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Obstacles to data access for research related to climate and water: implications for science and EU policy-making

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Abstract

This paper reports on the conclusions of a workshop dedicated to science and data gaps in EU-funded projects relevant to water resources and water management, where over 25 EU projects were represented. Institutional and financial obstacles to data access for use in modeling exercises were identified, and gaps in scientific knowledge that contribute to uncertainty were highlighted. The paper identifies a number of sectors where these gaps often represent crucial barriers to successful research outcomes, and suggests ways and means of alleviating some of these difficulties. One approach could be through the implementation of policies aimed at ensuring free and unrestricted access to data, especially those generated by the numerous research projects that focus on issues of water availability, quality and management. Another complementary initiative could be the setting up of a centralized "clearinghouse" for data exchange between scientists, end-users and policymakers. It is hoped that, if implemented, some of the recommendations formulated in the present paper may help pave the way for a more rapid and efficient production of research results that of importance for policy guidance at the local, national and supra-national (EU) levels.

1. Introduction

Various obstacles hinder access to data for use in environmental research in most parts of the world. Observation are crucial to analyze past and current environmental trends and for providing initial, boundary and validation information for numerical models; furthermore, access to socio-economic data of relevance to environmental research also frequently poses problems. Current difficulties in obtaining data represent genuine barriers to the successful outcomes of research on topics such as climate change, water, or biodiversity protection. These themes have direct policy relevance for individual countries or larger entities such as the European Union, and there is thus a clear mismatch between the objectives of research funded at the national or trans-national levels (e.g., EU R&D Framework Programmes), that are largely designed to help guide policy, and the obstacles of access to and limited availability of data that have a negative bearing on the results and conclusions of research (e.g., Viglione et al., 2010).

Access to data can be limited for a number of reasons, among them: 1) geographical sparseness of environmental information, where direct measurements of weather or hydrological data, for example, are lacking in remote areas, such as high latitudes or high mountain elevations; 2) the temporal sparseness of data, where the length of the record for a particular variable often differs largely from one site to another, with frequent temporal gaps in the record that can be the result of instrument failure; phase-out of a research site; interruption of data collection because of conflicts, hostile weather etc.; 3) the limited access of many researchers to numerical models that can in many instances be used as “intelligent interpolators” to fill data gaps in both time and space; 4) institutional barriers to data access, where little effort is made to centralize or secure different types of data, and/or where the same type of data is stored in various formats with little compatibility between them; and 5) financial obstacles to accessing data, often a major cause for concern among researchers who need to purchase data, often at high cost.

The financial constraints vary according to national data policies. In the United States, for example, environmental data is generally freely available under the “public dollars-public data” policy of providing to any end-user data and information that has been paid for by public money. This is not necessarily the case elsewhere where such data are restricted (for example, meteorological data may be under the responsibility of the Ministry of Defence in one country and that of the Ministry of the Environment in another) and/or available at a price.

There are currently many efforts under way in Europe to remove the obstacles and costs related to data access for the purposes of research and policy-making. In particular, the European INSPIRE directive of 2007 (http://inspire.jrc.ec.europa.eu/) is paving the way for "*establishing an infrastructure for spatial information in Europe to support Community environmental policies, and policies or activities which may have an impact on the environment*". At its 2002 meeting, the G8 (group of industrialized nations) recognized the need to enhance international collaboration for improving the collecting, archiving, and dissemination of "*Earth observations to support decision making in an increasingly complex and environmentally stressed world*". In this context, the Group on Earth Observations (GEO; www.earthobservations.org) was set up at the World Meteorological Organization headquarters in Geneva to build a Global Earth Observation System of Systems (GEOSS). Today, many government agencies, academic bodies, and research projects are actively contributing environmental data to GEOSS for a number of key thematic domains and with a common data format.

Despite these initiatives and advances, many policy-relevant domains of research today still face major problems of access to, and exchange of, data. The objective of the present paper is to document some of the issues faced by many large European projects investigating the consequences of climatic change for water availability, quality, allocation and use and the implications for water governance in Europe and elsewhere. The paper addresses in Section 2 the problem of science gaps , while Section 3 provides some views on the implications of identified data gaps for EU or national policies, and suggests means of improving the access to, and flow of, data that will ultimately help guide future national and trans-national water policies.

