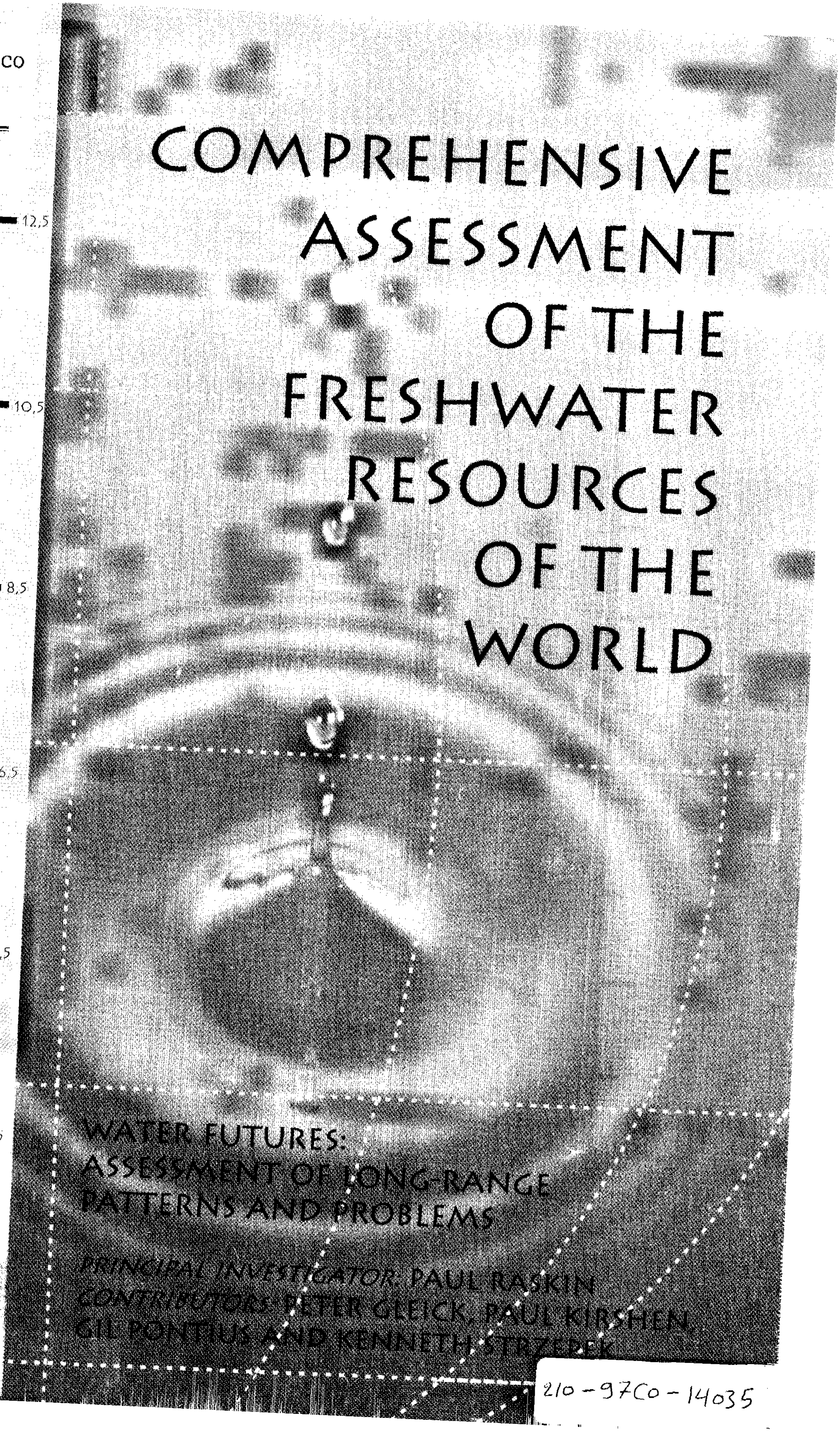
COMPREHENSIVE ASSESSMENT OF THE FRESHWATER RESOURCES OF THE WORLD



WATER FUTURES: ASSESSMENT OF LONG-RANGE PATTERNS AND PROBLEMS

PRINCIPAL INVESTIGATOR: PAUL RASKIN
CONTRIBUTORS: PETER GLEICK, PAUL KIRSHEN, GIL PONTIUS AND KENNETH STRZEPEK

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ISBN: 91 88714 45 4

FOREWORD

A rapidly growing demand on freshwater resources, resulting in increased water stress in several parts of the world, increasing pollution of freshwater resources and degraded ecosystems, made the UN Commission for Sustainable Development in 1994 call for a Comprehensive Assessment of the Freshwater Resources of the World. The final report (E/CN.17/1997/9), prepared by a Steering Committee consisting of representatives for UN/DPCSD, FAO, UNEP, WMO, UNESCO, WHO, UNDP, UNIDO, the World Bank, and Stockholm Environment Institute, is presented to the CSD 1997 and to the UN General Assembly Special Session June 1997.

Within the process of the Assessment a number of background documents and commissioned papers were prepared by experts with various professional background. The document *Water Futures: Assessment of Long-Range Patterns and Problems* is one of these. As a scientifically based document, any opinion expressed is that of the author(s) and does not necessarily reflect the opinion of the Steering Committee.

Stockholm, June1997

Gunilla Björklund
Executive secretary
Comprehensive Freshwater Assessment

ABSTRACT

Water requirements to the year 2025 at regional and national levels are examined in order to assess emerging problems of stress on freshwater resources. Long-range water patterns will be governed by such future factors as population, economic scale and structure, technology, consumption patterns, agricultural practices and policy approaches. This study focuses on *Conventional Development Scenarios* which are driven by: 1) commonly used demographic and economic projections, 2) a convergence hypothesis that developing region consumption and production practices will evolve gradually in a globalizing economy toward those of industrialized regions, 3) an assumption of gradual technological advance without major surprises, and 4) the absence of major policy changes affecting water needs or use.

