (Lakatos et al., 2014) and in the production of biogas were reported. Biotechnology (*sensu lato*) is however also being used to describe biological treatment that has a long pedigree. Conventional wastewater treatment works depend absolutely on bacterial and other biological processes, but the sophistication of the biological treatment described by the term is increasing. Denitrification ditches and systems are increasingly being examined. Constructed wetlands also fall under this heading and Wyrwicka et al. (2014) explore the use of plants in removing trace organic pollutants from sewage sludge to be used as fertilizer on agricultural land.

Extension of biological methods to solving global problems is still at a very early stage. Moss (2014) argues for a much more ambitious approach in re-creating biomes for carbon storage from large areas of existing farmland and recounts the major policies and strategies that would be needed to make this possible. However, it would be a less risky approach than the geotechnological approaches being suggested from a conventional engineering viewpoint. Many of these are yet to be invented and may have enormously damaging side effects. Re-creation of biomes is biotechnology at the ultimate scale but an approach already tested by half a billion years of evolution.

Urban ecohydrology (Session 4, co-chaired by Holger Robrecht and Iwona Wagner) is a particular speciality of the host institution of the Symposium. The City of Łódź has experimented with a number of systems to make best use of its rivers. Increasing urbanization has brought prominence to urban issues in international research and institutional and political agenda. Problems caused for the water cycle by transformations of urban landscapes, exacerbated by climate change, make water the most vulnerable element in the city system on one hand, whilst also the most cost-efficient and natural element of adaptation strategies for creating future resilient cities, on the other. Session 4 focused on emerging areas for implementation of ecohydrology in cities. The interdisciplinary presenters covered aspects related to urban ecohydrology implementation in Poland and France, engineering and integrated solutions for storm water management, resilient landscapes and architecture, green infrastructure, valuation of ecosystem services and, finally, human health implications of management based on blue (clean water) and green (vegetation) infrastructure in cities.

Storm water overflows to storage water bodies and better-designed sewerage systems that separate rainwater from wastewater are the systems that will give fewest problems in the future. Existing combined pipe systems should be replaced, where possible, especially as very heavy rainfall events arising from climate change may put pressures on combined sewerage systems that could otherwise bring very frequent pollution of urban rivers by overflow sewage. But this may be economically infeasible in the short term. Alternative solutions include storage of the overflow water in wetland systems that will give it at least partial treatment before eventual discharge to the rivers. The value of city woodlands and even relatively isolated street trees was explored and rainwater storage was seen as a sensible use of water for a variety of services and purposes. Xia et al. (2014) concern urban water management. One of the discussed systemic solutions based on ecohydrology principles is a Blue-Green Network concept (Zalewski et al., 2012) involving storm water retention and purification. It is aimed at adaptation of a city of the future to global climate change while reducing the costs of storm water management and improving the quality of life and health of the city inhabitants.

The session discussions were continued during the Urban Ecohydrology Workshop and meetings of the expert panels of the EU funded Operational Programme of the Innovative Economy project. The overall interest was to define more precisely the potential role which urban ecohydrology can play in the policy drivers for creating more resilient cities. European Union strategies related to cities and territorial development (Europe 2020, Territorial Agenda 2020, Thematic Strategy on the Urban Environment, the 2013 Communication from the European Community on Green Infrastructure) were all discussed, among others in the new perspectives for European Union financing (2014–2020). UNESCO's International Hydrological Programme Phase VIII (IHP-VIII) priorities, economic drivers and the role of local

strategies were addressed. The important question was the role of business and economy (including bioeconomy) in developing innovative research and implementation. The session linked to the conclusions of the Resilient Cities Congress organized by the International Council for Local Environmental Initiatives (ICLEI) in Bonn, 2013. Finally, the Symposium offered the possibility to participate in two technical field trips. The first one concerned the implementation of ecohydrological biotechnologies for reduction of non-point source pollution and was held in the Sulejów Reservoir, the UNESCO IHP demonstration project and LTER demonstration site. The second one focused on the topic of urban ecohydrology. These were ecohydrological innovations in storm water retention and purification in rehabilitation of a municipal river, and ecohydrological rehabilitation of recreational reservoirs "Arturówek" (Łódź) as a model approach to rehabilitation of urban reservoirs. The trip allowed participants of the Symposium to become acquainted with practical implementation of urban ecohydrology in two municipal rivers in Łódź.

