INTRODUCTION

The role of hydrology in water resources management

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HISTORICAL REVIEW

Presuppositions for a modern hydrology had been developed from the 17th up to the middle of the 20th century. Between 1930 and 1950, new methodological developments of basic modules describing water and mass flows in the diverse sub-systems of river basins and aquifers ushered in the era of modern hydrology. Innovative technical developments introduced since the 1950s, such as new measuring techniques (digital data recording, new measuring sensors, remote sensing, tracers, etc.), automatic digital data recording and transmission techniques, electronic data processing, data banks, geographical information systems (GIS), the development of modelling techniques and other developments allowed the practical utilization of new methods and opened up new fields of application for hydrological data. It became possible to process measured hydrological data in near real time.

However, the hydrologist's main task up to the middle of the last century consisted of measuring water levels and discharges and publishing these data in yearbooks. Only a very few countries had developed flood forecasting systems. During that period, planning of water projects was done solely by water engineers. Education in hydrology was non-existent and most hydrologists came from geography or water engineering.

This situation changed about 50 years ago. Along with the International Hydrological Decade (IHD) of UNESCO, from 1965 to 1975, a rapid development of hydrology started in many countries. Many nations created a hydrological research and education scheme. Ever since, and through the support of the International Hydrological Programme (IHP) of UNESCO, the importance of hydrology has become increasingly recognized in most countries. Today, the education of hydrologists as well as the availability of hydrological methods has improved worldwide. Hydrologists are aware of water-related problems at all levels and scales, and they are also aware of environmental issues. Today, hydrologists can resort to a broad spectrum of tools and hydrological models for solving water-related problems and improving the planning of water projects. Nevertheless, hydrologists in many countries are currently insufficiently involved in planning and operation of water projects.

THE WORLD WATER CRISIS

In the course of the last 50 years the world has changed dramatically. During the last 100 years the population of the world has increased threefold, water demand sevenfold and irrigated agricultural areas sixfold. In the last century, water use increased at twice the rate of population growth. Water scarcity is one of the main global problems in this century. The number of regions with chronic water shortages is increasing globally. It is expected that 1800 million people will live in countries or regions with absolute water scarcity in 2025 and two-thirds of the world population could be affected by water stress conditions (UNESCO-WWAP, 2003, 2006).

Water as a renewable resource is only renewable within limits. The extent to which the increasing demands of water can be met is finite. Today, the ground- and surface water resources are overexploited in many countries and their water quality is often critical (UNESCO-WWAP, 2003).

With population growth and concerns about water scarcity increasing, several countries are developing desalination plants to convert seawater, brackish water or treated wastewater into freshwater. At US$0.50 for one cubic metre, the present price of this water is still very high. Efforts must be made to reduce these costs by more efficient technology and management.

Drinking water consumption usually varies between 2 and 3 litres/person/day, while other domestic water requirements for personal and household hygiene necessitate between 30 and 300 litres/person/day. In most countries, usable water resources are decreasing due to water pollution. This trend has been accelerating in the course of the last decades. Each litre of wastewater pollutes at least 8 litres of freshwater. Therefore some 12 000 km^3 of the globe's water resources are unavailable for many uses each year. At present, only about a tenth of the domestic wastewater in developing countries is collected and only about a tenth of existing wastewater treatment plants operates reliably and efficiently. Over one billion people around the world still use unsafe drinking water sources. Globally, some 1.8 million people die annually due to inadequate sanitation or water supply. Some 90% of them are children under five years of age (UNESCO-WWAP, 2006).

Food and agriculture are the largest consumers of water. The production of food requires water volumes of between 2000 and 5000 litres/person/day. Most of the water used for crop production originates from rain stored in the ground. Up to 70% of the water withdrawn from rivers and groundwater is used for irrigation purposes. Arid and semi-arid regions, where irrigation plays an important role in agriculture, have the highest level of water withdrawal for agriculture. Poor drainage and irrigation practices have led to salinization and water-logging resulting in diminished agricultural productivity. Salinization and water-logging in large-scale irrigation projects are often the result of an unavailable drainage infrastructure, lacking because it was not included in the engineering design in order to make projects look more attractive economically. Salinization seriously affects 20 to 30 million ha worldwide. That is about 25% of irrigated areas in arid and semi-arid zones and about 10% of all areas under irrigation. Remediation of salted soils is very costly.

