7 Hydrological Challenges: Scientific, Technological and Organizational Bottlenecks

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Over the last decade, it has become increasingly clear that if we are to face the water challenges of the future we must view the Earth as a single, though highly complex, system that includes the atmosphere, the hydrosphere, the geosphere and the biosphere. It has also become clear that these components are coupled and highly dynamic over various spatial and temporal scales; changes that occur in one component at one location can influence the environment somewhere else at later times. These complex, coupled and dynamic interactions between the different Earth system components are not well understood. The interactions between the physical and human systems are similarly complicated and are also not well understood.

The scientific community has a very important role to play in developing the tools and knowledge needed to understand and predict water quality and quantity in the context of these heterogeneous and coupled systems, and to use those tools and knowledge to guide the effective management of water resources. However, many challenges must be addressed in order to tackle this grand challenge. The Hydrology 2020 Working Group has divided these critical “bottlenecks” into the following three categories: (1) scientific; (2) technology and infrastructure; and (3) organizational capacity. Challenges associated with each of these categories are outlined below. We also provide “barrier analysis trees” or flow charts that identify routes to overcoming one particular challenge identified in each category. The flow charts also demonstrate that the scientific, technological and organizational bottlenecks are all interrelated.

7.1 SCIENTIFIC CHALLENGES

In order to investigate these interactions within and ultimately manage natural systems, better tools and approaches are needed for measuring and predicting the flow, transport, and residence times of water and contaminants at time scales of hours to decades through the system, including the atmosphere, land surface, vadose zone, and groundwater. In this section, we discuss two key hydrological challenge areas and two crosscutting themes that we feel most prevent us from effectively managing our water resources. The scientific gaps are associated with our lack of understanding of water and contaminant flow through hydrological systems over space and time scales that are relevant to water resource management, and gaps in our understanding of the coupling between hydrological systems and ecological, atmospheric, and human systems. The crosscutting themes are problems that are prevalent across many areas of natural science, and include effective prediction of processes and scaling/integration. These two challenges and themes are briefly discussed below.

7.1.1 Hydrological processes at the basin scale

As basins are the fundamental unit of water resources management, deficiencies in our ability to assess basic hydrological processes at the basin scale handicap our efforts to sustainably manage our water resources and remediate environmental contaminants. As crucial as the water cycle is to human and ecosystem existence, there are still many gaps in our understanding of the mass balance, residence time, and flowpaths within each of the key components of the water cycle, as well as gaps in understanding of fluxes within and between the different components (National Research Council, 2001; Water Cycle Study Group, 2001; Pfirman & the AC-ERE, 2003; National Science and Technology Council, 2004). For example, we have a poor understanding of flow through preferential flow pathways or through the vadose zone, of the linkages between hillslopes and surface water bodies, of aquifer recharge, and of flux across atmospheric–surface and vadose zone–groundwater boundaries. Until recently, hydrologists have typically worked on problems within certain hydrological compartments (i.e. groundwater or land surface) and with datasets of particular parameters important to specific processes. The consequences of ignoring the interactions between atmospheric, surface and subsurface hydrology may have enormous consequences for human activities and aquatic ecosystems. For example, 75% of the average annual recharge of the chalk aquifer underlying the River Ver catchment in southeast England is licensed for abstraction, of which approximately half the abstracted water is used for water supply outside the basin. As a consequence, the upper 10 km of the river has largely dried-up, resulting in loss of fisheries and watercress farming and major environmental degradation (Owen, 1991). Another example is the increase in nitrate concentrations that has occurred in the past 50 years in many aquifers throughout the world, primarily due to agricultural intensification and the concomitant increase in application of fertilizers and manures (Heathwaite *et al.*, 1996). As a result of contamination with nitrate, in 1983–1984, 125 groundwater sources supplying 1.8 million people in the UK exceeded the World Health Organization (WHO) limit for drinking water of 11.3 mg l^{-1} NO_3-N.

There are many fundamental questions associated with the hydrological cycle that are as yet unanswered, such as: How do the spatial and temporal variability of soil properties and land surfaces influence water budget at the basin scale? What are the dominant processes and critical parameters that best capture the dynamics of the system? How do these processes and parameters vary between different basins? What are the critical space and time scales for measuring hydrological parameters and processes when investigating basins? What is the degree of spatial organization within a river basin and how does it impact the water budget? Currently, our models are often populated with some aggregation of properties collected at a much smaller scale than may be relevant for the basin scale. We do not understand if, and how, small-scale insights or measurements are appropriate for use within basin (or larger scale) models, or if new hydrological theory can be developed that better captures the system dynamics at the larger spatial scale and over longer timeframes. Reconciling fragmentation across hydrological sub-disciplines, basins, and scales is necessary in order to assess water balance and feedbacks through the entire hydrological system. Development of new hydrological understanding of basin-scale processes and properties is expected to be an active area of hydrological research.