Currently the concept of ecosystem goods and services is reaching a higher political profile, partly because valuation of these services, or at least some of them, largely provisioning and cultural services, will allow incorporation of them into cost-benefit analyses of future development projects, and may lead to avoidance of destruction of valuable natural systems. Loss of such systems was attributed to increases in urban asthma and allergies in the consideration of urban hydrology, but further examples were revealed in the following session.

Session 5, led by Giovanni Bidoglio and Daniel Orenstein, focused on the interaction between hydrological cycles and human management and land use, and on ecosystem service assessment. First there were overviews of the entire socio-ecological system, then of human activities around water management, the impact of human activities on hydrological systems, bio-physical aspects of water bodies, and an inventory of ecosystem services across the European Long Term Ecological Research Network's (LTER) sites. Finally, Orenstein discussed how humans perceive the ecosystem services they receive.

The concept of ecosystem services was felt to have been well accepted by environmental economists and social scientists, but there was more scepticism from ecologists and physical scientists. Partly this is due to a fear that the most important regulatory services, for example regulation of atmospheric and oceanic chemistry, which are crucial in mitigating climate change, would always be undervalued. They are irreplaceable by any human-designed scheme simply because the scale of the need is so great. Valuation of regulatory services has been described as 'an underestimate of infinity'. On the other hand, some social scientists are critical of the over dependency on monetization of ecosystem services, including cultural services that must be measured in spiritual and aesthetic terms and whose value transcends monetary value.

Perception of what is a service differs also from stakeholders to experts and there are difficulties with trades-off, particularly where an ecosystem cannot mutually provide all the services that different stakeholders want, at the levels each individual group might think they need them. This is a fundamental problem of economic valuation. Natural scientists often object that there cannot be a conventional market for what is irreplaceable. However, the power of ecosystem service assessment as a tool for convincing decision makers to take action in order to ensure a sustainable use of resources must not be underestimated. The ecosystem services concept may be particularly useful in Africa and other developing regions where some of the destruction of natural systems that has been rife in the temperate zones might be avoided and where there may be a mismatch between where ecosystem services are produced and where they are delivered.

Ecosystem services were also included in a discussion in Workshop 2 to define the current status and future scientific programmes, infrastructure, monitoring and networking needs for long-term ecological research. Patrick Bourgeron led the discussion, with the active collaboration of many international LTER researchers and other interested participants. There were many topics raised broadly around two themes: (1) how best to improve the state of policy-relevant scientific research; and (2) how to improve the integration of science into policy and decision-making. LTER specializes in assessing slow-changing variables (with the commitment to long-term observations and experimentation) and in working across large areas (with a coordinated network of many sites).

However, LTER is also interested in creating more policy-relevant science, and has brought in a focus on socio-ecological issues, environmental history, and trans-disciplinary (stakeholder-integrated) research. Questions were raised and challenges discussed about LTER strengths and weaknesses, and how the network should revise and/or strengthen its scientific programme to meet these challenges. Answers to these questions began to coalesce around proper data analysis, transformation of results into language accessible to the public, and transportation of results to relevant stakeholder groups and end-users (e.g. for infrastructure development). It was concluded that a holistic, integrated perspective is required to manage adequately our increasingly scarce water supplies, but, as witnessed by the many presentations, scholars and practitioners continue to focus on relatively narrow issues. This is sometimes logical and desirable, because depth of expertise should not be sacrificed, but, to address environmental issues such as climate change and global water availability, scientists need an interdisciplinary broad view and a conceptual framework that can integrate their diverse expertise into a truly transdisciplinary picture. This, however, is more easily stated than done given the inevitably biased and limited training of every professional.