Today, approximately 3% of the world's land surface is covered by urban areas which are still growing rapidly in almost all regions. The proportion of the global population living in urban settings grew from 29 to 47% between 1950 and 2000. Between the years 2008 to 2010, it is estimated that more than 50% of the world's population will live in urban centres. This number is expected to rise to 56% by 2020. Over 900 million urban residents are living in slums (UNESCO-WWAP, 2006).

Water is also used for electric power generation. In many countries hydropower is the only truly sustainable energy source. Providing 19% of total electricity production, hydropower is a major contributor to the world's energy balance. Water is also essential for cooling purposes for thermal and nuclear power generation.

Climate change is intensifying the problems in many countries, adding a whole new dimension to the issues. All human activities connected with the use of water are affected by this process. All developments mentioned in the previous paragraphs will result in a worldwide water crisis affecting all spheres of life and society.

ENVIRONMENTAL ISSUES

Human activities have dramatically reduced biological diversity on land and in water bodies such as oceans, lakes and rivers around the whole Earth. Water bodies have attracted human settlements for thousands of years. As a result, humans have altered coastlines, rivers, lakes and wetlands (Millennium Ecosystem Assessment, 2005; UNESCO-WWAP, 2003).

Degradation of land in arid, semi-arid and dry sub-humid areas is mostly caused by human activities and climatic variations. One third of the world's land surface is covered by dry land ecosystems. These areas are very fragile and react strongly to inappropriate land use. Worldwide, more than 250 million people are affected by desertification. It is an alarming fact that another one billion people are at risk, residing in over 100 countries. Over 70% of the world's dry lands, excluding hyper-arid deserts, are degraded.

Accommodating the human demand for logging and land conversion has shrunk the Earth's forests by half. These activities contribute to the rise of soil erosion and water scarcity.

Wetlands are among the world's most productive environments. Human practices are degrading and destroying these wetlands at a rapid rate. Wetlands are the basis of biological diversity and provide the foundation for countless species of plants and animals. They are home to a plethora of birds, mammals, reptiles, amphibians, fish and invertebrate species. Wetlands are important stores of plant genetic material. They contain only 10% of the water in lakes and other surface waters. About 50% of the wetlands that existed in 1900 had been lost by the late 1990s as a result of the conversion of land for agricultural purposes.

The main causes of aquatic species decline and ecosystem degradation are physical alteration, habitat degradation and destruction, water withdrawal, overexploitation, pollution, overfishing, the introduction of non-native invasive species, the disruption of river flows by dams and other diversions. Over 3000 freshwater species are threatened, of which more than 1000 are fish and nearly 1900 amphibians (Millennium Ecosystem Assessment, 2005).

All the human activities mentioned above are also affecting the water cycle and water resources; preventing the rapid and accelerating degradation of ecosystems is essential for all life on Earth (UNESCO-WWAP, 2006). Hydrologists should keep this, as well as the environmental effects in mind, and water managers should consider these problems when planning new projects.

OTHER WATER RELATED ISSUES

For the last 30 years, the world has suffered from a dramatic increase in the number of natural disasters and their effects, ranging from extreme droughts to huge floods. More than 665 000 people died in 2557 natural disasters between 1990 and 2000, of which 90% were water-related events (UNESCO-WWAP, 2003, 2006). This development is caused by poor water and land management and probably by climate change. Some 75% of the world's population is living in areas affected by earthquakes, tropical cyclones, floods or droughts. Some 184 deaths per day are triggered by these disasters in different parts of the world. Along channelized rivers, more than 100 000 people were killed by floods in the 1990s, with damages amounting to US$243 billion.