The scenarios show a rapid increase in water requirements, especially in developing regions. Several indices are introduced for assessing the level of future water vulnerability at the country level. These include the *use-to-resource ratio*, a gauge of average overall pressure on water resources and threats to aquatic ecosystems; *coefficient of variation of precipitation*, a measure of hydrological fluctuations; *storage-to-flow ratio*, an indicator of the capacity of infrastructure to mute such fluctuation; and *import dependence*, an index of reliance on inflows from contiguous countries. To supplement these physical indices of vulnerability, a socio-economic coping capacity index (*average future per capita income*) represents a country's ability to endure emerging water problems and uncertainties. Together, the indices are used to signal changing water vulnerability for each country as the scenarios unfold. The information is capsulated in a series of "water stress" maps.

The *Conventional Development Scenarios* are not predictions. Their power is to reveal the consequences of common assumptions about the future and of

policy complacency. We learn that such scenarios would bring a continuing deterioration of water conditions in those areas that are already water scarce, and an extension of new water stress conditions in many places throughout the world. *Conventional Development Scenarios* do not represent a satisfactory future when judged on sustainable development criteria. However they are not inevitable. It is suggested how we might envision more sustainable and desirable futures, and act to achieve them.

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1. CONTEXT AND GENERAL CONCEPTS

1.1 Purpose

At its Second Session in 1994, the United Nations Commission on Sustainable Development (CSD) called for a comprehensive assessment of current and future freshwater resources, needs and problems. The Stockholm Environment Institute (SEI) was commissioned by the Swedish Government to assume the Swedish responsibilities for preparing the assessment together with United Nations organizations. A Steering Committee for the Comprehensive Freshwater Assessment (referred to below as CFA) was established with representatives from SEI and relevant United Nations organizations (the ACC Subcommittee on Water Resources, FAO, UNEP, WMO, UNESCO, WHO, UNDP, UNIDO, and the World Bank).