Several conceptual models can offer such a framework for coordinated research. Collins et al. (2011) features a social system in which people respond to environmental cues (ecosystem services) and respond through economic, social and political behaviours, policies, and technologies, and a biophysical system in which ecosystem structures and processes operate according to ecological rules. The model then introduces pressures and pulses, due to both human and natural global processes, linking human systems to biophysical systems and presents the many

ways humans, through their activities, affect ecological systems. It also incorporates ecosystem services.

The value of this model is not only its simplification of human-environment interactions, but also its delineation of six areas of research where scientists can locate themselves in the larger picture. This way, the scientist can continue his or her focused research, but at the same time understand how his or her research relates to the broader picture. The six areas of research also highlight the critical roles of both natural and social scientists, as well as engineers and other practitioners in meeting the needs of integrated water policy and management.

The first two areas are the many ways humans affect hydrological systems, and how changes in ecosystem structure affect processes. These are generally the purview of the natural sciences, but can also engage engineers. The third area assesses how changes in ecosystem structure and processes affect the quality and quantity of water as an ecosystem service. The fourth investigates how humans perceive and are directly affected by the changes in the provision of water and the fifth elucidates how humans respond to changes in water provision, through their behaviour. For example, are agricultural practices altered when water is less available? Do water prices respond to deficit? How do communities and institutions respond to water pollution? Finally, the sixth area looks at which human activities create pressures/pulses that will affect hydrological systems (e.g. the extension of agricultural land, damming waterways, or implementing water conservation technologies at the household level). With the application of the model, a policy maker can gain a better understanding of the holistic system and its dynamism, and can readily identify research needs. The scientist benefits from a broader perspective without having to compromise the specificity of his or her research.

Forum 1, hosted by Robert Pietrowsky, explored future opportunities in Africa for integrating the concept of ecosystem services with that of ecohydrology within a framework of integrated river basin assessment and management. This forum provided a practical context for applying the concepts across the symposium's seven themes, whilst encouraging synergy between the symposium and UNESCO's International Hydrological Programmes linked to ecohydrology. The participation in the forum of a high government representative of Ethiopia, His Excellency Ato Alemayehu Tegenu, Minister of Water and Energy of the Federal Democratic Republic of Ethiopia, and the research representative Dr. Dogara Bashir, Deputy Director of the Regional Centre for Integrated River Basin Management of UNESCO, in the National Water Resources Institute of Nigeria, who added an informed view of ecological aspects of energy and water problems in the Horn of Africa and West Africa. Ongoing cooperation is taking place between the European Regional Centre for Ecohydrology under the auspices of UNESCO and Ethiopia's Ministry of Water and Energy which should soon result in establishing the African Regional Centre for Ecohydrology u/a UNESCO in Addis Ababa. The challenges faced by Nigeria in implementing a comprehensive new national water law based on integrated river basin management were discussed, and the potential value of technical exchanges indicated. Foundations for further collaboration between parties and regions were laid down.

The Symposium also served as a platform for launching the Polish Committee of International Hydrological Programme of UNESCO for implementation of the VIII Phase of IHP. The goal of this meeting was the integration of the research domains of participants around the challenges identified during the Symposium and the themes of IHP Phase VIII (2014-2021).