At present, worldwide, there are more than 47 000 large dams (dams higher than 15 m) and 800 000 smaller ones. The amount of water impounded behind dams has quadrupled since 1960. There is still a need for new dams for energy generation, irrigation, water supply, flood protection and other purposes. But in many countries there are conflicts because of the construction of new dams. Big dams are not sustainable, but they continue to be built. Globally, 80 million to 100 million people have been displaced by dams. And, some 400 million people living downstream have been affected by the loss of fisheries, fertile land and coastal erosion.

More than 18 000 people have been killed by some 60 dam failures outside of China in the past 50 years. Inside China, some 3200 dams have failed since 1950 and more than 90 000 people have died as a direct consequence. The largest number of dam breaks occurs in connection with floods.

Around the world, 5000 large dams are at least 50 years old. Many dams are still unsafe. The dam industry must take their responsibilities regarding dam safety seriously. The safer the dam the more it will cost. Dam safety depends on the capacity of its spillways to cope with floods, the quality of its construction materials and the extent of local geological exploration. Building of dams in regions with a high degree of seismicity should be avoided. It must also be kept in mind that large reservoirs may induce earthquakes of up to a degree of 6.3 on the Richter scale. Furthermore it is alarming that in the planning of existing large dams the effects of possible climate changes have not been taken into account (WCD, 2000).

It should be recalled, however, that, without the existence of dams, particularly large dams, a significant percentage of the world population would be unable to exist. On the other hand, large dams have probably done more harm to freshwater ecosystems than any other human intervention. Some 40 to 80 million people have been displaced due to dam construction in the past six decades.

At present two million people are displaced every year as a consequence of the construction of large dams. In many cases, they have received no or insufficient compensation. In many countries in Africa, Asia and Latin America people have been violently displaced. A great majority of dam refugees have been economically, culturally and psychologically ruined (UNEP Dams and Development Project, 2007).

Larger rivers and lakes are also used for inland navigation and transportation. Large water schemes for irrigation, like those in Central Asia (Aral Sea), and river regulation works or flow regulation have destroyed the ecosystems in downstream areas. Many people have lost their livelihood as a consequence yet their losses were inadequately compensated (UNESCO-WWAP, 2006).

There are some 263 transboundary river basins world-wide. One third of them are shared by more than two countries, and 19 involve five or more sovereign states. In total, 145 nations include territories within transboundary basins; 21 of these lie entirely within a transboundary basin. In the last 50 years, 200 water-related treaties were negotiated and signed. There have been a total of 1831 negotiations over water between two or more nations during the past 50 years, of which 507 ended in conflicts and 1228 were settled amicably. World-wide there are some 273 transboundary aquifer systems (UNESCO-WWAP, 2003, 2006; UNESCO, 2008).

Reaching agreements on international water courses is very difficult to achieve. In 1997, after 27 years of development, the UN Convention on the Law of the Non-Navigational Uses of International Watercourses was adopted. The Convention sets out the basic rights and obligations between states relating to the management of international watercourses. Ten years later the Watercourses Convention was ratified by 16 nations only, with 35 being needed for the Convention to enter into force.

Worldwide there were over 17 million refugees and people displaced by wars, persecution and other causes. These people often have tremendous impacts on the water resources in the area to which they have been displaced. Conflicts are almost always followed by environmental crises such as chemicals leaching into water bodies, damage of irrigation systems, deforestation, destruction of infrastructure, and collapse of local and national governance structures.

The issues of a degraded environment and the declining health of water resources increase the gap between rich and poor. Poverty remains high and inequalities are growing. Over one billion people survive on less than US$1 a day, and up to two billion are severely affected by water scarcity and water pollution (UNESCO-WWAP, 2003, 2006).

Taking into account the complexity, uncertainty and increasing vulnerability of both natural and human systems, water managers around the Earth are agreed that the best way forward is through an inclusive and integrated approach – Integrated Water Resources Management (IWRM) – which recognizes the need to ensure a holistic protection system.