7.1.2 Coupled hydrological–ecological–climate and human systems

The intersection of hydrology with ecology, global change, and the built environment is discussed in Chapter 6. Although a milestone in understanding the causes of runoff (flows) and water quality has been the recognition of the complex interactions between surface and subsurface hydrology and the atmosphere, ecosystem, and human activity, there are still gaps in our understanding of the coupled systems at the scale necessary for basin management. Water within the hydrological cycle interacts with other element cycles (including the carbon, nitrogen, sulphur, and phosphorus cycles) as demonstrated by long-term studies in instrumented basins (such as the Hubbard Brook basin, northeast USA (Likens *et al.*, 1977)). Research focusing on freshwater acidification in the 1970s and 1980s (e.g. Bishop *et al.*, 1990; Rosenqvist, 1990) showed that the pathways that surface and subsurface water take through a basin are a fundamental control on water quality. Furthermore, many catchment studies (e.g. Uhlenbrook *et al.*, 2002) have demonstrated that the differentiation of groundwater contributions (e.g. shallow *vs* deep groundwater) can also be significant for understanding streamwater chemistry. Consequently relatively small portions of a hydrological system can significantly impact water quality. This was found, for instance, in the Panola basin, Georgia, USA, in which only small percentages of the total basin area can define the streamwater chemistry during different parts of an event (Burns *et al.*, 2001; Hooper, 2001). In addition to the role of water in biogeochemical cycles, water impacts ecosystem productivity and, in turn, ecosystems influence water cycling through canopy interception and evapotranspiration. Climate change impacts water availability and can influence the initiation of extreme events, and changes in land surface–atmosphere interactions can impact climate.

Many gaps in our understanding of coupled processes and feedbacks exist, and these gaps prohibit the successful management of our basins. Examples of such questions include: How do biogeochemical processes influence the fluxes of nutrients, contaminants, and sediments to surface water at the basin scale? How does climate variability affect soil moisture variability, and how does soil moisture impact climate? What role does groundwater play in land surface and climate processes, and how does climate variability impact groundwater resources? How, and to what extent, do vegetative processes modify atmospheric water content and subsurface soil/groundwater? In addition to these complex hydrosphere–ecosphere–atmosphere interactions, human activity (such as exploitation or pollution of water resources or through modification of the natural environment) greatly impacts all aspects of the hydrosphere and must be considered as part of a coupled system investigation.

Improving our understanding of coupled hydrological–ecological–atmospheric processes and the impact of human activity is needed in order to guide water resources management at all scales. Synthesis across disciplines, as well as space and time scales, is needed to appropriately frame and address the grand questions for investigation (Water Cycle Study Group, 2001). Integrated theory and modelling, coupled with nested scale experiments (laboratory, plot, hillslope, basin and regional) will improve our understanding of processes and feedbacks at various spatial and temporal scales.

As described below, such studies will require the collection of hydrogeological, biogeochemical, ecological, and atmospheric measurements over the appropriate spatial scales and over long periods of time, followed by analysis and meta-analysis of the developed datasets. Successful synthesis of such data will require advances in our approaches to prediction, data integration, and scaling. Brief descriptions of some of these crosscutting problems are given below.

7.1.3 Crosscutting problems

Prediction Models are important to test our hypotheses, integrate our datasets, and predict coupled hydrological–ecological–atmospheric processes. Many different modelling approaches have been developed, ranging from deterministic to stochastic and from data-driven to physics-based. The success of these models varies on a case-by-case basis. There is little consensus about which models work best under which circumstances, and why. Without such an understanding, it is difficult to generalize the insights gained from one model for use elsewhere.

Model validation serves as both a driving force and an impediment to prediction studies. As was discussed in Chapter 5, model validation, model comparison, and error assessment are not currently performed on a routine basis, there are few accepted methods of data assimilation or standard validation, and few studies realistically assess the simulation error associated with the input data. It is well recognized that good datasets are needed with good models to obtain reasonable simulation results, and it is not uncommon in cases of data scarcity to adjust model choices so that the simulations best match the observations. In some cases, it is difficult to measure a hydrological "signal" that is representative of the natural response of an unmodified system thus, although calibration may be improved, it is often not clear if the hydrological processes are being represented properly. Because data are scarce in much of the world (especially in developing countries that perhaps need hydrological predictions the most), a recent movement initiated by the IAHS called PUB (Predictions in Ungauged Basins; Sivapalan *et al.*, 2003b) has focused on reduction in predictive uncertainty through a better understanding of processes (and other strategies) rather than on relying on field data and model calibrations to improve predictions.