The CFA will submit a report for submission to the CSD and ultimately to the UN General Assembly. The report will be organized into four chapters:

1. A statement explaining the need for such an assessment;
2. A description of the availability, quality and variability of freshwater resources of the world and the use to which they are put at present;
3. An investigation of current and future water needs and the problems that must be faced at the global, regional and national levels;
4. Strategies and options for the sustainable development of freshwater resources of the world.

This document provides background information and analysis for Chapter 3 on water needs and problems. The focus is on emerging water problems to the year 2025.

Toward this end, the remainder of Part I of this document describes a conceptual framework for exploring long-range water issues. Part II examines a baseline *Conventional Development Scenario*, and reports a range of regional and global water withdrawal requirements for the year 2025. Part III considers the implication of the scenario at the national level by introducing *water stress* and *vulnerability indices*, and applying them to identify current and emerging water problems. Finally Part IV discusses strategic implications, and sketches a vision of a water future offering a more positive alternative to conventional development scenarios.

1.2 A Systems Perspective

Water plays a complex and multifaceted role in both human activities and natural systems. Consequently, an analytic framework for the *comprehensive* assessment of water issues must understand water uses and resources as embedded in wider ecological and development processes. Two broad concepts critical to our consideration of long range water issues are *sustainability* and *socio-ecological systems*.[1]

At the 1992 Earth Summit, the nations of the world acknowledged that a new development model was needed for reconciling social, economic and environmental goals at global, national and local levels. *Sustainable development* would seek to

[1] The discussion is based on Raskin et al. (1996).

provide for the people of today while protecting the quality of natural resources and ecosystems for future generations.

Given the breadth of this new concept, it is not surprising that the term sustainable development has been used in a variety of ways (Lele, 1991). This is especially the case since the concept has normative aspects. Indeed, a basic principle of sustainability -- the call to protect ecological systems for future generations -- is an ethical appeal. Definitions of sustainability to some degree reflect the values of those using them -- a banker can speak of sustainable economic growth, an environmentalist can stress the idea of the intrinsic value of nature, or a social reformer can insist that sustainability embrace the goals of social justice and poverty eradication.

To develop the sustainability concept further, it is useful to introduce the notion of the *socio-ecological system.* As illustrated in Figure 1, the socio-ecological system is comprised of economic, social and ecological subsystems and their interactions (Shaw et al., 1991; Gallopin, 1994). The economic system includes capital, production and labor; the social subsystem includes consumption patterns, demographics and culture; and the ecological subsystem includes ecosystems, natural resources and biophysical processes. Socio-ecological systems defined at river basin, national, regional and global scales interact through cultural influence, environmental impacts, transnational corporate and financial institutions, trade, global governance, etc. (see Figure 2).

In the broadest sense, sustainability refers to the capacity for socio-ecological systems to persist unimpaired into the future. This by no means implies stasis -- an impossibility in complex and dynamic systems -- but rather the capacity to adapt and develop. A sustainable system is *resilient* in the face of extreme perturbations and *flexible* in responding to changing circumstances. Sustainability as a *process* of development, not a final state, has ecological, social and economic dimensions. While it is difficult to define that process precisely, it is less difficult to identify *unsustainability*, patterns that place the socio-ecological system at risk of devolution and collapse.

