Global Water System Project

ESSP Report No. 3

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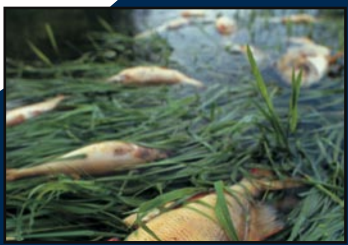
The Global Water System Project


Science Framework and Implementation Activities

Earth System Science Partnership

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The Global Water System Project

Science Framework and Implementation Activities

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Abbreviations

AO	Arctic Oscillation
APN	Asia-Pacific Network for Global Change Research
BAHC	Biospheric Aspects of the Hydrological Cycle
CEOP	Coordinated Enhanced Observing Period
CGIAR	Consultative Group on International Agricultural Research
CGIAR CP	CGIAR Challenge Program
CLIVAR	Climate Variability and Predictability (World Climate Research Programme)
CSD	Commission for Sustainable Development
CSEs	Continental Scale Experiments
ENSO	El Niño Southern Oscillation
ESSP	Earth System Science Partnership
FAO	Food and Agriculture Organization
FRIEND	Flow Regime from International Experimental and Network Data
GAIM	Global Analysis, Integration and Modelling
GEC	Global Environment Centre Foundation
GECAFS	Global Environmental Change and Food Systems
GECP	Global Environmental Change Programme
GEWEX	Global Energy and Water Cycle Experiment
GLP	Global Land Project
GWS	Global Water System
GWSP	Global Water System Project
HELP	Hydrology for Environment, Life and Policy
IAI	Inter-American Institute for Global Change Research
ICSU	International Council for Science
IGBP	International Geosphere Biosphere Programme
IGBP-BAHC	IGBP - Biosphere Aspect of Hydrological Cycle

IGBP-GAIM	IGBP – Global Analysis, Interpretation, and Modelling
IGOS-P	Integrated Global Observing Strategy Partnership
IGWCO	Integrated Global Water Cycle Observations (IGOS-P)
IHDP	International Human Dimensions Programme
IHP	International Hydrological Programme
iLEAPS	Integrated Land Ecosystem-Atmosphere Processes Study
IPCC	Intergovernmental Panel on Climate Change
IPCC TAR	Intergovernmental Panel on Climate Change Third Assessment Report
IPO	International Project Office
IRS	Integrated Regional Studies
IWMI	International Water Management Institute
LOICZ	Land-Ocean Interactions in the Coastal Zone
LUCC	Land-Use and Land-Cover Change
MDGs	Millennium Development Goals
NAO	North Atlantic Oscillation
NOAA	National Oceanic and Atmospheric Administration
PAGES LIMPACS	Past Global Changes - Human Impact on Lake Ecosystems
PAGES LUCIFS	Past Global Changes - Land Use and Climate Impacts on Fluvial Systems
SCOPE	Scientific Committee on Problems of the Environment
SSC	Scientific Steering Committee
START	Global Change SysTem for Analysis, Research, and Training
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCD	World Commission on Dams
WCMC	UNEP World Conservation Monitoring Center
WCRP	World Climate Research Programme
WEHAB	Water, Energy, Health, Agriculture and Biodiversity
WRI	World Resources Institute
WSSD	World Summit on Sustainable Development
WWDR	World Water Development Report

Executive summary

The Concept of a Global Water System

One of the important consequences of the rapid growth of global environmental science has been our growing awareness of the linkages, interconnections and interdependencies in the global water cycle. We now realize that the various human and non-human facets of the cycle make up a *global water system*. The scientific community affirmed this concept in the Amsterdam Declaration of the 2001 Open Science Conference "Challenges of a Changing Earth".

As a working definition, we define the global water system as the global suite of water-related human, physical, biological, and biogeochemical components and their interactions (Figure 0-1, later in this report). These components include:

1. *Human components* – These are the sum of water-related organisations, engineering works, and water use sectors. Society is not only a component of the global water system but also a significant agent of change within the system in that society is not only exposed to changes in water availability but also takes various actions to mitigate or adapt to these changes.

2. *Physical components* – These are the physical attributes and processes of the traditional global hydrologic or "water cycle", including precipitation, runoff, geomorphology, sediment processes, evapotranspiration, moisture transport. The global water cycle encompasses not only hydrologic processes over and under the land surfaces of the earth, but also in its oceans and atmosphere.

3. *Biological and biogeochemical components* – This category includes the sum of aquatic and riparian organisms and their associated ecosystems and biodiversity. These organisms are also integral to the geochemical functioning of the global water system and not simply recipients of changes in the physico-chemical system. We also include here the biogeochemistry of the global water system and water quality.

The global water system plays a key role in the abiotic dynamics of the Earth System. For example, through couplings with the carbon and other biogeochemical cycles, water helps regulate the release and sequestration of CO_2 and other radiatively-important gases. The hydrologic cycle controls the transport of waterborne substances from continents to the oceans. The global distribution of clouds, snow cover and water vapor regulate the energy balance of the earth.

While the global water system is an essential aspect of the non-living dynamics of the Earth System, it also plays a central role in human society. The global aspects of the water system become more relevant due to increasingly tight economic, social, technological and other couplings among society we term "globalization". As an example, the water policies carried out by large international organisations have direct impacts on the levels of water abstraction and water diversions worldwide, and hence on the level of wastewater discharges, hydrologic regimes, the biogeochemistry of waters, and the integrity of aquatic ecosystems.

The Challenge of Understanding the Global Water System

Along with the recognition of the global water system has come the awareness that human activities are significantly and rapidly changing this system. Box 1, later in this report, lists some of the many "syndromes" that are causes and manifestations of rapid changes in the global water system. Although we are aware of these changes, we urgently need to improve our understanding of their underlying causes. Otherwise we will be unable to counteract the current and future threats to public health, economic progress, and biodiversity caused by these changes.

We should recognize that improving our understanding poses special challenges to scientific research. First of all, scientists must take a global view of the water system, although most water research and management up to now has been concerned with regional and local processes. In addition, rather than concentrating on a particular aspect of the global water system, scientists must especially study the linkages and feedbacks in the system. Scientists must also give equal attention to the many social science and natural science aspects of global water resources. For this reason, researching the global water system requires a multi-disciplinary and/or an interdisciplinary approach.

Establishing the Global Water System Project (GWSP)

In response to the urgent need to better understand the global water system the organisations of the Earth System Science Partnership (ESSP) – i.e. the International Geosphere-Biosphere Programme, the International Human Dimensions Programme on Global Change, the World Climate Research Programme, and DIVERSITAS – proposed to establish a *Global Water System Project* (GWSP). This is one of the new Joint Projects of the ESSP.

The central tenet of the GWSP is that human-induced changes to the water system are now global in extent, yet we lack an adequate understanding of how the system works and responds to disturbances, and how society can best adapt to rapidly-evolving new system states.

The organisations of the Earth System Science Partnership (ESSP) are in a unique position to establish the project and increase our understanding of the global water system because between them they cover scientific research on the most important elements of the system. At the same time they lead current efforts to understand both the natural science and social science aspects of global change. Through the joint GWSP these organisations will catalyze interdisciplinary understanding of the role of water in the Earth System as well as the role of society as a key element in the global water system. Through this project, the resources of the ESSP will also contribute new insights to some of society's most pressing issues such as the role of world water in sustaining biodiversity and ecosystem services, agriculture, health and sustainable development.

At the initiative of the ESSP, the Global Water System Project emerges from a broad, community-based dialogue that has progressed since the summer of 2001. The GWSP joins the ranks of other joint projects – the project on Global Environmental Change and Food Systems (GECAFS), the Global Carbon Project, and the project on Global Environmental Change and Human Health.

The GWSP Scientific Questions and Themes

The goal of the GWSP is to address the following overarching scientific question:

How are human actions changing the global water system and what are the environmental and socio-economic feedbacks arising from anthropogenic changes in the global water system?

Three core questions follow from this overarching question, and these questions make up the three major *research themes* of the GWSP.

Theme 1. What are the magnitudes of anthropogenic and environmental changes in the global water system and what are the key mechanisms by which they are induced?

Theme 2. What are the main linkages and feedbacks within the earth system arising from changes in the global water system?

Theme 3. How resilient and adaptable is the global water system to change, and what are sustainable water management strategies?

As noted above, the physical water cycle of the earth encompasses not only the freshwater systems over and under its land surfaces, but also its oceans, atmosphere and cryosphere. However, the Global Water System Project will focus *on the world's freshwaters*, and will work with existing research programmes to include their expertise and knowledge of the world's oceans and atmosphere in studies of the global water cycle.

Implementation Activities

The GWSP has laid out an ambitious programme of research to broaden scientific knowledge about the current workings and future prospects of the global water system. This programme is divided into three phases:

I. (Years 0 to 2) *Programme definition and initiation* in which the project finalises its plan and launches a mix of short, medium and long term initiatives.

II. (Years 3 to 5) *Programme implementation and product delivery* in which the first short and medium term results become available.

III. (Years 6 to 10) *Data synthesis and application of results* in which results of the project are synthesised, disseminated and applied.

The implementation of the GWSP research is organized into research activities that fall under the above three themes, as well as cross-cutting activities that address issues common to all research themes (such as data consolidation and modelling), and educational and capacity building activities. The following paragraphs give an overview of the implementation activities of the GWSP.

Theme 1: Magnitudes and Mechanisms of Change.

Under this theme we examine the magnitudes of anthropogenic and environmental changes in the global water system and study their underlying mechanisms.

Activity 1.1: Water Governance and the Global Water System. Systems of water governance have a profound impact on worldwide water use and water services. In this activity researchers will compare and classify systems of water governance, analyse their impact on water resources, and catalog governance systems worldwide. A systematic database on water governance systems and their influence on the global water system will also be developed.

Activity 1.2: Land Cover Changes and the Global Water System. Large-scale changes in land use/cover are having a worldwide impact on water resources. In this activity researchers will analyze historical patterns of land and water use by continent and major river basins. They will compile trajectories of land use/cover change for different regions of the world taking into account demographic, economic, cultural and other factors. These trajectories will support studies of future land use impacts on the global water system. In addition, researchers will also study how land cover change has affected the hydrological cycle, water quality and the integrity of freshwater ecosystems.

Activity 1.3: Climate Change and the Global Water System. Although we suspect that climate change is accelerating the water cycle, the possible impacts of this acceleration (on drought, flooding, seasonal discharge) are unclear. In this activity researchers will analyze the impacts of climate change and variability on water use and availability worldwide, including feedback mechanisms between anthropogenic climate change and the global water system.

Activity 1.4: Water Diversions and the Global Water System. The pandemic alteration of surface and ground water through impoundments, irrigation projects, and other large diversion projects has lead to fragmentation of river systems, alteration of flow regimes, and changed water budgets. At the same time the development of rivers has provided electricity, flood protection and other "goods and services" to society. In this activity researchers will analyze and quantify the cumulative consequences of large water diversions on regional hydrologic regimes including their impacts on biodiversity and the services that aquatic ecosystems provide to society.

Activity 1.5: Nutrient and Sediment Transport and the Global Water System. Human activity is known to substantially affect sediment and nutrient fluxes in the global water system. Activities such as crop fertilization accelerate these fluxes, while impoundments tend to reduce them. The impacts of these changes on, for example, coastal ecosystems could be large. In this activity researchers will identify key variables and functional relationships describing worldwide nutrient and sediment transport. They will assess and identify global hot spots contributing to nutrient and sediment transport and hot spots of nutrient and sediment accumulation, and assess the demographic, cultural and other factors that affect the global transport of nutrients and sediments. Researchers will also study the implications of this global transport on ecosystem structure and services and human health.

Theme 2: Linkages and Feedbacks

Under this theme we investigate the main linkages and feedbacks within the Earth System arising from changes in the GWS.

Activity 2.1: Linkages at Di erent Spatial Scales in the Global Water System. Studies have shown that the global water system is characterized by important long-distance connectivities operating at the regional to global scales. Yet we are only in the early stages of understanding these linkages. In this activity researchers will organize a series of river basin studies to examine the historical interactions between river basins and their human inhabitants with the aim to better understand spatial connectivities. Researchers will develop a general framework for globally analyzing these connectivities. A key issue to be examined is whether spatial connectivities lead to unexpected non-linear changes in the global water system. Another topic will be an examination of a different kind of connectivity – the international trade in virtual water.

Activity 2.2: Legacy of Human and Natural Interactions in the Global Water System. Many water systems have long residence times and therefore long response times to human and natural actions. Research is needed on these "legacy effects" including ecological effects, so that we can develop better strategies to avoid long term negative impacts on our water resources. Here researchers will use the worldwide river basin studies in Activity 2.1 to address the question, "What are the long term disturbances to the global water system caused by human activities and natural events?" Participants of the GWSP will develop a conceptual framework for studying "legacy effects" on different types of water systems. They will also work with researchers in other GWSP activities to extend the ability of world water models to simulate legacy effects.

Theme 3: Resilience and Adaptation

Under this theme we examine the resilience and adaptability of the global water system to change. Related to this we investigate methods for supporting sustainable water strategies.

Activity 3.1: Water Requirements for Nature and Humans. One major gap in water assessments has been a systematic and global comparison of water requirements of society with those of aquatic ecosystems (both the flow regime, and quality requirements). Researchers in this activity will develop a framework for the worldwide assessment (at different scales) of tradeoffs between environmental water requirements and the goods and services provided by freshwater resources.

Activity 3.2: T e Nature of Adaptive Capacity of the Global Water System. The adaptive capacity and vulnerability of the GWS is not well understood, but is expected to depend on the complex interplay of environmental, social, and other factors. In this activity, researchers will identify/ quantify the factors (e.g. population and land use changes, institutional and industrial transformation) that influence adaptive capacity of the GWS. The goals here are to identify the nature of the adaptive capacity and to develop indicators that can help us monitor threats to this capacity.

Activity 3.3: Approaches to Enhancing Adaptive Capacity (the role of institutions, governance, industrial transformation). Under Activity 1.1 we investigate how water governance leads to changes in the global water system. Under Activity 3.3 we examine how water governance affects the adaptive capacity of society to these changes. Although most research on water governance to date has focused on local and regional scales, here GWSP researchers will examine how different models of governance can affect the adaptive capacity of society on the global scale. One topic to be examined is how different concepts of governance can help with managing water in a sustainable way at the global level. An example of this is to identify how water requirements for ecosystems can be embodied in international and national legislation and legal structures.

Activity 3.4: T e Provision of Ecosystem Goods and Services by the Global Water System. Recent assessments (e.g. Millennium Assessment) have begun to systematically quantify the value of natural systems to human society. Nevertheless, much work needs to be done in estimating the ecosystem services provided by freshwater. Under this activity, researchers will identify ecosystem services provided by the global water system. They will also evaluate the impact of global change and society's activities on the provision of these services.

Cross-Cutting Research Activities

The cross-cutting activities of the GWSP ensure continuity across the three themes of the GWSP and provide opportunities for joint activities/products that help focus the activities of the project. Other aims of the cross-cutting activities are to produce quantitative information needed by researchers inside and out of the GWSP, and to improve communication between the scientific disciplines involved in global water research.

Activity 4.1: Building the GWSP Information Base. Because an integrative picture of the changing state of the Global Water System is at the heart of the GWSP, a key cross-cutting activity will be the development of a GWSP Information Base. The development of the Information Base includes:

- constructing a meta-database of information sources about the global water system;
- identifying critical data gaps in global water studies;
- developing new indicators to include the ecological status of the global water system;
- mapping and assessing the current and past state of water systems worldwide;
- building a comprehensive GWSP Database about the global water system.

Activity 4.2: T e GWS-Discourse: Integrating the Natural Science and Social Science Approaches to the Global Water System. The GWSP aims to bring together scientists from different disciplines to study the global water system and to work together on activities that would generate new insights in the water sciences. Under this activity, the GWSP will support cooperation between the disciplines by activities such as developing a GWS lexicon of common terminology and constructing a common conceptual framework for studying the global water system.

Activity 4.3: Developing World Water Models and Analyzing Scenarios. An important goal of the GWSP will be to integrate perspectives on the global water system by encouraging and supporting the development of "world water models". These models will depict linkages and feedbacks among the various components of the GWS. One set of models will focus on a particular aspect of the global water system (e.g. hydrology, biodiversity, or water use) and another set will be "integrated" models in that they will couple two or more major components of the global water system (e.g. water abstraction and hydrology). These models will be used for scenario analysis of worldwide water resources and in this way will further the project's goal of helping to create visions of future states of the global water system.

Synthesis, Capacity Building, and Education

Critical to the implementation of the GWSP are efforts to reach out to a larger audience in the scientific community and society-at-large. The GWSP will carry out a special programme for reaching this larger community in cooperation with START and other programmes.

Special attention will be given to synthesizing the large body of information that is expected to be gained about the global water system. This synthesis will be in the form of "assessment reports" and other synthesizing documents and materials.

Throughout the project an information exchange will be sought with stakeholders and policymakers (see next paragraph). Various actions will be taken for capacity building including actively engaging young scientists in international teams of water researchers. A dynamic educational programme will also be pursued in the form of training and research workshops for young scientists, development of new university curricula, and production of innovative web-based teaching packages, among many other educational activities.

Dialogue with Stakeholders and Policy Makers

The GWSP focuses on scientific questions and is motivated by a unique perspective on global water problems not addressed elsewhere. Although the project is science driven, it is clear that it must be relevant to the needs of the larger stakeholder and policy communities. Therefore, special efforts will be made to engage stakeholders, policy makers and others in a dialogue about the connection between the global dimensions of the water cycle and local and regional water problems. This dialogue will take the form of GWSP workshops and other meetings, as well as a series of joint "White Papers" on pressing water issues co-written with stakeholders. The GWSP will also make early contact with existing multi-stakeholder networks (e.g. the EU water initiative, World Water Council, etc.) and will ensure the representation of stakeholder interests on the GWSP steering committee.

Cooperation with Other Research Efforts

To achieve its goal of integrative understanding of the global water system the GWSP must cover a wide range of scientific topics and disciplines. Therefore, a measure of overlap is expected between GWSP research interests and those in other research programmes and organisations. In the text of this report we indicate some of the national and international research activities that the GWSP should cooperate with on particular activities.[1] To be more general, the GWSP will actively seek cooperation with programmes and organisations whose interests overlap with those of the GWSP. The types of organisations will include:

- National programmes on water research;
- International water-related research programmes sponsored by DIVERSITAS, IGBP, IHDP, and WCRP.
- Other international research programmes related to water problems;
- Organisations sponsoring international assessments and policy studies of global water issues.

Rather than duplicating these efforts, the GWSP will seek to work with these groups by building linkages and partnerships with them.

[1] A partial list of these programmes and organisations includes: the Challenge Program on Water and Food, BAHC, CEOP, CLIVAR, FRIEND, GEWEX, HELP, IGWCO, iLEAPS, IWMI, GLP, LIMPACS, LUCC, LUCIFS, LOICZ, PAGES, START, UNESCO transboundary programme "Water and Peace" (the names behind these acronyms are given in the section "Abbreviations" at the beginning of this report).

Products of the GWSP

The following are expected to be some of the main products of the GWSP:

- Consolidation of disparate efforts at studying the global aspects of water resources into a unified, dynamic research programme.
- Broadened knowledge about important changes in the global water system and their drivers and mechanisms.
- New understanding about the linkages and feedbacks that characterize the global water system and a greater competency to anticipate non-linear changes in the system.
- A global assessment of the water requirements of freshwater ecosystems.
- Enhanced knowledge of freshwater biodiversity.
- Greater comprehension of factors determining the resilience and adaptive capability of the global water system.
- New sets of indicators that increase the ability of society to monitor and anticipate changes in the global water system.
- New numerical models for understanding the current global water system and anticipating its future states.
- A vastly improved knowledge base about the global water system with practical tools such as the GWSP database which will be made widely available for supporting global water research.
- A better informed public and scientific community about the influence of the global dimensions of the water cycle on local and regional water problems.

Introduction

Water plays a key role in the development and functioning of society by serving as a basic resource for activities such as irrigation, livestock production, fisheries, aquaculture, and hydroelectric power. Adequate water use in households, businesses and manufacturing is a prerequisite of economic growth. Since many of the world's diseases are waterborne, we need clean water and sanitation for reducing the incidence of these diseases. And, most significantly, water provides habitat and sustenance for a rich diversity of plant and animal species that make up aquatic and riparian ecosystems, providing the basis for many of the goods and services received by society.

The behaviour and development of the land-based water cycle and aquatic ecosystems have thus remained a major preoccupation of individual civilizations for thousands of years. Today, there is an emerging recognition that such concern can be justified *over a global realm*.

Moreover, society has also identified water scarcity and other issues related to water resources as one of the highest priorities on its sustainable development agenda. This was confirmed by the declarations and reports of the World Summit on Sustainable Development in Johannesburg 2002, the World Water Forum 3 in Kyoto 2003, and the ongoing World Water Assessment Programme of the UN Water Alliance. To underscore this importance, water also plays the central role in one of the Millennium Goals adopted in 2000 at the 55th Session of the United Nations General Assembly – namely to halve by 2015, the proportion of people without access to safe drinking water. Water is also a vital prerequisite for achieving the other Millennium Goals of reducing poverty, hunger, and infant mortality.

The Emerging Concept of a Global Water System

One of the important products of the recent rapid growth of global environmental science has been new knowledge about the linkages, interconnections and interdependencies in the global water cycle. We now realize that the various human and non-human facets of the cycle make up a *global water system*. The scientific community affirmed a similar concept for the earth system as a whole in the Amsterdam Declaration of the 2001 Open Science Conference "Challenges of a Changing Earth" by saying:

> **The earth system behaves as a single, self-regulating system, comprised of physical, chemical, biological, and human components.**

The other assertions of the Amsterdam Declaration are similarly important to the emerging concept of a global water system:

- Human activities are significantly influencing the global water system in many ways in addition to greenhouse gas emissions and climate change;
- Global change and the hydrosphere cannot be understood in terms of simple cause-effect relations;
- Some water systems are characterized by critical thresholds and abrupt changes;
- Facets of the global water system have moved well outside the range of recent natural variability and are increasingly modified by anthropogenic activities.

As these points assert, society is forcing unprecedented changes on global water resources through worldwide abstraction and pollution of water. Society also has a pervasive indirect impact because anthropogenic greenhouse gas emissions are causing long-term global changes in weather extremes and climate.

Changes in the global water system are difficult to understand with simple cause-effect relationships because of the intense and complex linkages and feedbacks between different parts of the system. These changes and linkages also sometimes lead to abrupt changes in water systems such as the eutrophication of coastal aquatic systems, loss of biodiversity, the exceedance of safe water supply in urban areas, or intense competition between different water sectors for remaining water resources. Box 1 lists some of the many "syndromes" that are causes and manifestations of rapid changes in the global water system.