Although many models exist for simulating flow within particular hydrological compartments (i.e. groundwater, rainfall–runoff, water quality, land surface, climate), coupling of such models to fully simulate water balance through an entire system and coupling that system with ecological models is an active area of research. These models are typically decoupled: groundwater flow models often do not consider how climate changes will influence transport, and climate models often do not consider the role of groundwater or subsurface rapid flowpaths on water predictions. Climate models run at the large spatial scale may neglect geomorphology, soil erosion and other factors that influence runoff at the basin scale. In order to fully simulate water balance through a system, we must recognize the key processes and parameterize and couple the models appropriately. Among other considerations, coupled models must address how to reconcile the different spatio-temporal scales of processes and data needed to parameterize the different models and governing processes, how to reconcile varying levels of development associated with different types of models (for example, between well developed groundwater flow models and often empirically based ecological models), and how to best quantify the error associated with the different datasets, processes, and models. Finally, the coupling of water-related models to water management, infrastructure development, human health or ecosystem management is still in its infancy and represents an important growth area that requires hydrological input.

Scaling and integration Problems related to scale and integration are persistent across all aspects of hydrological sciences as well as in many other natural sciences. Data are collected at the point, field, basin, regional and global scales. The space and time scales of these measurements and the processes that they are attempting to capture vary widely, as does the organization of these datasets and processes. Improved understanding of space–time organization of parameters and processes, improved integration techniques, improved and standardized calibration procedures, and routine uncertainty assessment are all needed to address scaling and integration problems. In contrast to the discussion of scaling in Section 7.1.1, in this context input is required from across the sciences, for instance, concepts of fractals, self-organization and systems theory.

7.1.4 Steps to overcome scientific bottlenecks in hydrology

This section has identified two key scientific bottlenecks and two crosscutting problem areas that hinder our ability to understand, monitor and predict hydrological processes and interactions within the atmosphere, the hydrosphere, the geosphere and the biosphere, at a level that is needed to guide resource management. There are many approaches that could be undertaken to tackle these challenges and problem areas. In an effort to describe the steps that might be taken to advance one of these issues (prediction) barrier analysis techniques were used to develop a flow chart.

Flow chart development and discussion The barrier analysis trees, or flow charts, that follow the discussion in each category were developed by the entire Hydrology 2020 Working Group to determine what steps could be taken to overcome particular scientific, technological, or organizational barriers to progress in hydrology. This was done by posing a specific question that asks “*How might we achieve* [*a particular aim*]?” The aims selected were those that repeatedly arose in discussions by the Hydrology 2020 Working Group. The flow charts provide a chronology of tasks that must be conducted to achieve the aim, but in reverse order. A white box in the flow chart indicates an individual task that needs to be accomplished before the task given above it. Therefore, to achieve a particular aim identified at the top of the flow chart, one must begin with the tasks given in grey boxes first, and then work upwards.

Flow chart A, shown in Fig. 7.1, illustrates a path for addressing “How might we improve our predictive capabilities of hydrological processes and parameters?” Underlying this question is the assumption that improved predictive capability would stem directly from improved understanding. Figure 7.1 reveals several overlaps between the three main branches of the flow chart and statements made earlier in this section. Below, we discuss some of the steps in these branches, as well as indicating how these steps coincide with others identified in the two other challenge areas, which will be examined further in Sections 7.2 and 7.3. The left branch of Flow chart A involves data accessibility issues, and thus, boxes A5, A6 and A7 are naturally continued through Flow chart B, which discusses data issues (Fig. 7.2). The task identified in box A5 is related to box B2, which will be presented in Section 7.2.3. These boxes suggest that