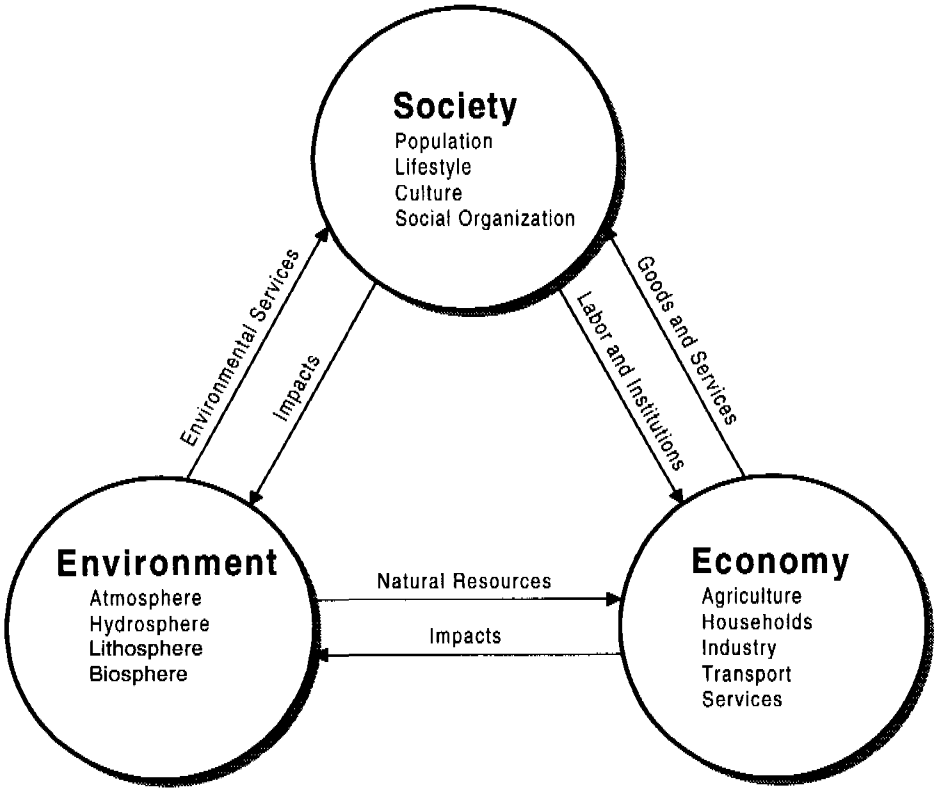

Figure 1. The Socio-Ecological System

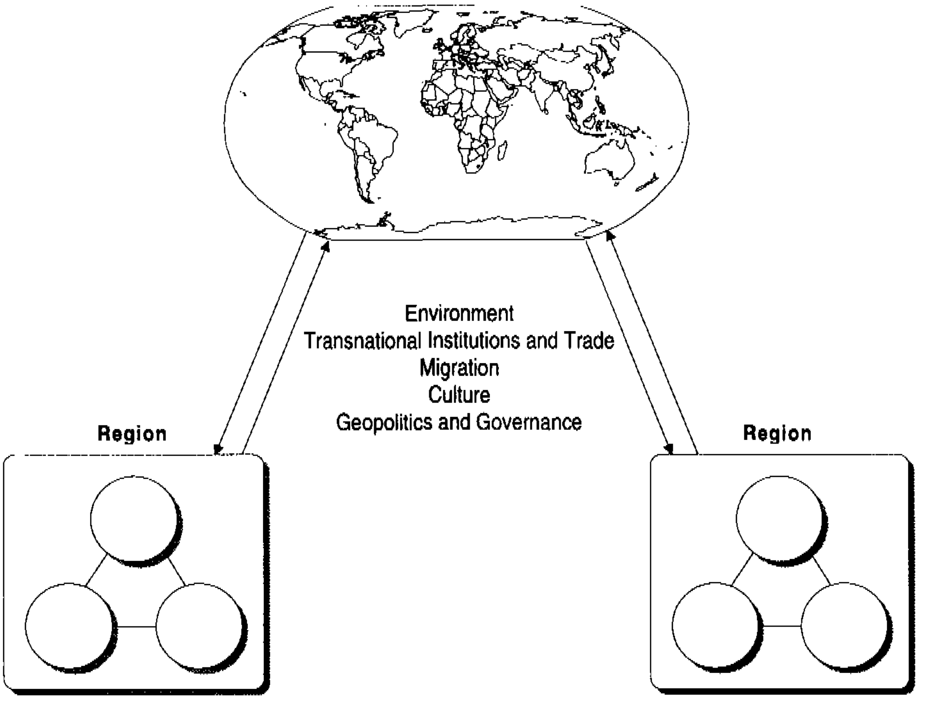

Figure 2. Global Linkages

It is useful to separate two dimensions of the sustainability problem -- biophysical and socio-economic. In biophysical terms, sustainability implies the maintenance of ecosystems, bio-geochemical cycles, and the natural resource base at levels that maintain the functional and structural integrity of natural systems. This means that they can continue to support human material well-being, provide ecological services and preserve the natural heritage for human appreciation. Beyond these pragmatic goals, many would add as an ethical imperative that the protection of the biosphere is a valid end-in-itself. Biophysical sustainability requires that human activity not destroy the regenerative capacity of natural capital or irreversibly stress atmospheric, hydrological or terrestrial ecosystems with waste and pollution.

Sustainable development, from a biophysical perspective, puts focus on reducing the *throughput* -- flows of materials and energy into and waste out of production and consumption activities -- toward levels that are within renewable resource flows and assimilative capacities of ecosystems. Sustainability implies living on natural "interest", not unduly drawing down natural capital. Throughput levels, in turn, are dependent on consumption patterns, population levels, production technologies, land-use management and other factors that determine the requirements for virgin materials and pollution loads. In one sense, the problem of sustainability is the conflict between rising throughput rates, driven by growing economies, and finite biospheric capacities.

In addition to the issue of the scale of biophysical impacts, there are critical socio-economic aspects of sustainability. The notion of social sustainability calls attention to the level and quality of stability, social cohesion and solidarity in society. To the degree that distributional equity, political participation, and access to education and health services are perceived to be acceptable, a social system will enjoy the commitment, loyalty and affiliation of its participants, and be prepared to respond better to changing endogenous and exogenous circumstances. At the other extreme, a system which is inequitable and coercive tends to be more rigid, prone to conflict and less able to adapt gently to internal or external disturbances.

Finally, economic development may be a precondition for a transition to sustainability. The wide adoption of sustainability principles will require that economic systems and distribution patterns provide basic human needs, reliable livelihoods and freedom from drudgery. Desperate people often focus on immediate survival questions, and discount the long range value of ecological preservation. The economic development of poor countries and communities to meet these goals is critical to sustainability. Rich countries and communities also have a development challenge -- the transformation of the model for development from ever-increasing growth in consumption, to a culture of material sufficiency and the growth of quality values through, for example, the resurrection of stronger community ties, more meaningful leisure activities and greater regard for nature.