2. Research and data needs for water-related research

2.1 Floods and extreme events

Research on extremes needs to be embedded into a multi-hazard framework that may include several sources of risk, taking a holistic approach to the physical, environmental, ecological and social systems, and their interdependencies and interconnectivities. Economic and social development of infrastructure (physical, governance, institutional, social etc) has become so complex that the occurrence of an extreme event produces a shock to the ambient state leading to unforeseen consequences and impacts. The analysis of extremes could usefully apply concepts and methods from complexity theory to generate a greater and richer understanding of the range of potential impacts of an extreme in one or more hydrometeorological driver. If the ambient state of the system is close to a tipping point, the extremes may cause transition to reach a new and different (dynamically) stable state. The result of non-linear processes and complex interactions can produce non-intuitive behaviour which scientists need to communicate carefully to non-specialists.

Important gaps in information on extremes exist for reasons which may arise from lack of technology, organizational deficiency or novelty of application. Floods are comparatively infrequent and during an event the concentration of public resource is usually on responding to the emergency rather than collecting information.

Extremes are experienced infrequently and the question arises to what extent should there be an attempt to control the extreme and to what degree physical and social infrastructure should be designed as adaptable and resilient to extreme conditions. A particular difficulty is that the typical time-scale between extremes and their effects may be two or more generations and thus the impacts lie outside the scope of life-time memory of much of society; perceptions with respect to extremes may change, however, as certain events may increase in frequency and/or intensity in a warmer climate. Moreover, natural processes that respond to these extremes may undergo step changes from an event upsetting an apparent benign appearance of equilibrium to which the public is accustomed. Scientific research is necessary on such processes including sediments and substances mobilized and transported during extreme events, pathogens and pollutants, all of which augment the potential for damage and risk to life and property.

Policy development accounts for climate change over multi-generational timescales but investment decisions cover generational (decadal) timescales. The need is urgent to improve understanding and reduce uncertainty on decadal timescale changes to water-related extremes and their impacts. This includes climate projections for short-duration extremes which are relevant in risk management of impacts extremes on society. Better understanding is needed on the degree to which changes in the intensity of extremes can be attributed to natural variability or to anthropogenic influence on climate. Current research suggests that climatic signal in the trend in hydrological response may be discernable from natural variability within one or two decades.

Improved data, and access to data, is needed to better understand the historical frequency and extent of floods and their impacts on infrastructure and society. While it is clearly impossible to generate new observations in many cases data does exist or can be inferred.

Work needs to be done consolidating physical, engineering and social datasets and also developing guidelines and strategies to develop comprehensive data sets for future events.

While floods are obviously a source of major concern in terms of the damages that they are capable of generating, other forms of extremes need attention too. For example, extended heat waves that reduce surface runoff, with adverse effects for domestic water supply, agriculture, or the energy sector (both hydropower and water for conventional or nuclear power stations)are projected to increase in the future, and will therefore impact more and more on these sectors.

2.2. Freshwater biodiversity and conservation

Freshwaters are almost completely neglected in biodiversity conservation despite the fact that freshwaters contain 10% of all animal species and 1/3 of all vertebrate species, while covering only 0.8% of the earth surface. Currently, the decline in diversity is much faster than in terrestrial or marine systems, and pressures are higher than in most other ecosystem types (Tockner and Stanford 2002, Dudgeon et al. 2006, Vörosmarty et al. 2010).

There are well-established indicators to assess species diversity. However, evolutionary aspects, ecosystem processes and services, and governance-related indicators are not yet fully developed, and integrated, in biodiversity conservation policy. Moreover, more is known about trends in biodiversity change than about the pressures causing this decline (i.e. multiple stress indicators).