RECENT REQUIREMENTS

At present, there continues to be a societal need for planning, construction and operation of different types of water management projects. Water authorities, politicians, developmental, planning and environmental agencies, consulting engineers and building contractors are responsible for the implementation of such projects. Local and regional stakeholders play an important role in the advancement of new projects.

All the potential negative effects mentioned in the previous paragraphs should be taken into account in planning, implementing and managing water related projects and systems. Negative impacts on water resources, ecology and society must be avoided. More attention should be devoted to future developments, such as population growth, mitigation, climate change, potential future conflicts and others. Key objectives such as the economical use of water, a fair distribution of water, protection of water against pollution, water hazard protection and the security of water projects should be achieved, as well as protection of ecosystems, as much as possible.

In this regard, hydrology plays an important role in water resources management. It is the task and the challenge of hydrologists to assist and advise water resources managers and decision makers in solving future water-related problems and to contribute in diminishing negative effects. Hydrologists should oppose the over-exploitation of water resources and offences against the principle of sustainability.

Water resource projects require historical and new hydrological data in the fields of surface water and groundwater (quantity and quality), forecasts and predictions and other information for application in planning, design, construction and optimizing the water-related systems. In this respect, hydrological networks constitute the basis for planning and operation of water projects and systems. These networks must provide for the monitoring of water quality data. The networks must be sufficiently close-meshed to cover all regions with human population. Efficiency and reliability in managing water resource systems depends largely on the quantity and quality of the hydrological information used in their planning and operation.

In the papers presented at the Symposium on *The Role of Hydrology in Water Resources Management* and published here, some of the problems mentioned above are discussed. Besides general discussions, case studies are also included. These problems are considered against the background of small or medium-sized catchments. No papers were presented on large river basins or transboundary rivers, and only one paper deals with a large water scheme. Nearly 40% of the papers deal with issues concerning IWRM. The remainder address the four themes *Hydrology and Dams*, *Hydrology for Flood Protection*, *Hydrology and Water Supply Systems*, and *Hydrology for the Protection of Ecosystems* and are represented by three to seven papers; only two papers deal with *Hydrology for Groundwater Management*. Twenty-two papers are from Europe, five from each of Africa and North America and only one from each of Asia and Latin America. Therefore, the papers presented here have a regional imbalance.

Many interesting papers announced were withdrawn. Unfortunately, many scientists, especially from Africa and Asia had to decline their participation in the symposium owing to a lack of travel funds, problems in obtaining visa or other reasons.

The first paper of these Symposium Proceedings is a keynote lecture by the incoming IAHS President, Gordon Young, which deals with the tasks and responsibilities of water managers and enlarges upon some of the issues mentioned in the previous paragraphs. It is followed by a paper on the functions of hydrologists and decisions-makers in water resources management. The next paper considers the legal aspects of hydrology in the management of international water resources.

After these more general papers, is a group that present hydrological models as well as models for integrated water resources management including ecological, economic and social aspects.

Five of the contributions published consider the influence of possible climate changes on water resources management. Others deal with risk management or vulnerability assessment. Water resources management generally is considered in case studies of rivers, lakes or coastal zones. Furthermore, there are papers discussing the real-time access of hydrological data, data monitoring, remote sensing and data transmission systems. Some authors present results from special investigations. One paper deals with the application of the European Water Framework Directive (WFD) and the assessment of minimum flow in rivers, while another paper presents the transfer of hydrological knowledge to managers or the public by a national hydrological atlas.

Discussion of the interdependence between the tasks and work of hydrologists and those of water managers was one of the main goals of the symposium organizers. The presentations given at the symposiums revealed, however, a dominance of papers dealing with hydrological modelling (including also ecological, economic and social aspects), but the inclusion of such important information in water management decisions seems not to be well enough established, yet. However, some interesting approaches in this direction were presented and it is hoped that in the near future more formalized decision support systems (DSS) will be developed and actually implemented in practice. This could enable decision makers in the field of water management to make their highly complex multi-criteria decisions with a higher degree of confidence. This will require a closer cooperation between water managers and hydrologists in the future than visible at present.

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