In general, the concept of socio-economic *development,* the expansion or realization of potentialities, must be distinguished from economic *growth,* or material accretion (Goodland et al., 1992). The latter is the hallmark of the industrial era and does not appear to be indefinitely maintainable. Human cultural, intellectual, artistic, social and technological development, together with the provision for basic physical needs, is not only compatible with sustainability, but essential for its realization.

The socio-ecological system as a whole is quite complex with many important interactions and linkages within and between social, economic and ecological subsystems. Consequently, it is natural for policy-relevant exercises to concentrate on specific aspects of the problem, e.g., energy use, agriculture, cities, atmospheric chemistry, marine biology and, the subject of this study, freshwater resources. There is no substitute for detailed treatments of themes and sectoral planning exercises.

At the same time, only by placing the sectoral components in the context of the socio-ecological whole can we gain adequate understanding and offer wise policy directions. It would be a perverse, albeit unintentional, outcome if efforts to achieve sustainability in one area undermined the prospects for others.

The comprehensive water assessment illustrates the need for a systems perspective. The historic tendency to view *water sector* problems from a narrow technical emphasis -- hydrology, engineering, water management -- is not sufficient to support the sustainability idea. In addition to the sectoral emphasis, evaluation of water resources, uses, and constraints in the context of sustainable development requires consideration of several types of linkages. First, at the level of *sectoral interactions*, water issues are linked to agriculture, industry, commercial and domestic uses. Water policy must pay attention to the demand side of the equation, and to the problems of efficiency of water use, and the mix of economic activities. Second, water issues are linked spatially, as the analysis of *competition for scarce water resources* often requires a comprehensive spatial framework to balance water allocation between competing demand centers -- urban and rural, upstream and downstream, and among countries where shared international river basins raise water planning to a geo-political level. Third, water as an *ecological resource* requires that the question of the long term preservation of the integrity of water-dependent eco-systems and the hydrological system can no longer be ignored in water assessments and development.