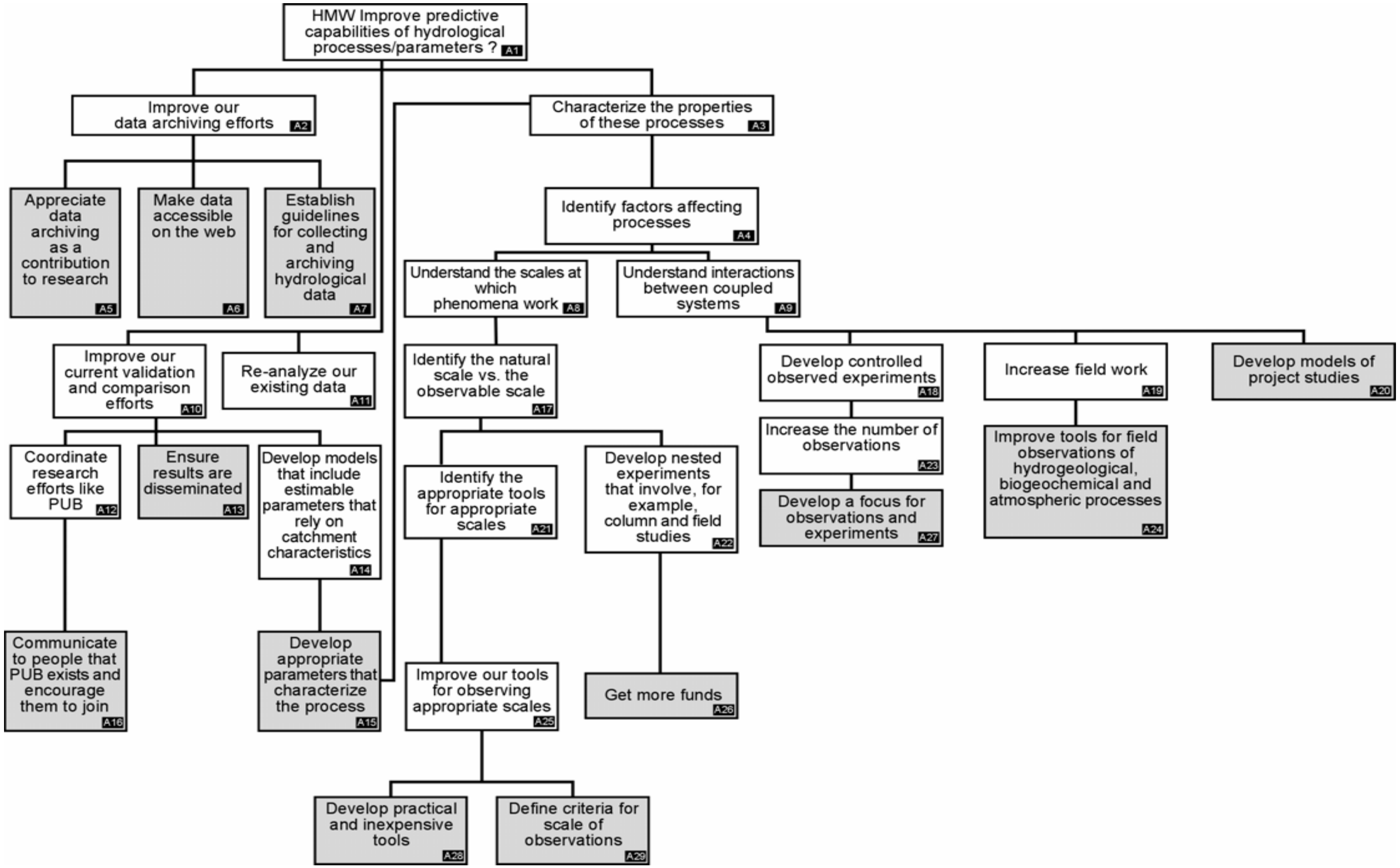

Fig. 7.1 *Flow chart A. How might we improve our predictive capabilities of hydrological processes and parameters?*

we should not only demonstrate the value of data sharing, but should also consider the value of data collection, management and archiving in research activities. This would require a change in attitudes by both researchers and policy makers as well as those that fund research. Box A6 links directly to B5, and A7 is similar to B7. Both of these leftmost branches of Flow charts A and B highlight the need to raise the status of data collection activities. The middle branch of Flow chart A also involves other data issues and boxes A13 and A16, which are grey, and therefore, initial tasks to be overcome, directly link to box C14 of Flow chart C (Fig. 7.3). Flow chart C discusses policy issues and will be examined in Section 7.3.2. Box A15 feeds directly into the rightmost branch of Flow chart A. The right branch of Flow chart A provides actions dealing both with the problem of scale and the continued issue of data collection related to scale. The branch identifies box A26 “Get More Funds” as a first task (shown in grey). This is often considered to be a necessary first step in flow charts attempting to address needs in many scientific disciplines.

From the barrier analysis some of the first steps that should be undertaken to address the central question of how to improve the predictive capabilities of hydrological processes/parameters include:

- define the criteria for the scale of observations;
- develop a focus for observations and experiments and models (templates) of process studies;
- improve tools for field observations of a coupled nature;
- obtain adequate and consistent funding to support long-term efforts.

7.2 TECHNOLOGY AND INFRASTRUCTURE

Characterization and monitoring datasets, tools, and integrated synthesis approaches are needed to obtain information about significant hydrological, biogeochemical, climatological, and ecological processes, variations, and interactions. Such measurements are needed to elucidate the states, stocks, fluxes and residence times of water through the atmosphere, land surface, and subsurface domains. In this section, we discuss the gaps associated with our current technological capabilities.

7.2.1 Measurement and sampling approaches

In order to better understand environmental processes and feedbacks and to accurately parameterize and validate our models, improved observations of properties and processes are needed, including: water vapour, clouds, precipitation, evapotranspiration, surface runoff, infiltration, streamflow, groundwater recharge, soil moisture, and snow and ice thickness and distribution. These measurements must be collected over various spatial and temporal scales, must have enhanced resolution and increased accuracy relative to current technologies, and should be collected over long periods of time relative to the hydrological phenomena under investigation. Additionally, systematic and strategic sampling strategies or observation systems are needed that take into consideration the priority of measurements for different basins and conditions, and the use of space-time patterns of organization.

