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Harnessing science and technology for sustainable development: water, sanitation and human settlements

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I. Introduction

1. This paper, prepared by the scientific and technological community, provides a brief review of recent scientific and technological progress and identifies priorities for implementation of measures aimed at strengthening science and technology for supplying and managing freshwater resources in a sustainable manner (chapter 18 of Agenda 21). While focusing mainly on freshwater, this paper also addresses cross-linkages between freshwater, sanitation (chapter 21) and human settlements (chapter 7). Sections dealing with technology address more fully needs related to sanitation and human settlements.

2. The United Nations Millennium Declaration called upon all members of the United Nations "to stop the unsustainable exploitation of water resources by developing water management strategies at the regional, national and local levels which promote both equitable access and adequate supplies". Improving water management can make a significant contribution to achieving most of the Millennium Development Goals established by the General Assembly in 2000, in particular those with regard to poverty, hunger, child mortality, maternal mortality and major diseases. To stop the unsustainable exploitation of freshwater is at the centre of Goal 7: "Ensure environmental sustainability", including three targets: (i) to integrate the principles of sustainable development in country policies and programmes and reverse the loss of environmental resources; (ii) to halve, by 2015, the proportion of people without sustainable access to safe drinking water; (iii) by 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers. Other related targets have been established, also in 2000, by the Water Supply and Sanitation Collaborative Council (WSSCC), including the target "to provide water, sanitation and hygiene for all by 2025".

3. In order to meet these targets, massive efforts aimed at developing and applying science and technology will be needed. The World Summit on Sustainable Development in 2002 recognized this need. The Johannesburg Plan of Implementation, adopted by the World Summit, includes separate sections on measures needed by Governments and other stakeholders concerning strengthening science, technology and education for sustainable development. Water and sanitation received particularly great attention by the Summit. The specific section in the Johannesburg Plan of Implementation on water and sanitation starts with an agreement on a target "to halve, by the year 2015, the proportion of the people who are unable to reach or to afford safe drinking water (as outlined in the Millennium Declaration) and the proportion of people who do not have access to basic sanitation". As already recommended in chapter 18 of Agenda 21, the Plan also focuses on the need to develop and apply integrated approaches to water resources management.

4. Four recommendations in the section of the Johannesburg Plan on water and sanitation specifically deal with science and technology issues. These recommendations are:

(a) Improve water resource management and scientific understanding of the water cycle through cooperation in joint observation and research, and for this purpose encourage and promote knowledge-sharing and provide capacity-building and the transfer of technology, as mutually agreed, including remote-sensing and satellite technologies, particularly to developing countries and countries with economies in transition;

(b) Support developing countries and countries with economies in transition in their efforts to monitor and assess the quantity and quality of water resources, including through the establishment and/or further development of national monitoring networks and water resources databases and the development of relevant national indicators;

(c) Support the diffusion of technology and capacity-building for non-conventional water resources and conservation technologies, to developing countries and regions facing water scarcity conditions or subject to drought and desertification, through technical and financial support and capacity-building;

(d) Support, where appropriate, efforts and programmes for energy-sufficient, sustainable and cost-effective desalination of seawater, water recycling and water harvesting from coastal fogs in developing countries, through such measures as technological, technical and financial assistance and other modalities.

5. In focusing on science and technology, this paper emphasizes the integration of the environmental, social and economic pillars of sustainable development related to freshwater, sanitation and human settlements. In order to better inform decision makers on integrated approaches and to influence the institutional, technological and behavioural responses needed to address interrelated environment-development issues, scientific research must become more policy relevant; participatory; address a variety of geographic scales from global to local; integrate various epistemologies; and be holistic and systemic. This requires integrating the natural, social, engineering and health science domains, so that the relationships among driving forces such as economic development, changes in the environment, and poverty alleviation and quality of life can be better understood. At present, application of science and technology is often hampered by barriers existing between the different domains and disciplines of science and technology.

II. The challenges

A world water crisis?

6. There is growing concern that the world will be facing a water crisis as the middle of the century approaches, should current consumption trends continue. Countries in the Middle East, parts of Africa and Asia already face considerable stress, because demand for water is outstripping the available resource. The situation in the basin of the Aral Sea is a pointer towards the future. By 2050, with a world population increase of some 4 billion, water requirements will probably be double today's figure, particularly water for food, about 70 and 80 per cent of all demands. At the same time, mounting pollution and the impact of climate-change on hydrological regimes will further stress the available resource. The result will be greater strains on water resources and aquatic environments over widening areas of the globe.

7. The population increase also means that many more people will suffer from floods, droughts, soil erosion and other hazards — hazards which are likely to be intensified by continuing land use changes, especially urban growth in the third

world. The vitality of freshwater ecosystems, as we know them, will be changed, possibly for ever.

8. The impacts of climate change will exacerbate water problems in agriculture, forestry, fisheries, power generation, environmental integrity, and in many other areas. The climate link, through changing precipitation patterns, will certainly also have major implications on other water-related processes, such as erosion and sedimentation. In turn, these will likely have unprecedented impacts on storage space that might be reduced significantly over the coming three decades. Half of Africa's reservoir capacity, for instance, could be lost to siltation with dramatic impacts on water supply .