Ultimately, exploring the interplay between human activities and water resources raises fundamental questions. Will the resource intensive consumption patterns of the industrial countries persist and even grow? Will this type of life-style remain the development goal universally? What will be future population levels? Will there be greater economic and social equity among countries and among people within countries? What are the alternative forms of development for achieving the goals of meeting human needs and aspirations and environmental sustainability? What are the implications for lifestyles, values, institutions and policies?

Different sets of answers to questions like these imply different water futures. As we begin to imagine alternative futures -- and their water implications -- we enter the world of *scenarios*, a subject to which we now turn.

1.3 The Scenario Approach

Long range socio-ecological futures are inherently unpredictable. Three types of indeterminacy can be distinguished. First, insufficient information on both the current state of the system and on forces governing its dynamics lead to statistical dispersion over possible future states. Second, even if precise information were available, complex systems are known to exhibit turbulent behavior, extreme sensitivity to initial conditions and branching behaviors at various thresholds which thwart prediction (Gleick, 1987; Funtowicz and Ravetz, 1993). Finally, the future is unknowable to the degree it is the result of freely determined human choices.

While we cannot know what will be, we can use *scenarios* to tell plausible and interesting stories about what could be. In theater parlance, a scenario is a summary of a play. Analogously, a development scenario is a structured narrative for describing the contours of alternative human futures. As applied to long range resource assessments, the scenario draws on both science -- our understanding of historical patterns, current conditions and physical and social processes -- and the imagination to conceive, articulate and evaluate a range of socio-ecological pathways.

In so doing, scenarios can illuminate the relationships within the total system, and the relationship between human actions and the whole complex of interconnected outcomes. It is this added insight, leading to more informed and rational action, that is the foremost goal of scenarios, rather than prediction of the future. Scenarios help policy makers and managers understand how the world might change, recognize when it is changing, and if it does change, know what to do (Schwartz, 1991). Scenarios are not projections or forecasts; indeed, scenarios may not even be probable. Rather, they provide a cognitive aid for visualizing alternative futures, for examining the interactions of socio-economic and environmental change, and for guiding policy formulation.

A water scenario includes assumptions about many interacting elements: population and demographic patterns, life-styles and consumption patterns, economic scale and structure, technology and efficiency, policies and institutions. A scenario is a *what if* proposition. What are the implications if a vision of a possible future were to occur, as described by assumptions for each of these factors? What are the consequences for the sustainable use of freshwater resources?

Current socio-ecological states are subject to initial *driving forces*. The scenario narrative is, in part, a story of how the driving forces evolve (see Figure 3). However, the system evolution is not a simple mechanical unfolding from the past, because it is subject to human intention. Images, symbols and visions of the future can be sufficiently powerful to redirect beliefs, behaviors, policies, and institutions toward some futures and away from others. Thus Figure 3 shows also *attractive* and *repulsive forces*. Attracting attributes of future states might include consistency with sustainability principles -- futures which remain within certain biophysical *boundary conditions* -- and human well-being -- futures which meet various criteria for human welfare and fulfilment.

Negative images of possible future states also play a role in galvanizing efforts to redirect system evolution away from pathways leading to undesirable outcomes. So a spectrum of scenarios ranging from utopian to dystopian extremes are useful for bringing visions of future possibilities back to the present. In this sense, the attractive and repulsive forces may influence the driving forces and human development.

The final set of interactions illustrated in Figure 3, the *sideswipes*, are surprising future occurrences which can powerfully influence the evolution of the system. However, they are very difficult to predict. Extreme events -- a third world war, the diffusion of cheap nuclear fusion power, the ascendancy of fundamentalism as a dominant world movement, a major natural disaster, a rampant global epidemic, a breakdown of the climate system -- would have a strong influence on the global future, though probabilities cannot be assigned, nor can the universe of possible events even be described.