Although still not routinely used, unconventional measurements are increasingly being incorporated into hydrological investigations, such as geophysical measurements, remote sensing data, and geochemical and isotopic tracer data. New remote sensing capabilities, for example, offer the potential to obtain information about regional scale fluxes of water from the landscape to the atmosphere through evapotranspiration, and for tracking changes in storage of water as ice and snow. Additionally, cheap, small, automated, microsensors for monitoring environmental parameters offer great potential for obtaining high-resolution measurements in a distributed manner, although development of these sensors is at an early stage. Detailed discussions of measurement techniques, gaps, and developing methods are provided in Chapter 4.

7.2.2 Data access and database issues

Concomitant with long-term commitment to establishing and maintaining measurement networks in order to better assess and manage the world's water supplies and prevent hydrological catastrophes, it is critical that scientists have free access to current hydrological data. Water resources cannot be managed unless we know where they are, in what quantity and quality, and how variable they are likely to be in the future. A worldwide water resources database is needed to collect, structure, archive, and disseminate via web services, such data over long enough timeframes to document hydrological extremes (~50–100 years). Development and maintenance of a database using high quality data is crucial for assessing global to local scale water resources, which are in turn needed to verify hydrological models or to develop hard solutions (such as dams, reservoirs, and conveyance structures).

Several organizations exist that collect hydrological data using different platforms and over different spatio-temporal scales, such as the National Water Information System (NWIS) of the US Geological Survey (USGS), WMO, National Aeronautics and Space Administration (NASA), US Environmental Protection Agency (US EPA), National Ocean and Atmosphere Administration (NOAA), Atmospheric Radiation Measurement (ARM) programme, Unidata, and the Global Runoff Data Center (GRDC at BfG Germany). Although collectively these databases offer a wealth of hydrological information, such data are fragmented over space and time, and range widely in content and structure. This fragmentation and variation renders it difficult for a scientist to effectively use the data without devoting extensive time to collecting, sorting and transforming the data, and becoming literate in information technology issues. Additionally, as datasets are collected by many different agencies, there are great difficulties in evaluating the data accuracy and relative biases that may exist. In the USA, attempts are now being made to curate such datasets under the auspices of the Consortium of Universities for the Advancement of Hydrological Science, Inc. (CUAHSI) (Maidment *et al.*, 2003).

7.2.3 Steps to overcome technology and infrastructure bottlenecks in hydrology

Flow chart B (Fig. 7.2) illustrates some of the complexities involved in addressing how we might improve our database support in order to better manage our water resources. The three branches of Flow chart B address different problems. The left branch suggests technical tasks should begin with boxes B13 and B18. Box B18 asks that existing databases be made accessible and inexpensive and is similar to box A6 of Flow chart A. While both boxes B13 and B18 are shown as separate first tasks, perhaps B13 is also the first step to achieving task B18. This is because B13 suggests that we need a single