More theoretical concepts were explored in Session 6, co-chaired by Patrick Bourgeron and Kinga Krauze, which dealt with the resilience of both ecological and social systems. One problem is in obtaining good data with which theoretical concepts might be explored. The best studies combine long-term and large data sets focusing on several variables and are essential for research on climate change effects and ecological assessments and their linkages. A case study was used to argue that sustainability is better defined locally at landscape levels and that spatial tools are most appropriate to quantify sustainability, but there are many sources of uncertainty. Study of a severely degraded watershed in Nepal showed that by empowering local communities, especially the most under-represented and vulnerable members (such as women and street children), locally designed solutions to watershed management succeeded where top down, politically motivated policies and regulations had previously failed. Decision makers try to reconcile the demand for increasingly reliable services drawn from the environment (including water and power) with the desire for both a better environment and more environmental amenities but there are notable problems in current management practices. Adaptive management may allow ecologists and the authorities that operate large water and hydropower systems to reconcile the tension between maintaining reliability of services and promoting ecological rehabilitation of aquatic–terrestrial ecosystems, but clarity of goals and objectives is essential. Modelling of flood mapping and forecasting provided an example of how a decision support system could be used to assess the probability and intensity of flooding in urban and suburban areas and estimate the risk of catastrophic structural failure.

The discussion following this session focused on the complex interplay among different aspects, which produced surprising effects on: hydrological variables (e.g., evapotranspiration, stream flow, soil moisture); changes in ecosystem patterns and functions and on ecosystem services; complex interactions with anthropogenic disturbances and land-use changes; and the direct impact of management style on ecosystem services. Further research on the importance of site-specific changes should be useful for revealing the key determinants of sustainability, and the human valuation and use of ecosystems. Results from these detailed studies need to be combined with modelling, experiments, and long-term monitoring. Coordination of such efforts and development of common approaches will improve our understanding of and response to the challenge that global changes present to science and society. But the needs are urgent and action may be necessary in advance of a completely articulated theory in support of ecosystem and Earth stewardship (Chapin et al., 2010, 2011).

Session 7, led by Pascal Breil and Artur Magnuszewski, on modelling in river basin management offered different approaches involving water discharge, regulation and pollution reduction issues. Some talks were dedicated to whole basins and others to specific water bodies including reservoirs, wetlands, drainage channels and rivers. Three papers (Xia et al., 2014; Piper, 2014; Guo et al., 2014; Zhang et al., 2014) included in this special issue are examples of engineering-orientated approaches to water resources management that sometimes open some ground to incorporation of ecological knowledge. Conventional approaches are efficient, however, when scientific results can be translated into maintenance rules and delivered by training. Water allocation between aquatic ecosystems and human needs, and improvement of riparian and channel management were topical issues, with aquatic ecosystem needs and functions gaining some, but still limited, recognition in the water management rules.

The first modelling approach generally used was based on statistical inference of biological behaviour from water amount (or proxy) variations. This approach requires enough observations for reliable statistical meaning but is an initial necessary step in complex environments. These might include, for example, several inflowing sources with differing timing and water quality features. It is necessary to identify the most important physical and chemical drivers shaping aquatic ecosystem behaviour as it responds to changing flows and copes with limited water storage capacity. A second approach was predictively based, with some necessary simplification because fitting of complex models requires huge quantities of data to describe a variety of conditions determined by both natural and anthropogenic features. Modelling complexity increases with fluctuations in time of inputs and processes driven by water flows. Such "systemic" models allow simulation of scenarios, which can inform water managers, and distributed hydrological modelling, coupled with chemical data, is a first step in locating pollution sources.

Both statistical and processes-based models are needed to make use of existing data and real examples are required to convince decision makers to act and invest. A local basin scale should be a priority for the development of ecohydrological approaches. Extension to much larger areas, with backing from ecosystem services results, will then be easier. In the future, incorporating data on processes (biomass uptake, mineralization, bio-accumulation, trapping of sediments) will become easier as more data accumulate. A dedicated ecohydrological model should be able to simulate nutrient, pollutant and energy fluxes and associated processes over time and support eco-engineered solutions. Use of remote sensing data will also help basin scale ecohydrological modelling but a main challenge for ecohydrology remains the modelling of basic processes for metabolism of nutrient and pollutant loads. Ecosystem services, as previously noted, are widely underestimated by civil engineers who may see them solely through water quality variables and sanitation systems. It was concluded that nonetheless, engineers often produce ecohydrologically sensible solutions without knowing or thinking about it and that conventional information about natural systems as well as classical engineering approaches is currently not used enough to support the convergence of engineering and ecology. It was felt that ill-considered routine monitoring often leads to chaotic data and does not help anyone, and that many solutions to problems are already known but are not put into effect because of lack of cooperation among engineers and ecologists, and prejudices among both these groups.