The Nagoya Conference of the Parties to the CBD (Convention of Biological Diversity) reinvigorated the commitment to the goal of halting global biodiversity loss by adopting a 'Strategic Plan for Biodiversity 2011-2020' and setting up new goals and targets (so called Aichi targets). A key goal of these targets is to make the vast amount of biodiversity data publically available. This is underpinned by the recent efforts through projects such as BioFresh ('Biodiversity of Freshwater Ecosystems: Status, Trends, Pressures, and Conservation Priorities') and the Global Biodiversity Information Facility (GBIF). At the same time there is pressure from funding agencies, and more also from scientific journals, to make data on biodiversity publically available while protecting the intellectual properties rights.

The rapid development of new techniques and tools offers great opportunities in filling the gaps in biodiversity monitoring and assessment. It includes real-time biodiversity monitoring using image and acoustic analyzing tools, remote sensing tools such as unmanned aircraft linked with various sensors to map biodiversity change at large scales, and to engage citizen in monitoring biodiversity change using smart phones and new communication tools that are in development, or will perhaps be available within the coming decade.

Protected areas are one of the primary responses for maintaining biodiversity. This “man-outside nature concept” still underpins biodiversity conservation despite the fact that we are living in a human-dominated world with the formation of novel ecosystems and novel communities that contain a mix of native and exotic species (e.g. Hobbs et al. 2009). What is the role of human-created ecosystems such as ponds, ditches, agricultural sites or brownfields in biodiversity? What are the conditions that make novel ecosystems to sinks or sources for species, including invasive exotic species? Novel communities may be critical in stimulating evolutionary processes, and may facilitate key ecosystem processes. It is becoming more and more obvious that a pure conservation-oriented approach will simply not work, as the failure of the 2010 targets already have demonstrated. Therefore, a fundamental weakness of the European Water Framework Directive (WFD) is that past reference conditions (of biotic communities) are used as targets for management of freshwaters and transitional water bodies.

Biodiversity targets are mostly out of step with targets defined for other global challenges such as climate change, food production, or sustainable energy production. For example, in the expansion of hydropower exploitation that treatens the last remaining near natural rivers sections, a deterioration that is not in accordance with the targets of the WFD. Therefore, clear cross-sectoral strategies are required to developing how mutual benefits among the actually competing targets can be achieved.

2.3 Freshwater ecosystems and management

Freshwater ecosystems face a range of interacting pressures from climate, land use and hydro-morphological change, pollution and resource use (Kernan et al., 2010). Predictions of these combined impacts pose a substantial management challenge of major practical relevance for implementing strategies to protect aquatic ecosystems (e.g. the Water Framework Directive (WFD) (EU, 2000) and the Habitats Directive (HD) (EU, 1992).

While many of the current threats to freshwater ecosystems stem from catchment activities or atmospheric deposition, in future the effects of climate change (both direct and in tandem with other stresses) will increase in relative importance. Therefore there is a need to understand how climate change will affect the ecological functioning of freshwater ecosystems, especially with respect to changes in community structure, its impact on keystone taxa and the crossing of ecological thresholds. Predicting the ecological impact of changes in food chains and the response of ecosystem functions to the crossing of critical thresholds is especially difficult, not least because of inadequate knowledge of the functional roles of species in ecosystems and our current inability to quantify adequately the processes involved (Scheffer et al., 2009). In terms of novel approaches the development and use of molecular biological techniques are required to understand the effects of climate change on genetic diversity and the ability of freshwater organisms to adapt to increasing temperature (Van Doorslaer et al., 2009). With regard to interactions between climate change and other drivers, we need to understand and model the generation, fate and impact of nitrogen and dissolved organic carbon on the structure and function of freshwater ecosystems as a result of changes in land-use/management, climate change and acid deposition. We also need greater knowledge of the migration, remobilization, re-deposition, eco-physiological and food-chain impact of toxic substances (especially Hg and POPs) in remote regions in the face of climate change (Grimalt et al., 2010), particularly with the development of the WFD Priority Substance daughter directive.