Box 1: Examples of Major Syndromes Transforming the Contemporary Global Water System

Biodiversity loss	Altered flow regimes, destruction of habitat and pollution have caused widespread loss of species and/or decline of fisheries. (Jackson et al., 2001; Moyle and Leidy, 1992).
Climate change impacts	Global surface temperature continues to rise throughout the instrumental record with new evidence of an accelerated hydrologic cycle. Regional increases in extreme precipitation, systematic reductions in snow cover and mountain ice, and more frequent and intense quasi-periodic events (e.g. ENSO, AO) have been tabulated during the last several decades. (Arnell and Liu, 2001).
Erosion	Sediment load to aquatic systems has substantially due to poor land management inducing erosion. (UNEP, 2002).
Eutrophication	Due to development and increasing use of water, the eutrophication of inland waterways continues to increase; impacts persist to the coastal zone where they cause anoxia and toxic algal blooms, and endanger fisheries. (Meybeck et al., 1989).
Groundwater contamination	Groundwater resources have been contaminated with salts, pesticides and other substances from agricultural activities, and with chemicals and pathogens from industrial activities and settlements (see "Loadings of micropollutants").
Intensive water abstraction	In heavily populated regions water withdrawals sometimes exceed natural river flow and the rate of groundwater recharge (mining of aquifers); water is reused many times, with concomitant public health and pollution problems. (UNEP, 2002).
Interception of sediment flux	Dams trap 30% of global sediment flux with downstream impacts influencing many coastal zones of the world. Reservoir siltation from upland erosion results in substantial economic loss in many parts of the world (Vörösmarty et al. 2003).
Introduction of alien species	As a result of increasing world trade, invasive species are replacing native species and changing the biodiversity and character of natural ecological systems. (Ricciardi and Rasmussen, 1991 for North America).
Land-coastal linkages	Because of water diversion and evaporative (irrigation) losses, connections between the land and coastal zones are being severed with respect to water, nutrients and sediment. Well-known examples include the Yellow and Colorado Rivers, among many others in arid regions. (Vitousek et al, 1997).
Loadings of micropollutants	The loadings of micropollutants to water systems are on the rise in many parts of the world including natural (e.g. arsenic and other metals) and engineered (e.g. pesticides) species, with impacts on human health and biodiversity. (Stanners and Bourdeau, 1995 for Europe).
Nitrogen loadings	Global nitrogen loadings of rivers have increased by a factor of 2 to 3 compared to pristine conditions with 10-fold increases in some regions (Green et al. 2004, Galloway et al. 2004).
Salinization	Intensive and prolonged agricultural activity has led to large scale leaching of salts from cultivated areas and caused elevated salinity concentrations in groundwater and surface waters, with impacts on terrestrial and freshwater ecosystems. (Meybeck et al., 1989).

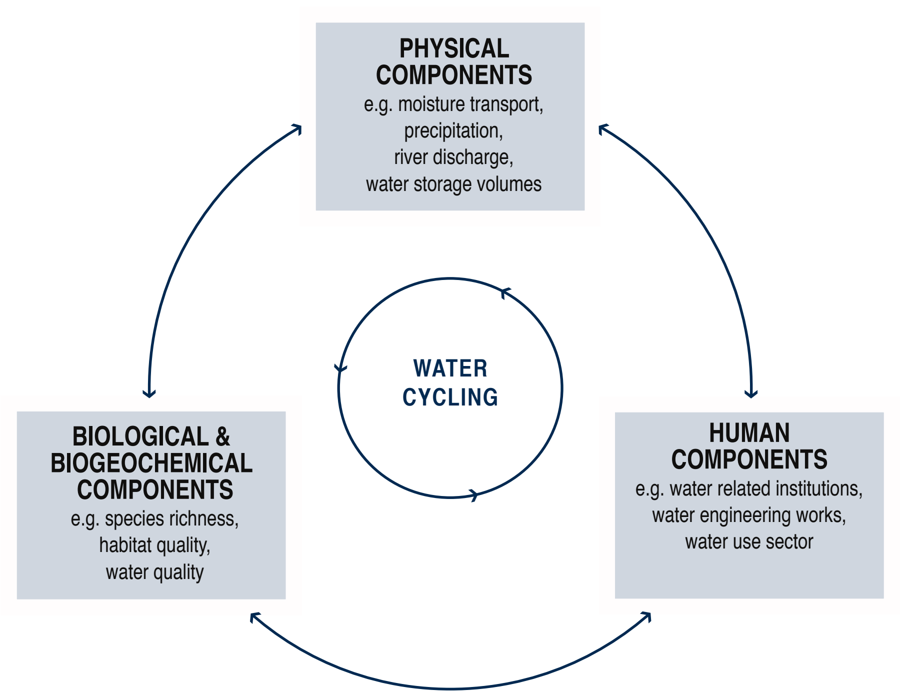


Figure 0-1

Main components of the global water system.

A synthesis of current information indicates that the cumulative direct effects of human activities, such as land cover change, urbanization, industrialization and water resources development, are likely to surpass the effects of recent and anticipated climate change over decadal time scales. As asserted by the last point from the Amsterdam Declaration (cited above), the global water system has already moved well outside the range of natural variability to *a non-analog state* and is increasingly modified by anthropogenic activities.

Defining the Global Water System

The concept of a global water system is only now taking shape. As a working definition, we define the global water system as the global suite of water-related human, physical, biological, and biogeochemical components and their interactions (Figure 0-1). These components include:

Human components – These are the sum of water-related organisations, engineering works, and water use sectors. Society is not only a component of the global water system but also a significant agent of change within the system in that society is not only exposed to changes in water availability but also takes various actions to mitigate or adapt to these changes.

Physical components – These are the physical attributes and processes of the traditional global hydrologic or "water cycle", including precipitation, runoff, geomorphology, sediment processes, evapotranspiration, moisture transport. The global water cycle encompasses not only hydrologic processes over and under the land surfaces of the earth, but also in its oceans and atmosphere.

Biological and biogeochemical components – This category includes the sum of aquatic and riparian organisms and their associated ecosystems and biodiversity. These organisms are also integral to the geochemical functioning of the global water system and not simply recipients of changes in the physico-chemical system. Hence we also include here the biogeochemistry of the global water system and water quality.

By 'water' in the global water system we mean water in its largest sense, that is, as a vital resource for society, as a medium and habitat for plant and animal life, and as a conduit for transporting energy and materials in the Earth System. Indeed the global water system plays a key and integrative role in the abiotic dynamics of the entire Earth System. It has, for example, enormous importance for climate because clouds, snow cover, and water vapor regulate the planetary heat balance. Through linkages with the carbon and other biogeochemical cycles, water helps regulate the release and sequestration of CO_2 and other radiatively important trace gases. The hydrologic cycle is also the principal vehicle controlling the mobilization and transport of waterborne constituents from continents to the oceans. Water is essential to maintaining the integrity and biodiversity of both terrestrial and aquatic ecosystems.

Yet the global water system is not only a feature of the dynamics of the Earth System, but an equally important if more subtle feature of human society. It can be argued that the global water system has emerged along with the increasingly tight economic, social, technological and other couplings among society we term "globalization". Indeed, global changes in society have brought parallel changes in the global water system. For example, worldwide changes in the structure of water policy and use have a direct impact on the levels of water diversions and water abstraction worldwide and therefore on the level of wastewater discharges, the state of hydrologic regimes and the biogeochemistry of waters. The impacts of pricing policies of water companies with a global reach, and the international trade in water technology, are only two of many examples of how society acts as an integral part of the global water system.

The Challenge of Understanding the Global Water System

In previous paragraphs we have emphasized that the global water system is an *emerging concept*, and its boundaries and characteristics need to be better defined and quantified. This should be one of the first tasks of the Global Water System Project, to be mentioned shortly.

The complexity of the global water system, like other components of the Earth System, poses a special challenge to scientific research. To better understand this system, scientists must focus on its linkages and feedbacks. They must take a continental or global view, although most water research and management up to now has been concerned with regional and local processes. Scientists must also give equal attention to the many social science and natural science aspects of the system. For this reason, researching the global water system requires a multi-disciplinary and/or an interdisciplinary approach. This approach must assemble, and sometimes combine, a wide variety of different research methods borrowed from the socio-economic, political, physical and ecological sciences. These methods will range from social science surveys, to hydrological field measurements, remote sensing, or mathematical modelling.

Establishing the Global Water System Project (GWSP)

In response to the urgent need to better understand the global water system the organisations of the Earth System Science Partnership (ESSP) – i.e. the International Geosphere-Biosphere Programme, the International Human Dimensions Programme on Global Change, the World Climate Research Programme, and DIVERSITAS – proposed to establish a *Global Water System Project* (GWSP). This is one of the new Joint Projects of the ESSP.

The central tenet of the GWSP is that human-induced changes to the water system are now global in extent, yet we lack an adequate understanding of how the system works and responds to disturbances, and how society can best adapt to rapidly-evolving new system states.

The organisations of the Earth System Science Partnership (ESSP) are in a unique position to establish the project and increase our understanding of the global water system because together they cover research on the most important elements of the system. At the same time they lead current efforts to understand both the natural science and social science aspects of global change. Through the joint GWSP these organisations will catalyse interdisciplinary understanding of the role of water in the Earth System as well as the role of society as a key element of the global water system. At the same time they will address some of society's most important issues concerning water (Box 2).

At the initiative of the ESSP, the Global Water System Project emerges from a broad, community-based dialogue that has progressed since the summer of 2001. The GWSP joins the ranks of other joint projects – the project on Global Environmental Change and Food Systems (GECAFS), the Global Carbon Project (GCP), and the project on Global Change and Human Health.

Box 2: The GWSP Working on Society's Important Issues

Water plays an important role in many of the great challenges facing society today. But these challenges have many different dimensions and hence cannot be handled by a single area of expertise or scientific discipline. Indeed they require the cooperation of many different disciplines and perspectives, including those of the GWSP. Here is the role that the GWSP could play in addressing some of these important issues.

World Water and Agriculture. Changes in the global water system will have an important effect on world agriculture in that the availability of water for agricultural production will change. Conversely, agriculture already plays an important role in the global water system because of its large abstraction of water for irrigation. In this research area, the GWSP will work with colleagues in another ESSP cross-cutting project, GECAFS, to improve our understanding of the important interaction between global agriculture and the global water system.

World Water and Health. Many diseases are either water-borne, water-based, or caused by insect vectors living primarily in water. Hence, clean water and sanitation are essential to reducing the spread of disease and the vulnerability of people to disease. Changes in the global water system will undoubtedly affect the coverage of disease and human vulnerability, although it is unclear what these impacts will be. In this research area the GWSP will work with colleagues in the newly established "Global Change and Human Health" Joint Project of the Earth System Science Partnership, as well as other research programmes, on improving our understanding of these impacts.

World Water and Carbon. An important aspect of the global carbon cycle are the carbon fluxes and stocks associated with water. For example, large quantities of carbon are conveyed via inland waters from the continents to the coastal zone. In this research area the GWSP will work closely with the Global Carbon Project on better defining the role of water in the carbon cycle.

Climate Change Impacts on World Water. It is expected that increases in greenhouse gas emissions and changes in land use will lead to significant changes in temperature and precipitation which in turn will profoundly affect the availability and use of water, and the frequency of extremely high and low runoff events. The GWSP will serve as a forum for stimulating research in understanding the extent and nature of climate change impacts on water resources.

Ecosystem Services. The concept of ecosystem services provides an important link between the material needs of society, aesthetics, cultural and recreational benefits, and the conservation of natural resources. In short, ecosystem services are the benefits society obtains from ecosystems. An important element of the world's ecosystem services are the services provided by freshwater such as drinking water, irrigation water, dilution capacity for the assimilation of wastes, and habitat for the freshwater fishery. But research in understanding and assessing global freshwater ecosystem services is in its very early stage, and the GWSP will provide a platform for encouraging this research.

Sustainable Development. One of the key ideas of our time is the search for a pathway to the future that encompasses ecological sustainability, social equity and economic growth. Water, of course, plays a major role here. The GWSP aims to make a scientific contribution to the transition towards a sustainable global water system by (1) helping to devise an inclusive and comprehensive definition of "sustainable global water system" and (2) by delivering the needed scientific support for a transition to a sustainable global water system.

World Water and Conservation. Water is essential for the conservation of species and ecosystem-scale processes. The availability of water in sufficient quantities and qualities, and at the correct times, underpins the life histories of aquatic and many terrestrial organisms, and shapes many ecosystem-scale processes (e.g., habitat formation, plant growth, elemental cycling, fish migrations). Effective conservation of the world's continental biota, and a significant amount of the coastal zone biota, rely on processes taking place in freshwater.

World Water and Aquaculture. Aquaculture is a rapidly growing human activity with a potential to enhance local evaporation and thereby reduce water availability. Wide-scale expansion of aquaculture could cause major water quality problems in lakes, rivers and the coastal zone.

The GWSP Scientific Questions and Themes

The goal of the Global Water System Project is to marshal the necessary scientific resources to address the following overarching scientific question:

> **How are human actions changing the global water system and what are the environmental and socio-economic feedbacks arising from anthropogenic changes in the global water system?**

Three core questions follow from this overarching question, and these questions make up the *three major themes* of the GWSP.

Theme 1 What are the magnitudes of anthropogenic and environmental changes in the global water system and what are the key mechanisms by which they are induced?

Theme 2 What are the main linkages and feedbacks within the Earth System arising from changes in the global water system?

Theme 3 How resilient and adaptable is the global water system to change, and what are sustainable water management strategies?

These three themes are elaborated in Chapters 1, 2 and 3 of this report.

Into which Research Niche does the GWSP fit?

While the above questions are challenging and broad, how will the GWSP address them in a unique way? What will be its special niche in the research landscape?

1. *T e GWSP is science-driven.* The GWSP is primarily driven by scientific questions, and aims to improve our scientific understanding of changes in the global water system. This sets it apart from world water assessments that center around policy issues. Nevertheless, it will address contemporary issues of great importance to society (see Box 2) and aims to inform stakeholders and decision makers about key global water issues, and buttress water assessments and sound policy development.
2. *T e GWSP takes a global perspective*. The GWSP focuses on the full spectrum of global environmental change issues with respect to water. This includes identifying which water issues are (i) global in the sense that they are the sum of critical local problems, or (ii) global because of their impacts and feedbacks on the Earth System. The GWSP will focus on developing tools, collecting data, and carrying out analyses to better understand the global- and large-scale facets of the global water system. Nevertheless, the GWSP must also take into account local- and watershed-scale processes because these processes are often decisive to the functioning of the global water system. When working on the local- and watershed-scale the GWSP will seek strong ties with existing networks of researchers and organisations working on these scales.
3. *T e GWSP takes a broad temporal perspective*. The GWSP will cover a wide range of time scales and periods. A special focus of the GWSP will be on changes of the global water system over the last two centuries since agricultural development, population growth, and the industrial revolution have had a worldwide impact on water resources. Another special focus will be on a future period of one hundred years so that the long term consequences of current and future interventions and impacts on the water system can be analyzed. In some cases the pre-industrial and paleo time periods may be studied in order to better understand the long-term evolution of the global water system.
4. *T e GWSP is scientifically integrative*. The GWSP takes a multi- and interdisciplinary approach to studying water resources. It reflects the collection of perspectives of the Earth System Science Partnership, covering many relevant social and natural sciences.
5. *T e GWSP will focus on the world's freshwater systems and fill gaps in global research.* As noted above, the physical water cycle of the earth encompasses not only the freshwater systems over and under its land surfaces, but also its oceans, atmosphere, and cryosphere. However, the Global Water System Project will focus *on the world's freshwaters*, and will work with existing research programmes to include their expertise and knowledge of the world's oceans, atmosphere, and cryosphere in studies of the global water cycle.

More generally, the aim of the GWSP is to address gaps and integrate results from the global water research programmes of the ESSP. The various opportunities for collaboration between the GWSP and other research programmes are laid out in Section 6.6 and throughout the report.

The combination of the above five facets give the GWSP a unique place in global science, complementary to other water and global change research programmes.

The Goals and Vision of the GWSP

We can sum up the goals and vision of the GWSP as follows:

To gain new understanding about the global water system. The GWSP aims to develop a comprehensive description and quantification of the functioning of the global water system, including its past and present states. The project will have a global and integrative perspective, and will bring together scientists of many different disciplines. It will be science-driven yet it will inform policy and address the central role that world water plays in sustainable development and other key issues of society.

To redefine society's view of water. The global studies of the GWSP will help society extend the concept of "water availability" beyond local water quantity to include the many feedbacks and connectivities in the global water system. Similarly the GWSP will help society to rethink the notion of "water demand" and incorporate the requirements of aquatic and riparian ecosystems, behavioral changes in water consumption patterns, virtual water trade and other aspects of worldwide water systems.

To create a vision of future possible states of the global water system. The GWSP is concerned not only with the current global water system, but also in developing prototypes/scenarios of the future state of the global water system that incorporate the viewpoints of both the natural and social sciences and of civil society. As part of this accent on the future state of the global water system, the GWSP will help to deliver the needed scientific support for the transition to a sustainable global water system.

Objectives of this Document

This document has two main objectives:

1. To *frame the scientific issues* having to do with the Global Water System Project. The scientific issues for increasing our understanding of the global water system are presented in the Introduction and in more detail in Chapters 1 through 3, which correspond to the 3 key research themes of the GWSP.
2. To lay out the *main activities for implementing* the project. The research activities for implementing the GWSP are described in the last sections of Chapters 1 through 3. Chapter 4 presents a number of cross-cutting activities that are key to implementing the GWSP. The activities having to do with the important issues of dialogue, education and capacity building are covered in Chapter 5. Meanwhile, Chapter 6 presents additional steps for implementing the project.

Together these chapters provide a road map for beginning an exciting new effort to understand, appreciate and sustain the world's water system.

Theme 1. Magnitudes and Mechanisms of Change

The core question of Theme 1 is:

> **What are the magnitudes of anthropogenic and environmental changes in the global water system and what are the key mechanisms by which they are induced?**

1.1 Motivation

The Global Water System (GWS) is experiencing drastic changes due both to global scale stresses (e.g. climate change), and the cumulative effects of local and regional scale changes. The scope of these changes is potentially enormous (Table 1-1). To date, our best knowledge has been secured through well-documented case studies and over regional domains. However, we are unable to state if (a) local scale impacts collectively create a phenomenon that is globally significant and, if so, (b) whether they have modified the basic behaviour of the GWS. There is a need to inventory and analyze the broad range of anthropogenic change to the GWS to better articulate the full dimension of this issue. Moreover, we have yet to quantify most of the mechanisms of these changes and the existence of many are debated or simply unknown. More generally, the boundaries and characteristics of the global water system need to be better defined and quantified.

1.2 State of Knowledge and Research Needs

1.2.1 Magnitudes of Change

In this chapter we will see that we know much more about the physical aspects of the GWS, and much less about water-mediated global biogeochemistry, and still less about ecosystem state, biodiversity, and the human dimensions of the GWS.

Hydroclimatological Changes

Global warming is expected to accelerate the hydrological cycle with resulting changes in precipitation and evapotranspiration. (Although there could be many regional exceptions as discussed below.) The detection of such change is complicated by conjoined effects of climate variability over both short (e.g. intraannual) and longer term (e.g. interannual to decadal) time scales, and by the effects of water engineering and management. Of the changes in the hydrological cycle, precipitation and runoff are relatively better documented than changes in evapotranspiration and groundwater (including soil moisture), due largely to the existence of extensive observing systems for the former two variables.

The Third Assessment report of the Intergovernmental Panel on Climate Change (IPCC TAR, IPCC (2001)) provides the most comprehensive assessment of trends in precipitation during the twentieth century[2] (Figure 1-1). Key findings were that:

- Worldwide, most records of annual precipitation show upward trends, especially in the Northern Hemisphere. Areas of decreasing precipitation are generally not spatially coherent at the large scale;
- Changes in annual precipitation have been largest over much of the globe in the second half of the century, although this conclusion must be tempered by recognition of the lower gage density that prevailed earlier. The largest downward trends (e.g. equatorial Africa) occurred in the middle third of the century;

[2] Approximately 20,000 stations were analyzed and, for each station and each year in the historic record, anomalies were computed relative to the 1961-90 period. The anomalies were averaged over 5-degree latitude by longitude grid cells, and were added to the grid cell average precipitation for the 1961-90 period. Time series of seasonal and monthly values were then created for each grid cell, and normalized by the 1961-90 averages.

Table 1-1

Major global threats to the Global Water System and related issues (modified from Meybeck 1998 and Meybeck 2003). The scope and intersections of the numerous forcings and system impacts require an interdisciplinary and systematic research approach.

Environmental state changes	Major impacts	Global issues A	B	C	D	E	F	G
1. Climate change	Change in flow regime (runoff volume and timing)		●	●		●		●
	Indirect effects due to vegetation change		●	●		●		●
	Development of non-perennial rivers		●	●	●	●	●	●
	Segmentation of river networks					●	●	
	Alteration of extreme flow events	●			●	●	●	
	Changes in wetland distribution	●	●	●	●		●	●
	Changes in chemical weathering				●			●
	Changes in erosion and sedimentation				●	●		
	Salt water intrusion in coastal groundwater	●						
	Accelerated salinization through evaporation	●	●				●	
2. Water management (including dams, diversions, and channelization)	Nutrient and carbon retention				●			●
	Retention of particulates				●	●		●
	Change in flow regime (runoff volume and timing)		●	●		●		●
	Streamflow variability and extremes		●					
	Loss of longitudinal and lateral connectivity						●	
	Creation of new wetlands	●		●	●		●	
3. Land use change	Wetland filling or draining		●	●	●		●	
	Change in sediment transport				●	●		●
	Change in vegetation cover		●					
	Alteration of first order streams					●	●	
	Nitrate and phosphate increase	●		●	●			●
	Pesticide increase	●		●				●
4. Irrigation & water transfer	Change in flow regime (runoff volume and timing)		●	●		●		●
	Salinization through evaporation		●	●				
5. Release of industrial & mining wastes	Heavy metals increase	●		●				
	Acidification of surface waters			●			●	
	Salinization	●		●			●	
6. Release of urban and domestic wastes	Eutrophication	●		●	●		●	●
	Development of water-borne diseases	●						
	Organic pollution	●		●			●	
	Persistent organic pollutants	●		●				●

A : human health, **B** : water cycle, **C** : water quality, **D** : carbon balance, **E** : fluvial morphology, **F** : aquatic biodiversity, **G** : coastal zone impacts. Only the major links between issues and impacts are listed here.

- For most records, the change in annual precipitation over the 20th century is less than about 30%, and many local trends are probably not statistically significant, (although no statistical framework is provided). Even though upward trends dominate, downward trends in equatorial Africa and Chile are larger in magnitude than the largest upward trends.

The IPCC TAR also reported that single precipitation events have become more intense in many areas. These extreme events have caused significant losses in lives and properties, and have also threatened food security because of the destruction of crops and livestock (IPCC 2001). However, the effect of increased precipitation extremes on floods is still debated (Lins and Slack 1999; Douglas et al. 2000; Groisman et al. 2001; Robson 2002; McCabe and Wolock 2002).