Water and people — the dynamics of the changes

9. Water plays a key role in the development and functioning of society by serving as a basic resource for irrigation, livestock production, fisheries, aquaculture, and hydroelectric power. Adequate water use in households, businesses and manufacturing is a prerequisite of economic growth. Many of the world's diseases are waterborne, and clean water and sanitation are important for reducing the incidence of these diseases. Of course, water provides habitat and sustenance for a rich diversity of plant and animal species that make up aquatic and riparian ecosystems. 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.

10. Population growth and socio-economic development are currently driving a rapid increase in water demand. Agriculture is the largest "user" of water with 71 per cent of all withdrawals globally (up to 97 per cent for some countries), followed by industry with 20 per cent on average and domestic withdrawals amounting to 9 per cent. The need to feed a growing and developing population, including improved meat diets requiring huge amounts of grain and water, will be a major challenge for decades to come.

11. Humans use half of the runoff accessible globally. There are several regions in which water demand reaches or even exceeds renewable resources, leading to fossil water overuse. However, the issue is not one of only physical supply. Water pollution and a general lack of access to clean water have severe health consequences. Nearly 2.5 billion people are without adequate sanitation and more than 1 billion lack access to clean drinking water. Around 6,000 children die every day from diseases associated with lack of access to safe drinking water, inadequate sanitation and poor hygiene (WEHAB (water, energy, health, agriculture and biodiversity) Working Group; World Summit, 2002). Human health and livelihood are thus not only linked to water quantity (and access) but equally to the quality of that water. Further, it has been argued that the water crisis is mainly a crisis of governance, including economic, institutional, social, ethical and legal aspects. Direct human competition for water, changes in biogeochemical cycling and water quality, and looming global climate change, will all determine the future state of inland freshwater resources.

III. Recent progress in science and technology

12. Whatever we use today in terms of technology is by and large (say at least 70 per cent) the result of scientific research undertaken in the past 50 years — whether we speak about sewage treatment technologies or real-time flood forecasting systems. Looking at the last 10 years, we may conclude that considerable progress has been made in applying science at various scales, ranging from computer-assisted drafting (CAD) technologies in water supply design, through computer-controlled treatment plant operation to assessing the hydrological response to climate variability and change.

13. Progress in understanding water systems has developed considerably over the last 20-30 years, particularly through advances in modelling, modelling being a prerequisite of successful water resources management. Now a very wide range of models exists and more are being developed, including rainfall-runoff models, aquifer models, ecosystem models and catchments models, as well as management models backed up by decision support systems and expert systems. There are stochastic and deterministic models of different levels of complexity. However, there are several studies which demonstrate that the sophistication and likeness to reality of a model is no guide to its predictive success.

14. In recent years the application of more realistic models has improved capabilities for forecasting, prediction and control of water systems for various purposes. The increased reliability and range of weather forecasts, particularly forecasts of precipitation, including quantitative forecasts, has allowed more timely and precise river flow forecasts to be made. Longer-term seasonal forecasts of rainfall and the resulting forecasts of hydrological conditions has been the basis for mitigation measures (e.g., in north-east Brazil). Seasonal rainfall forecasts have been made for the same area and elsewhere from global circulation models. It is recognized that further improvements to these capabilities could lead to enhanced predictions of the magnitude and distribution of regional climate variables, especially with advances in the understanding of the incidence of El Niño/Southern Oscillation (ENSO) events.

15. The scientific and technological community has developed several initiatives focused on scientific and technological issues for safe drinking water. For example, the Third World Academy of Sciences (TWAS) in 2002 issued a report entitled "Safe Drinking Water: The need, the problem, solutions and an action plan".

16. In spite of the remarkable progress that has been achieved over the past 10 years in various fields of water sciences, their practical application is lagging behind. This is due to the lack of appropriate capacities, primarily in the case of developing countries, both institutionally and with regard to human capacity. Observation networks of basic hydrological phenomena, which are to serve as the bases of any water resources policy-making at all levels, further deteriorated over the past 10 years. As a combined effect of these, water related uncertainties have not been reduced and, consequently, the associated risks in water management have increased over the past decade instead of being minimized. A case in point is the increased occurrence of water-related extremes, such as floods, that are clearly linked to climate variability and change. The mechanisms involved, however, are not yet clearly understood, owing primarily to the very limited, and diminishing for that matter, availability of data.

Integrated assessments

17. Chapter 18 of Agenda 21 identified the need for water resources assessments, including technology assessments, as one of its high priority programme areas. It is fair to say that only limited progress has been made with regard to implementing that recommendation of the United Nations Conference on Environment and Development. There is a lack of national water assessments and even a decline in operating national water monitoring. At the international level, several initiatives have been launched with the aim of assessing our state of knowledge, technology available, the socio-economic context and the dynamics of this “water system”. The need for comprehensive assessments is also dictated by the need to provide assessment information for integrated water resources management. This reflects major progress since 1992. Current thinking accepts that the management of water, as well as sanitation and human settlements, must be undertaken using an integrated and ecosystem approach.