Some general issues emerged from this diverse collection of talks and thoughts. The linkages between land use, climate, human behaviour and their outcomes on the hydrosphere and biosphere are all parts of "wicked problems" created by uncertainty about future environmental conditions and differences in social values that make it virtually impossible to define an optimal condition. You cannot please all the people all the time. Indeed matters may be such that in the short-term you can please very few, if any, should maintenance of sustainable conditions on Earth not, as seems likely, favour continuation of our present human dominance. A wicked problem rests in whether or not secondary problems may be created by any policy that leads to local environmental solutions. Land, water, and climate change policy interactions and interdependencies have significant impacts on how social-ecological systems function. We can outline a pathway to potential solutions in a logical sequence of steps, with incremental increases in complexity, but may increase the complexity as a result.

4. Conclusions

The symposium provided an opportunity for researchers and practitioners from around the world to learn from each other, with a view to developing best practice for conserving and restoring sustainable ecohydrological systems to achieve water security and maintain ecosystem goods and services. This needs to be achieved through combining engineering with an understanding of ecology, in order to appropriately mitigate environmental and water quality impacts. Many of the speakers referred to climate change. Climate change is increasing the urgency to achieve this goal, especially where human (anthropogenic) development of floodplains occurs, particularly in urban areas. Such modification has reduced the size and extent of the flow path and increased flood risk and so necessitated a response to explore ways to manage this risk. A lot of attention was put on understanding socio-ecological systems, but for successful solutions a great deal relies also on developing an integrative science that will nurture the desired practice. Ecohydrology (Zalewski et al., 1997; Zalewski, 2000, 2011) can give a theoretical background for understanding the complexity of natural processes, by integrating knowledge from different disciplines towards the harmonising of biogeosphere potential with societies' needs, reducing over-engineering of the environment and lowering costs of water and environmental management. The Symposium provided a platform for using this theory as a new systematic framework for engineering practices that currently lead to over-engineering. Additionally incorporation of biotechnologies into ecohydrological solutions provides a