For the WFD it is widely believed that climate change exacerbates water quality problems, especially those of eutrophication (Moss et al., 2011) and toxic substance pollution but the extent of the impacts requires further research and a key requirement is to determine how important climate change is compared with other stressors so that strategic adaptive management requirements can be determined (Wilby et al., 2006). An important question here is whether the independent role of climate change can be separated from the effects of other environmental, social and economic changes. There is a need to assess and allow for the effects of climate change on the definition of reference conditions, especially with respect to the use of the reference state as a restoration target and to understand how climate change affects the ecological thresholds currently used to set WFD targets.

For the Habitats Directive there is the need to recognize more explicitly the threats to freshwater biodiversity posed by climate change and to re-define where necessary the list of habitat types and typical/target species as climate change will affect the status of both habitats and species. Additionally we need to understand the migration of freshwater species and their propagules in response to climate change and with respect to enabling dispersal and improving landscape connectivity. Management in this context should include and allow for the potential for species migration as a result of climate change, by encouraging habitat protection and connectivity and accommodating the difference between benign migration and invasions by undesirable alien species.

2.4 Mountain regions where snow and ice govern runoff

There are a number of complex interacting issues related to data availability in mountains. These are notorious for the difficulty in establishing, maintaining, and collecting dense environmental measurement networks because of the problems of access to high altitudes, the fragile nature of many instruments subject to hostile climatic conditions, and the shortness of many time series. Many catchments remain without gauges and in some instances the influence of the hydropower sector on uptake and release of water is little known because of the confidentiality of data related to dam operations. Furthermore, the simulation of many environmental processes in complex terrain is rendered difficult by the large topographic gradients that are difficult to reproduce adequately in many types of models (e.g., regional climate models). The use of numerical modeling approaches to fill data gaps both spatially and temporally is much more difficult in regions of high mountains than in more uniform lowland regions, thereby constraining one possibility of alleviating problems of sparse data. The estimation of changes in runoff in regions like the Alps where, under current climatic conditions, snow and ice arestill key contributors to river flows, requires data on the cryosphere at very high spatial resolution and on the modulating effects of alpine vegetation and forests. With few exceptions, these data are essentially lacking and those that are available are the result of efforts such as those of the World Glacier Monitoring Service (Haeberli et al., 2000). When attempting to address the impacts of changing water quantity, seasonality, and quality on a range of economic sectors, there are large difficulties in obtaining data from private sectors such as hydropower utilities that, for reasons of confidentiality or business philosophy, do not wish to release data or tend to impose restrictions on the publication of results that is contrary to usual academic practices (Beniston et al., 2011).

In general, new approaches to the estimation of precipitation in mountainous areas are necessary, because it is currently very difficult accurately assess precipitation from *in situ* measurements only. However, new techniques, involving satellite measurements, models and *in situ* measurements may provide usable data sets.

2.5 Northern India and the Himalayan "water tower"

In the Ganges basin in India the major climatic uncertainties for water management are (1) changes in glacier/snow melt in the Himalayas and (2) changing monsoon patterns. Both changes are likely to impact on the quantity of water (too much or too little) as well as lead to socio-economic impacts. A further factor is the ever increasing water demand as a result of increasing food demand related to population growth. In the past this increased water demand has largely been resolved by groundwater extraction. However, rapidly declining groundwater tables demonstrate the unsustainable nature of the present rates of extraction. How to allocate water in the present and in the future will be one of the essential questions that need to be addressed. To plan the distribution of water, accurate information is needed on the quantity and quality as well as the timing and location of water demand.

For planning purposes models capable of accurately simulating planning alternatives and future projections are essential. The performance of such models heavily depends on available data for input and validation and evaluation. At present the main gaps relate to: glacier volume and mass data, scarcity of precipitation data especially at higher altitudes, availability of discharge data (for political – trans-boundary – reasons) and data quality. For example different climate models applied the Ganges produce contradictory results. Regional climate models especially disagree on the future rain fall patterns (Moors et al., 2011). To improve these climate projections, evaluation of model performance using observation data is essential. The uncertainties associated with observed precipitation are potentially large primarily because of known gauge undercatch errors as well as the high spatial variability of precipitation which is often statistically under sampled. This under sampling could lead to an underestimation of precipitation in regions of highly variable orography if there is a bias in gauge location as is the case in the Himalayas (see e.g. Yatagai et al., 2009). The same issues are also valid for temperature, since this parameter is indeed one of the main drivers of snow and glacial melt.