18. The United Nations system has responded by undertaking a collective, system-wide continuing assessment process, the World Water Assessment Programme. Building on the achievements of previous endeavours, the programme focuses on the evolving freshwater situation throughout the world. The results of this assessment are to be published at regular intervals in the *World Water Development Report*. The first report was published in 2003. While the World Water Assessment Programme is undertaken by the concerned United Nations system bodies, with its secretariat based at UNESCO, many specialized members of the scientific and technological community worldwide have provided the basic scientific and technological input. The first edition of the *World Water Development Report* provides a comprehensive analysis of the nature and scope of the looming world water crisis. It also defines the problems with regard to sanitation, rural settlements and cities. Moreover, it presents tools available to mitigate risks and to introduce integrated water policies. The second edition of the report, to be issued in 2006, will put particular emphasis on policy-relevant tools for decision makers and planners to address the Millennium Development Goals, and to encourage behavioural and institutional changes.

19. Water-related indicators are indispensable for the assessment of progress of society in coping with water-related stress at the global, regional, national and subnational levels. Among the activities of the second phase of the World Water Assessment Programme, development of a comprehensive set of scientific and policy-relevant indicators has been stressed. At present, water-related sustainable development indicators are still woefully insufficient. Once an agreed-upon list of indicators has been established, indicator application must be based on a solid set of data and information. The programme, in close cooperation with the scientific and technological community, intends to develop a database system on metadata that could assist in assessing the most relevant and reliable data and information.

20. The Scientific Committee on Problems of the Environment (SCOPE) of the International Council for Scientific Unions is currently undertaking an assessment of the scientific validity and policy relevance of the most commonly used sustainable development indicator sets worldwide, with the aim of providing guidance for the further development and application of integrated indicators. Indicators on freshwater, sanitation and human settlements will be fully taken into account. It is expected that the assessment will be completed by the end of 2004.

21. Another integrated global assessment is the Global International Waters Assessment (GIWA) undertaken by UNEP in cooperation with relevant members of the scientific and technological community. The assessment is intended to support the implementation of the international waters component of the Global Environment Facility (GEF). It focuses on 66 transboundary water areas worldwide. The assessment, thus, includes marine water areas, surface freshwater areas and groundwater bodies. The results of the assessments are being published in a series of regional reports.

The information society

22. The first phase of the World Summit on the Information Society, held at Geneva in December 2003, highlighted the specific opportunities and challenges provided by the information revolution based on new information and communication technologies (ICTs). The science community presented an Agenda for Action (see www.icsu.org) to the Summit. The advancement of science and technology in the areas of freshwater, sanitation and human settlements, and of scientific advice for decision-making, can also benefit greatly from these new technologies.

23. Strengthening the public domain for science and ensuring free and open access to scientific data and information are essential steps in the construction of an equitable information society and in preventing the looming water crisis. Access to data and knowledge is dependent on infrastructure. The World Summit on the Information Society, inter alia, endorsed the need to ensure that all universities and research institutions worldwide should have affordable and reliable high-speed Internet connections within the next five years. However, the reality is that, even where the hardware is available, scientific data and information in many areas are not universally and openly accessible. Intellectual property rights regimes, database protection legislation, and the cost of some scientific journals are still contributing to a very significant knowledge divide in science and technology in general and science and technology for sustainable freshwater management in particular.

IV. The need for more appropriate water and sanitation technologies

24. Water resources are developed in a sequence which is determined by access and cost. Groundwater tends to supply the smaller settlements and small-scale agriculture, surface water, from rivers and lakes, is more typical for cities and larger-scale irrigated agricultural development (which itself tends to develop where there is an adequate supply of water). The quality in these sources usually requires only conventional treatment (e.g., settling, filtering, chlorination). As the local sources are exhausted, the supply systems are expanded further away and deeper in the ground, also tapping water that requires more advanced treatment, especially for domestic use.

25. There are various techniques and practices by which the availability of water in the soil, aquifers or pipes can be enhanced, and by which available water resources can be made more accessible to water users. With regard to pollution, emphasis should be placed on prevention rather than remediation.

Wise use and management of groundwater resources

26. Groundwater aquifers vary in susceptibility to uncontrolled exploitation and invulnerability to anthropogenic pollution. The vulnerability of aquifers needs to be assessed to improve protection of groundwater resources. The aim should therefore be to protect both the quantity and quality of groundwater. An integrated approach to municipal, private and industrial groundwater utilization and wastewater disposal is needed (it has never been achieved in the past). The aim for both urban and rural groundwater management is: to conserve groundwater for potable and sensitive uses; to maintain good yields of groundwater; to safeguard water quality; and to handle solid waste and liquid effluents effectively.

Technologies for water in agriculture

27. Rainwater-harvesting technologies combined with supplemental irrigation has proven to be a favourable approach for dry tropical regions to make better use of the erratic large intensive rainfalls. Instead of letting the rainwater wash away from the crop fields and feed into poorly used rivers or create damaging floods, it can be captured — to some extent — as runoff by simple technologies during intensive rainfalls, and thereafter used for supplemental irrigation during dry spells. To become cost-effective, natural gravity on sloping land should be taken advantage of for water conveyance.