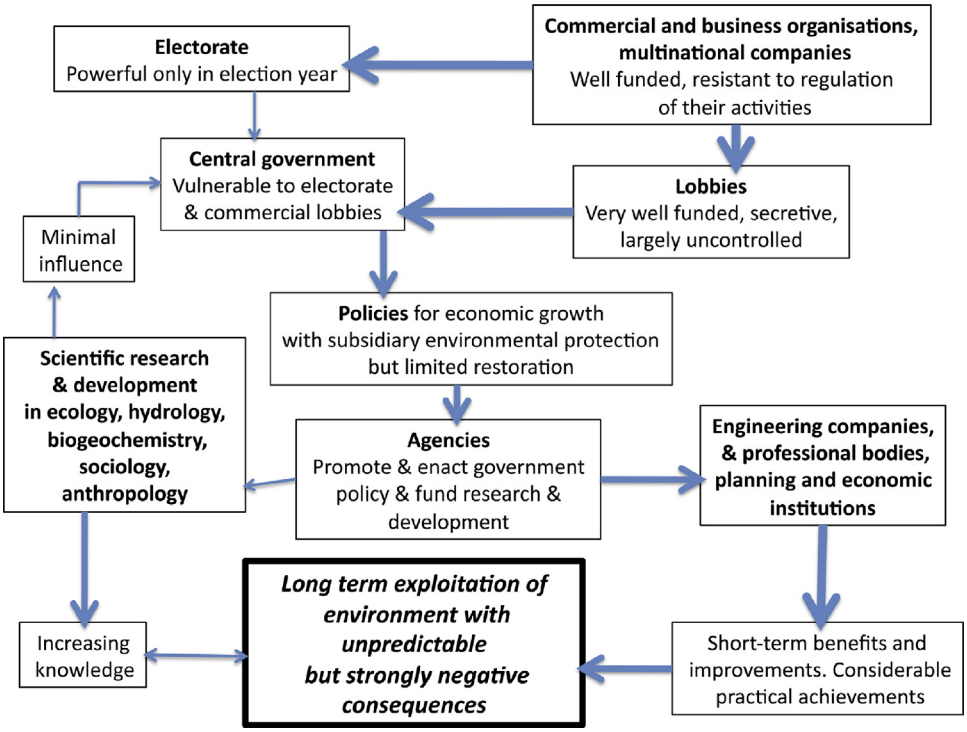

Fig. 1. Summary hypothesis of the balance of influence, at present, in decision-making and action on ecohydrological and other environmental issues. Thickness of arrows denotes strength of influence.

potential for further lowering the costs of technology and increasing the efficiency of solutions, which nowadays has become the driving option in the developing and developed world.

There is a need to invest in natural solutions to deliver the benefits of a 'blue and green' infrastructure. The promise of aligning the use of ecosystem services assessment with the needs of decision makers

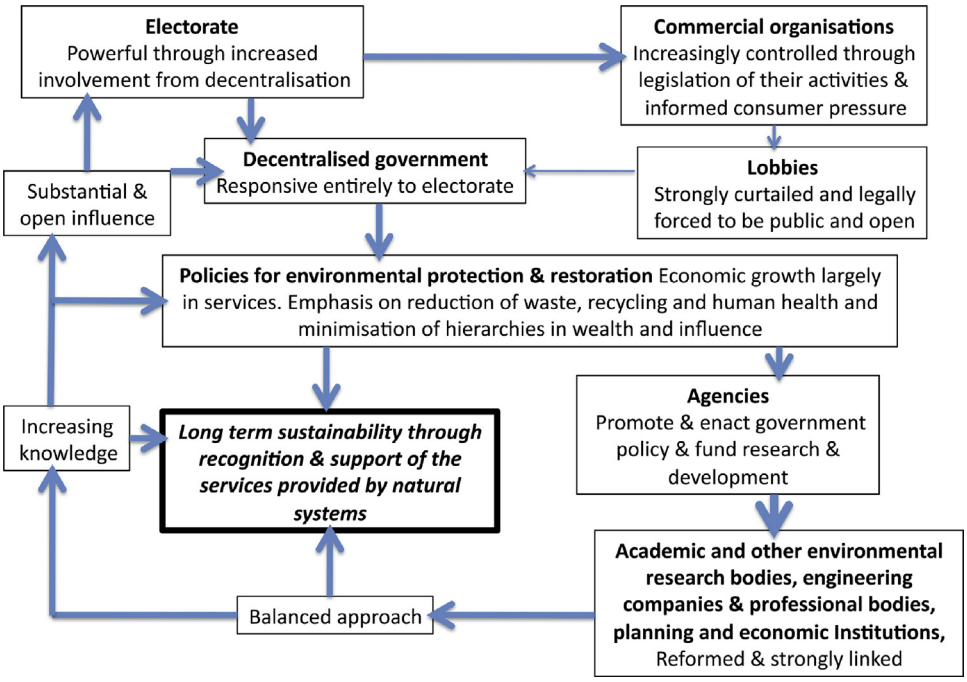

Fig. 2. Proposed revision of influences for decision-making that incorporates ecohydrological understanding into sustainable action. Thickness of arrows denotes strength of influence.