A number of studies are becoming available that describe changes in precipitation, soil moisture, and runoff data (streamflow) on the global scale (Dai et al 1998; Dai and Trenberth 2002; Dai et al. 2004; Shiklomanov 1998). Some studies show a possible intensification of the water cycle, for instance through more extreme precipitation in the U.S. (Karl et al. 1996; Karl and Knight 1998). Others (e.g. Dai et al 2004) have identified an increase in global areas with very wet and very dry conditions. Lins and Slack (1999) used approximately 400 unregulated stream gauging time series from the US with 50 years of continuous record to conclude that the variability of streamflow has actually decreased while mean runoff increased. Yue et al. (2003) found similar increases in minimum and mean daily flows in northern Canada. However they found the opposite to be true (significant decreases in minimum, mean and maximum daily flows) in southern Canada. Studies

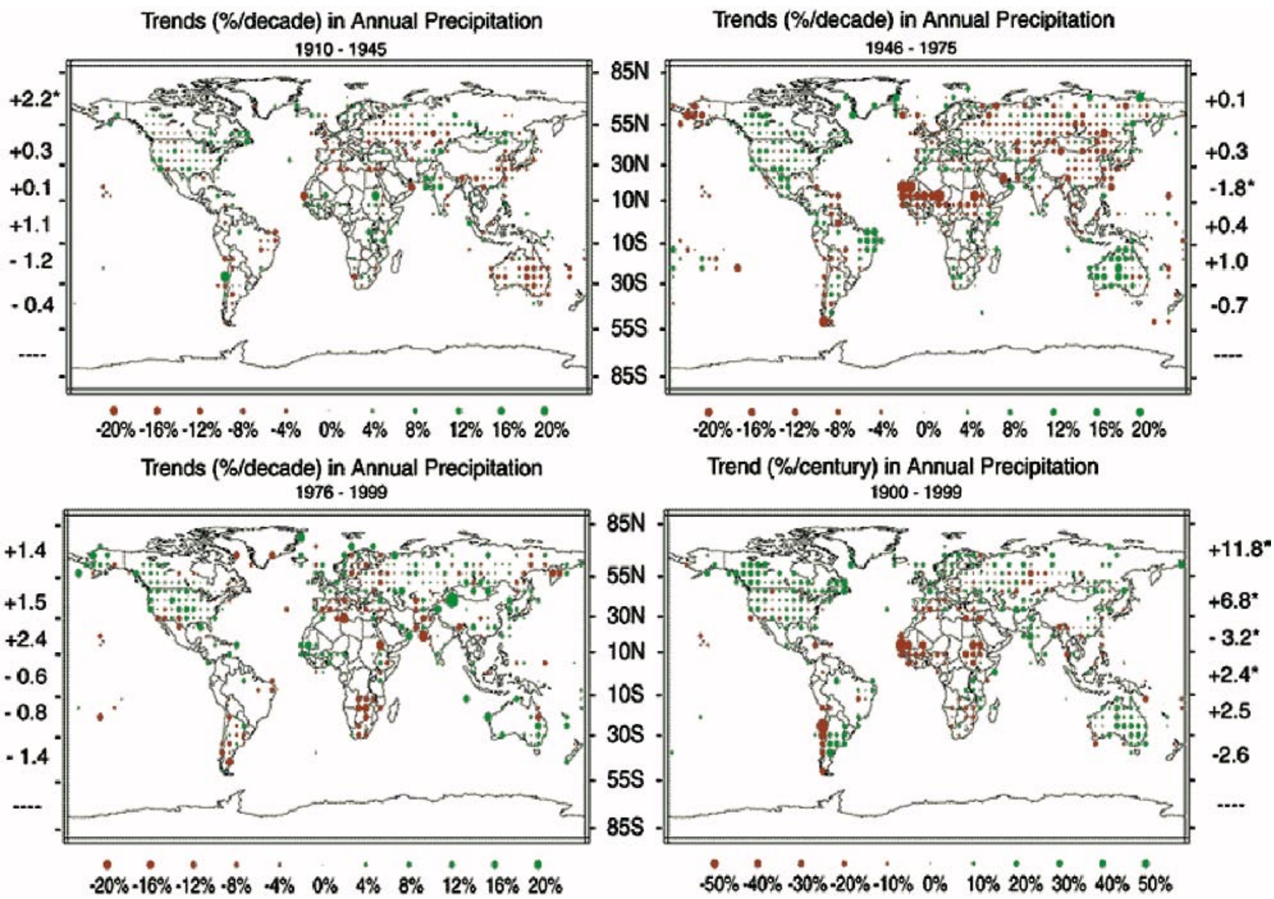


Figure 1-1

Trend magnitudes (proportional to the size of the circles) and directions (green upward, red downward) in annual precipitation over global land areas for 1910-45, 1946-75, 1976-99, and 1900-99. The results are generally spatially coherent, which suggests that large-scale features dominate the results (from IPCC 2001).

such as those referenced above have targeted streams with minimal water diversions so as to isolate climate signals. More broadly, the discharge of many rivers and streams have been heavily altered by dams, abstractions, transfers and other water management actions (see Section 1.2.2), the effects of which often are much larger than the effects observed due to climate change.

While global warming is expected in general to accelerate the hydrological cycle, some regions have a decreasing trend in precipitation because of local changes in land cover (removal of vegetation cover). Another factor in some regions is the regional increase in atmospheric aerosols which reduces surface heating and evaporation and therefore tends to decrease local precipitation. Summing up, there are still many uncertainties in estimating the effect of climate change on long term trends in precipitation and runoff, and research is urgently needed to reduce these uncertainties.

Biogeochemical Changes

Anthropogenic loadings of biologically active elements, metals and pollutants from point and non point sources (e.g. from agriculture, industry, and mining) and also from atmospheric deposition have increased several-fold since the beginning of the "Anthropocene" (Paul Crutzen's name for the current geological era, Crutzen 2002). Water contaminants such as arsenic, fluoride and nitrates (WEHAB Working Group 2002) and the production of an estimated 1,500 km^3 wastewater per year (WWDR 2003) are increasing pressure on water quality. Human-generated nitrogen loading currently totals more than 2000 Mt/yr, of which agriculture accounts for some 86% (Figure 1-2). However, only a small fraction of the additional loading discharges into the oceans, due to landscape retention, denitrification and other processes (Alexander et al. 2000; Galloway et al. 1996). A recent global-scale analysis (Green et al. 2004) documents a wide range of nutrient reten-

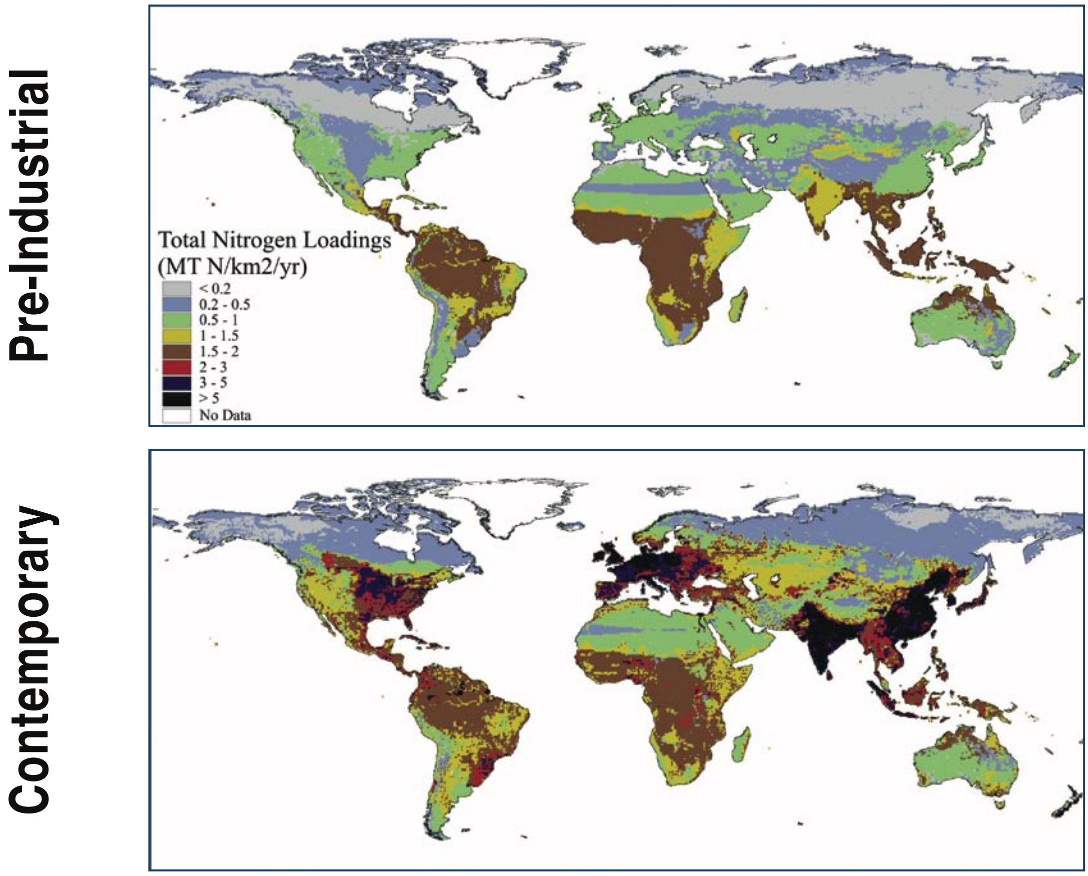


Figure 1-2

Human-induced nitrogen loads on the landmass now exceed N fixed naturally. This picture is spatially complex and arises from differential loadings of atmospheric deposition, industrial fertilizer use, sewage and animal waste, and fixation by crop legumes. Increased N loadings translate into order-of-magnitude increases in riverine fluxes of transport to the coastal zone in industrialized and heavily populated drainage basins (from Green et al. 2004).

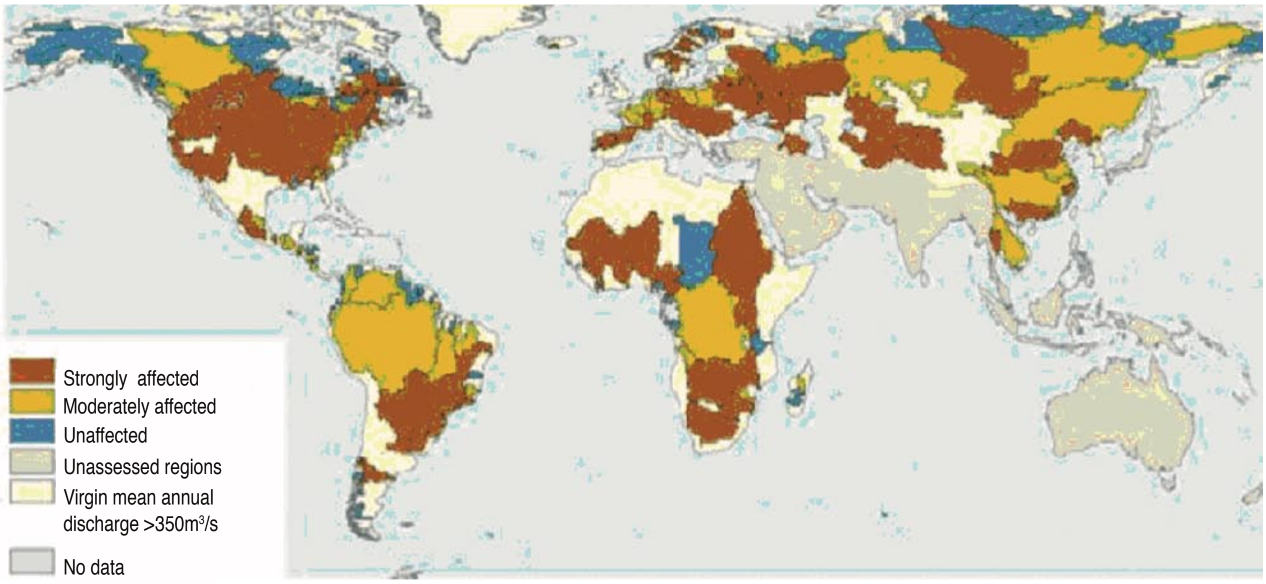


Figure 1-3

Fragmentation of inland water systems. Note the pandemic degree of modification. In addition to critical impacts on habitat and inland water biodiversity these changes are critical to the hydrology, water supply, and biogeochemistry of the impacted basins (from Revenga et al. 2000).

tion potentials. Many of these are potentially mapable using remote sensing and other geospatial methods that depict both biotic and abiotic attributes of drainage basins (Figure 1-2). A significant challenge to the community is to quantify these transformations along the full continuum of landscape and fluvial systems (Billen and Garnier 2000).

Hydrobiological / Ecological Changes

Aquatic ecosystems are the ultimate recipient of much of the wastewater loadings referred to in the preceding section. These loadings cause biogeochemical changes in freshwater that can limit the habitat of many organisms. Society is also increasing average stream temperatures which can affect chemical and biological processes, as well as reproduction and distribution of organisms and species (Gitay et al. 2001). Evidence of warming trends was found by Webb (1997) for European rivers, which he attributed to a mix of factors, in particular increasing effluents, impoundments and removal of riparian vegetation. Water management has also dramatically influenced aquatic habitat and resident organisms (Figure 1-3).

Changes in Water Quantity and Stress

At the global scale, water availability is influenced by water use, as well as climate variability and change. This can be demonstrated through differential water scarcity indices across various parts of the world. According to one estimate published by the World Water Commission, 2 out of every 5 people currently live in river basins affected by severe water stress (Cosgrove and Rijsberman 2002; Alcamo et al. 2000[3]).

New tools have been developed to analyze these changes. Global, geographically-specific studies are beginning to emerge (Alcamo and Henrichs 2002; Oki et al. 2001), which when placed into a single and consistent framework, allow us to map with a great degree of spatial specificity the patterns of water scarcity. This was done, for example, using a set of high resolution biogeophysical and socio-economic data sets that indicated a tripling (relative to traditional country-scale approaches) of the number of people exposed to water stress (Figure 1-4, Vörösmarty et al. 2000).

[3] Here severe water stress is defined as annual withdrawals to availability > 0.4 on a river basin basis (Alcamo et al. 2003).

Biodiversity Changes

Over the last century, there has been a major erosion of freshwater biodiversity worldwide due to mismanagement and/or competition with humans. Dramatic declines in many freshwater fish and bivalve populations have been observed (e.g. Moyle and Leidy 1992; Stiassny 1996; WCMC 1998; Bogan 1993; Ricciardi et al. 1998). The past century has seen the extinction of some 81 freshwater fish species in the wild with an additional 11 species surviving only in captivity, but many other species could well have disappeared before being recorded (see Harrison and Stiassny 1999) (Figure 1-5). More than 20% of the world's freshwater fish species have become extinct, endangered, or threatened in recent decades (Moyle and Leidy 1992).

In addition to species extinction, freshwater communities show structural changes in terms of species assemblages and interactions between populations. Indeed, the fragmentation of rivers leads to a lack of exchange between aquatic populations and may modify evolutionary processes in aquatic groups (Western 2001). Likewise, the introduction of exotic species tends to erase geographical differences in species assemblages with possible consequences on future evolution processes (Mooney and Cleland 2001).

1.2.2 Mechanisms of Change

In general, we understand much more about the physical factors causing changes in the GWS than the geochemical, biological or human factors. For instance, it is well known and relatively easy to predict how damming of rivers will change the variability of streamflow. On the other hand, how such streamflow changes manifest themselves in changes in sediment movement, the evolution of channel systems, viability of wetlands and other critical habitats, and the transport and storage of biogeochemical constituents is not as well understood. Furthermore, we lack the unifying concepts needed to build a predictive global scale model. This is a fundamental challenge to the GWSP. Below we review some of the mechanisms identified as potentially important.

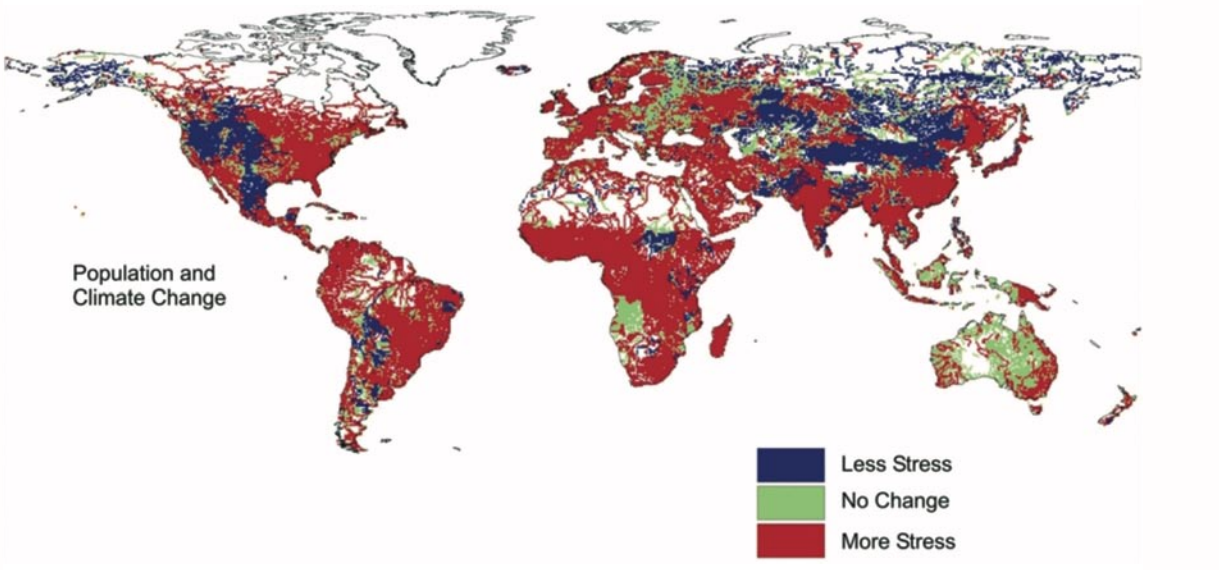


Figure 1-4

New earth systems science data sets permit high resolution mapping of water stress and the major sources of water scarcity. The field shown here (30' latitude x 30' longitude.) represents the conjunction of population growth/economic development plus climate on future patterns of stress to 2025. Although 80% of future global water scarcity is derived from increases in water demand, results are highly region-specific. While global patterns are evident, governance and other human-dimensions issues become highly relevant at the regional scale. Local-to-global and global-to-local scaling is also a proposed focal point of the GWSP activity (from Vörösmarty et al. 2000).

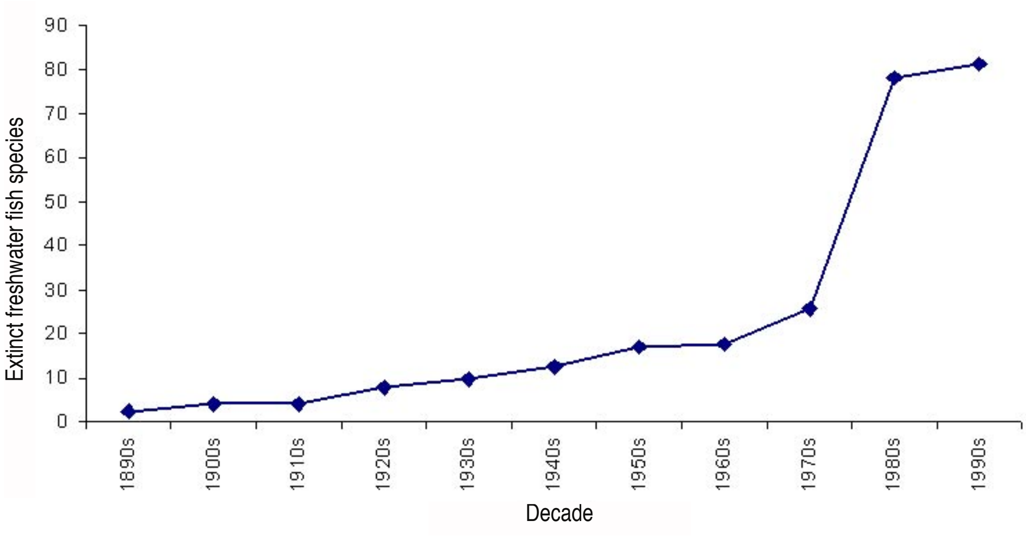


Figure 1-5

Freshwater fish extinctions: cumulative sum of known species extinctions by decade (from WCMC 1998).

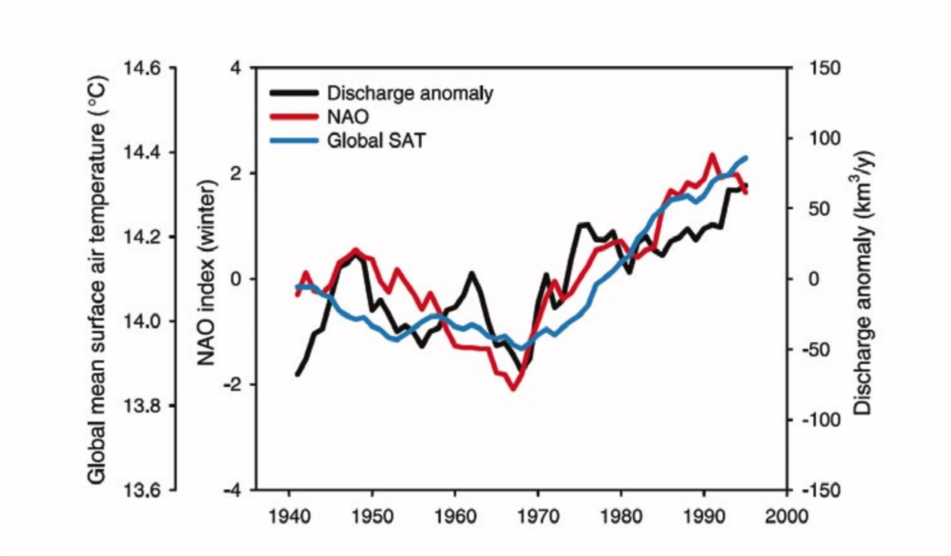


Figure 1-6

Discharge/runoff increases have been observed over the last several decades in the region of the Eurasian Arctic (Peterson et al. 2002). The figure suggests that this could be linked to global surface air temperature rise and/or the North Atlantic Oscillation (NAO), although the mechanisms are not well understood. One possible consequence is a reduction in Atlantic deep water formation and ocean circulation over a century time scale, making this hydrological change of planetary significance. Analysis of the mechanisms by which a closely affiliated process (the Arctic Oscillation [AO]) could entrain additional heat and moisture into the region (SEARCH Committee 2003) serves as a good example of the types of attribution studies that could be undertaken within the framework of the GWSP.

Climate Change

As previously mentioned, climate change is expected to accelerate the global hydrologic cycle. The local manifestations of climate change, however, remain uncertain. Trenberth et al. (2003), and others expect that not only the average amounts of precipitation will change but its essential character (intensity and duration of rainfall events) will change, and this obviously will have an important effect on the hydrology of rivers.

The higher latitudes are expected to experience a larger increase in temperature than elsewhere, and consistent with this, recent evidence points to a climate-related acceleration of the water cycle across the Eurasian Arctic. Runoff from the six largest Eurasian Rivers discharging into the Arctic Ocean has increased by about 7% from the mid-1930s to the present (Peterson et al. 2002). Figure 1-6 correlates this rise with global surface temperature and the North Atlantic Oscillation index. It also presents a systematic mechanism, originating in the atmosphere that links a climate oscillation to water cycle elements that are consistent with the observed runoff trend (SEARCH 2003). Though this particular analysis stresses the physical mechanisms, a similar approach could be applied elsewhere in the GWSP to disentangle the broad range of biogeophysical and social forces acting on the water system.

The high latitude example has implications that go beyond scientific challenges and interest – If sustained this trend could have potentially grave consequences on society arising from the possible changes in thermohaline circulation of the ocean and hence heat transfer from low to high latitudes.

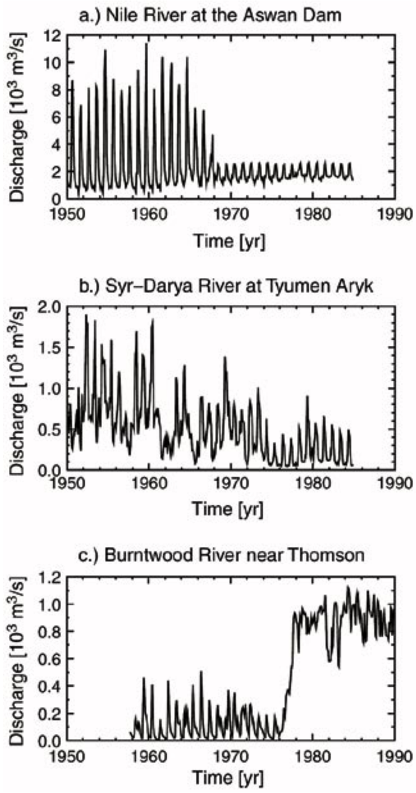


Figure 1-7

Flow distortion caused by water engineering in three heavily-regulated rivers. (a) Nile discharge, before and after construction of the Aswan High Dam; (b) Syr-Darya showing reduced flows due to irrigation. The contraction of the Aral Sea is closely linked to the discharge trend that is shown; (c) Burntwood in Manitoba with inter-basin transfer to maximise energy production. Similar changes can be found in many other rivers globally (from Vörösmarty 2002a). (Data from: www.watsys.sr.unh.edu).