28. Drip irrigation is another central technology for dry tropical regions where the evaporation losses from the fields generally are high. By dripping water directly to the cultivated plants from perforated surface or sub-surface pipes, the crop is supplied with only the necessary amounts of water within a small soil volume near the roots and at the right time. Water consumption by weeds (weed evapotranspiration) and soil evaporation is thereby dramatically reduced, and drainage losses and runoff are reduced to near zero. Instead, water uptake efficiency by the crop plant is greatly improved as well as the overall crop production output. Drip irrigation technologies are available for both large-scale commercial enterprises as well as for low cost small-scale farming systems

Mitigation of soil salinization by drainage and effective irrigation

29. Measures to mitigate and reduce soil salinization is critical for the maintenance of soil productivity of farmlands in semi-arid and arid (sub) tropical regions of the world. Technical measures to mitigate soil salinization are of different types: leaching methods, methods to maintain high soil water content, drainage methods, different irrigating method, use of salinity tolerant crops, etc. Some are field technical methods and some are computer model methods. They have advantages and disadvantages, which very often are site-specific. Most importantly, mitigation of salinized soils should be approached from an integrated land-water management perspective. Salinization of soils is practically unavoidable in the semi-arid and arid regions, and all measures available to mitigate this soil productivity-reducing process should be encouraged. Valuable irrigation water should be carefully applied and allowed to sufficiently drain off the land.

Water saving

30. Reparation of existent water storage and distribution systems should always be a high priority, as leakage from broken pipes and cisterns have caused high

unproductive water losses annually. Leak detection in water distribution systems is increasingly important in utility operations and maintenance, employing such tools as water audit, calibration and checking of master water meters, and the use of ICT monitoring devices and systems. Existing sewer lines should, however, not be extended, as they demand large water volumes that only increase the volume of wastewater and thus the cost of wastewater treatment.

31. An important economic advantage of reducing water demand is extending the use of a waterworks without expansion of facilities. Lower consumption also slows depletion of a limited water supply. Conservation programmes can be directed towards consumer consumption. Water conservation is based on public education, installation of water efficient plumbing fixtures and pricing. Modern water-saving plumbing features can reduce domestic consumption by approximately one half.

Desalination

32. At present, desalination of salty water (i.e., mainly sea and brackish water) to produce freshwater is now a realistic option only for energy-rich countries in the semi-arid and arid regions. The desalinated water is mainly intended for domestic and limited industrial uses, as it would be too expensive to use for irrigation (with current energy requirements for desalination). For Middle Eastern oil-rich countries, desalination provides an important part of the water supply for households. More than 25 per cent of the world's desalination capacity is found in Saudi Arabia, followed by 12 per cent in the United States of America, 10 per cent in Kuwait and the United Arab Emirates. However, even the best desalination plants currently in operation require nearly 30 times more energy than would theoretically be possible (which is 2.8 kJ for removing the salt from one litre of seawater). Through improvements in technology, the present energy requirement could be reduced to 10 times the theoretical minimum, at least.

33. The different desalination techniques are classified according to the energy required: thermal, mechanical, electrical, or chemical. The different techniques used are distillation, freezing, reverse osmosis (of sea or brackish water), and electro-dialysis (of sea or brackish water). Essentially, each desalination method also differs in the amount of energy required. Some modern desalination facilities are now being run with electricity produced by wind turbines (e.g., in Egypt and the Libyan Arab Jamahiriya) or other solar-electric technologies, such as photovoltaics (e.g., in the Libyan Arab Jamahiriya, Qatar, and Indonesia). Yet, most commercial desalination methods still take advantage of inexpensive fossil fuels.

Waste and wastewater practices

34. Efforts should be made to encourage on-site separation, local treatment and recycling. The central component is the physical separation of different wastes already at the source, in order to avoid the accumulation of wastes and wastewater that need later handling and treatment. Different types of wastewater can thereby be reused for suitable purposes, with regard to their respective quality.

35. Ecological sanitation (ecosan) is the alternative sanitary approach to the handling, purification, and recycling of human excreta. It has proven to effectively reduce health and pollution-related problems in the developing world. The ecosan approach has many advantages, not least for households where fertilizers are

expensive and financial assets are limited. It is affordable, simple, ecologically sustainable, and as effective as any other modern sanitary method.

36. Flushing-toilets consume large amounts of water for flushing, transportation, and dilution (about 40 per cent of the total residential water demand). Support should instead be given to the installation of urine-diversion toilets, which do not waste any water for flushing and disposal. Support should therefore be given to such local domestic sanitary practices. Other technologies which should be promoted include establishing dual-pipe systems for potable and non-potable water, and low-cost treatment of industrial and municipal wastewater.

Artificial recharge of groundwater

37. Artificial recharge of groundwater using waste water can by advantage be practised in semi-arid and arid regions if the discharge point is situated at a distance from the recharge area and the aquifer is a soil aquifer. Such practice has two advantages: on the one hand, it generates naturally purified water at low costs; on the other, it is a natural form of water storage and does not entail any evaporation losses. Technically, water is allowed to infiltrate and replenish the aquifer during short periods with excess of surface water. Artificial groundwater recharge can be used to naturally purify wastewater and turn into potable groundwater. Treated wastewater can be allowed to recharge the groundwater aquifer by first letting it pass through purifying material, e.g., sandbanks. Drinking water quality is thus obtained without using any or very few chemicals. Reuse of wastewater after local or central treatment, constitutes an important strategy for urban areas. Methods for recharging aquifers include in-stream recharge (river infiltration) and recharge through a series of ponds (bank infiltration).