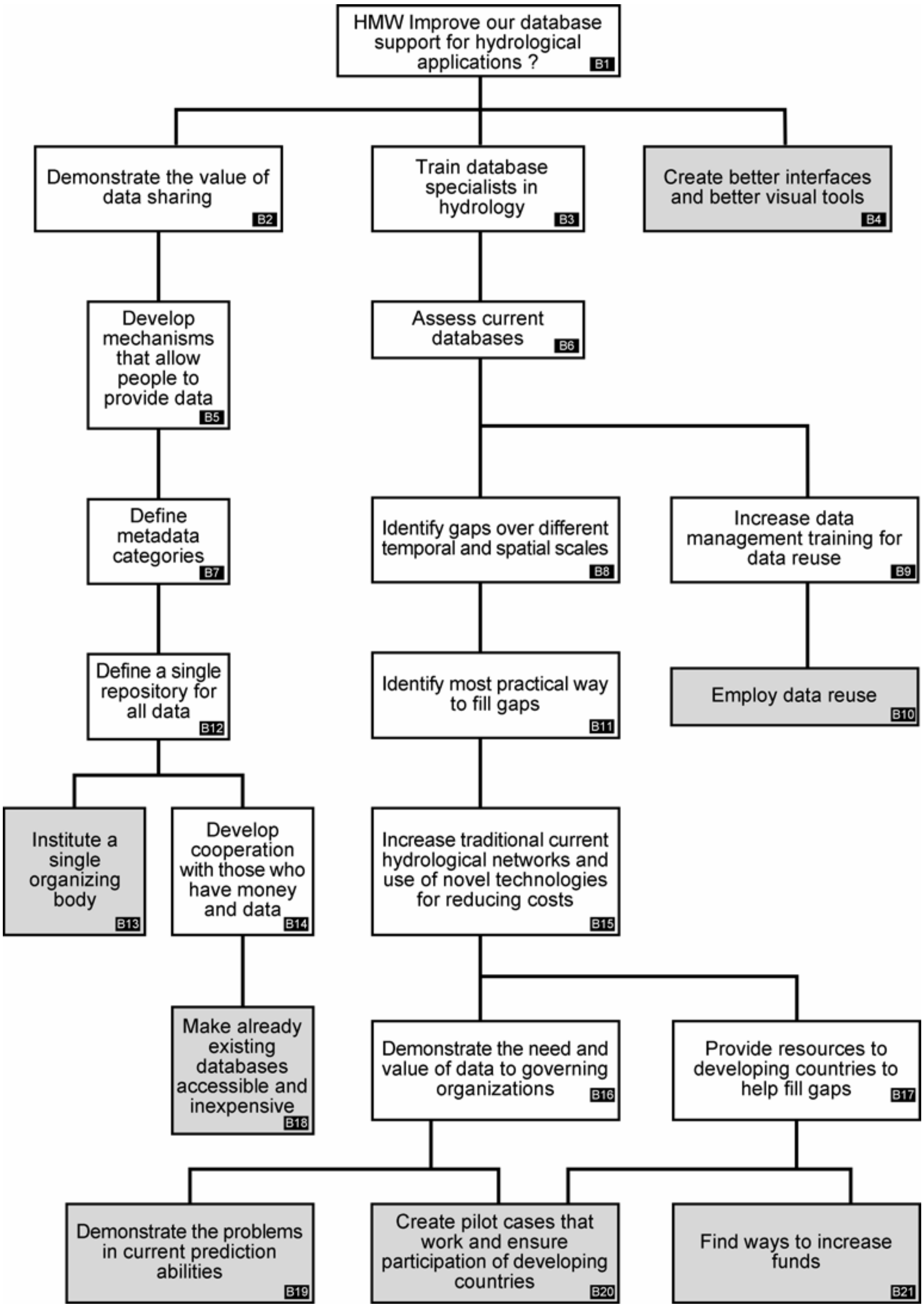

Fig. 7.2 *Flow chart B. How might we improve our database support for hydrological applications?*

organizing body to assist in the development and maintenance of a worldwide database. In the past few years in the USA, CUAHSI and the National Science Foundation (NSF) have supported the development of a digital hydrological library and digital basins in an effort to capture, structure, and disseminate hydrological data needed by researchers (Maidment *et al.*, 2003). Such efforts are required on a global scale, for example, to compile information about water storages and fluxes associated with all significant world aquifers, building upon the work started by the FAO (2003).

The right branch, which is only made up of one box (B4), indicates that a task as large as improving database support does involve fine details such as developing better Graphical User Interfaces (GUIs). The middle branch of Flow chart B involves actions associated with the lack of training in database issues and suggests that three initial tasks be undertaken in boxes B19, B20 and B21. Box B19 suggests that we need to "demonstrate" the problems with current predictive abilities, specifically to agencies that fund or have a vested interest in hydrological research. Box B20, suggests creating pilot cases that work, as well as ensuring the participation of developing countries. This is a two-pronged issue with the "pilot case study" action linking directly back to box A20 in Flow chart A. The "participation of developing countries" we believe can be ensured through the actions of one organizing body, as suggested in box B13. It should be noted as well that because data collection is costly, much of it occurs in wealthier nations. Filling the gap in less developed countries and reducing the fragmentation can be solved with one organizing body. Such organizational capacity discussions are the focus of the next section.

7.3 ORGANIZATIONAL CAPACITY

Water issues are complex, as water acts as a link between various societal demands and ecosystems. Calls are often made for integrated water resources management strategies, such as basin-wide hydrosolidarity, which focuses on water allocation principles based on equity and efficiency. However, such concepts are still poorly defined and even more poorly understood. It is clear that effective policies are needed to strike compromises among competing water uses, to develop sustainable water resource plans, to alleviate and mitigate pollution, and to allay water-related disasters. These policies must be driven by scientific knowledge and scientifically based recommendations, which stem from appropriately directed hydrological research and adequate funding.

7.3.1 Need for a global intergovernmental coordination mechanism for hydrological science and water resources

Although water quality and resource management cuts across political and national boundaries, and organization and coordination are needed to increase the role of hydrology in water and environment decision making, no strong and well-funded intergovernmental global organization currently exists that can coordinate and fund research within the broad range of hydrological sciences. A strong global intergovernmental coordination mechanism is needed to serve as the authoritative scientific voice of hydrology and also to organise research efforts towards resolving world water problems. It could have a role in facilitating integrated approaches to water development and management and offer a capacity to provide advisory services and implement and strengthen technical cooperation and investment projects targeting critical areas of water resource management. Such a mechanism should not be seen as a new organization, but rather as a coordination mechanism building on the collective knowledge of the many international organizations already involved in water issues. Scientific results must be translated into action-oriented recommendations so that they can be used in national and international policy evaluation, formulation, and planning. These recommendations should be formulated in terms that are clear, specific and realistic. With substantial funds and commitment, this mechanism could be an important contribution to sustainable water resources management.