River Regulation

The discharge of many rivers and streams has been heavily altered by pollution, wetland drainage, channelization, water abstraction, water transfers, as well as dams and impoundments (about 45,000 large dams exist, WCD 2000) (Figure 1-7). These alterations cause river and habitat fragmentation (Figure 1-3) and biotic stress that affect both freshwater and riparian ecosystems, their habitats, diversity, structure and function (Revenga et al. 2000). An example is the River Rhine, which after more than 100 years of channelization and riverside development, has been isolated from 90% of its original floodplain (WRI 1998). Some rivers, such as the Colorado and the Yellow rivers, no longer discharge into the ocean. Water diversions have caused the Aral Sea to shrink to 25% of its 1960 volume, yielding a salinity higher than the ocean and leading to extinction of most of its endemic fish species (Letolle and Mainguet 1993).

With increased population growth and rising expectations for higher standards of living, such reverberations will certainly continue. Globally, humans now use half of the runoff to which they have access, and by 2025 this appropriation may reach 70% (Postel 2000). The sources and impacts of water management in the GWS will be a key focus of the GWSP.

Land Use Change

The imprint of land use change on terrestrial water cycling is apparent at many scales. Irrigation is the single largest use of freshwater by humans and likely bears the largest anthropogenic footprint on the GWS. Irrigation (together with water use by livestock) accounts for 71 % of all global water withdrawals (Shiklomanov, 2000). Irrigation is associated with net basin water losses, salinization, and agrochemical pollution. In many places irrigated agriculture depends on the un-sustainable mining of aquifer water. The large scale evaporation of groundwater-derived irrigation water is also having an unquantified effect on the water cycle regionally and perhaps globally.

Other land use/cover issues are also important. The impacts on local water budgets of deforestation are documented extensively in the literature; substantial increases in long-term runoff and storm flow are a typical result. Fragmented landscapes generate changes in local weather (Avissar and Liu 1996; Pielke et al. 1997). Simulations by Pielke (1999) for example suggest that land cover change is responsible for about a 10% increase in precipitation over southern Florida. At drainage basin scales, the shifting mosaic of land cover creates complex patterns of changes in regional water balances (Shiklomanov and Krestovsky 1988). Over still larger domains, land cover change can weaken the fluxes in the water cycle and distort global atmospheric teleconnections (Chase et al. 1996; Costa and Foley 2000; Pitman and Zhao 2000). In addition, the impact of deforestation (with a current net rate of around 110,000 $km^2 yr^{-1}$, FAO 1999) on continental runoff has yet to be fully quantified.

Causes of Biodiversity Change

The decline and loss of freshwater species can largely be related to the widespread loss of freshwater habitats, especially waterfalls, rapids, riparian floodplains, and wetlands. Modifications of freshwater habitats are both ecological changes because habitats are a critical component of ecosystems and also drivers of ecological change at the community and species level. River flow alteration and fragmentation of freshwater systems as well as various types of chemical pollution have greatly reduced the suitability of freshwater habitats to sustain native fauna and flora (Naiman et al. 1995a,b). Some species may also benefit from increases in nutrient fluxes, as in the case of phytoplankton which sometimes explode in population as algal blooms.

The distribution of freshwater aquatic biodiversity is conditioned upon several factors including the historical/paleo setting under which the species developed, abiotic factors such as climate and water chemistry, the integrity of required habitat, and the community structure and function (Figure 1-8). Introduction of exotic species has further impacted ecosystem structure and function.

Changes in Water Supply/Use and Risk to Human Health

Population growth and socio-economic development are currently driving a rapid increase in water demand, especially in the industrial and household sectors. Despite an average of over 6000 m^3 of water available per capita and year globally (WRI), there are several regions in which water demand reaches or even exceeds renewable resources, causing for example groundwater overuse (amounting to some 160 km^3 in key basins, Postel 2000). As mentioned above, irrigated agriculture has by far the largest withdrawals globally (up to 97% in some countries), followed by industry with 20% on average and domestic withdrawals amounting to 9%.

The need to feed a growing and developing population may lead to the expansion of irrigated land as well as increased water demands for livestock. This will sharply increase water demands in some regions over the decades to come.

The issue is not just a case of increasing the quantity of water supply but also its quality. Indeed, water contamination has severe health consequences. In many developing countries cholera, dysentery, and other water-related diseases are on the upswing. According to WHO, nearly 250 million cases of water-related diseases are reported each year, causing between 5 and 10 million deaths (IWMI 2000; WEHAB 2002). The continued failure to provide clean water and sanitation services remains one of the world's most significant health problems. The GWSP will work with the newly organized "Global Change and Human Health" Joint Project of the Earth System Science Partnership in studying the effect of global changes on water borne diseases and human health. We return to the issue of water, human health and international policies in Section 3.1.

Furthermore, as we note below, the issue of insufficient water supply is closely linked with a crisis in water governance, which includes economic, institutional, social, ethical and legal aspects (see Chapter 3).

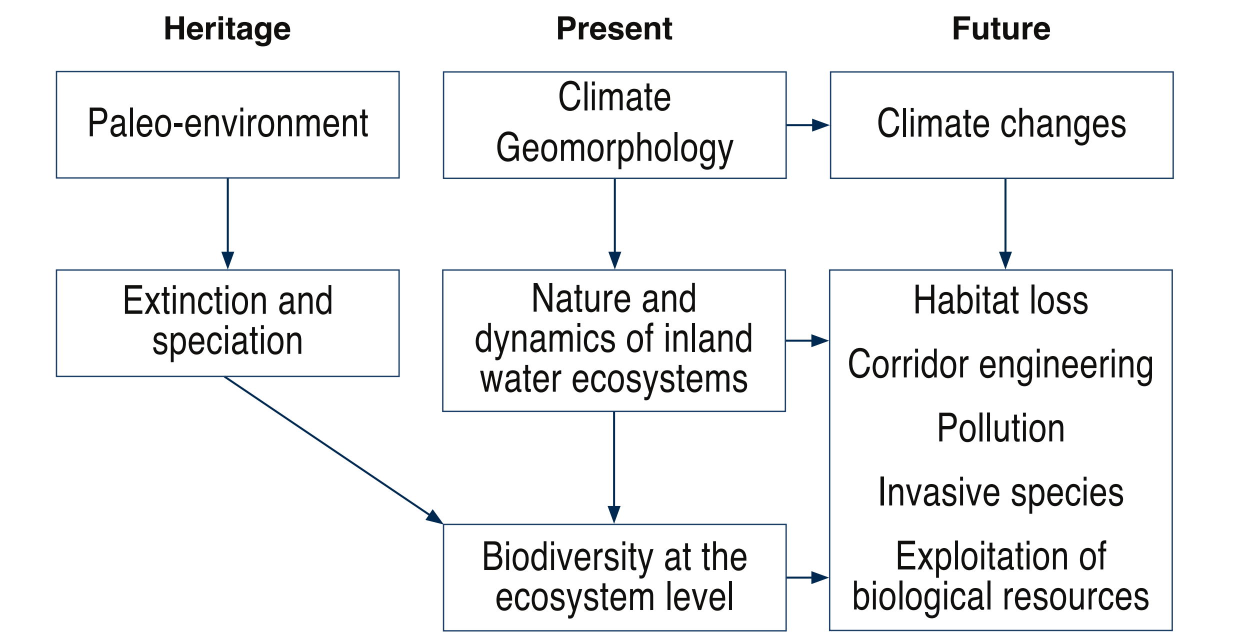


Figure 1-8

General factors influencing the dynamics of freshwater diversity (from Lévêque 2002).

To sum up, in studying changes in the global water system it is urgent to include an analysis of related changes in water supply and risk to human health.

1.3 Activities and Deliverables

In the previous paragraphs we have sketched out the many gaps in our knowledge about the magnitudes and mechanisms of ongoing changes in the global water system. We now propose five main activities to address these gaps.

Activity 1.1: Water Governance and the Global Water System

The system of water governance has a major impact on water use. Water quality, the distribution of water to various users, and the efficiency with which water-related services are delivered all depend on the water governance system.

Another critical issue here is that the failure of governance sometimes leads to water conflicts that suddenly change the water use and availability situation in a river basin or larger region.

The water governance system includes institutional aspects such as formal water rights or informal participatory approaches in more flexible management schemes. Governance also covers economic aspects (e.g. water pricing and valuation of different water uses) and organizational forms of water management (e.g. different forms of public-private partnerships).

To better understand the role of governance in the GWS we need to improve our knowledge about different governance structures.

Tasks

- Compare existing schemes for classifying systems of water governance, and catalog these systems worldwide.
- Develop a systematic database on water governance systems and their influence on the GWS.
- Analyze the effects and impacts of different types of governance of regional water resources on the global water system.

Deliverables

- A new systematic knowledge base about water governance systems in the world.

- New knowledge about the impacts of governance on the global water system.

- Compendium of the influence of current governance systems on the GWS (water quality and quantity)

Activity 1.2: Land Cover Changes and the Global Water System

In its assessments of climate impacts on global water resources, the IPCC (2001) did not consider the effects of changes in land cover or water use on the hydrological cycle, although the importance of both has been demonstrated in a number of regional studies cited above. A quantification of water use and land cover change, together with their regional geographies, and possible climate-regulating roles, is a key challenge for the GWSP.[4]

Tasks

- Analyze historical patterns of land cover and water use by continent and major river basins. Take into account demographic, economic, cultural and other factors.

- Compile trajectories of land cover change for different regions of the world based on existing information.[5] These trajectories should take into account demographic, economic, cultural and other factors

- Analyze the effect of crop production systems on the GWS in terms of biogeochemical fluxes and water use in selected large river basins.

- Analyze impacts of land cover changes on precipitation and evaporation and the linkage of these atmospheric changes with runoff.[6] This should be closely linked to Activity 2.1.

- Analyze how land cover change has affected the hydrological cycle, water quality and the integrity of freshwater ecosystems.

[4] This research should be linked with the on-going research initiatives of the International Water Management Institute (IWMI; www.iwmi.org) and the Challenge Program on Water and Food (www.waterforfood.org).

[5] This task should be linked to ongoing similar work in the LUCC Project of the IHDP and IGBP, and planned activities of the GLP project of IGBP and other organisations.

[6] This activity should be a cooperative effort with GEWEX, CLIVAR and COPES.

Deliverables

- Expanded knowledge about the effects of land cover patterns on the global water system.

- Improved global and regional databases of land cover and water use histories valuable for studies of the evolution of the global water system and as input to global and regional land surface and hydrologic models.

Activity 1.3: Climate Change and the Global Water System

The consequences of a possible acceleration of the water cycle caused by climate change are not well understood. Specifically, what will climate change imply for drought severity and extent, flooding, and seasonal patterns of discharge? The translation of observed and predicted changes in precipitation to water supply and to dryland agriculture have important policy implications that are not fully understood. Human modification of rivers makes it difficult to detect climate change signals in runoff, particularly for large river basins. The relative magnitudes of climatic variability and change (natural or anthropogenically induced) vs. direct human effects like water engineering on the GWS are also unknown. We must also study the effects of changes in the frequency and intensity of extreme events and their impacts on water quantity and quality as well as on water security. A close collaboration with Activity 1.2 is anticipated.

Tasks

- Assemble information from the climate research community on climate variability and change, for use in studying the GWS. This includes data and analyses of global trends in soil moisture, precipitation, and drought indices.

- Analyze the impacts of climate change and variability on runoff, water availability and water use worldwide.

- Study the feedback mechanisms between anthropogenic climate change and the GWS, e.g., through changes in evaporative demand, and/or changes in river discharge.

Deliverables

- A well-organized knowledge base on climate variability and climate change in a form usable for analysis of the global water system.

- New knowledge o n the impact of climate variability and climate change on the global water system.

Activity 1.4: Water Diversions and the Global Water System

In populated regions of the world, the pandemic alteration of surface and ground water has lead to fragmentation of river systems, alteration of flow regimes, and changed water budgets, while at the same time providing flood protection, stable water supplies, food security, and other "goods and services" to society. The full dimension of this issue has yet to be quantified. A wide range of studies are needed – Not only further research on the physical and biogeochemical impacts of water diversions, but also on their human and societal impacts. At the same time these impacts need to be compared to the goods and services provided by these diversions.

Tasks

- Analyze and quantify the cumulative consequences of the different aspects of water diversions including dams, large irrigation projects, and large-scale aquifer extractions, on regional hydrologic regimes.

- Compare the condition of biodiversity to the degree of modification of lakes, wetlands and river systems on a global scale. Work with Activity 3.1 to determine required minimum flows and variability in flow regimes required to sustain local ecosystems.

- Analyze the social impacts of relocating people (including ethnic groups) from sites of large dams and other projects. Take into account the social and cultural transformations that occur because of the disruption of livelihoods. (In cooperation with researchers in Theme 3.)

- Conduct case studies on water use competition and conflicts. Compare the goods and services provided by water diversions (flood protection, water supply, food security) to their impacts (cultural, political, biodiversity) for different case studies. Analyze how multiple uses of river basins can be achieved.

- Carry out integrative analyses of connections between virtual water trade, water pricing, water institutions, water diversions. (Together with Activity 2.1.)

- Analyze and compare the influence of water governance systems on decisions to carry out large water diversion projects in different world regions. Take into account issues related to water ethics and water rights. (In cooperation with Activity 3.3).

Deliverables

- New understanding of the relationship between biodiversity and modification of river systems.

- New globally comprehensive information on the impacts of water diversions on hydrologic regimes.

- Increased understanding of the impacts of water diversions on people.

- Better understanding of the connections between water diversions and virtual water trade, water pricing, and water institutions.

- New globally comprehensive information on water governance systems as they relate to decisions about large water diversion projects.

Activity 1.5: Nutrient and Sediment Transport and the Global Water System

Globally-significant interactions between humans and the major geological and biogeochemical cycles are now taking place. While it is well known that humans have accelerated the loading of nutrients onto land, and that human activities (notably agriculture) have enhanced erosion, it is less well-known that human activities in many cases have simultaneously reduced fluxes of many constituents due to the diversion and impoundment of continental runoff. The interplay between this acceleration and deceleration is poorly known and requires an interdisciplinary, quantitative approach that could be an integral part of the GWSP.

Tasks

- Identify key variables and functional relationships describing worldwide nutrient and sediment transport in the global water system.[7]

[7] This and the following tasks will be closely coordinated with activities of the LOICZ project (see Section 6.6).

- Develop observable and measurable indicators of global "hotspots" of soil erosion, nutrient depletion, and land degradation that have a likely influence on accelerating nutrient and sediment transport in the global water system.

- Using newly developed indicators, assess and identify global hot spots contributing to nutrient and sediment transport in the global water system as well as hot spots of nutrient and sediment accumulation.

- Identify and assess the demographic, cultural and economic factors that accelerate nutrient and sediment transport in the global water system.

- Carry out a comparative analysis of changes in water-based nutrient and sediment transport in different world regions.

- Study the implications of changes in water-based nutrient and sediment transport on aquatic and riparian species.

Deliverables

- New knowledge about the nature of worldwide transport of nutrients and sediment in the global water system.

- New indicators and information concerning global "hotspots" of soil erosion, nutrient depletion, and land degradation that have a likely influence on accelerating nutrient and sediment transport in the global water system.

- New insight into human dimensions of accelerating nutrient and sediment transport in the global water system.

- New information about the geographic variability of water-based nutrient and sediment transport.

- New knowledge about the interactions between nutrient transport/export and aquatic ecosystems.

2 Theme 2. Linkages and Feedbacks

The core question of Theme 2 is:

> **What are the main linkages and feedbacks within the Earth system arising from changes in the GWS?**

2.1 Motivation

The global water system, as every system, is conceived to have both components and linkages. Earlier in our discussion of Theme 1 (Chapter 1) we focused on the important changes that components of the global water system are undergoing. Here in Theme 2 our goal is to study and analyze the *linkages* between components of the GWS and how they lead to other connectivities in the Earth System. The importance of linkages in the GWS has been pointed out in a report of the German Advisory Council on Global Change (1997) and other publications. To understand the functioning of the global water system we must understand the nature of these linkages and how they interact with other facets of the Earth System, including its climate, biology and biogeochemistry (Box 3). Moreover, we must grasp how these linkages affect society through population dynamics, land use changes, food production and global trade. Another important aspect of understanding linkages in the global water system is to identify and assess the *feedbacks* (and their consequences) that emerge from these linkages.

A better understanding of linkages and feedbacks in the global water system could provide important information for society. For example, this understanding will help illuminate the key vulnerabilities of water systems to abrupt changes and surprises. A better grasp of linkages and feedbacks could also provide information for the development of early warning systems that can alert decision makers and the public about undesirable changes in the global water system.

The linkages within the global water system and with other facets of the Earth System take different forms. One type of connectivity are *spatial linkages* between different parts of the global water system and Earth System over long distances. Another type are *temporal linkages* by which natural or human actions have a long-lasting effect on the global water system. Research under Theme 2 will give attention to both these types of connectivities.

2.2 State of Knowledge and Research Needs

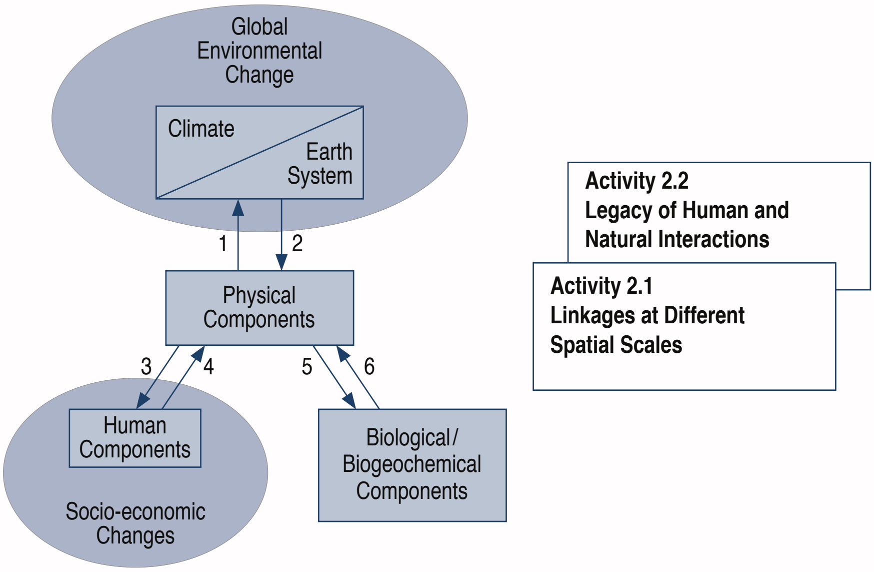
2.2.1 Linkages Over Space: Regional to Global Scales

Regional Scales. After decades of water-related research we now realize that the global water system is characterized by long-distance connectivities that play an important role in the dynamics of water systems. These connections operate at the regional to global scales and between these scales as well. An example of regional connectivity is the impact of changes in runoff, sediment transport and river nutrient chemistry on river morphology and biogeochemistry very far downstream from the original changes. In the 1850s, for example, hydraulic gold mining released tons of sediment into the upper reaches of the Sacramento River in California. This caused sedimentation hundreds of kilometers downstream that raised the riverbed by several meters over the course of only a few decades. Another example is the Huang Ho river basin in China where deforestation on the Loess Plateau increased the sediment load by a factor of 10 and caused long term shifts of the river bed, higher bed elevation, and more frequent flooding hundreds of kilometers from the Plateau.

Global Scales. The research community has also made substantial progress in identifying connectivities operating on the global scale. One example is our new knowledge about the linkages between terrestrial ecosystems, the

Box 3: Interactions, thresholds, and surprises are a key aspect of the questions dealt with by the Global Water System Project

An important aspect of the Global Water System Project is the integration of biogeophysical and human dimensions. In the figure below, elements ranging across these thematic boundaries are joined by two-way interactions (numbered arrows). Change can occur in both directions.



As an example, the potential for changes in drought frequency and severity **(1)** could be caused by either natural climate variability or anthropogenic climate change. The resulting anomalous scarcity of water in turn would create an impact on regional agriculture **(3)** or forest ecosystems **(5)**. Human response to these changes **(4)** might include, for example, reservoir construction. Such a strategy would affect the water budget **(2)** by altering evapotranspiration, runoff and groundwater recharge. Associated fragmentation of river systems could affect wetland ecosystem and biodiversity, and invoke an unexpected collapse of sensitive fish species **(5)**. The decision to build reservoirs also implies a reduction in sediment transport **(2)**, which produces surprises in downstream coastal ecosystems via increased coastal erosion and nuisance blooms caused by altered nutrient chemistry at river mouth **(6)**. Changes in forest ecosystems may alter evapotranspiration and moisture transport.

atmosphere and the climate system, with a specific focus on the water cycle. For example, we now better grasp the feedback loop between the atmosphere and terrestrial biosphere by which the atmosphere provides some of the moisture supply for terrestrial vegetation while terrestrial ecosystems pump moisture back into the atmosphere through evapotranspiration (Pielke et al. 1999; Claussen et al. 2003; Kabat et al. 2003).

Our concepts to describe global systems and their feedbacks have gradually become more complex. Early on researchers identified that energy and momentum fluxes drive the coupling between the land surface and the atmospheric boundary layer. Later they included in their concepts the coupling of terrestrial ecosystems, through their moisture and CO_2 fluxes, with the atmospheric boundary layer and regional/global climate (Goutorbe et al. 1994; Sellers et al. 1997). Researchers are now clarifying additional linkages between the biosphere, climate system and global water cycle through the emissions of biogenic aerosols, volatile organic compounds, ozone, methane and other substances (Andreae et al. 2001; Kabat et al. 2003). Although our knowledge is increasing, we are still in the beginning stages of comprehending the mechanisms of global feedbacks. For example, researchers have hardly begun to include the role of society into global feedback concepts.

Global Teleconnections. There are other large-scale spatial connectivities that are so subtle that researchers sometimes call them "teleconnections" (meaning a cause-and-effect chain that operates through several intermediate steps and leads to a linkage between two parts of a system that – to researchers at least – is unexpected or surprising). One such teleconnection is the postulated linkage between world trade and the water cycle through international trade in goods (Hoekstra and Hung 2002). This is termed trade in "virtual water". The basic idea is that arid countries compensate for their water deficits by importing water-intensive products and commodities rather than producing these products themselves.

A frequently cited example is the case of arid Middle Eastern countries that import large quantities of grains from water-rich countries in exchange for oil or other commodities (Allan 2003). In other words, *virtual water* is traded for oil. The concept of virtual water trade is significant because it implies a large global flux of water that is mediated exclusively by society. For example, according to Hoekstra and Hung (2002) roughly 1000 km^3 of water are embodied in the annual international trade of crops and livestock products.

International commodity trading not only leads to a virtual trade in water, but can also lead to local water quality degradation. For example, one negative consequence of large scale international commerce in fish, fish meal and other aquacultural products is water quality degradation downstream of aquaculture facilities around the world.

There are many outstanding questions about the virtual water concept. First of all, the water balances in countries exporting water-intensive products/commodities have not been examined in detail. (Since the exporting countries also import some products, some aspects of virtual water trade may have been overlooked.) Second, only a few traded products have been examined in any detail. In addition, trade in "virtual water" has some interesting implications on international water management that need to be explored. In sum, the question of water embodied in international trade is an interesting and relevant research subject for the GWSP.

2.2.2 Linkages over Time: Legacy of Human and Natural Interactions in the Global Water System

Another important aspect of linkages in the global water system are the time lags they produce between causes and effects. The residence time of free-flowing river water is usually from days to months, in impoundments from months to years, and in deep aquifers up to decades or centuries. Changes will thus propagate at greatly different rates. This also means that actions of society can have a long term "legacy" in the world's waters. For example:

- *Land use/cover changes* (e.g. deforestation, agricultural expansion or intensification, and desertification) can have long term effects on rates of erosion and sediment transfer as well as on nutrient fluxes.