Agricultural practices and techniques

38. In order to minimize unproductive soil water losses, agricultural practices and techniques need to be adapted to the climatic and soil-related conditions at hand. First of all, in climatic regions with high evaporative demand and where water is demanded by other competitive uses, large-scale irrigation — particularly with non-renewable (fossil) groundwater — should be avoided to the greatest extent possible. Instead, irrigation should be limited and supplied by recycled water of adequate quality (such as grey water, e.g.). Secondly, irrigation practices should be combined with effective drainage practices in order to reduce soil evaporation, runoff, and water logging. Irrigation should be carried out in ways that minimize the need for additional water application to mitigate salinization. Thirdly, crop selection may be an important measure to lower the evapotranspiration from crops, as water is consumed at different rates by different crop varieties. Fourthly, soil conservation measures could help to minimize evaporation losses from the soil and transpiration from weed, and could enhance water infiltration, the availability of water in the root zone, and/or the recharge rate of groundwater into aquifers.

Industrial practices

39. Implementation of favourable effective industrial practices and technologies is a central and indispensable part of pollution prevention programmes. Successfully adopted, these can help to: (a) reduce the extraction of valuable raw material; (b) reduce the generation of hazardous wastes; (c) increase recycling of valuable rest

products; (d) reduce wastewater volumes; and (e) reduce the volume of fluid and solid wastes. The pressures on ecosystems and water resources, from resources extraction and pollution, can thereby be significantly reduced. Before selection or assessment of a particular technology is made, the entire lifecycle of the product should be investigated, i.e., the extraction of raw materials; the production of primary products; product manufacturing; utilization; discharge landfill, or shredding; production of recycled product; and back to a new phase of product manufacturing (etc.).

40. Pollution prevention should prioritize waste reduction over recycling, but if waste-reduction technologies are not available, recycling is a good approach to reducing waste generation. The cleaner technology must reduce the quantity and/or toxicity of the waste produced. The textile, mining, metal, and oil-refinement industries are heavy polluters of nearby watercourses for which clean technologies exist.

V. Declining capacity to monitor water resources

41. The scientific understanding of water systems is, of course, only as good as the available data. Hence, sound scientific advice to decision makers cannot be provided without improved data obtained on a continuous basis through effective monitoring systems. However, the assessments of water resources which have been conducted together with other surveys invariably indicate that water data are lacking over much of the globe. This lack of data applies to surface and groundwater, and to quantity and quality. Indeed the reliability and availability of data have declined since the mid-1980s, largely because national hydrological and allied networks have been retrenched. Data on water chemistry, for example, are lacking, as are data on productivity and biodiversity. Data on water use are in even worse condition. There are effective national systems for collecting and managing water-use data and allied information in, at most, 30 countries. For the remaining 180 or so, estimates of water use rely on population figures and assessments of the irrigated area. Several international initiatives have been launched to counter these problems.

42. The use of remote sensing offers increasing potential for monitoring a growing number of hydrological variables and overcoming the difficulties of determining meaningful spatial patterns from ground-based observations. Data provided by geographical information systems along with digital terrain models are becoming very important. Data produced by tracer techniques are also proving to be very useful in quantifying sources of stream flow and residence times and in exploring flow paths. The advent of global data centres, such as the Global Runoff Data Centre in Koblenz, Germany, has eased the problem of access to world and national data sets and the International Association of Hydrological Sciences Global Databases Metadata System facilitates finding existing data sets. The Internet is a prime tool in accessing these data.

43. At the sixth session of the Commission on Sustainable Development, in 1998, the report of the Secretary-General on strategic approaches to freshwater management (E/CN.17/1998/2) already identified this issue of a declining capacity in freshwater data generation as one of the main current gaps in freshwater management. The situation described in paragraph 18 of that report has not improved but rather worsened:

> "18. The effective assessment and management of water resources, including the prevention and mitigation of water-related disasters, is not possible without adequate physical and socio-economic information flows. Yet the capability to provide accurate water quality and quantity data is deficient in many countries. For years, the capacity of hydrological offices in developing countries, particularly in Africa, has been declining in terms of operation and maintenance and the extent of hydrologic networks. Few, if any, developing countries have a significant capability for water quality monitoring. In addition, the fragmentation of national organizations dealing with water resources assessment and the lack of integration of hydrological and land-use data, as well as of economic and demographic data, severely limit the usefulness of existing information."

Consequently, the need for the establishment or improvement of national water monitoring programmes is evident, as well as the need to standardize the methods of monitoring at the international level as much as possible.

44. Several international initiatives have been developed to address this problem. WMO has launched a global network of national hydrological observatories, the World Hydrological Observing System. UNEP coordinates the Global Water Quality Monitoring Programme (GEMS/WATER). FRIEND (Flow Regimes from International Experimental and Network Data) is an initiative of the International Hydrological Programme of UNESCO assisting in the setting up of a regional networks for analysing hydrological data. Other initiatives of the International Hydrological Programme such as the International Groundwater Resources Assessment Centre, the map Groundwater Resources of the World and Internationally Shared Aquifer Resources Management are contributing towards these goals by inventorying information from physical data on aquifers to monitoring guidelines.

45. The capacity to monitor the availability and variability of freshwater in mountain areas is even more precarious than the generally insufficient situation in most lowland areas. Mountains and highlands are often called the world's natural "water towers", because they provide essential freshwater for populations both upstream and downstream. The mean annual contribution of mountainous catchments sections to total discharge in large river basins is disproportionately high, in comparison to its lowland part. Distinctions can be made, as expected, according to climatic regions, clearly highlighting the vital role of mountain runoff in lowlands in arid and semi-arid regions.