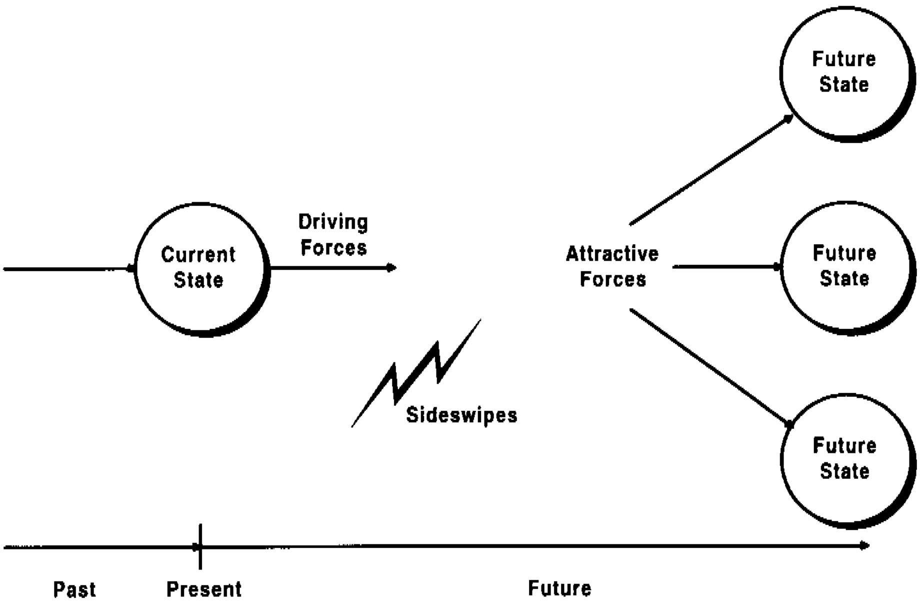

Figure 3. Driving Forces, Attractors, Sideswipes

How can the scenario framework be used to illuminate emerging water issues in the 21st century? We begin to address this question in the next section.

2 SCENARIOS OF WATER DEVELOPMENT

2.1 Driving Forces[2]

We begin by identifying several significant driving forces now operating at the global level. These transnational trends condition future activities and ultimately influence the scale and pattern of water use. Significant trends and processes include *population growth*, *urbanization*, *economic globalization*, *cultural homogenization*, *environmental degradation* and *technological innovation*. Together, they are strongly interacting aspects of a unitary global phenomenon, a process which we call *conventional development.*

Although the linkages between population growth and the environment are not straightforward, for a given set of socio-economic development conditions, population growth tends to increase the pressure on resources and the environment. This effect is most pronounced among the very rich (where each additional person accounts for large incremental resource use) and the desperately poor (where the logic of survival may lead to the over use of natural capital to meet immediate needs). Beyond environmental and resource pressures, population growth can add to the risk of social friction, illegal migration, and international tension.

Global population will nearly double to over ten billion people by the year 2050, according to mid-range United Nations forecasts (Bulatao et al., 1989; United Nations, 1992a; UNPF, 1995). Fully 95 percent of the additional population will be in developing countries where population is projected to grow from about 4 billion in 1990 to 8.6 billion in 2050. With current populations in poor regions heavily weighted toward the young, there is inherent momentum for growth. Almost half of the projected population growth in developing countries would occur even if fertility rates instantly decreased to replacement levels (Bongaarts, 1994).

Rapid urbanization is another significant demographic trend with important implications for water infrastructure. The world is in the midst of a massive planetary transition from a predominately rural to a heavily urban society. Urban population increased between 1950 and 1990 by a factor of 3 with substantial further growth expected, mostly in developing regions. At current growth patterns, 85% of additional population will be urban, and the urban fraction of total population is expected to continue to rise from less than 50% today to nearly 70% projected for 2025 (United Nations, 1991).