- *Large-scale water diversions* (e.g. impoundments, hydroelectric production, and irrigation projects) will affect the hydrology and quality of inland waters over decades to centuries.

- The legacy of *mining operations* on water quality can range from many decades to centuries. Masses of mine tailings are an ongoing source of high concentrations of trace elements in freshwater.

- The *direct and indirect contamination* of waters by agricultural, aquacultural and industrial sources (e.g. chemical releases, fertilizer use, sewage and sludge disposal, and atmospheric deposition) can have a legacy of decades or longer if toxicants are adsorbed onto river sediment and deposited onto the river bed.

Of course, legacy effects come not only from human actions but also from nature. Continental land subsidence leads to coastal saltwater intrusion and in turn saltwater contamination of coastal aquifers. Likewise, volcanic eruptions lead to sedimentation especially in the headwaters of river systems and acidic deposition onto surface waters. Hence, researchers should factor in both human and natural processes in their studies of legacy effects in the GWS.

Our experience with legacy studies up to now suggest that many other such effects have yet to be uncovered. What, for example, are the long term impacts of intensive fertilization on the level of nitrate in underlying aquifers? And, in a more general sense, what is the impact of sustained habitation on river basins? An additional point is that we do not fully understand the legacy effects that we have uncovered. For instance, will the contamination of groundwater and surface waters by world mining activities continue over decades or centuries?

2.2.3 The Challenge of Understanding Linkages

As mentioned above, while the scientific community has made substantial progress in understanding some aspects of linkages and feedbacks in the global water system, we are still in the early stages of studying these phenomena. A particular research need is to carry out a *global scale* assessment of their cumulative effects, their geographic distribution, and potential hotspots and/or propagations through the Earth System. Related to this is the need to assess whether linkages and feedbacks will cause a critical threshold to be exceeded in water systems. For example, will a combination of water diversions, land cover changes and disposal of water pollutants have a combined impact far from their location on the use of a water resource? A global assessment of the cumulative effects of linkages and feedbacks can provide the information we need to address this key question.

In addition most of our knowledge in understanding linkages and feedbacks has to do with the physical, biological, and/or biogeochemical aspects of the global water system rather than with its human dimensions. As a rule, studies of complex water systems have included society either as a driver of change or as a recipient of negative impacts of changes. The aim of GWSP studies, however, will be to include human activities and institutions as one of the core components of the global water system, interacting with physical and biological/biogeochemical components (as in Figure 0-1 in the Introduction).

2.3 Activities and Deliverables

The activities carried out under Theme 2 (described in this chapter) will have a direct connection with other research activities in the GWSP. Results from Theme 2 will complement research in Theme 1 (Magnitudes and Mechanisms of Change) because they will show the implications of the environmental changes going on in the global water system. Likewise the results of Theme 2 will be important to Theme 3 research (Resilience and Adaptation) because an understanding of linkages and feedbacks provides insight into the vulnerabilities and adaptive capacity of society and ecosystems.

Theme 2 will also be connected to the GWSP cross-cutting activities to build world water models described in Chapter 4. As described below, integrated models will provide an invaluable tool for studying the feedbacks and linkages in the global water system.

Activity 2.1: Linkages at Different Spatial Scales in the Global Water System

We pointed out above that a high priority for research is to make a global assessment of linkages and feedbacks. Another high priority is to study these linkages through the lens of human-nature interactions, rather than simply from the perspective of society as a driver of change. Hence a major focus of our research activity here will be to carry-out worldwide comparative studies of the historic co-development of human activities and river basin characteristics.

Tasks

- Organize a worldwide series of river basin studies focusing on the long term interactions between river basins and their human inhabitants and institutions. The main research question of these studies will be, "What are the spatial connectivities between changes in different parts of the water system?"[8] Remote sensing can provide some of the basic data for the comparative studies and ultimately provide a mechanism for extrapolating to the global scale. This task is related to Activity 1.4 that focuses on the impact of water diversions on the GWS.

- In connection with the preceding worldwide river basin studies, develop a general framework for analyzing spatial connectivities in the global water system and their consequences.

- Work with researchers under GWSP Cross-Cutting Activity 4.3 ("Developing World Water Models") to develop models that better represent the linkages and feedbacks in the global water system.

[8] In these studies the GWSP should collaborate closely with PAGES LUCIFS, LIMPACS, CLIVAR and other global change studies related to this topic. Maximum use will be made of databases and monitoring networks developed within the global change programmes (e.g. LOICZ) and by associated organisations, such as CEOP, HELP, FRIEND, IGWCO and others.

- Use the models above to investigate emerging spatial connectivities in the global water system, especially those that can lead to surprising non-linearities or thresholds. For this task models from outside the sphere of the GWSP modelling activities should also be used.[9]

- Use the models above to investigate interactions and feedbacks across scales and feedbacks, such as the cumulative effects of changes in water recycling from the land surface to the atmosphere.[10] An example research question could be: How does land use management in one part of the world affect rainfall and water availability in other distant parts of the world?

- Organize studies of the occurrence and implications of international trade in virtual water, including an elaboration of current studies of world food trade, and new studies of the water embodied in the international trade of other products and commodities.

Deliverables

- A new set of comparative case studies that examine the historical interaction between river basins and their inhabitants.

- A new framework for examining spatial connectivities in the global water system.

- New models that better represent the linkages and feedbacks in the global water system.

- New insights into the spatial connectivities and non-linearities in the global water system, including new information about the nature and intensity of linkages between land, atmosphere and hydrosphere.

- New knowledge about linkages and feedbacks between the regional and global scales in the global water system.

- An elaboration of the virtual water concept, including an investigation of its limits and possible applications to water policy.

- New information about thresholds in the global water system.

[9] Including models from IGBP-BAHC, WCRP-GEWEX and iLEAPS that simulate land cover-climate interactions.

[10] This task should be carried out in collaboration with Theme 1, and with iLEAPS and GEWEX.

Activity 2.2: Legacy of Human and Natural Interactions in the Global Water System

Above we noted that the long residence times of different water systems cause long lag times in their response to human and natural actions. We pointed out that research is needed on these "legacy effects" so that we can develop better strategies to avoid long term negative impacts on our water resources. Here we carry out research activities to gain a better understanding of legacy effects from a historical perspective and develop models to anticipate long term impacts on the global water system.

Tasks

- In connection with the worldwide river basin studies of Activity 2.1, develop a conceptual framework for classifying and understanding different types of long term effects in different types of water systems.

- Use the worldwide river basin studies in Activities 2.1 and 4.3 to address the question, "What are the long term effects of human activities and natural events on disturbances of the water system?"

- Work with researchers in Activity 2.1 to extend the ability of world water models to simulate legacy effects including ecological effects.

- Use the models in the preceding task to investigate strategies needed to mitigate current long term effects of human actions on water systems and to avoid new effects.

Deliverables

- New understanding about the historical, long-term impacts of humans and nature on water systems.

- A new conceptual framework for understanding differences and similarities in the "legacy effect" worldwide.

- New models that better simulate long term impacts of humans and nature on water systems.

- New information about strategies to mitigate the long term impacts of human actions on water systems.

3 Theme 3. Resilience and Adaptation

The core question in Theme 3 is:

> **How resilient and adaptable is the GWS to change, and what are sustainable management strategies?**

The basic assumption underpinning the GWSP is that environmental processes and human activities are coupled through the water cycle across a variety of scales – up to global – and that this coupling is crucial to our full understanding of human and ecosystem vulnerabilities and adaptive capacities. An important contribution of the GWSP will be to demonstrate the implications of the interaction of processes across scales and the influence of human activities. Another important contribution will be to investigate response strategies that follow from a better understanding (to be gained by research under Theme 2 of the GWSP) of the linkages and feedbacks in the global water system.

3.1 Motivation

Global change is affecting the global water system in various ways, one of the most important of which is *increased water stress in many regions*. Water stress implies that the withdrawal of water for different human uses is a large fraction of its availability. The ability of a region to cope with a certain level of water stress is related to its vulnerability and to its ability to adapt to change. Human needs as expressed in the Millennium Development Goals have to be integrated with the need to preserve and rehabilitate ecosystems and their functions as part of the Earth System. Water governance issues have to be addressed under Theme 3 of the Global Water System Project in order to identify adaptive management approaches, that help us avoid “unwanted futures”. One has to be aware that the present situation requires immediate action to increase the capacity of the water system to cope with future challenges.

In his “Challenge to the World’s Scientists” the UN Secretary General raises one issue (among many) whose solution depends on crucial input from the scientific community; that is the “blue revolution” which the world “so urgently needs to deal with current and emerging water crises” (Annan 2003).[11] From the perspective of human suffering, the current “water crises” are illustrated by statistics frequently brought up in global policy discussions:

- At least 1.2 billion people lack access to safe drinking water.
- At least 2.4 billion do not have adequate sanitation services.
- Two out of every five people currently live in river basins experiencing water scarcity.
- By 2025, at least 3.5 billion people will face water scarcity.

Humans health and livelihoods are closely linked to both availability and quality of water. The World Summit on Sustainable Development in Johannesburg affirmed the Millennium Development Goal to halve, by 2015, the proportion of people who are unable to reach or afford safe drinking water. This clearly indicates the strong political support for including both human and ecosystem needs in water governance. It is widely acknowledged that the world’s water crises are to a large degree crises of governance rather than of scarcity (see, e.g. the report of the World Water Vision Exercise, Cosgrove and Rijsberman 2002). With increasing pressure and change on the GWS this may of course shift in the future. This fact gives a clear direction for the need to focus research and analysis on the

[11] In other places Kofi Annan has talked about this blue revolution as the need to make more efficient use of the water that society uses, particularly in agriculture.

human dimension and the environmental consequences of near term changes in the GWS (Pahl-Wostl 2002; Pahl-Wostl et al. 2002).

How to increase resilience is a key development issue, and is closely related to the issues of environmental, social and economic security (Germany Advisory Council on Global Change 2000; Adger 2000). It is therefore important to explore how current trends in institutional change, land use change, and industrial transformation influence the vulnerability and the adaptive capacity of society and nature.

3.2 State of Knowledge and Research Needs

3.2.1 The Concepts of Resilience, Vulnerability and Adaptation

From the perspective of dynamic systems we can define resilience and other key terms as follows:

- *Resilience* is the ability of a system to maintain and/or return to its current state if boundary conditions change.

- *Vulnerability* refers to the sensitivity of a system to detrimental changes in its state caused by changes in the boundary conditions or external inputs. Basic functions and the overall integrity or vitality of the system are affected.

- *Adaptation* refers to the ability of biological and societal systems to change their current state as a result of changes in boundary conditions or external inputs. Adaptation implies that the basic functions and overall integrity of the system are maintained.

Another way to view resilience is that it is the capacity to absorb shocks while maintaining function. When change occurs, resilience provides the components for renewal and reorganization (Folke et al. 2002; Berkes et al. 2002). Vulnerability is the flip side of resilience: when a social or ecological system loses resilience it becomes vulnerable to change that previously could be absorbed (Kasperson and Kasperson 2001).

Adaptive capacity is the ability of a socio-ecological system to cope with new situations without losing options for the future, and resilience is key to enhancing adaptive capacity. Adaptive capacity in ecological systems is related to genetic diversity, biological diversity, and the heterogeneity of landscape mosaics (Carpenter et al. 2001; Peterson et al. 1998; Bengtsson et al. 2003). In social systems, the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem solving and balance power among interest groups, play an important role in adaptive capacity (Scheffer et al. 2000; Berkes et al. 2002). Adaptive capacity is also linked to access to resources, which is often lacking for marginalised social groups. Addressing how people have responded to periods of change, and how society reorganized following change, are the most neglected and the least understood aspects in conventional resource management and science (Folke et al. 2002). We should give more attention to drawing lessons from the past and using our knowledge to reduce the vulnerability of water management systems. More precisely, we must better understand the various adaptation strategies available to society and nature, and how to evaluate these strategies.

3.2.2 The Different Scales of the Water Problem

Up to now water problems have mainly been perceived as regional or even local problems. However, the forces of globalisation and the extent of world population have led to a strong coupling of water problems at the global scale. The water sector is undergoing major changes including the fact that global companies are claiming a larger and larger share of some national water markets. Among other effects, this may lead to a decrease in the variety of available products and services and reduce the number of culturally-distinct management approaches. This is also happening in other economic sectors with the result that there is a global spread of increasingly uniform management- and life-styles. Such trends towards globalisation require more attention since they may prevent the development of solutions adapted to the cultural, institutional, and legal settings of a region and thus reduce its adaptive capacity.

Water scarcity is a regional problem – globally there is sufficient water available but it is distributed unequally. The emerging patterns of virtual water transfers (mainly via food) from water-rich to water-poor countries are a clear indication of a response to this unequal distribution (see Section 2.2.1). Also, the long-term implications of such developments have received little attention up to now.

For local and regional scales, a compendium of management options in response to climate change and variability, including policy instruments, technological and structural measures, risk sharing and spreading and risk avoidance has been developed by the Dialogue on Water and Climate and could be used in the context of the GWSP. Globally, *virtual water trade* has been suggested as a possible way to use scarce water resources more efficiently (see Section 2.2.1) – The basic idea is that arid areas would import food rather than use local water to produce food on irrigated crop lands. Hence they would save their scarce water supplies for manufacturing goods and services that could be exported (Oki and Kanae 2004).

3.2.3 Extreme Events, Shifts in Ecosystems, and Critical Thresholds

The resilience of ecological and socio-economic systems depends largely on slowly changing and interwoven variables such as climate, land use/habitat, nutrient stocks, human values, life history strategies, and cultural perspectives and policies (see also Chapters 1 and 2). Typically, ecosystems are exposed to gradual changes in climate, nutrient loadings and habitat fragmentation. However several ecosystem studies have shown that smooth changes can be interrupted by sudden drastic switches to a contrasting state (Scheffer et al. 2001). Such shifts can cause large losses to ecological and economic resources, as in the case when freshwater lakes become eutrophic and turbid. Rehabilitating a system to its previous state can be complicated, expensive and sometimes even impossible (e.g. the Aral Sea is likely to remain in its shrunken state over the next centuries). Such shifts can only be prevented by long range planning because responding to visible changes is likely to be too late in the case of rapid system transitions. Research on non-linear changes and threshold effects for socio-economic and coupled human-environment systems is lacking.

The degree of resilience of a system is related to the magnitude and type of disturbance required to fundamentally disrupt the system. Examples of random events that can trigger state shifts are hurricanes, floods, droughts and disease outbreaks, all of which are usually difficult to predict or control. Such threshold events are not easily predictable for natural systems and fundamentally unknown for socio-economic systems.

Climate change will likely lead to a more arid climate in a number of regions (e.g. a number of climate models compute that Southern Africa and the Mediterranean region will have decreasing precipitation and increasing temperature), with negative consequences for natural ecosystems and rainfed agriculture. Meanwhile water demand in many parts of the world continues to increase. FAO (2000), for example, estimates that an additional 3000 km^3 of water withdrawals may be needed for agriculture between now and 2025. This is roughly the average upstream runoff of 75 Nile Rivers.

Competition for water will grow, in particular between expanding urban and rural demand, with almost two thirds of the world's population expected to live in urban areas by 2025. Along with increasing competition will come increasing risk of conflict over water resources. But most researchers believe that a conflict over water has rarely been the main factor in causing a war (see, e.g. Beaumont 1997). More frequently water plays a subsidiary role in conflicts, for example, as a military tool or target (as in the case of World War II when dikes were flooded in the Netherlands to slow down the Allies), or as a political tool (as in 1989 when Turkey threatened to cut-off the flow of the Euphrates River to Syria), or when a water pipeline or other part of the water infrastructure becomes a target of terrorists (Gleick 2000).

But the potential for conflict may be increasing. At the United Nations Habitat II Conference in Istanbul in June of 1996, the Secretary General of the Conference, Wally N'Dow, warned that "the scarcity of water is replacing oil as a flashpoint for conflict between nations in an increasingly urbanized world" (Lonergan 1997). Similarly, Ismail Serageldin a World Bank Vice President proclaimed in 1995 that wars in the 21st century would be fought over water and not oil (Beaumont 1997). The likelihood of wars will depend on many factors such as the intensity of water scarcity, the availability of alternative water sources, the extent to which the water resource is shared by the belligerents, and their relative power. There is an urgent need to collect global data on these and other factors that help us assess the risk of conflict. The GWSP could contribute greatly to the collection and analysis of these data.[12]

[12] In cooperation with, among others, the UNESCO transboundary program "Water and Peace".

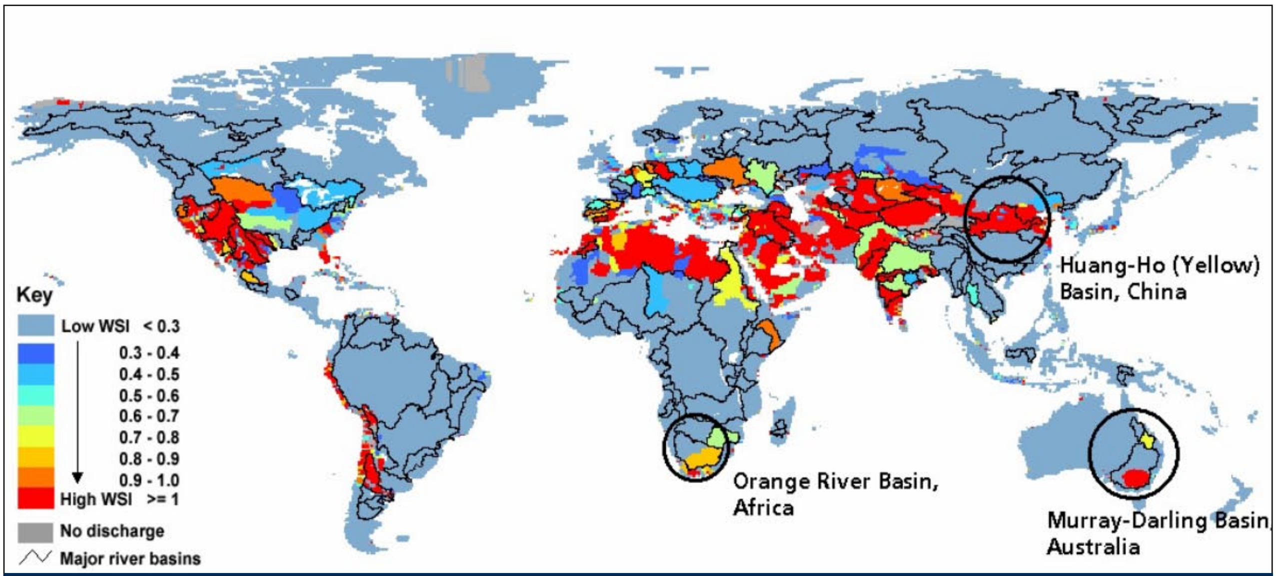


Figure 3-1

Water stress in mid-1990s (defined as the ratio between annual withdrawals and availability on a watershed basis) resulting from the combined effects of changing water availability and changes in demand by humans and ecosystems (Smakhtin et al. 2003 and Alcamo et al. 2003). The circles indicate selected river basins in the severe water stress category.

3.2.4 Water Stress: The Human-Nature Dichotomy

Environmental water requirements are defined as the quality and quantity of water necessary for protecting the structure and functioning of ecosystems and their dependant species and processes. It is essential that environmental requirements for water are known in order to ensure ecologically sustainable development and utilization of water resources. A best guess of environmental water requirements range from 20 to 50% of the total water available.[13] An important question is, will the satisfaction of these requirements mean less water for society?

Recent mapping of water stress (Figure 3-1) suggests that strong competition occurs between water users over broad areas of the Earth. This includes not only competition between different water use sectors, but also between the needs of society and ecosystems. The GWSP should provide an improved database for supporting decisions on the distribution of water in different parts of the world.

Such coarse estimates cannot give a detailed picture about the degree of water stress experienced in a region. Some regions may have a tradition in dealing with scarce water resources whereas in other regions water shortage is a new phenomenon. Given the fast pace of climate and global change more and more regions will encounter unprecedented situations. Hence adaptive capacity will be crucial.

3.3 Activities and Deliverables

GWSP research on resilience and adaptation will address a number of central questions. To what extent is the global water system (from the perspective of its living and social components) resilient to global change? The vulnerability of these systems will depend largely on the type, magnitude, duration and location of the stress and the coupling between regional and global scales. Where will be the hot spots in relation to water stress? These are fundamental questions and the list of supporting research issues is large. From a practical standpoint, the GWSP has identified four activities under Theme 3 which constitute critical new scientific and management challenges and that can be executed in the foreseeable future.

[13] Although it is recognized that the type of flow regime plays at least as important a role as average water availability in sustaining aquatic and riparian ecosystems.

Activity 3.1: Water Requirements for Nature and Humans

Assessment of water availability, water use and water stress at the global scale has been the subject of substantial on-going research. Over the past year environmental flow requirements have received increasing attention at regional scales. However, water requirements of aquatic ecosystems (quality and quantity of water for protection of the structure and functioning of an ecosystem and its dependent species and processes) have never been estimated globally and considered explicitly in these assessments. Likewise these environmental requirements have not been systematically compared to the water required to provide "goods and services" to society such as water supply for municipalities, electrical production, manufacturing and irrigation.

The GWSP can make an important research contribution by quantifying the water requirements of both nature and humanity. A related theme is to identify the potential impact on aquatic and riparian ecosystems of providing adequate water for rapidly growing cities. The water-related implications of a world in which more than 60% of the human population will live in large urban agglomerations by 2025 are fundamentally unknown. Other important issues loom on the horizon such as the connection between water management and health, hygiene, and flooding.

Tasks

- Develop a framework for the combined assessment of environmental and human water requirements worldwide.
- Assess trade-offs between the goods and services provided by freshwater resources and environmental water requirements at different scales (including variability in space and time). (In conjunction with Activity 3.4.)

Deliverables

- A global database of environmental flows, providing information for studies about vulnerability and functionality of aquatic ecosystems.
- New global database for goods and services provided to society by freshwater resources. (With Activity 3.4.)
- New insight into trade-offs between human and environmental water requirements for different spatial and temporal scales as a basis for developing scale-dependent response strategies.

Activity 3.2: The Nature of Adaptive Capacity of the Global Water System

Adaptive capacity and vulnerability of the GWS result from the complex interplay of many different environmental, social, and other factors. An important contribution will be made by the GWSP to identify and quantify the factors influencing adaptive capacity at different scales and their interaction. Addressing this complex issue will benefit greatly from the GWSP's interdisciplinary perspective, given the important geophysical, ecosystem, and societal factors at work in adapting to change. Water stress as well as adaptive capacity is strongly regionalized, varying with global patterns of economic, political and other variables. At the same time, local or regional changes in the water system can have continental or global repercussions on the adaptive capacity of citizens or ecosystems (e.g. large scale transboundary migration, disruptions of markets and trade, losses of aquatic species).

To sum up, an improved understanding of the nature of adaptive capacity is crucial for adapting to future changes in the global water system.

Tasks

- Determine the nature of adaptive capacity of the global water system and develop indicators of its state.
- Evaluate the impact of population pressure and land use changes on adaptive capacity.
- Evaluate the influence of institutions & industrial transformation on adaptive capacity.
- Investigate the influence of changes in the natural environment on adaptive capacity.
- Assess the relationship between water stress and adaptive capacity at different scales.
- Assess global aspects of potential conflicts/security problems having to do with water resources.

Deliverables

- Improved understanding of the processes that determine resilience and adaptive capacity of the GWS documented in scientific publications and policy reports.
- New information about the impacts of industrial and institutional transformation on the water sector.
- Identification of key developments at the global scale that could affect the vulnerability of the global water system, and implications on the regional scale.