The primary responsibilities of such a global coordination mechanism could include:

Coordinated research management A central focus of the global mechanism could be to develop, fund and coordinate long-term research programmes and ensure that they are linked to policy development and implementation. Included in this task is the coordination of research programmes that are developed by individual countries and organizations in order to most effectively tackle the existing scientific challenges, and the development and maintenance of hydrological funding opportunities. In developing a framework that links together related research, the global coordination mechanism should also identify key hydrological research priorities.

Water policy The coordination mechanism could both coordinate and contribute to water policy activities, serving as the central spokes-organization for global hydrology and water management. The intersection between water science and policy is explored in more detail in Chapter 3.

Testing centres and education and outreach efforts The coordination mechanism could be responsible for establishing linked testing centres/areas that scientists can use to test models and approaches, to share data/instrumentation and to train students or representatives from developing countries. The centres should work together to establish acceptable data standards, formats and calibration approaches and to coordinate long-term data acquisition, archiving, and digital dissemination.

The coordination mechanism could establish standards and advocate public education in hydrological sciences. It could oversee outreach efforts to engage young and bright scientists into the discipline, and to make formal connections between the many sub-disciplines that interact within hydrology. The Institute of Water Education UNESCO-IHE in Delft, The Netherlands, is well established in postgraduate training and serves as a standard setting body for life-long professional training. However, its impact might be increased if the funding is increased and, consequently, the number of students of different levels and sub-disciplines is increased. In addition, more efforts should be made to develop e-learning modules for hydrological subjects, and the coordination mechanism could establish and maintain regional hydrological training centres in cooperation with relevant organizations.

Public awareness An important component of the coordination mechanism would be to raise public awareness about the impending water crisis in a manner similar to the raising of awareness about climate change and ozone depletion issues. Greater awareness translates into more political support and more funding geared toward hydrological sciences, as well as an appreciation of the value of freshwater to society.

Technology transfer and capacity building The global hydrological coordination mechanism could strive to strike a balance between supporting fundamental research and devoting resources toward capacity building and finding practical solutions to hydrological and water management problems in developing countries. In many locations there is a current disconnect between the state of the art in hydrology (represented by complex research advances) and the state of the practice (the tendency to implement the approaches from developed countries in the field). While many hydrologists in developed nations focus on issues such as resolution, uncertainty, and accuracy of advanced prediction/estimation approaches, those in less developed nations are enthusiastic about, for example, the development and dissemination of inexpensive treadle pumps that can deliver irrigation water to their crops using human (cycling) power. Thus, in addition to supporting fundamental research (which will be described below), there also needs to be support and guidance for well-trained hydrologists and water managers who can focus on solving practical solutions, often in the face of incomplete fundamental theory, using currently available approaches and instrumentation.

7.3.2 Steps to overcome organizational bottlenecks in hydrology

In view of the discussion in this section, Flow chart C was developed to address the question of "how might we better integrate hydrological science into the decision-making process?" This flow chart (Fig. 7.3) shows a highly interconnected array of tasks that yields six initial steps. Box C15 suggests that educating those involved in developing academic assessment metrics is necessary because the academic community, which is conducting much of the research, is often assessed by standards that demean the value of practical work or data archiving efforts. Boxes C12, C26, and C30 are all ultimately tied to efforts in public relations, and the recognition that all hydrological researchers must not only be excellent at science, but must be actively involved in public relations and communication. Advertising what we do to the right groups is an essential first step in incorporating hydrological science into decision making. Box C30 stresses the importance of interdisciplinary research (already discussed in Chapter 6). Boxes C16 and C28 are targeting funding agencies but again the onus is ultimately on the hydrologist to educate those that set research boundaries through funding.

One could argue that the primary action, or final recommendation, that results from these flow charts is that the hydrological community needs a single overlying body that can help in directing and coordinating research projects, ensure integration between research and practice, increase data accessibility, educate and involve the public, and find ways to increase funds. There have been unsuccessful attempts to develop such a global water organization in the past. The attempts met with resistance, not only because of protectionism among existing organizations, but because of the lack of willingness to support additional intergovernmental organizations among national funding agencies. Water issues are far too often considered to be part of national security with a strong unwillingness to open up for international cooperation. However, the current situation, typified by a lack of coordination and the duplication of efforts, is not an effective way to handle the challenges that we face. Water quality and quantity trends are not auspicious, and no clear solutions are on the horizon. We urge the hydrological sciences and water policy communities to support the strengthening of