Although the creation of networks of databanks was envisaged in India's National Water Policy of 2002 and data access was announced at the Indian Water Forum in 2011, the access to crucial data is still problematic.

2.6 Global water cycles

Increasing temperatures associated with increasing greenhouse gases may lead to increased evaporation, particularly over the oceans, and hence rainfall overall. However, as has been shown by Beer et al. (2009), it is possible that higher CO_2 concentrations may lead to increased water use efficiency and decrease evaporation rates. Shifts in radiative flux exchange will also have a bearing on future evaporation rates. In addition, and perhaps more importantly, climatic variability is likely to increase. Regional and local changes are difficult to predict because they depend on the vagaries of the circulation patterns, for which there is less consensus across the climate models. The response of runoff and river flows will be the result of a of a complex balance between changes in rainfall and evaporation and changes in vegetation and human influence (such as land use, dams, water extractions etc.).

Adaption responses to the changing hydrological cycle are likely to be local and regional in nature but in an increasingly globalized world are likely to be strongly modulated by global influences. Therefore the global commodity trade will influence how agriculture will adapt regionally. This is evidenced by the increasing interest in the concept of virtual water. There is therefore a pressing need for consistent and accessible data on water flows (and scarcity) at a global scale.

Data accessibility is patchy across the world. Substantial global datasets of climate data are available from the meteorological community (e.g. GPCC and CRU). These gridded datasets contain large error in data sparse regions, such as high altitude, high latitude and developing regions. They also lack the time resolution required to resolve many significant hydrological events. Reanalysis products from the weather forecasting community are increasingly available (refs). These are derived from weather forecast models which have assimilated the routine meteorological and satellite products. They provide fields of precipitation and meteorological variables across the globe which are consistent with the energy and water conservation in the atmosphere and the best available routine observations. They are, however, model products and suffer from well documented biases.

Mean river flows from the major river basins are generally available from GRDC and others but river flows on short time scales (such as daily) and small basins are either not available or not accessible to the global community. Equally in situ information on soil moisture, groundwater levels, river extractions, etc,, are often not available for practical, political or institutional reasons. In the future Earth Observation may be able to fill some of these gaps. A good example is the GRACE satellite data (e.g. Rodell et al 2009), which now provides an over eight dataset of terrestrial water storage.

Global data sets to drive hydrological models have become available in recent years (Sheffield et al 2006, Weedon et al 2011), for example the WATCH Forcing data has been created by combining the CRU climatology, ERA40 reanalysis data and satellite data. It gives our best estimate of meteorological factors affecting runoff (precipitation, radiation, temperature, humidity and wind speed) on a fine time scale (6 hourly) and space scale (50 km) for the entire 20th Century. These data sets, in combination with hydrological models, provide a useful approach to fill in the gaps in observational records.

However there are still many uncertainties in our ability to model the surface hydrological cycle globally. The WaterMIP project has brought together 13 global models – these consist of stand-alone global hydrology models, land surface models (which typically are part of climate models) and ecosystem models. The first phases of this inter-comparison have shown considerable variability among models, both globally and regionally (Haddeland et al 2011). All models were run at 0.5 degree spatial resolution for a 15-year period (1985-1999) using a newly-developed global meteorological dataset. Simulated global terrestrial evapotranspiration, excluding Greenland and Antarctica, ranges from 415 to 586 mm $year^{-1}$ (60,000 to 85,000 km^3 $year^{-1}$) and simulated runoff ranges from 290 to 457 mm $year^{-1}$ (42,000 to 66,000 km^3 $year^{-1}$). The large range in evapotranspiration (which leads to the large range in runoff) is similar to that of observation-based estimates and remains a major challenge to hydrologists to improve this. The simulations of large scale floods and droughts have been tested against a dataset of over 500 flow series from small catchments over Europe. Again the models show a large range of responses with some models performing very well and others not capturing the variability in flows in many instances. Overall no model, or class of model, simulates the hydrology better in all cases. The inability of many models to capture the observed variability in runoff is a reflection of a lack of a comprehensive model which includes the influences of groundwater, impoundments and extractions. At present the conclusion from these inter-comparisons is that an ensemble mean of the model outputs provides the best representation of the observed data. This should not however obscure the need to improve the overall physical representations within the macro-hydrological models.