46. In this respect, another international initiative aimed at setting up an international network of monitoring stations in mountain regions worldwide deserves support. This initiative has been launched by the Mountain Research Initiative, a consortium of several non-governmental and governmental, national and international scientific programmes and organizations involved in mountain research, in cooperation with the Global Terrestrial Observing System and UNESCO's scientific programmes on freshwater and terrestrial ecosystems.

47. With regard to setting up a comprehensive monitoring system at the global level, the Integrated Global Observing Strategy, with the active participation of its scientific community partners, in 2000 identified water-cycle observations as a critical area that required the development of a specific Integrated Global Observing Strategy theme entitled "The Integrated Global Water Cycle Observations". In

addition to promoting the development of and capacity for water resources observations, the Integrated Global Water Cycle Observations will be geared towards producing or contributing to: products for improved water management decisions on a variety of time and space scales; weather and climate forecasting; and enhanced understanding of the global water cycle.

VI. The need for research focused on sustainability issues and policy relevance

48. Implementing Agenda 21 and the Johannesburg Plan in the areas of freshwater, sanitation and human settlements, during the next decade and beyond, will build on progress made during the past 10 years in generating knowledge targeted at sustainable development objectives and in developing cleaner and more affordable technologies. However, enhancing the scientific and technological community's capacity to contribute to sustainable development will require significant changes. The scientific and technological community is committed to implementing necessary changes and developing appropriate partnerships. These changes include:

(a) *More policy-relevant science*. A much greater share of research must integrate problem-oriented and interdisciplinary research that addresses the social, economic and environmental pillars of sustainable development. Good science is essential for good governance.

(b) *Broad-based, participatory approaches*. Traditional divides between the natural, social, economic, and engineering sciences and other major stakeholders must be bridged. Research agendas must be defined through broad-based, participatory approaches involving those in need of scientific information. The scientific and technological community accepts its responsibility to improve cooperation with other parts of civil society, the private sector, Governments, and intergovernmental bodies.

Science and technology for sustainable development

49. At the World Summit on Sustainable Development, the scientific and technological community pledged to address, in a policy-relevant context, priority issues of what science and technology can contribute to sustainable development. In 2003, ICSU, together with the Third World Academy of Science and the Initiative for Science and Technology for Sustainability formed a consortium to this end. The three partners are currently developing a plan for future activities needed in research, capacity-building and linking knowledge to action. The results from this planning exercise will be ready in late 2004 and will be the foundation for a concerted effort by the scientific and technological community to address the World Summit challenges.

50. Support for science for sustainable development has also been expressed in the communiqué from the G8 Summit in Evian (2003) and the meeting of OECD Ministers for Science and Technology in January 2004.

Relevant ongoing international research programmes

51. Several major ongoing international scientific programmes are either focused exclusively on freshwater and related issues, or include major research components

focused on the global hydrological system. These programmes are the International Hydrological Programme of UNESCO; the World Climate Research Programme, jointly undertaken by ICSU, WMO, and the Intergovernmental Oceanographic Commission of UNESCO; the International Geosphere-Biosphere Programme of ICSU; and the International Human Dimensions Programme on Global Environmental Change, jointly undertaken by the International Social Science Council and ICSU.

52. The International Hydrological Programme, UNESCO's intergovernmental scientific cooperation programme in freshwater, aims at the improvement of the scientific and technological basis for the rational management of water resources, including the protection of the environment. The research activities of the International Human Dimensions Programme address regional priorities worldwide. The overall focus of the current International Hydrological Programme-VI (2002-2007) is on "Water Interactions: Systems at Risk and Social Challenges". That programme promotes a holistic integrated approach, by simultaneously addressing quantity and quality, science and policy, and water and civilization aspects. Through its network of related centres and institutes, and the network of university chairs, UNESCO's International Hydrological Programme builds capacities and distributes science-based information on water and sanitation in the regions.

53. The World Climate Research Programme includes among its main scientific activities the Global Energy and Water Cycle Experiment aimed at determining the fluxes of water and energy globally, using both observations and computational models. Another relevant World Climate Research Programme activity is the Study on Climate Variability and Predictability. Among the current scientific challenges for the World Climate Research Programme are the lack of an integrated global precipitation product and the uncertainties in climate change projections of hydrologic variables, owing to the uncertainties in the feedback between warming, water vapour and clouds. An example of water-related research questions addressed by the International Geosphere-Biosphere Programme is the Biosphere Aspects of the Hydrological Cycle Project. The Geosphere-Biosphere Programme, the World Climate Research Programme and the International Human Dimensions Programme on Global Environmental Change work together in joint efforts to enhance scientific training and capacity-building in developing countries.

Sustainability of the global water system — a new frontier of research

54. A new concept of a global water system is currently being developed by the international scientific community which will focus on integrating the human component with the physical, as well as biological and biochemical components. This approach will provide the basis for a new interdisciplinary frontier of research for the years to come.

55. The global water system is not only a feature of non-living dynamics of the earth system, but an equally important if more subtle feature of human society. The global water system has co-evolved along with the process of increasingly tight economic, social, technological and other couplings among societies that 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 water abstraction rates worldwide and

therefore on the level of wastewater discharges, the state of hydrologic regimes and the biogeochemistry of waters.