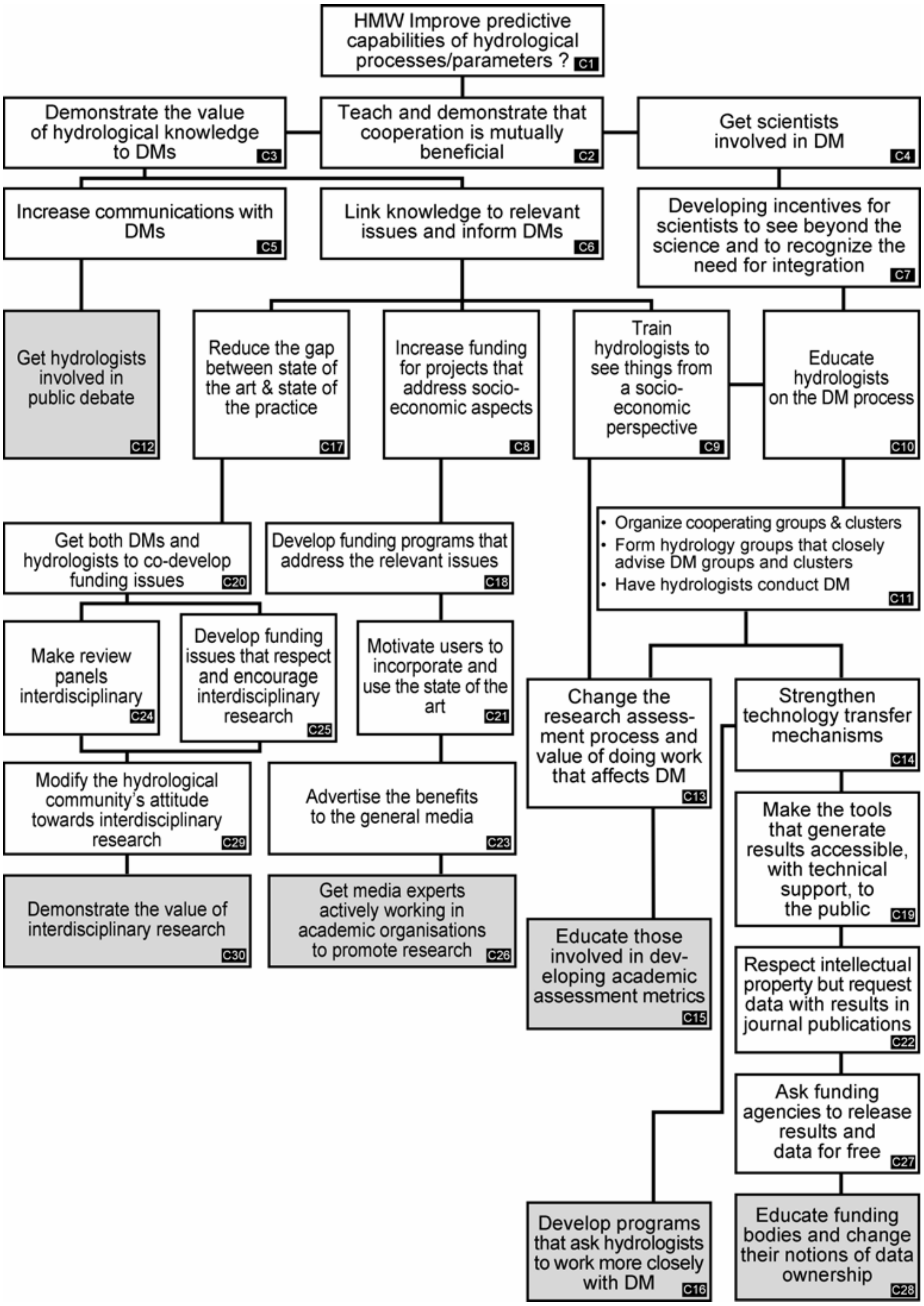

Fig. 7.3 *Flow chart C. How might we better integrate hydrological science into the decision-making process? DM = Decision Makers or Decision Making.*

a global hydrological intergovernmental coordination mechanism that would serve as the authoritative scientific and education voice of hydrology and organize coherent research efforts toward resolving world water problems, as done in the past by, for instance, the WMO Commission of Hydrology and UNESCO/IHP.

7.4 SUMMARY

The bottlenecks described above focus on scientific, technological, and organizational obstacles that the Hydrology 2020 Working Group has identified as major impediments that hinder the advances needed in hydrological science in the 21st century. The associated barrier analysis trees suggest paths that hydrologists can take to overcome these obstacles; the analysis trees suggest that several of the tasks in each of these categories are interrelated. We are at a point in the evolution of hydrology where many of the complex problems that exist can often only be solved with prioritized, coordinated, improved political and organizational support, with more funds committed over the long term to technological development, research and monitoring, and with an emphasis on coupled, cross-disciplinary, and integrated scientific approaches. The fusion of different types of information and strong cooperation of specialists (including natural scientists and water policy specialists) to solve hydrological problems is perhaps a central theme of how hydrology should evolve scientifically to meet the world water challenges. Although the list of bottlenecks is extensive and the approaches towards solutions would be costly to implement, the repercussions of not addressing these obstacles now may be much more costly to future generations.