Activity 3.3: Approaches to Enhance Adaptive Capacity (the role of institutions, governance, industrial transformation)

Governance plays an important role in society's ability to cope with water-related problems. Improving adaptive capacity requires better understanding of current governance styles and identifying new options for governance at global scales. However, most of the research on water governance to date has focused on local and regional scales. While the importance of transboundary issues has received increasing attention, (see for example, the Water and Peace transboundary waters programme of UNESCO), hardly any work has been done in identifying institutional regimes and management styles at the global scale. Current developments in the water sector and in virtual water transfers are emergent phenomena that may lead to an unwanted "management" at global scales. Hardly anyone has devoted serious thought to the implications of such developments or their long-term sustainability.

The functional interlinkages between water and other social and environmental pressures is also of vital importance for analysing aspects of human security and livelihoods in communities. At the local level people are exposed not only to water stress, but also to poverty, economic globalisation, climate variability and many other stresses which can reduce their resilience to water problems.

A more obvious human security issue surrounding water are the various types of water-related conflicts. Water is not scarce at the global scale but it is distributed very unevenly. As noted in Section 3.2.3, water plays different roles in conflicts between states, and the risk of conflicts may be increasing. Various indicators of risk (relative water scarcity in international river basins) urgently need to be assembled.

A recent development in the international regime of human rights could have significant impact on national water policies as well as local livelihoods and is likely to raise new research questions. The United Nations Committee on Economic, Cultural and Social Rights has issued a "General Comment" on "The Right to Water". This document stresses that countries which have ratified the International Covenant on Economic, Social and Cultural Rights are now obligated to ensure access to clean water "equitably and without discrimination" (United Nations 2003). Moreover "economically developed" parties to the Covenant are obligated to help people in other countries to realize their "right to water". Furthermore, the Comment states that water is a social and cultural good, not merely an economic commodity.

Institutional arrangements for water governance need to be analysed in relation to a wider context. Indeed, water as a public policy issue is being linked to more and more other issues. For example, in the WSSD preparatory process the role of water was seen not only as stimulating sustainable social and economic development but as a "catalyst for sustainable development" supporting other policy-priorities (WEHAB Working Group 2002).

As noted already, cities in developing countries and emerging economies are undergoing rapid changes caused by economic growth and urbanization. As a result physical development is in many cases overtaking policy development and the planning processes required to meet the demands for water supply and sanitation. In addition huge uncertainties arising from climate change pose major challenges to risk management. Moreover, little attention has been given to potential implications of the development of a global water industry and the global diffusion of technologies and management styles on the vulnerability of the GWS and its ability to cope with change.

Tasks

- Compile and analyse data in international river basins needed for anticipating water conflicts, e.g. data for assessing relative water scarcity, the availability of alternative water sources, the extent to which the water resource is shared by the riparian countries, and political factors affecting the risk of conflict.

- Develop a methodology for evaluating different management options and governance styles on the sustainability of the global water system.

- Use the preceding methodology to evaluate possible models for governance of water at the global scale that could lead to sustainable water resource use.

- Compare the impacts of governance at the global, regional and local scales on the sustainability of water resources.

- Identify patterns of industrial transformation in the water sector at the global scale.

- Identify global options (e.g. virtual water trade) to alleviate regional water shortages.

- Identify and evaluate different legal institutions and frameworks for providing adequate water for ecosystems.

Deliverables

- New knowledge about the risk of international conflicts over water.

- New methodology to evaluate the impacts of management styles and governance on sustainable water development.

- Identification of regimes for governance of the GWS at different scales and their effectiveness in promoting sustainable water use.

- Compendium of industrial and other human developments of the global water system.

- New knowledge about global options for mitigating regional water shortages.

Activity 3.4: The Provision of Ecosystem Goods and Services by the Global Water System

Recent assessment activities are beginning to systematically quantify the value of natural systems to human society (e.g. Millennium Ecosystem Assessment). Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions. Water provides goods and services that guarantee human health and life itself and is essential for the preservation of biodiversity. Moreover, freshwater biodiversity itself provides an important service by helping to regulate aquatic ecosystems.

Water is an essential ingredient in the production of other goods (such as crops) and services (such as energy and tourism). The natural water cycle also provides a service by ensuring the integrity, and in turn the functioning, of ecosystems. On a larger scale water maintains the atmospheric circulation which in turn makes most of the earth's land masses habitable.

In addition, water's function in shaping and sustaining traditional culture, religious rituals and practices, are part of the "social" function of water. Quantifying the capacity of the GWS to continue providing this full range of goods and services is urgently awaited. Such knowledge provides a base for the assessment of changes in the GWS and implications of management strategies.

Tasks

- Identify ecosystem services provided by the global water system, building on the efforts of the Millennium Ecosystem Assessment and other efforts.

- Assess the impact of global change on the provision of services by the global water system.

- Investigate how human activities affect ecosystem services provided by freshwater systems.

Deliverables

- New information about potential losses and gains of ecosystem goods and services due to anthropogenic activities related to the use and distribution of water.

- New insight into potential impacts of global change on ecosystem goods and services.

Theme 4. Cross-Cutting Research Activities

4.1 Motivation

This report has articulated a broad set of motivations for a multi-disciplinary and interdisciplinary approach to studying the global water system. This approach requires a solid foundation in both conceptual and quantitative terms (see Pahl-Wostl 2002 and Vörösmarty 2002b for strategy). To ensure continuity across the three GWSP research themes, it is helpful to conduct joint activities and produce joint products that focus the effort of GWSP scientists and ensure synthesis of results as the project matures. Three core Cross-Cutting Activities are proposed to be consolidated under the GWSP, two centered on developing quantitative information and one dedicated to linking disciplinary expertise (Figure 4-1):

1. Building the GWSP information base
2. Integrating the natural science and social science approaches to the global water system
3. Developing world water models and scenarios

4.2 Activities and Deliverables

Activity 4.1: Building the GWSP Information Base

Because an integrative picture of the global water system is at the heart of the GWSP, a key activity will be development of the GWSP Information Base. The data holdings are anticipated to be broad, combining human dimensions, physical, biological, and biogeochemical data sets. They will also span local, regional, and global domains, and thus be hierarchical in organisation, representing a variety of spatial and temporal resolutions. The GWSP Information Base will serve each GWSP research theme, and thus will be used to identify the magnitudes and mechanisms of change (Theme 1), the linkages and feedbacks in the global water system (Theme 2), and measures of resilience and adaptive capacity (Theme 3).

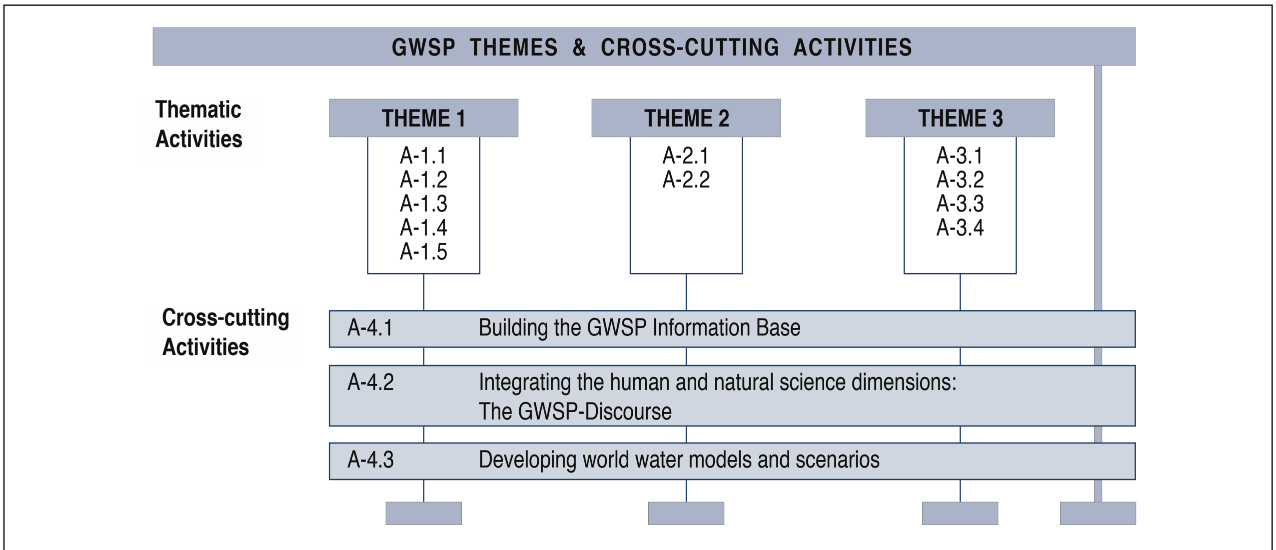


Figure 4-1

Overall structure of the GWSP cross-cutting research activities.

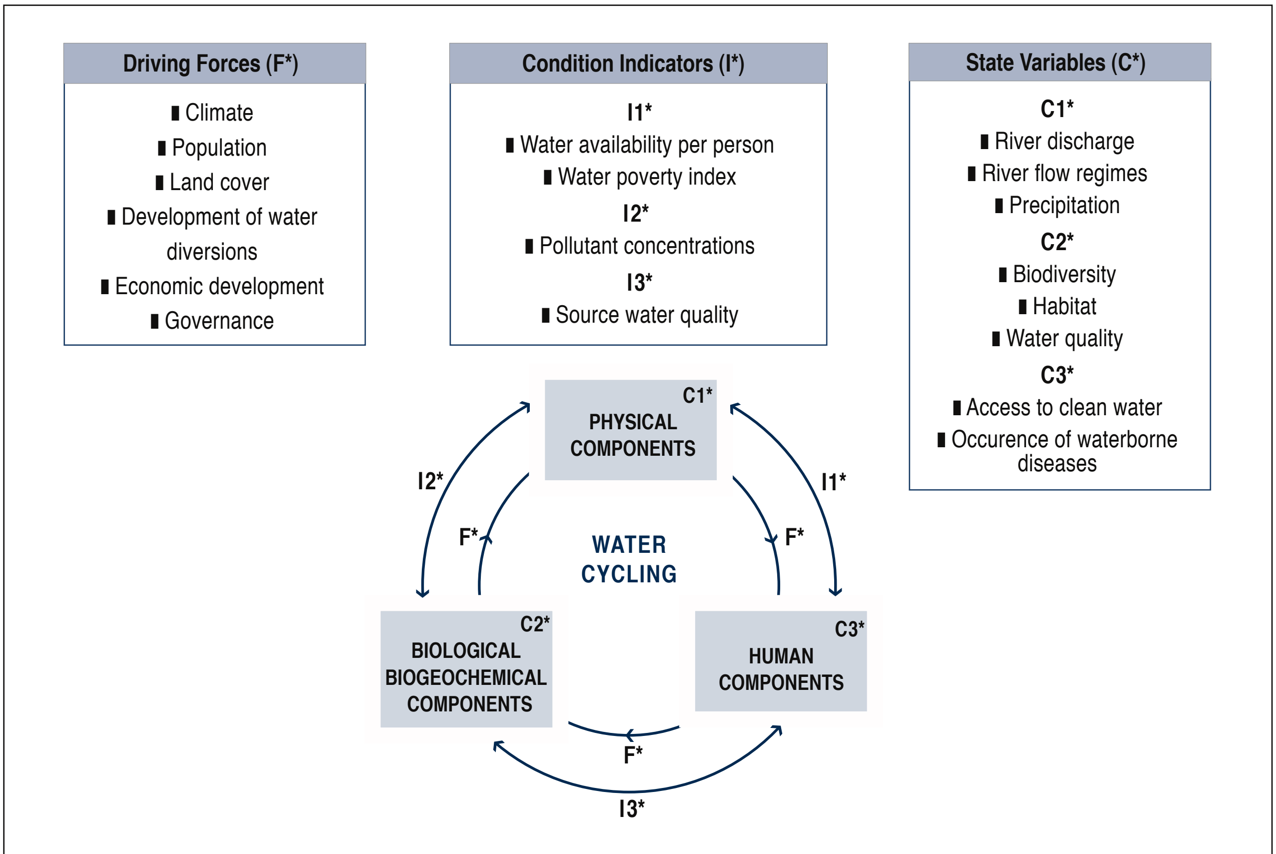


Figure 4-2

Elements of the Global Water System, showing the three classes of data of particular importance in the GWSP – driving forces, condition indicators and state variables (defined in the text). Also shown are their linkages and some examples. The box and arrows marked "F" show examples of different driving forces operating between the major components of the global water system. The box and items marked C1, C2 and C3 are examples of variables depicting the state of the physical, biological/biogeochemical and human components (or "realms") of the global water system. The box and arrows marked "I" are special state variables (called "condition indicators") that provide information particularly relevant for policymaking. As shown in the diagram, condition indicators are derived from the interaction of two components of the GWS.

What type of data will be most important for the GWSP Information Base? Three classes of data are particularly relevant (Figure 4-2):

- *Driving forces*, both natural and anthropogenic, that control and transform the system and shape human-environment interactions. These can be further broken down into *direct* driving forces that have a direct impact on the water system (e.g. water diversions) or *indirect* driving forces that lie behind the direct driving forces (e.g. population and economic growth that stimulate the need for water diversions).

- *State variables* that depict the state of the different realms/components (physical, human, biological/biogeochemical) of the global water system.

- *Condition indicators*, a special class of state variables, that span two of the components of the global water system (Figure 4-2) and are of particular interest as indicators of the health of the global water system. They could provide especially relevant information for the policy community. An example of a condition indicator spanning the physical and human components is the amount of water available in a river basin per person. Other examples are given in the middle box of Figure 4-2.

The overall set-up of the Information Base is designed to identify in concrete terms the primary variables of importance to the GWS and their critical feedbacks. Integration of the consolidated data set with the GWSP modelling efforts is also essential.

Tasks

Building the GWSP Information Base (Box 4) will involve the following tasks:

- *Constructing a Meta-Database of Information Sources.* Since many databases of water-related information already exist, in this task we begin by compiling a list and description of existing data sources and databases relevant to research on the global water system.

- *Identifying Gaps in Data.* After constructing a meta-database, it will be clear where the main gaps exist in information about the global water system. These gaps will be identified and described.

- *Developing New Condition Indicators of the Global Water System.* The GWSP integrated database will be a critical source of information for developing new classes of indicators of the global water system. These condition indicators, as described above (see Figure 4-2), should combine information from two or more of the components of the global water system and should provide information for comparative analysis and for policy studies. For instance, an index of resilience or vulnerability might be developed which is a function of available water resources and their variation in time and space, human access to freshwater, storage capacity and use. Such an index should also incorporate the level of poverty and other factors that affect society's ability to cope with scarcity.

- *Mapping and Assessment of the Current and Past State of the Global Water System.* Up to now relatively little effort has been devoted to globally mapping state variables and indicators of the current state of the global water system (e.g. Indicators for freshwater ecological state, such as eutrophication, have only been mapped for individual water bodies and in a few regions). In this task new effort will be devoted to the mapping of relevant indicators, taking advantage of the development of new indicators and other aspects of the GWSP Information Base. The overall goal of the mapping effort will be to assess the past and current state of the global water system, with particular emphasis on identifying locations of rapid and intense change.

- *Constructing the GWSP Database.* An especially important cross-cutting task will be to compile a comprehensive database of the global water system. In this task we consolidate and extend existing databases so that the data are readily accessible to researchers of the global water system. Among the other applications of these data, they could be used for the development of new indicators, for mapping the global water system (see below) or for developing and testing new models of the global water system (described later in this chapter).

The types of data to be included in the GWSP database are given in Box 4.[14] Special emphasis will put on providing open-access to the database (it will be Internet-based, but available in other electronic forms). We note here that the construction of this database will be a major undertaking and will require significant resources.

Deliverables

- A meta-database cataloging currently available data sources useful for research on the global water system.

- A report identifying key unknowns and gaps in data on the global water system.

- A consolidated and widely-available database of primary data to encourage and support extensive research on the global water system.

- A report describing new indicators for monitoring the global water system.

- A series of reports describing the mapping of key indicators of the state of the Global Water System across paleo, historical, and contemporary time horizons as well as possible future time horizons derived from scenario analysis. These reports will point out the regions of particularly important change in the global water system.

- Special purpose data sets for calibration/validation of world water models (see below) and algorithms for processing remote sensing data.

[14] The effort to construct a GWSP database should build on existing data sets from IGBP, WCRP, IHDP, DIVERSITAS, and elsewhere.

Box 4: The GWSP Information Base and Database

The GWSP Information Base ...

… will provide a valuable tool for studying the global water system. The Informaton Base will be realized by :

- constructing a meta-database of information sources about the global water system;
- identifying critical data gaps in global water studies;
- developing new indicators of the status of the global water system;
- mapping and assessing the current and past state of water systems worldwide;
- building a comprehensive GWSP Database about the global water system.

The GWSP Database ...

… will consist of the following types of data:

1. *Human dimensions* – These data will include, for example, water use data according to social and cultural groups, data relevant to the vulnerability of social groups and institutions, locations and quantities of water abstraction, information on the source of abstraction (groundwater or surface water), return flows to rivers, discharge of pollutants, and other data sets describing the human dimensions of the GWS. This effort should build upon existing comprehensive social science data compilations (e.g. "Geoscope"). Additional data are needed about hot spots of potential conflicts about water. A compendium of official international declarations and treaties on water will also be included.
2. *Physical* – This part of the database will consolidate, expand, and/or make a link to data already available from existing sources (e.g. the Global Runoff Data Center in Koblenz, Germany). These data include river discharge, volumes of water storage, locations and attributes of water diversion projects and flow modifications, and other data sets that describe the physical, non-living aspects of the GWS.
3. *Biological and Biogeochemical* – These data include descriptors of aquatic and riparian ecosystems around the world (types and numbers of species, quantitative measures of aquatic plants and animals, data concerning biological interactions and functional diversity) and the biogeochemistry of waters (nutrients, dissolved solids, sediment, etc.).
4. *Scenario data* – The GWSP database will also be used to organize and store the scenarios computed in Activity 4.3. Open access to these data will increase their usefulness in scientific and policy studies.

Activity 4.2: The GWS-Discourse: Integrating the Natural Science and Social Science Approaches to the Global Water System

The GWSP aims to bring together different perspectives on the global water system (for example, economic, political science, sociological, anthropological, biological, and geophysical) and to focus these perspectives on specific scientific themes designed to generate important new insights in the water sciences. To achieve this alliance of perspectives, it will be necessary to bridge both the conceptual and practical gaps currently separating the disciplines. Gaps arise from differences in nomenclature, in quantitative and qualitative approaches, and in the scope and scale of typical studies. To bridge these gaps, the GWSP will sponsor the "*Global Water System Discourse*". The purpose of the Discourse will be:

1. To develop a joint terminology of the global water system
2. To develop a common conceptual framework for understanding the global water system

Tasks

- *Developing a GWS Lexicon.* A central and early focus of the Discourse will be the development of a lexicon of terminology to be shared by GWSP participating scientists and users of its output. This early GWSP product will help to merge knowledge gained from years of case study experience from human dimensions research with a growing technical capacity to monitor the changing state of the hydrosphere from the Earth Systems sciences. Developing a GWS Lexicon would encourage clear enunciation of terms such as "water availability", "demand", and "stress".

- *Developing a Common Conceptual Framework for Studying the GWS.* In this task we articulate new approaches for studying the global water system by taking into account both human dimensions and natural science perspectives. Included here will be the following sub-tasks:.

  - *Elaborating the concept of the global water system.* Since the concept of a global water system is new and not fully elaborated, we give special priority here to further developing the ideas behind this concept.

  - *Scoping interdisciplinary studies of the global water system.* Here we address the issues important to scoping a GWS study from the interdisciplinary perspective. For example, what is the appropriate level of detail for local, regional, or global-scale studies? What is the appropriate time step? How should water engineering be explicitly considered in defining water supply? These scoping questions have yet to be addressed or even articulated in a consistent fashion.

  - *Incorporating human dimensions aspects.* Here we address the question. How can human dimensions aspects of the water system be included in interdisciplinary studies? How can qualitative and quantitative information on perceptions and values, social norms, framing of problems, conflicts of interest, etc. be linked to quantitative natural science data?

  - *Incorporating technology development.* Another important task is to identify and include major trends in technology development in studies of the global water system. For the prognostic work envisioned, an archive of quantitative data and "story lines" associated with GWSP future scenarios is advised. Scaling techniques are urgently needed to extrapolate socioeconomic indicators developed from case-based studies or over administrative units to the fully global domain. The simultaneous participation of several communities is required

Deliverables

- A joint GWS Lexicon of water-relevant terminology from an interdisciplinary perspective.

- A report on scoping studies of the global water system from the interdisciplinary perspective.

- Workshops and reports on incorporating human dimensions aspects into studies of the global water system.

- Workshops and reports on incorporating technology development into studies of the global water system.

Activity 4.3: Developing World Water Models and Analysing Scenarios

An important goal of the GWSP will be to integrate different perspectives on the global water system by encouraging and supporting the development of "world water models" and scenario analysis of the global water system. This activity will rely heavily on an appropriate set of models for simulating feedbacks among physical, biological and biochemical, and human components of the GWS.

The objectives of this task are to promote the development of models that can be used to increase our understanding of key system behaviors and the impacts of natural events and human-related actions on the global water system. The modelling and scenario analysis will ultimately permit the GWSP to address many key policy-informing questions such as:

- What are the feedbacks and water transfers (e.g. trade in virtual water) arising from human intervention in the water cycle?

- What impact does modern irrigated agriculture have on natural ecosystems and biodiversity?

- What are the future areas of critical change in the global water system?

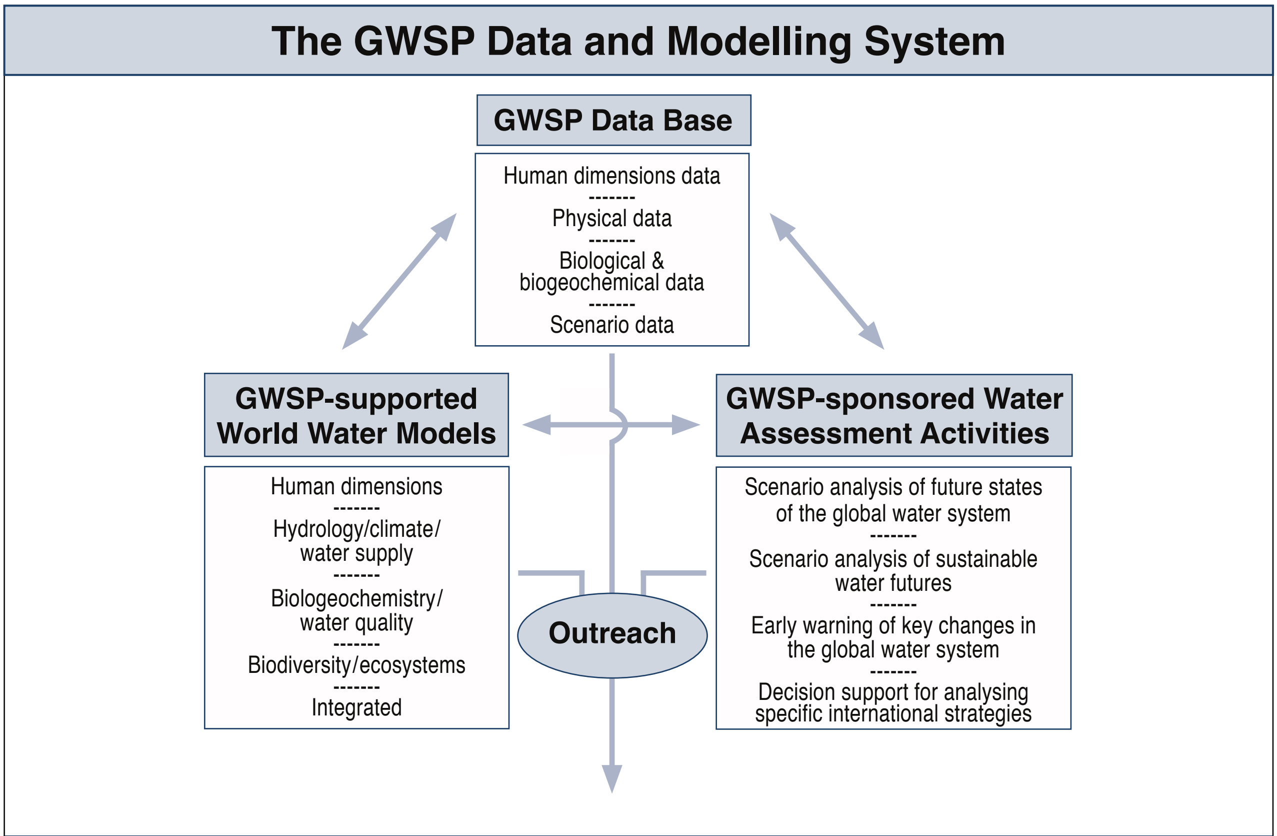


Figure 4-3

A framework for combined data, modelling, and assessment activities within the GWSP.