to achieve synergies across a range of policies to achieve comprehensive benefits was emphasized. To do this there is a need to develop innovative financing, which can attract the necessary capital funding. This has been the practice in England, where the UK Government requires private contributions to publicly funded projects, primarily aimed at reducing flood risk. But events in early 2014 may promote a review of this. Many rivers overtopped embankments, flooded expensive properties close to London, and isolated villages in the south-west for many weeks, after a month of rainfall unprecedented since records began in 1760 AD. Society as a whole needs to embrace the concept of valuing ecological improvements, such that national governments are influenced to adopt ecosystem services valuation as part of the business case, for publically funded projects.

The need for ongoing development and practical application of a sustainable ecosystems approach was echoed by a number of speakers. However, there may be a need also to recast the fundamental philosophies around which human societies operate to bring about the hugely well-intentioned proposals of the participants of the symposium. Fig. 1 creates a hypothesis about how we currently operate. Fig. 2 is a possible revision of this system that may more likely ensure a reasonably comfortable civilized existence for the future. It seems very likely that manipulations of 'business as usual' might be insufficiently radical to achieve the solutions that most of the participants would undoubtedly wish to see. There is still a very large bullet to be bitten.

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Conflict of interest

None declared.

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Appendix 1

A.1. Symposium Chairs

- Maciej Zalewski, Chairman of the Steering Committee, Director of the European Regional Centre for Ecohydrology of Polish Academy of Sciences u/a UNESCO; and Department of Applied Ecology, University of Łódź, Poland
- Robert A. Pietrowsky, Director of Institute for Water Resources (IWR), US Army Corps of Engineers (USACE),

and the International Centre for Integrated Water Resources Management (ICIWaRM) u/a UNESCO, USA
- Graham Piper, Past Chairmen of the Chartered Institution of Water and Environmental Management (CIWEM), Rivers and Coastal Group UK; Environment Agency, UK

A.2. Scientific Committee members

- Blanca Jimenez-Cisneros, Chairman of the Scientific Committee, Director of the Division of Water Sciences, Secretary of the International Hydrological Programme (IHP)
- Stanisław Bielecki, Rector of Technical University of Łódź, Poland
- Patrick S. Bourgeron, ILTER Science and Programmes Committee, Institute of Arctic and Alpine Research, University of Colorado Boulder, USA
- Leon Braat, Chair of Management Board, ALTER-Net, Senior Researcher International Biodiversity Policy, Alterra, Wageningen-UR, the Netherlands
- Pascal Breil, National Research Institute of Science and Technology for Environment and Agriculture (Irstea), France
- Johannes Cullmann, Chair of the Intergovernmental Council of the International Hydrology Programme (IHP) of UNESCO, Federal Institute of Hydrology in Koblenz, Germany
- Iwona Jasser, Vice-President of the Polish Hydrobiological Society, Department of Microbial Ecology, Faculty of Biology, University of Warsaw, Poland
- Stanisław Kaniszewski, Head of Vegetable Cultivation and Fertilization Department, Research Institute of Horticulture in Skierniewice, Poland
- Zbigniew Kundzewicz, Chairman of the Committee for Research on Water-related Risks; Institute for Agricultural and Forest Environment, Polish Academy of Sciences, Poland
- Basant Maheshwari, Member of American Society of Agricultural and Biological Engineers, University of Western Sydney, Australia
- Lech Michalczuk, Deputy Director, Research Institute of Horticulture in Skierniewice, Poland
- Michael Mirtl, Chair of European Long-Term Ecosystem Research Network; Head of the Department of Ecosystem Research and Monitoring, Environment Agency, Austria
- Tomasz Okruszko, Head of the Department of Hydraulic Engineering, Warsaw University of Life Sciences (SGGW), Poland
- Sławomir Ratajski, Secretary-General of the UNESCO Polish Committee, Poland
- Azime Tezer, Urban and Regional Planning Faculty, Istanbul Technical University, Turkey
- Jose G. Tundisi, Director of the International Institute of Ecology in Sao Carlos, Brazil
- Wojciech Wąsowicz, Head of the Department of Toxicology and Carcinogenesis, Nofer Institute of Occupational Medicine, Poland
- Martin Whiting, Immediate Past Chairman of the Chartered Institution of Water and Environmental Management (CIWEM), Rivers & Coastal Group; Haskoning UK Ltd., UK
- Jun Xia, Chair Professor & Dean, The Research Institute for Water Security (RIWS); Wuhan University; Distinguished Professor, Chinese Academy of Sciences, China