Even without climate change increasing population and water demands will increase water scarcity globally in the coming decades. Many of these problems can be overcome with suitable water governance, although to make the solutions robust in the face of climate change need to be based on a complete analysis of the current situation, future projections (and uncertainties) and possible system feedbacks.

3. Implications for EU and national policies

There are many institutional barriers and increasing financial barriers to data access, including recharging for data and information already collected (sometimes with public resources) and license conditions on the use of the data and publication of results. In some cases the monitoring or the research content may be a highly political and beyond the influence of the scientific community. In some cases data are collected for compliance issues or legal enforcement and once compliance is established the data may be discarded and the full value of the data collection is not achieved for research where long-term trends and developments are critical.

The current data situation for scientific research is often difficult due to a number of recurring reasons: incomplete and un-standardized time series data (e.g. climate, hydrology) are a major drawback for many research projects, as the collection and harmonization of data is costly, time-consuming and frequently redundant. The main reason for the latter is an abundance of wide-spread, yet unknown or inaccessible data sources. This means that data are available in principle, but scientists are simply not aware of their existence or do not have the legal or financial means to access them. Different national regulations and/or legal frameworks hinder the uniform provision of organized information. Finally, the high cost of maintaining field stations (especially at remote locations) in combination with the availability of remote sensing data sometimes triggers decision makers to discontinue field stations, ignoring the fact that remote sensing data heavily depend on field data for their quality assurance. In addition some data (such as remote sensing imagery from private providers) often calls for work-around or waiving of beneficial information.

Harmonized hydro/meteorological time series data are an essential pre-requisite not only to improve scientific knowledge i but also the exchange of information within and between research projects. Further, it must be emphasized that there is still a tremendous lack of reliable information and knowledge at the interfaces between disciplines, which makes it particularly difficult to assess the process connectivity between the environment, economics and society across all spatiotemporal scales of possible scientific application, i.e. be it on a continental or catchment scale. Such limitations can only be overcome by means of cooperation between projects and integration across scientific disciplines.

However, no common methods to monitor, analyse and evaluate data are available to describe in an integrative manner interactions between natural and social processes. This is due to large differences in the way various disciplines formalize, term and describe their understanding and concepts of respective processes and interconnections. Trans-disciplinary integration is required to provide the knowledge base to tackle current and future challenges related to water related research. One possible solution to this persistent problem in cross-cutting water science is the clustering of projects dealing with similar topics, but from different perspectives, as the co-operation between partner projects from different disciplines creates scientific synergies: it allows researchers to identify and utilize complementary monitoring and modeling methods, harmonize and share data, discuss, elaborate and propose dissemination strategies or adaptation alternatives. To optimize benefits from the variety of cluster partners' competences, joint research must be devoted towards a better understanding and description of interfaces in complex systems; this includes the development of robust strategies for data mining, data exchange and conjoint information retrieval. Integrating different methods from natural and social sciences can contribute to better conceptualization of each project's research findings and identification solutions for water resource management under climate change, especially when a variety of different situations can be covered in complementary case studies.

The joint research forces provided by clustering expand the possibilities for data mining and exchange. Data uncertainty can be reduced by creating a potent and multi-scale data repository that serves to parameterize integrated models. Further, the lack of awareness or understanding of complex water-society dynamics often leads to a persistent gap between science and policy making.