56. The 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.

57. 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 the linkages and feedback of the system that operate on the global or large-scale. They must also give equal attention to the many social science and natural science aspects of the system. Current scientific methods are also likely to be inadequate because they have evolved in a tradition of solving single disciplinary problems. By comparison, researching the global water system will require a wide variety of multi- or interdisciplinary approaches spanning the socio-economic, political, physical and ecological sciences. These methods will range from social science surveys, hydrological field measurements, remote-sensing, and mathematical modelling.

Establishing the Global Water System Project

58. In response to the urgent need to better understand the global water system, the organizations of the Earth System Science Partnership — i.e., IGBP, WCRP, IHDP and DIVERSITAS — propose to establish the Global Water System Project. These institutions are in a unique position to establish the project because between them they cover scientific research on the most important elements of the global water system. At the same time they lead current efforts to understand both the natural science and social science aspects of global change.

59. Among the themes selected by the scientific community for this new international scientific undertaking the following figure prominently: How resilient and adaptable is society and the global water system to change, and what are sustainable water management strategies? The Global Water System Project will have a built-in major education, and capacity-building component, with particular attention to developing countries, as well as a process of dialogue with other stakeholders, in particular policy makers at all levels.

The social sciences agenda

60. Over the past years the awareness of the importance of the human dimension and of integrated rather than technological solutions in water management has increased. More research was done on integrated assessment and human dimensions aspects of water management. The following important areas of research, while they already have received some attention, need to be pursued vigorously:

- Participatory, poly-centric, multi-scale governance
- Public-private partnerships
- Water rights and water pricing
- Institutional innovations, such as water user associations or water markets
- Empowerment of marginalized groups and gender issues

- The problem of institutional fit (biophysical scales defined by river basins and administrative boundaries) and interplay (vertical — local, regional, national — and horizontal — e.g., agriculture, spatial planning, water management — institutional fragmentation)
- Governance, conflicts-of-interest resolution and other issues to be addressed by social sciences research
- Integrated indicators related to water, sanitation and human settlements.

61. What is needed in particular is the design of mechanisms that guide individual human behaviour and the interaction among different actors in such a way that the whole system is managed in a sustainable manner.

62. Institutions can be defined as rule systems governing the behaviour of human actors. The market is a formal rule system where the information about an environmental good is only inherent in its price. However, institutional resource regimes are more complex and cannot be reduced to market mechanisms. Major research issues are institutional change and the combination of different instruments to achieve more sustainable resource management regimes. Participatory methods are increasingly developed for the assessment and implementation of "socio-technical" solutions tailored to the local environmental, cultural, institutional and historical setting. More comparative research would foster progress in this field. An improved understanding of the role of participation (stakeholder groups and the public at large) and of the production and role of different types of knowledge during the various stages of tackling water resource management issues is also needed.

63. The importance of economic instruments increased considerably, in particular for the valuation of environmental goods and services and the development of pricing schemes. The latter is also required for implementing a full cost recovery under the polluter-pays principle. Currently, valuation schemes and specific tools are explored that combine factual knowledge and subjective stakeholder perceptions.

VII. Water education, training and scientific and technological institutional capacity-building

64. One of the biggest tasks facing those addressing the challenge of sustainable development, both in developed and developing countries, is the need to generate the capacity to apply science and technology to this goal. There is a need to rethink water education at all levels.

65. Chapters 7, 18 and 21 of Agenda 21 call for education for water users and public awareness-raising educational programmes, training of water scientists and managers at all levels, strengthening training capacities in developing countries, training of professionals and improving career structures, establishing or strengthening capacities for research and development programmes. In Johannesburg, in 2002, a number of key institutions signed the Ubuntu Declaration, with pledges to develop coordinated activities related to education for sustainable development.

66. The scientific and technological community has identified two crucial areas which require concerted action by all stakeholders concerned, as described below.

Improving education and capacity-building

67. The importance of addressing capacity-building issues has recently been highlighted in a report from the InterAcademy Council (Inventing a Better Future: A Strategy for Building Worldwide Capacities in Science and Technology). The report was presented by the Secretary-General, Kofi Annan, to United Nations delegations in early February 2004.

68. Enhanced science teaching at both the primary and secondary levels is central to scientific and technological capacity-building and to a better public understanding of sustainable development issues. A further target should be to increase the percentage of university-level students enrolled in science, mathematics, and engineering. Current enrolment is decreasing in most developed and developing countries alike. Three core components are critical in enhancing capacity: skilled individuals, efficient institutions, and active networks. Capacity-building at the international, regional, and subregional levels must be given increased attention, as it is often the most cost-efficient way to build a critical mass of scientific and technological capacity.

Bridging the North-South divide in scientific and technological capacity

69. While it is necessary to build and enhance strong scientific and technological capacity in all regions of the world, this need is particularly pressing in developing countries. The OECD countries annually spend more on research and development than the economic output of the world's 61 least developed countries. Developed countries employ 12 times the per capita number of scientists and engineers in research and development than developing countries, where there is woefully weak institutional scientific and technological capacity. Ten years after the United Nations Conference on Environment and Development — the Earth Summit (Rio de Janeiro, 1992), this challenge remains a major obstacle to sustainable development. Developing countries must address this problem and significantly enhance investment in higher education and scientific and technological capacity. Developed countries must accept their responsibility for much improved knowledge and technology sharing. Bilateral donors and other funding mechanisms should substantially increase the funds they allocate to science and technology for sustainable development, especially in the area of scientific and technological capacity-building.