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- Jun Xia, Chair Professor & Dean, The Research Institute for Water Security (RIWS); Wuhan University; Distinguished Professor, Chinese Academy of Sciences, China
- Maciej Zalewski, Chairman of the Steering Committee, Director of the European Regional Centre for Ecohydrology of Polish Academy of Sciences u/a UNESCO; and Department of Applied Ecology, University of Łódź, Poland

A.4. Photo Gallery (Photos 1–3)

Photo 1. Symposium speakers: (a) Plenary opening lecture; (b) Maciej Zalewski, Symposium Chair, European Regional Centre for Ecohydrology of Polish Academy of Sciences, and University of Łódź, Poland, (c) William J. Mitsch, Florida Gulf Coast University, USA, (d) Alessandra Pugneti, National Research Council, Italy, (e) Brian Moss, University of Liverpool, UK, (f) Giovanni Bidoglio, Joint Research Centre of EU, Italy, (g) Robert A. Pietrowsky, Institute for Water Resources, US Army Corps of Engineers, USA, (h) His Excellency Ato Alemayehu Tegenu, Minister of Water and Energy of the Federal Democratic Republic of Ethiopia, (i) Pascal Breil, National Research Institute of Science and Technology for Environment and Agriculture (Irstea), France, (j) from left to right, Włodzimierz Nykiel, Rector of the University of Łódź, Giuseppe Arduino, Division of Water Sciences, International Hydrological Programme, UNESCO, Robert A. Pietrowsky, Johannes Cullmann, Federal Institute of Hydrology (BfG), Germany, Jun Xia, Wuhan University and Chinese Academy of Sciences, China, (k) Jolanta Chełmińska, Governor of Lodzkie Region, Poland, (l) Graham Piper, Chartered Institution of Water and Environmental Management (CIWEM), Rivers and Coastal Group, UK. Photos: Edyta Kiedrzyńska (a), Paweł Dobrowolski (b–l).

Photo 2. Symposium participants. Photo: Paweł Dobrowolski.

Photo 3. Workshops and field visits: (a) Tomasz Jurczak from University of Łódź explains functioning of the principles of ecohydrological rehabilitation of urban reservoirs 'Arturówek' in Łódź; (b) Workshop discussions, Iwona Wagner, Symposium Convenor and Joanna Mankiewicz-Boczek, European Regional Centre for Ecohydrology of Polish Academy of Sciences, and University of Łódź; (c) Workshop chaired by Long Term Ecosystem Research Network (LTER), at the forefront Kinga Krauze, European Regional Centre for Ecohydrology of Polish Academy of Sciences and Michael Mirtl, European LTER, and Environment Agency, Austria, in the background on the left Iwona Jasser, Warsaw University; (d) Johannes Zerihun Negussie, Ministry of Water and Energy of the Federal Republic of Ethiopia (left) and Dogara Bashir, Deputy Director of the Regional Centre for Integrated River Basin Management of UNESCO, National Water Resources Institute of Nigeria (right), the participants of the African Forum; (e) Katarzyna Izydorczyk, European Regional Centre for Ecohydrology of Polish Academy of Sciences; (f) the first meeting of the Polish Committee of the International Hydrological Programme (IHP) of UNESCO. Photos: Paweł Dobrowolski (www.okiemboclana.pl).

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