- How do specific political or economic decisions affect different aspects of the global water system?

The GWSP will support the development of a suite of models. Some of these will focus on a particular aspect of the global water system (e.g. hydrology, biodiversity or water use) while others will be "integrated" models in that they will couple two or more major components of the global water system and usually some aspects of its human dimensions (e.g. water abstraction and hydrology or water use and ecological health). Together, we term these "world water models" (Figure 4-3). These models should have an explicit representation of uncertainty, allowing for a better assessment of risks and opportunities involved in the dynamics of the GWS. One of the main challenges of this activity will be to represent and anticipate human activities and behaviour including technology development and economic ownership (privatization).

Integrated models are essential to the effort, for they explicitly bring a human dimension into the analysis. It is expected that the integrated models will be developed in a step-by-step manner, moving from current stand-alone simulations of individual models to an integrative framework in which models of varying degrees of sophistication could be embedded and exercised in coupled simulation studies.[15]

Given the likely computational demands of detailed world water models, this part of the GWSP effort could advance and benefit from new computer science methods for handling large data sets, carrying out numerical integration, and achieving complex scientific visualisation.

In order to build models with global coverage we must address some critical technical issues:

- Information from studies of biodiversity and human dimensions are typically place-based and therefore must be generalised and upscaled in global models. To do so a set of regional studies will be used to test different up-

[15] Here the GWSP should collaborate especially with researchers designing models under IGBP-AIMES and the WCRP Working Group on Coupled Modeling.

scaling methods. An important precursor to this effort is the Geoscope social science data collection effort of IHDP. Also of particular interest are agent-based models used for representing human behaviour. The upscaling of agent-based models poses a particular challenge because of their extensive data requirements.

- The climate change data needed from GCMs for assessing climate impacts on the global water system are globally available with a relatively coarse grid resolution. However, these data must be downscaled before serving as input to world water models. Alternatively, data from regional climate models with finer resolution can be directly used.

Since one of the major goals of the GWSP is to create a vision of future states of the global water system, one of the most valuable outputs of the GWSP-endorsed data and modelling activities will be their use for developing scenarios of worldwide water resources.

These scenarios will provide information for addressing the scientific questions posed under Themes 1, 2 and 3. Many different types of scenarios will be computed, including descriptions of the possible development of the global water system under different levels of global change, and normative scenarios that aim to identify sustainable water futures.

An optional aim of the GWSP scenario analysis could be developing global "reference scenarios" useful as a departure point for scenario analysis on the local or river basin scale. These reference scenarios could perform a harmonizing function in global water research in the way that emission scenarios of the IPCC have helped to harmonize scenario analysis of climate change.

A framework for integrating data, modelling, and assessment activities within the GWSP is given in Figure 4-3. The database (part of Activity 4.1) will be the repository of GWS data and a main source of data for running, calibrating, and testing the world water models. The models, in turn, will be used to compute scenarios of future patterns of hydroclimatology, biogeochemistry, and attributes of aquatic ecosystems. The scenario outputs would become part of the database and would support various GWSP-endorsed water assessment activities. The database and modelling provide input to water assessment activities such as analysis of important changes in the global water system (Figure 4-3). Another assessment activity could be the direct support of international decision makers in their evaluation of particular international strategies – For example, assessing the positive impact on eutrophication of international controls of nutrient loadings to the coastal zone. The assessment activities of the GWSP should be clarified in the first stage of the project.

Tasks

The following tasks will be carried out to support GWSP modelling and scenario analysis:

- Assembling input data sets needed for running and calibrating models as well as input to scenario analysis (output of Activity 4.1).

- Assembling data sets for validating the models (output of Activity 4.1) as well as a protocol for validation tests. Carry out model intercomparison exercises.

- Working with computer scientists to develop techniques for visualization and presentation of model outputs.

- Developing guidelines for error and uncertainty analysis of models.

- Developing comprehensive scenarios of the global water system with GWSP-sponsored models.

- Making scenario results widely available (as part of the GWSP Information Base in Activity 4.1, and in the activities described in Chapter 5).

- Developing an integrated framework for data, modelling, and assessment within the GWSP.

Deliverables

- A new set of world water models describing individual major components of the global water system (e.g. biodiversity or hydrology).

- A new set of integrated models that incorporate two or more major components of the global water system.

- New information from the model intercomparison exercises about the capabilities of world water models.

- New guidelines for error and uncertainty assessment of world water models.

- A report describing methods for upscaling place-based studies into a global context and downscaling global results to case study domains.

- A report and data set describing scenarios of possible future states of the global water system. These scenarios will include an evaluation of the impacts of different levels of global change and different future strategies for managing water resources.

- A report and data set describing global "reference scenarios" which can be used as a departure point for scenario analysis on the river basin or local scale.

- A new framework for combining key activities of data management, modelling, and assessment of the global water system

5 Dialogue, Capacity Building, and Education

5.1 Motivation

While the state of freshwater resources at local and even national scales is often a highly visible policy concern, the international and global scope of the issue is only now becoming clear to stakeholders and decision-makers. Recent consciousness-raising milestones such as the three World Water Fora, the World Summit on Sustainable Development in Johannesburg with its emphasis on water, and the UN World Water Development Report have placed the global water situation in the spotlight. Nonetheless, there is a well-recognized lack of scientific information and concepts directly useful for policymaking. Thus an important role of the GWSP will be to articulate the information needs of policymaking, to support the development of this information, and to communicate it through an *active dialogue* between scientists, policy-makers, water managers and other stakeholders, and the general public. Dialogue implies learning on both sides – Policymakers and planners need to be informed about the global water system, while scientists need to learn more about the urgent problems of society and the information needed to solve these problems.

Apart from promoting dialogue, another important aspect of the mission of GWSP is *education and capacity building*. This is needed because much of the world's population faces important water-related issues on a daily basis, yet there is little appreciation of the relevance of the global dimensions of the water cycle to local and regional water problems. From the side of the GWSP, we will implement a broad-based programme on capacity building, education, and awareness-raising that incorporates knowledge from research collaborations. This programme should transcend the traditional dichotomy between water resource development and environmental issues – and also consider cultural aspects of the GWS. To make the education and capacity building programme a success, we will address some important issues at the beginning of the project:

- How can capacity building be integrated with the GWSP research programme?
- How can cultural perspectives be integrated into regional and global research teams?
- What educational materials and approaches take into account regional cultures and perspectives?
- How can the efforts of science and policy be combined for developing successful strategies against unwelcome changes in the global water system?

An important aspect in the promotion and advancement of GWS science is for the GWSP to enhance the capacity of research scientists from developing countries. One approach to achieve this is through collaborative research activities on GWS issues between northern and southern scientists by working on integrated regional studies linked to the GWSP research agenda. Capacity building can also be facilitated through formal and informal training programmes in universities and research organisations as well as through research activities involving young scientists from developed and developing countries. The GWSP will cooperate with international programmes[16] to implement training programmes oriented not only to scientists but also to water managers, planners and others involved in water resource management. Furthermore, the GWSP will actively promote the science of the global water system through non-degree training activities and workshops, as well as short-term collaborative research involving young researchers.

[16] such as START (www.start.org), APN and IAI

5.2 Activities and Deliverables

The GWSP has identified ten focused strategies or activities as the foundation for dialogue, capacity building, and education. They range from the most basic of communication strategies – educating young students and the general public – to organizing intensive activities for professionals actively engaged in freshwater research and policy formation.

Activity 5.1: Dialogue

Tasks

- Engage in dialogue with students, professionals, the public, and their leadership about indirect and remote impacts of local water use on the global water system (including virtual water). A number of media can accomplish this: written materials, the Internet, television documentaries, press conferences, newspaper articles, and so forth.

- Develop 'White Papers' cooperatively with stakeholders on pressing contemporary global water issues. This will ensure an ongoing and effective exchange of ideas and information.

Deliverables

- Regional meetings and stakeholder dialogues co-organized with international and regional organisations related to the GWS. This may also be accompanied by a regular Science-Policy dialogue and networking via Internet established through the initiative of the GWSP International Project Office.

- Regular international workshops acting as catalysts to address large-scale freshwater issues. An additional output would be the actual formation of scientific/policy teams to address continental-scale freshwater questions.

- A set of 'White Papers' on contemporary GWS issues.

Activity 5.2: Capacity Building

Capacity building should be oriented towards the needs of society. Therefore as a first step we will survey the water resource community to assess what they believe are the needs for capacity building. In the meantime, the following points are some preliminary ideas for capacity building activities for the GWSP:

Tasks

- Actively support students and postdoctoral fellows as members of international, multidisciplinary research teams. It is vitally important to impart the next generation of scientists with both a global and interdisciplinary view of freshwater issues.

- Form advisory teams of researchers and educators for countries or regions requesting short-term assistance. The scope of the global freshwater issue is daunting. This necessitates having small groups of researchers or other specially trained professionals that can provide technical or educational assistance when requested by affected regions. This is an area where GWSP can form effective partnerships with international organisations having experience in 'outreach' programmes.

- Promote collaborative research projects through integrated regional studies. These activities may be implemented through the visiting scientists programme and/or the scientists exchange programme. Scientists in the ESSP who are working in a particular region may also be invited to participate in collaborative or joint research projects. (These regional projects could be linked with the worldwide river basin studies to be organized as part of Activity 2.1, under Theme 2.)

- Identify opportunities for space & other governmental agencies to take a lead in capacity building in developing countries. Several governmental agencies have needs for information from developing countries and this represents an excellent opportunity for long-term collaboration.

Deliverables

- Setting up and maintaining large-scale observational or demonstration sites. The level of participation in these sites would be a measure of the success of this capacity building activity.

- The formation of continental consortia for understanding patterns and trends in the freshwater cycle and their environmental and human-related consequences – and the incorporation of new understanding into international policy agreements. In effect, creating a GWS community of students, researchers, and stakeholders.

- Development of the next generation of global water scientists with the skills and perspectives to effectively address GWS science issues. Young scientists from industrialized and developing countries would be encouraged to participate in training programmes implemented in collaboration with other international training and research organisations.[17]

- Establishment and evaluation of pilot studies for using globally derived data to address local issues.

Activity 5.3: Education

Tasks

- Create templates and modules for global water system curricula for high schools, universities and practicing professionals that are culturally and regionally relevant. These curricula would inform the next generation of scientists and policy makers about the scope of the issues, current research efforts, and how that research is contributing to the betterment of their lives. It is essential that the curriculum templates be broadly implemented in schools and other educational institutions.

- Develop an interactive web site to convey information about the GWSP and the scope of global water issues, and make it relevant to local and regional concerns. This can be a powerful tool for educating people in remote regions and may even serve to help organize them into a distributed network of individual 'observatories' that can support the broader GWSP research effort.

- Provide ongoing workshops and training for international decision-makers and high-level managers. The purpose is to facilitate knowledge transfer and to build continental-scale teams that are articulate in global freshwater issues and the associated research. The special needs and responsibilities of this societal sector will require special approaches.

- Organize training and research workshops for young scientists. This will primarily involve the training of young scientists from developing countries through regular formal graduate degree programmes, or through sponsored research case studies in the home countries of young researchers. GWS science courses also will be instituted in the undergraduate and graduate programmes of academic organisations with the available critical mass of GWS science experts.

Deliverables

- Publications such as textbooks and references books (perhaps modeled after the well known SCOPE publication series[18]), journal articles, popular papers. The development of a 'Distance Learning' module using Internet capabilities.

- Adoption of curricula or educational materials by schools and professional organisations. This may be the most important measure of ultimate success because it could influence how countries and regions respond in the near future to changes in the global water system.

- Collaborative research projects focused on key regional issues. These projects will be conducted to provide location-specific information for better understanding of the global water system. This may also include comparative analyses across regions involving researchers from north and south, and could be linked to the worldwide river basin studies of Activity 2.1.

- Development of simulation games based on the models described in Activity 4.3, and their use as teaching tools for students and managers and other stakeholders.

- Theses and dissertations from graduate research projects, and the resulting professional publications.

Other Activities

- In addition to the above activities, the GWSP International Project Office (GWSP-IPO) should work with relevant regional organisations and international programmes[19] on joint activities such as workshops, training programmes, and case studies. This can also be accomplished by working with regional/national coordinators of ESSP programmes.[20]

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[17] e.g. START, APN, IAI, UNESCO

[18] See www.icsu-scope.org for more information.

[19] e.g., START, Challenge Program on Water and Food, and the Global Water Partnership, IAI, APN

[20] e.g., National Committees or National Coordinators of IGBP, IHDP, WCRP, DIVERSITAS

6 Steps to Implementation

6.1 Introduction

The pervasiveness of water issues and their complexity have been recognized by the Earth System Science Partnership (ESSP) – i.e. the International Geosphere-Biosphere Programme, the International Human Dimensions Programme on Global Change, the World Climate Research Programme, and DIVERSITAS – and this has led to the development of the GWSP. This project combines the expertise of the biogeophysical, climate, human dimensions, and biodiversity communities. These communities have developed a project that will create the foundation for increased understanding of the global water system.

The implementation of the GWSP should proceed in a way that will ensure that each of the four research programmes of the ESSP has an opportunity to bring its strengths and interests to the table. It must also be implemented in a way that will show the added-value of the project overall to each of the programmes. It is recognised that it would be inefficient to try to involve all of the programmes in all of the activities of the GWSP. Hence, each of the activities of the GWSP will be carried out with inputs and involvement of at least two of the programmes. In addition, one programme will generally take the lead for a given activity.

6.2 Facets of GWSP Implementation

What does implementation involve? The basic task of implementation is to move from the framing of scientific issues and identification of knowledge gaps to a concrete programme of research. Implementation has several facets, including:

- *Specifying research activities.* Perhaps the most important step for implementation is to concretely define the activities for realising the research of the GWSP. These activities and their deliverables are described in some detail in Chapters 1 through 4 with an overview in the Executive Summary.

- *Defining outreach and education activities.* Critical to the implementation of the GWSP are activities such as outreach and capacity building to ensure that the GWSP has a broad impact on the scientific community and society as a whole. These activities are described in Chapter 5.

- *Elaborating a timetable of research deliverables.* Not only must we define what activities will take place but also their time sequence. This is necessary to ensure that research activities that depend on output from other activities receive the output in a timely fashion. Moreover, activities requiring several years (e.g. development of new complex models) must be planned well in advance. Preliminary time planning is covered in this chapter.

- *Developing a management structure.* This facet of implementation involves specifying the structure by which the GWSP will be steered and managed. To develop a final management structure requires consultations with many different individuals within the Earth System Science Partnership. These consultations will take place after the publication of this report. However, later in this chapter we present a tentative proposal for the management structure of the GWSP.

- *Cooperation with other organisations.* Consideration must be given to the relationship of the GWSP with other organisations. Many examples of this cooperation have already been cited as footnotes to the text in Chapters 1 through 5. Later in this chapter we again address this topic.

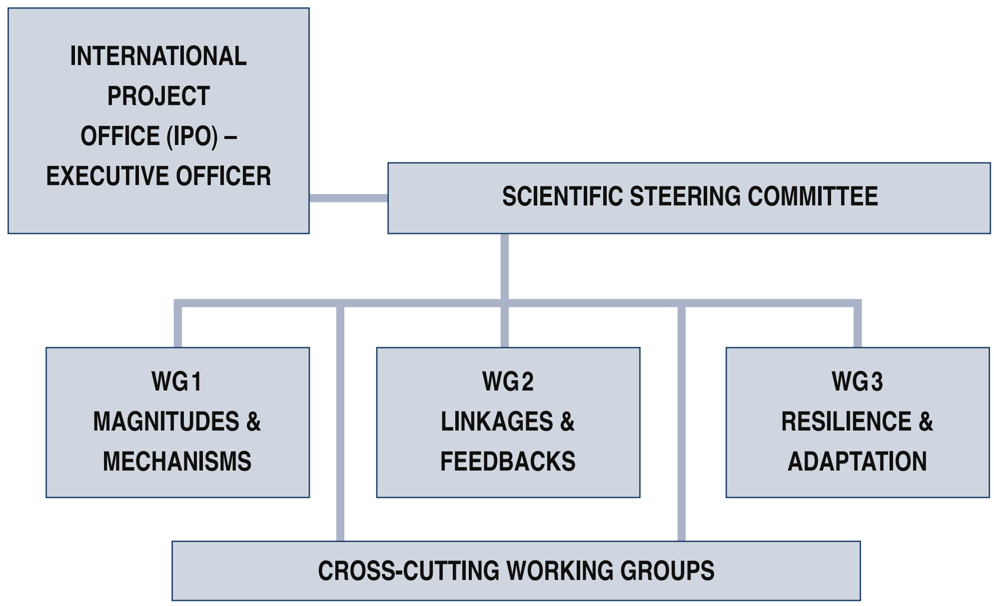

Figure 6-1

Overview of proposed management structure of the GWSP. The three Working Groups (WG) correspond to the three main research themes of the GWSP. To promote communication between the research themes, some cross-cutting activities (modelling, information base, and so on) will also be organized in cross-cutting working groups containing participants from all themes.

6.3 Implementation: Research Activities

The GWSP has laid out an ambitious programme of research to broaden scientific knowledge about the current workings and future prospects of the global water system.

The research activities of the three main research themes have been described in Chapters 1 through 3. They are:

1. Magnitudes and Mechanisms of Change

2. Linkages and Feedbacks

3. Resilience and Adaptation

A set of cross-cutting activities are carried out that address issues common to all research themes such as data consolidation and modelling. These activities are described in Chapter 4. We note that the activity plans described both in this chapter and in Chapter 4 are of a preliminary nature and will be finalized later.

6.4 Management Structure[21]

The approach used to manage this project will be marked by diversity and inclusiveness. We recommend that the final management structure be developed after consultation with many different individuals within the Earth System Science Partnership. Here we propose a tentative management structure as a basis for discussion.

Overview

The GWSP will be guided by a Scientific Steering Committee (SSC) consisting of distinguished scientists and other experts. In addition to the SSC, each of the three major research themes will have a Working Group for organizing activities within the research theme. These Working Groups will answer to the Scientific Steering Committee. In addition, Cross-Cutting Working Groups will be set up on a need basis for selected Cross-Cutting activities (e.g. information base, modelling). The Cross-

[21] Tentative Structure. For the current management organisation of the GWSP please consult the GWSP website www.gwsp.org.

Cutting Working Groups will also answer to the Scientific Steering Committee. There should be a partial overlap in the membership of the various committees to ensure good communication and coordination of activities. Figure 6-1 depicts an overview of the proposed management structure.

Scientific Steering Committee

A Scientific Steering Committee (SSC) will be established to oversee the implementation and scientific integrity of the project. The Committee will have representation from a broad cross sector of scientists with expertise related to different aspects of the GWSP. Experts will be added to the Committee as warranted. The SSC will be chaired by a prominent scientist selected by the Directors and Chairs of the four sponsoring programmes (DIVERSITAS, IGBP, IHDP, WCRP). Deputy Chairs and members of the SSC will be selected to ensure that all the sponsoring organisations are represented fairly on the SSC. The length of membership terms on the SSC will be set later, and will be staggered so that the initial SSC is replaced over several years. The SSC will work with the Executive Officer in developing, implementing and promoting the Science Plan of the GWSP, and in supervising the Dialogue, Education and Capacity Building activities of the GWSP.

Executive Officer and International Project Office.

The Executive Officer and his/her staff in the International Project Office in Bonn will be responsible for the day-to-day management of the GWSP. Working with the SSC, the Executive Officer will develop plans for implementing GWSP activities and ensure that the plans are carried out. The Executive Officer will plan and facilitate integration and synthesis exercises, including conferences, and develop and supervise a quality assurance programme for the GWSP. He/she will also supervise the Dialogue, Education and Capacity Building activities of the GWSP in conjunction with the SSC and develop an external communication (or "outreach") programme.

Thematic Working Groups

The Scientific Steering Committee together with the Project Executive Officer will organize a Working Group for each of the main research themes of the GWSP. The purpose of these Working Groups is to organize the research activities within the research themes. The Chairs of the Working Groups will be selected by the SSC and will also serve on the SSC. Membership terms in the Working Groups will be for 2 years with possible extensions up to 6 years.

Cross-Cutting Working Groups

The cross-cutting activities (e.g. model building, constructing the Information Base, and developing a common research framework) are particularly important for promoting communication and cooperation between scientists in the different research themes. The Scientific Steering Committee together with the Executive Officer will organize, on a case-by-case basis, ad hoc Working Groups for particular cross-cutting activities. Clear Terms of Reference for these Working Groups will be devised by the SSC.

6.5 Communication with Stakeholders and Policy Makers

The GWSP focuses on scientific questions and is motivated by a unique perspective on global water problems not addressed elsewhere. Although the project is science driven, it is clear that it must be relevant to the needs of the larger stakeholder and policy communities. Therefore, special efforts will be made to engage stakeholders, policy makers and others in dialogue about the relationship between the global dimensions of the water cycle and local and regional water problems. This dialogue will take the form of GWSP workshops and other meetings, as well as a series of joint "White Papers" on water issues co-written with stakeholders (see Chapter 5). The GWSP will also make early contact with existing multi-stakeholder networks (e.g. the EU water initiative, World Water Council, etc.) and will ensure the representation of stakeholder interests on the GWSP steering committee. Dialogue with stakeholders and policy makers is addressed in Chapter 5.

6.6 Cooperation With Other Research Efforts

It is clear from previous chapters that the GWSP must cover a wide range of scientific topics and disciplines in order to achieve its goal of integrative understanding of the global water system. Therefore, a measure of overlap is expected between GWSP research interests and those in other research programmes and organizations. In the text of this report we have indicated where possible the national and international research activities that the GWSP should cooperate with on particular activities.[22] To be more general, the GWSP will actively seek cooperation with programmes and organizations whose interests overlap with those of the GWSP. The types of organizations will include:

- National programmes on water research;
- International water-related research programmes sponsored by DIVERSITAS, IGBP, IHDP, and WCRP.
- Other international research programmes related to water problems;
- Organizations sponsoring international assessments and policy studies of global water issues.

Rather than duplicating these efforts, GWSP will seek to work with these other groups by building linkages and partnerships with them.

In the following paragraphs we describe in more detail the expected cooperation between the GWSP and selected other research programmes. We present these *as examples of the kinds of cooperation that* the GWSP will seek with other organizations active in global water-related research.