In order to make best use of available (infra-)structures, all initiatives that focus on better and easier access to data and information in water and climate related sciences and related integrative projects should be strongly advocated, promoted, strengthened and proactively supported. The establishment of a general well-defined and easily accessible clearinghouse of relevant and structured data, including meta-data, which hosts not only data from public and other services but explicitly includes a comprehensive collection of relevant data produced by EU-funded and related projects offers great potential for substantial improvement. There would be several ways to ensure that the use of available information is improved, maybe even optimized: It could be assured by means of signing a 'Memorandum of Understanding' between the European Commission and respective projects, assuring that data used or elaborated during a project must be made available to subsequent initiatives and projects. All new FP-project proposals should contain a dedicated section on data sources, their availability and utilization within the project. It must be understood that it will be of the utmost importance to demonstrate the benefit of a better database for policy making and to try to get policy makers involved in supporting the idea of a European Data and Information clearinghouse.

Ultimately, the implementation of guidelines, maybe even an EU Directive, on the good governance of data (sharing) could be envisaged as a possible framework, providing advice and general rules on data formats and standards, data storage after the completion of projects or the general terms of access. At the European level, the adaptation clearinghouse that from March 2012 will be hosted by the European Environmental Agency (EEA) can be considered as an excellent start of such efforts. This clearinghouse will place the EEA in a good position to coordinate further actions to assure availability and high quality of data and information.

Whatever solution is ultimately decided upon, clearly it is necessary to ensure at the very least making sure that the results from projects are freely and readily available not only to scientists, but also to managers, policy makers and the full range of potential users in a way that is accessible and enables them to employ the results usefully. This is often neglected by the research community in favour of publishing papers, particularly when the project is finished. A further step is to secure data following the end of large projects. Much effort is expended in the initial phases of each new project to collate existing data which has already been generated in prior projects but which is often difficult to access, buried in the grey literature or on lost on inaccessible databases.

4. Conclusions

This paper stemmed from a workshop that was held to address the problems that have been highlighted in the previous sections. There is a clear need for a more integrated and comprehensive approach to water use and management. In particular, beyond the conventional water basin management perspective, there is a need to consider other socio-economic factors and the manner in which water policies interact with, or are affected by, other policies at the local, national, and supra-national levels. As an example, it is unclear whether current EU water policies are consistent with energy, agriculture, and other industrial policies. One of the areas of concern, from the scientific community's point of view, is the extent to which the results of EU-funded projects actually guide or influence policy.

The problems highlighted above are also due to the inconsistencies between physical and socio-economic data and models. For example, data on water uses may not be available at the temporal and spatial detail required by hydrologic models. Hydrological information is often based on basins whereas economic (and social) data is aggregated into administration regions. Thus, economic and physical data are often incompatible, because they are collected by different entities for different purposes. Future research should thus address the development of compatible data sets and the conversion between different data formats, as well as the development of toolboxes for up-scaling, downscaling and bias correcting data. In addition, socio-economic research related to water resources has been hitherto limited. Most water related research projects are led by physical scientists, which may to some extent bias the scope and outcomes of the projects. Furthermore, the use of water in production processes is often not mediated by the market. The use of economic flexibility mechanisms in the allocation of water resources is quite rare, despite their potential in improving the efficiency of water resources allocation. More research and policy initiatives in this direction are thus necessary.

Other data gaps are found in groundwater data and exceptional weather events leading to hydrological extremes. More generally, there is a need to make information available to new research projects, for example through a data repository, as discussed in Section 3 of this paper.

Finally, many scientists working in large integrated projects highlight a large gap between Science and Policy. This is certainly at least partly due to problems of communicating in an appropriate manner the key research results that would be of use to policy-relevant strategies. Awareness of this problem is increasing within the EC and other policy institutions, and hopefully this new momentum will be sustained over time so that conclusions from EU and other water-relevant projects will be widely incorporated into future policies at the local, national, and supra-national levels. Ultimately, the implementation of guidelines, maybe even an EU Directive, on the good governance of data (sharing) could be envisaged as a possible framework, providing advice and general rules on data formats and standards, data storage after the ending of projects or the general terms of access.

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