70. Important issues in the water education sector include the exchange and development of educational and training materials, community-based learning, demand assessment and articulation systems, information and communication technologies, and networking as a tool for water education and training delivery. Many developing countries, where the need is the greatest, have not yet been able to develop and integrate the necessary human and institutional capacities for an effective water management regime.

71. The UNESCO-International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE) Institute for Water Education, in the Netherlands, addresses the need for training opportunities for water scientists and managers from developing countries. The Institute is generally aimed at strengthening and mobilizing the global educational and knowledge base for integrated water resources management. FAO, the United Nations Centre for Human Settlements (Habitat),

UNESCO, UNEP, WHO, WMO and other international organizations within and outside the United Nations system offer science and technology training programmes in their respective areas of competence related to freshwater, sanitation and human settlements. Another forum for relevant human capacity-building is provided by the International Water Management Institute of the Consultative Group on International Agricultural Research.

72. A major instrument for enhancing education focused on water, sanitation and human settlements issues will be the United Nations Decade of Education for Sustainable Development, 2005 to 2014. Within different domains of education for sustainable development (basic education; higher education; reorienting existing education programmes; developing public awareness and understanding of sustainability; specialized training) the specific sustainability issues related to freshwater, sanitation, hygiene, health and human settlements should receive particular attention. The scientific and technological community for its part is committed to make an active and important contribution to the Decade in this respect.

73. There are a number of other issues which the scientific and technological community considers of great importance in efforts to increase relevant science and technology. These issues include:

- The key of international cooperation, both North-South and South-South, together with the need to address the impact of the so-called brain drain (or "brain gain") on science capacity-building
- The need to recognize that sustainable development topics in general are more likely to be interdisciplinary in their focus, to incorporate issues related to social impact, to include local knowledge, and to draw upon work with communities
- The need to pay particular attention to education and training for girls and women, as well as to place particular emphasis on the role of girls and women in freshwater, sanitation and human settlement issues.

VIII. Conclusion and recommendations

74. This paper has presented some of the main issues related to the essential contributions that science and technology must make towards implementing Agenda 21 and the Johannesburg Plan in the areas of freshwater, sanitation and human settlements. While indicating fields of science and technology where some progress has been achieved during the last 12 years, the conclusion can be drawn that progress is too slow given the crisis situation with regard to water, sanitation and human settlements in most of the developing regions of the world. Science and engineering must give higher priority to identifying solutions for these pressing problems with enhanced support by society and government. Investments in science and technology continue to be inadequate, especially in developing countries, where funding for research and development is often less than 0.5 per cent of annual GDP. Investments in science and technology are among the highest-yielding investments that a nation can make.

75. Science and technology for sustainable development must be global in its reach, yet local and regional in its implementation. It is not possible, however, for

science and technology to effectively contribute to sustainable development if countries do not have basic scientific capacity. The responsibility for building and maintaining this capacity lies squarely on the shoulders of national Governments but requires significantly enhanced collaboration and partnerships with the global development assistance community and the scientific and technological community.

76. The scientific and technological community has a responsibility to inform and participate in decision-making processes in order to increase the impact of science in policy discussions and decisions. In an international arena increasingly defined by knowledge, in a global economy depending more and more on science and technology for its success, and in a world challenged by environmental problems that spill across political and cultural boundaries, scientists and engineers have an obligation to become more and more involved in sustainable development policy issues and implementation.

77. The scientific and technological community is conscious that it must reach out more to the other major groups and to the broad array of stakeholders in the sustainable management of freshwater, sanitation and human settlements. Participatory approaches in developing local science and technology agendas for sustainable development will in future be important instruments to this end.

78. Specific recommendations resulting from a review of science and technology issues related to freshwater, sanitation and human settlements presented in this document are the following:

- Review, maintain and most often improve national data collection/monitoring networks, including those that provide real-time data for floods and drought forecasting
- Strengthen the freshwater-related components of global environmental observing systems and make these systems fully operational, including enhanced support for efforts aimed at implementation of observing systems such as the Integrated Global Observing Strategy and the proposed Integrated Earth Observation System or Systems
- Undertake national, regional and international integrated assessments on water and related sanitation and human settlements issues
- Review, develop further and apply respective integrated indicator sets
- Review, develop further and apply more appropriate water and sanitation technologies
- Develop and undertake interdisciplinary, policy-relevant research at the national level focused on sustainability issues related to freshwater, sanitation and human settlements addressing the local context
- Support international scientific cooperation programmes in this field and knowledge sharing
- Invest in relevant scientific and technological capacity-building at the national level and support respective measures in those developing countries which lack this capacity
- Contribute to rethinking and reorienting water education at all levels

- Enhance specialized training facilities everywhere but in particular in developing countries
- Ensure high-priority attention to freshwater, sanitation and human settlements in the activities of the United Nations Decade of Education for Sustainable Development (2005 to 2014)
- Pay particular attention to education and training for girls and women.