GEWEX (Global Energy and Water Cycle Experiment)

The following are promising areas for close cooperation between GEWEX and GWSP:

- *Coupled modelling of climate, land and hydrologic processes*. Water management practices have modified land cover and water storage to such an extent that, arguably, they are influencing both the regional climate and weather patterns. The GEWEX and GWSP will work together in developing coupled models of changes in climate, land cover and hydrology. These models will be used in particular to better understand the impacts of coupled changes on regional climate, runoff, and water quality. In addition, scenarios will be developed to determine the best response for conserving water under different development and climate scenarios in different basins.
- *Inventories of surface water storage*. Inventories of surface water storage and its changes are needed for water planning and for monitoring the impact of management decisions. New satellite sensors and data processing methodologies may provide new and important measurements of runoff and volume of surface water. GEWEX will help develop these data and will work with the GWSP to ensure that this tool supports any decision support system that GWSP may put in place.
- *Data and prediction of climate variability.* The impact of climate variability on water management differs from basin-to-basin because of differences in water infrastructure, economic activities and water management practices. GEWEX is developing satellite data sets and prediction capabilities that can be used in supporting water management in all parts of the world. In addition it has developed an excellent capability for land data assimilation which enables the production of outputs that are uniform over the world's land surfaces and that can be used for future analysis and in the initialization of hydrologic models used in prediction and modelling studies. GEWEX will provide its data sets to GWSP scientists and could link its data systems to the GWSP system as part of a distributed data network.
- *Identifying worldwide impacts of water management*. An important open question is whether long term trends in runoff can be explained by changes in human manipulation of rivers (water use and storage) or by variability/changes in climate. To address this question GEWEX will work with GWSP in analyzing long term data sets of climate and hydrologic variables obtained through GEWEX-sponsored Continental Scale Experiments (CSEs) and other sources. Hydrological models will also be developed and used to extend existing records back over longer time periods when system development has occurred rapidly in some areas.
- *Regional climate modelling*. Information at appropriate scales can be used to improve the efficiency of the management of water systems. GEWEX is involved in the development of regional climate models that can be

[22] A partial list of these programs and organisations includes: the Challenge Program on Water and Food, BAHC, CEOP, CLIVAR, the DIVERSITAS Freshwater Committee, FRIEND, GEWEX, HELP, IGWCO, iLEAPS, IWMI, GLP, LIMPACS, LUCC, LUCIFS, LOICZ, PAGES, START, UNESCO transboundary program "Water and Peace" (the names behind these acronyms are given in the section "Abbreviations" at the beginning of this report).

used to downscale global analyses and prediction products for application to water management at scales that are important for management decisions. This modelling activity will be integrated with the other modelling activities of GWSP.

- *Global climate change and water availability.* Climate and global change will have major impacts on water availability and use. GEWEX, in collaboration with other WCRP projects, specifically CLIVAR and CliC, is developing a capability to assess climate change and its impacts on water availability. This work will focus especially on important physical processes such as the effect of climate change on snow melt processes and soil moisture. This knowledge will contribute to activities on climate change and water resources in the GWSP.

- *Urbanization and water resources.* Rapid urbanization will continue to impact water systems, local water availability and regional climate. The effect of urbanization on climate will be amplified by the effects of land use change and water distribution occurring around large cities. GEWEX will address this problem by modelling of surface and boundary layer fluxes and by using Large Eddy Simulation (LES) models to assess the effects of these changes in fluxes on local and regional distributions of clouds and precipitation. This new knowledge will make a valuable contribution to the activities of the GWSP in the research area of the worldwide impact of urbanization on water resources.

IHP (International Hydrological Programme)

It is expected that the GWSP will intensively work with UNESCO's International Hydrological Programme (IHP) in the following areas:

- *Linking hydrological research with needs of society.* The objectives of the HELP project of the IHP is to carry out activities that will improve the links between hydrology and society in a global network of river basins. There is a potentially close relationship between the aims of the GWSP to conduct policy-relevant global research and the objectives of HELP. Since the GWSP is interested in studying the global water system at different scales, including the river basin scale, the GWSP will complement and gain from working with HELP. It is expected that the two projects will work closely together especially by sharing data and organizing joint meetings, including a conference jointly planned for February 2005 in Bonn. Other opportunities for collaboration include river basin studies as part of the joint isotope hydrology programme between UNESCO and IAEA.

- *Studying the connectivities in the global water system.* An obvious partner for the GWSP in its research of spatial connectivities in the global water system will be the UNESCO-IHE (Institute for Hydrologic Education). In particular, the GWSP and UNESCO-IHE could cooperate on a study of the trade in virtual water in the world's economy. A cooperative project could address questions of: the environmental and socio-economic impacts of virtual water trade; the usefulness of virtual water trade as a tool in an integrated water resources management context; and the potential for compensation mechanisms for the water footprint that countries leave in other regions. The GWSP will also cooperate with UNESCO-IHE on capacity building and educational programmes.

- *Assessing the magnitude of changes in the global water system.* A fruitful cooperation is expected between the GWSP and the IHP-supported World Water Assessment Program. Both organizations can gain greatly by cooperating in compiling and analyzing data about the current state of the global water system. The two organizations could also mutually benefit by cooperating on the development of indicators that can be used to monitor the condition of the global water system, to identify hotspots of water scarcity, and to assess the adaptability of the system.

LOICZ (Land-Ocean Interactions in the Coastal Zone)

The following areas are particularly promising for cooperation between LOICZ and GWSP:

- *Investigating the changing boundaries of the estuarine environment.* Large scale diversions of freshwater and climate change will make long-term and profound changes in the volume of freshwater inputs to estuaries. At the same time, sea level rise will increase the inland penetration of saltwater. The combination of these drivers could lead to major changes in the salinity boundaries of estuaries and in the effective long-term spatial extent of the estuarine environment. Identifying the future change in estuarine boundaries is an important topic of interest to both the GWSP and LOICZ.

- *Assessing the impact of river diversions and land use change on coastal processes.* Upstream river diversions and land use changes profoundly affect physical, biogeochemical and ecological processes in the coastal zone. In this activity GWSP and LOICZ will work together with the Global Land Project (GLP) to identify and quantify these impacts on coastal zone processes.

- *Studying the e ect of global change on the integrity of aquatic ecosystems*. Various research activities of the GWSP concern the impacts of large-scale, long-term hydrologic and biogeochemical changes on the integrity of freshwater aquatic ecosystems. But in large rivers the integrity of freshwater ecosystems are intimately tied to estuarine ecosystems through the migration of fish species and other processes. Hence GWSP will cooperate with LOICZ in studying global change and its impact on aquatic ecosystems.

- *Studying the issue of saltwater intrusion to coastal aquifers*. The saline contamination of coastal groundwater is a major water supply issue in many populated coastal areas. Contamination stems from both coastal processes such as sea level rise, but also from inland processes such as the upstream diversion of freshwater. Considering the interaction of freshwater and coastal systems, this is a good area for cooperation between GWSP and LOICZ.

- *Characterizing the large-scale nutrient cycles*. This is an area where activities of LOICZ and GWSP will be complementary. The GWSP has a particular interest in observational and modelling studies of the nutrient cycle in *freshwater systems* while LOICZ has a parallel interest in these studies in the *coastal zone*. Joint activities need to be identified to bring the outputs of these parallel activities together.

- *Providing inputs to coastal studies*. As part of its database effort, the GWSP will make key data available to LOICZ researchers about inputs from inland freshwater systems to estuaries. Possible examples of these data are: the volume and variability of freshwater flow, nutrient loads, and sediment loads.

6.7 Products of the GWSP

The following is a partial list of some expected products of the GWSP:

- Consolidation of disparate efforts at studying the global aspects of water resources into a unified, dynamic research programme.

- Broadened knowledge about important changes in the global water system and their drivers and mechanisms.

- New understanding about the linkages and feedbacks that characterize the global water system and a greater competency to anticipate non-linear changes in the system.

- A global assessment of the water requirements of freshwater ecosystems.

- Greater comprehension of factors determining the resilience and adaptive capability of the global water system.

- New sets of indicators that increase the ability of society to monitor and anticipate changes in the global water system.

- New numerical models for understanding the current system and anticipating future states of the global water system.

- A vastly improved knowledge base about the global water system with practical tools such as the GWSP database which will be made widely available for supporting global water research.

- A better informed public and scientific community about the relevance of the global dimensions of the water cycle to local and regional water problems.

6.8 Research Schedule

An important aspect of implementation of the GWSP is to specify the timetable of research activities. This is necessary to ensure that research activities that depend on output from other activities receive the output in a timely fashion. Moreover, activities requiring several years (e.g. development of new complex models and international case studies) must be planned well in advance because of the diversity of country funding that may be needed to make this research feasible. Here we give a *preliminary time table of research activities and deliverables* that should be refined after further discussion.

The GWSP research programme is divided into three phases:

Phase I. (Years 0 to 2) *Programme definition and initiation* in which the project finalizes its plan and launches a mix of short, medium and long term initiatives.

Phase II. (Years 3 to 5) *Programme implementation and product delivery* in which the first short and medium term results are produced

Phase III. (Years 6 to 10) *Data synthesis and application of results* in which results of the project are synthesized, disseminated and applied.

In some cases these phases represent new aspects in the development of a long-term thrust, while in other cases the transition from one phase to the next marks the completion of investigations related to a certain topic. The success of each phase will be evident from the achievement of the key deliverables on the schedule outlined and by the readiness that is demonstrated for moving to the next phase of the programme.

In Table 6-1 (at the end of chapter) we present a preliminary time table of the main research activities and tasks in the GWSP. The following paragraphs present a *tentative list* of deliverables that are expected during each phase of the implementation. These deliverables are adapted from the deliverables given in Chapters 1 through 5. This list must be discussed and refined by the Scientific Steering Committee of the GWSP and the larger GWSP community.

Phase I (years 0-2) Programme Definition and Initiation

During this phase GWSP will finalize its implementation plan and launch a mix of short, medium, and long term initiatives. In many cases an initiative will require strategy papers to be developed and presented to the scientific steering committees for approval. The following deliverables will be produced:

Planning and Programme Development

a. A white paper on a capacity building strategy will be prepared.

b. An inventory of ESSP projects relevant to GWSP will be developed. Based on this list the first phase of the implementation plan will be finalized.

Theme 1: Magnitudes and Mechanisms of Change

a. A scoping document for the GWSP Information Base will be prepared. This activity will rely on data 'mined' from the four sponsoring ESSP programmes. The scoping document will deal with issues of a centralized database versus a distributed one, ways to cope with uncertainty in data, gaps in the data and opportunities for integration.

b. A set of land use trajectories will be compiled or developed for studying the effects of land use change on the GWS.

c. A report summarizing the impacts of climate change on water-related Millennium Development Goals (MDGs) and other policy initiatives will be written.

d. Plans for a worldwide assessment of the large scale impacts of water diversions on the GWS will be drawn up.

e. A systematic study of water governance systems worldwide will be initiated.

Theme 2: Linkages and Feedbacks

a. A set of worldwide river basin studies will be planned to gain insight about the spatial connectivities, legacy effects, and thresholds in the GWS.

b. Reports will be written on conceptual frameworks for studying spatial connectivities and legacy effects in the global water system.

c. A set of new activities will be carried out to define the nature of connectivities in GWS. These could include new field programmes or the analysis of data from other programmes. These activities will include, among others, the study of land-ocean linkages of moisture, sediment, and biogeochemical substances.

d. A report will be prepared that documents the connections between the GWSP and the Millennium Development Goals.

e. Studies will be initiated on virtual water trade, including the international trade of non-agricultural products.

Theme 3: Resilience and Adaptation

a. A framework will be developed for the assessment of environmental and human water requirements worldwide.

b. A report will be prepared that describes the nature of adaptive capacity of the GWS and indicators of adaptive capacity.

c. A report will be written on the impacts of worldwide industrial and institutional transformation on the water sector.

d. A report will be prepared on worldwide freshwater ecosystem services and the potential impacts of global change on these services.

Cross-Cutting Activities

a. A white paper will be prepared on a common conceptual framework for studying the global water system, and an elaboration of the concept of the global water system.

b. A lexicon of common GWS terminology will be compiled.

c. An evaluation of existing models relevant to GWSP issues will be undertaken. This review will identify the most relevant modelling modules, integrating frameworks for GWSP and gaps in modelling capability.

d. Existing prototype scenarios and indicators (e.g. of water quality, scarcity, etc.) will be evaluated and used to explore past, present and future states of the global water system and its key vulnerabilities.

e. A meta-database will be produced that describes sources of data for global water research.

f. A report will be written on data gaps in describing the global water system.

g. A first version of the structure of the GWSP database will be built.

Dialogue, Capacity Building, Education

a. A regular set of symposia and workshops will be established for exchanges between scientists and stakeholders.

b. Dialogues between scientists and managers and decision makers will be established.

c. Pilot projects will be initiated to use globally derived data sets to address local problems

Phase II (years 3-5): Programme Implementation and Product Delivery

During this period the following deliverables will be produced:

Planning and Programme Development

a. A mid-term review of the GWSP programme will be conducted to identify gaps and help define/refine further studies.

Theme 1: Magnitudes and Mechanisms of Change

a. New estimates of the magnitude of change arising from land use change will be developed.

b. A compendium summarizing the comparative performance of different water governance systems on the GWS will be prepared.

c. A report summarizing the contribution of large scale water diversions on hydrologic regimes and global climate change will be prepared.

d. A report assessing the impacts of water diversions on global water security will be prepared.

e. A report will be written on hot spot indicators of areas where land degradation and nutrient depletion could lead to large nutrient fluxes in the global water system.

f. A report will be written summarizing the consequences of accelerating nutrient and sediment transport on surface and ground waters worldwide.

Theme 2: Linkages and Feedbacks

a. Based on the planning in Phase I, globally representative case studies (regional) will be initiated. The choice of cases will focus mainly on enhancing existing basin and continental scale studies[23], but allow for GWSP

[23] For example CSE, HELP, CGIAR CP, and others.

case studies in new areas where the will and commitment exist.

b. A report on the relationship between biodiversity and other characteristics of river systems will be prepared.

c. A report on the transition from natural to human dominated GWS will be prepared.

d. A report will be written on current capability to model the non-linearities in the GWS (e.g. technological breakthroughs, biophysical, land-water interaction).

e. Studies will be organized to examine the existence of critical threshold levels in the GWS.

Theme 3: Resilience and Adaptation

a. A report will be written on options for managing water at the global scale in order to attain sustainability goals.

b. Assessment reports will be prepared on the impacts of

- population pressure and land use changes on the adaptive capacity of the GWS,
- institutions & industrial transformation on the adaptive capacity of the GWS
- water stress and adaptive capacity.

c. A report will be prepared that quantifies the natural adaptive capacity of the GWS.

d. A global database will be constructed of estimated environmental flows required to preserve resilience and functionality of aquatic ecosystems.

e. An assessment report will be written on global aspects of potential conflicts/security issues and water resource management.

f. A report will be prepared on the possible role of global management of world trade (virtual water in food trade) in minimizing local/regional water stress.

g. A report will be written that evaluates different models of governance as tools for global management of water.

h. An assessment report will be prepared regarding concepts of water stress and methods for computing them.

i. A report will be written on new global indicators of adaptive capacity.

Cross-cutting Activities

a. Maps will be prepared that depict globally-significant areas of change and vulnerability of the global water system.

b. Special purpose data sets will be assembled for calibrating models and remote sensing algorithms.

c. The first version of the GWSP database will be made available.

d. Protocols for testing model results will be developed.

e. New integrated assessment models will be developed for global analyses of GWSP issues.

f. New hydrologic and other single-component global models will be developed.

g. Scenarios of the future state of the GWS will be developed with the new models.

Dialogue, Capacity Building and Education

a. Large-scale observational or demonstration sites will be set up and maintained in one or more countries.

b. White papers will be developed in collaboration with stakeholders (e.g. the World Bank) on global water issues.

c. Continental consortia will be organized for studying patterns and trends in the freshwater cycle and their environmental and human-related consequences.

d. GWSP curricula and educational materials will be developed.

e. Theses and dissertations will be produced from graduate research GWSP projects.

Phase III (years 6-10): Data synthesis and application of results

During this period the following deliverables will be produced:

Planning and Programme Development

a. Adjustments will be made to plans and programmes on the basis of the mid-term review results and the evolving context for the GWSP.

b. Synthesis activities will be organized.

Theme 1: Magnitudes and Mechanisms of Change

a. An assessment report on the impacts of economic and political factors and regulation on the GWS will be prepared.

b. A report on the relative magnitude of the impacts of long-term climate variability versus anthropogenically-induced climate change on the GWS will be written.

c. An assessment report of the consequences of current and projected water abstraction rates (for surface and ground water) on the GWS will be prepared.

d. An assessment report of changing nutrient loading and eutrophication worldwide will be written.

e. An assessment of the impacts of water diversions on people and socio-economic systems will be prepared.

f. An assessment report on the consequences of climate extremes on the GWS will be prepared.

Theme 2: Linkages and Feedbacks

a. A report on the consequences of linkages in the GWS will be prepared.

b. A report will be prepared on the long term effects of human actions and natural events in the global water system.

c. A report will be written on new models to better simulate the linkages and feedbacks in the global water system.

Theme 3: Resilience and Adaptation:

a. An assessment report will be written about trade-offs between human water requirements and environmental water requirements at different scales.

b. Model simulations will be prepared to assess implications of different global management options.

c. A report will be prepared on the analysis of the appropriate scales of governance of the GWS.

d. A report will be written on potential losses and gains for ecosystems goods and services due to anthropogenic activities related to the use and distribution of water.

Cross-Cutting Activities

a. The final version of the GWSP database is made available

b. An assessment report is prepared that ranks major impacts, linkages and feedbacks, and identifies remaining data and information gaps.

c. A new suite of GWSP-sponsored World Water Models will be available incorporating new upscaling and downscaling techniques.

d. GWSP models, methods and capacities will be transferred to new basins/areas through systematic studies.

Dialogue, Capacity Building and Education

a. Key policy relevant conclusions will be elaborated and disseminated to the science and policy communities and society.

b. GWSP curricula and educational materials will be introduced into schools and professional organizations.

c. Educational programmes will be organized for universities, schools and distance learning regarding the GWS.

d. Collaborative research projects will be initiated through integrated regional studies.

e. New training programmes will be developed and implemented through START, UNESCO, others.

Table 6-1

Schedule of research activities and tasks. To be updated.

	Phase 1 years 0 - 2	Phase 2 years 3 - 5	Phase 3 Years 6 - 10
Theme 1: Magnitudes and Mechanisms of Change			
A 1-1. Water governance and the GWS			
- Compare and catalog water governance schemes	■		
- Develop water governance data base	■	■	
- Analyze effects and impacts of governance types		■	■
A 1-2. Land cover changes and the GWS			
- Analyze historical patterns of land and water use	■		
- Compile land change trajectories	■	■	
- Analyze crop production effects	■	■	■
A 1-3. Climate change and the GWS			
- Assemble information on climate variability and change	■		
- Analyze impacts of climate change/ variability on water availability/ use	■	■	■
- Study feedback between climate change and the GWS	■	■	■
A 1-4. Water diversions and the GWS			
- Analyze and quantify consequences of dams and irrigation		■	■
- Identify relationship between river diversions and biodiversity	■	■	
- Analyze social impacts of relocating people from sites of large dams	■	■	■
- Conduct case studies on water use competition and conflicts	■	■	
- Analyze connections between virtual water trade, water pricing, water institutions, water diversions	■	■	■
- Analyze and compare the influence of water governance systems/ carry our large water diversion projects	■	■	■
A 1-5. Nutrient and sediment transport and the GWS			
- Identify key variables and functional relationships of nutrient and sediment transport	■	■	■
- Develop indicators of soil erosion, nutrient depletion, land degradation	■		
- Use new indicators to assess global hot spots		■	
- Identify and assess factors that accelerate nutrient and sediment transport	■	■	■
- Carry out analysis of changes in nutrient and sediment transport		■	■
Theme 2: Linkages and Feedbacks			
A 2-1. Linkages at Different Spatial Scales			
- Organize river basin studies	■	■	■
- Develop framework for analyzing spatial connectivities in the GWS	■	■	
- Develop models for representing linkages and feedbacks	■	■	■

Table 6-1 (cont.)

Schedule of research activities and tasks. To be updated.

	Phase 1 years 0 - 2	Phase 2 years 3 - 5	Phase 3 Years 6 - 10
- Use models to investigate spatial connectivities in the GWS		■	■
- Use models to investigate interactions across scales		■	■
- Organize studies about international virtual water trade	■	■	■
A 2-2. Legacy of Human and Natural Interactions			
- Develop a framework for classifying and understanding long term effects in different water systems	■	■	
- Investigate long term effects of human activities and natural events on the GWS	■	■	■
- Extend models to simulate legacy effects	■	■	■
- Use models to investigate mitigation of human actions and avoidance of new effects on the GWS		■	■
Theme 3: Resilience and Adaptation			
A 3-1 Water Requirements for Nature and Humans			
- Develop a framework to assess environmental and human water requirements	■		
- Assess trade-offs between environmental and human water requirements at different scales	■	■	
A 3-2 The Nature of Adaptive Capacity of the GWS			
- Determine nature and indicators of adaptive capacity of the GWS	■	■	■
- Evaluate impact of population pressure, land use changes, institutions and industrial transformation on adaptive capacity of the GWS	■	■	
- Investigate impact of changes in natural environment on adaptive capacity of the GWS	■	■	
- Assess relationship between water stress and adaptive capacity	■		
- Assess global aspects of potential conflicts/ security problems related to water resources	■	■	■
A 3-3 Approaches to Enhancing Adaptive Capacity			
- Compile and analyze data for anticipating water conflicts	■	■	
- Develop methodology for evaluating management options and governance styles	■	■	
- Evaluate possible models for global water governance		■	■
- Compare impacts of water governance on sustainability of water resources	■	■	■
- Identify patterns of industrial transformation in the water sector	■	■	■
- Identify global options to alleviate regional water shortages		■	■
A 3-4 The Provision of Ecosystem Goods and Services			
- Identify Ecosystem Services provided by the GWS	■	■	
- Assess impact of global change on ecosystem services of the GWS		■	■
- Investigate how human activities affect ecosystem services of the GWS		■	■

Table 6-1 (cont.)

Schedule of research activities and tasks. To be updated.

	Phase 1 years 0 - 2	Phase 2 years 3 - 5	Phase 3 Years 6 - 10
Cross-cutting Activities			
A 4-1 Building the GWS Information Base			
- Construct meta-data base of information sources	X		
- Identify gaps in data	X	X	
- Develop new condition indicators of the GWS	X		
- Map and assess the current and past state of the GWS	X	X	X
- Construct a GWSP data base	X	X	X
A 4-2 GWSP Discourse			
- Develop a conceptual framework for studying the GWS and elaborate the concept of the GWS	X		
- Develop a GWS-lexicon	X		
A 4-3 Develop World Water Models and Analyze Scenarios			
- Assemble input data sets for model runs and calibration	X		
- Assemble input data sets for model validation	X	X	
- Develop standardized validation tests/ model intercomparison	X	X	
- Develop guidelines for error and uncertainty analysis	X	X	
- Develop visualization and presentation techniques for model output	X	X	
- Use models to generate scenarios of the GWS	X	X	
- Make scenario results widely available		X	X
- Develop integrated framework for data, modelling and assessment	X	X	
Dialogue, Capacity Building and Education			
Dialogue			
- Organize GWSP-Dialogue activities	X	X	X
- GWSP media outreach	X	X	X
- Develop 'White Papers' cooperatively with stakeholders		X	X
Capacity Building			
- Support students and postdocs as members of research teams	X	X	X
- Form advisory teams of researchers and educators for regions requesting short term assistance	X	X	X
- Promote research projects through integrated regional studies	X	X	X
- Identify opportunities for governmental agencies for capacity building in developing countries	X	X	X
Education			
- Create a GWS curriculum for schools, universities and practicing professionals	X	X	
- Develop an interactive GWSP website	X	X	X
- Provide workshops for decision-makers and managers	X	X	X
- Organize training and workshops for young scientists	X	X	X

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