The number and size of huge megacities has expanded apace. In 1950, there were two metropolitan areas with populations over eight million, New York and London (Harrison, 1992). By the year 1990 there were twenty (fourteen in developing countries). By 2000, there will be fifteen to twenty megacities with population over 20 million. Almost universally, urban planning institutions have been too weak to cope with rapid urban growth, turning towns into cities, cities into megacities, and, if current trends continue, megacities into continuous networks of urban centers. The deterioration of inner cities in some areas and the growth of shanty towns on the periphery in others, undermines social cohesion with the visible rise of social disparities, crime and violence. The elite adopt affluent urban life styles amidst a

[2] The discussion draws from Raskin et al. (1996).

growing underclass living in squalor, often with inadequate sanitary, health and educational services.

As the urban population increases, so do urban water stresses related to increased spatial concentration of households and industry. These include the need for expensive infrastructure to supply and distribute high quality water, and to dispose of waste products to protect human health and environmental quality.

Another major transnational process is the expansion and transformation of the world economy. Accelerated by advances in information technology and the growth of international trade agreements, the organization of production and consumer markets are becoming progressively *globalized.* Two fundamental trends -- the emergence of new national economic powers and the growth in transnational corporations -- will alter the political and economic landscape in the coming decades.

The world economy is becoming more regionally pluralistic as economies expand in developing countries, Japan and the European Union. The economy of China could grow past that of the United States in the next twenty years, with other Asian and Latin American countries becoming progressively more significant players in the global economy. Under mid-range economic projections, the size of the economies of developing countries taken in aggregate in 2025 will be about the size of all industrial countries today.

Interacting with the emergence of new national centers is the second structural transition, the increasing role of transnational corporations. The growth of huge enterprises operating in a planetary marketplace is a extension of the expansionist dynamic inherent in competitive market systems. Beyond the growth of the world economy itself, technological and institutional factors have accelerated the transition from national to transnational corporations. The revolution in communications technology, information processing, and transportation have facilitated the ability of transnationals to move facilities, products and people to the corporation's economic advantage (Reich, 1991).

At the same time, new trade agreements and the globalization of financial and currency markets have combined with post-World War II economic liberalization to challenge residual protectionist restrictions. Meanwhile, the expansion of modern infrastructure and stable legal frameworks facilitates the globalization process. An unusual coalition of forces resists these trends including nationally based economic interests, geopolitical isolationists and environmentalists who raise serious concerns about the impact of global competition on environmental protection and community stability (Daly, 1993). There is significant potential for political tensions to grow between *stateless corporations* with little allegiance to any country and the nation-state of the 21st century. Whether these tensions are resolved through a gradual balancing of global and national governance and regulatory structures, or whether they are the source of clashes and destabilization, will be an important sub-theme in the story of the 21st century (Wager, 1992).

Catalyzed by the explosion of information technology and ubiquity of electronic media, American consumer culture is rapidly permeating many societies. The rise of a global consumerist culture -- acquisitive, youth-oriented, hedonistic -- is both a result and a driver of economic globalization. At the same time, the forces of global culture homogenization trigger reactions that can increase tensions between and within nations, while reducing cultural diversity.

Several *next wave* technological innovations and trends may be identified that have the potential for affecting global dynamics significantly. Information technology (IT) -- computers, the internet, telecommunications -- was identified above as a catalyst for the globalization of financial, labor, and product markets. IT will likely continue to impact massively the structure of production units (down-sizing, just-in-time manufacturing), the nature of work (telecommuting, marketing and sales techniques) and leisure time (home shopping, interactive gaming, media access). The technology also has the potential to exacerbate tensions between those societies who are connected and those who are not connected to the *information superhighway.*

Advances in biotechnology could have an array of significant effects on future society including increased crop yields with lower chemical inputs, more effective pharmaceuticals, and, if the human gene is successfully mapped, identification and prevention of disease. The technology also raises a host of environmental risks (e.g., introduction of bio-engineered genomic material in plants that leads to population explosions and centers of disease resistance), ethical problems (e.g., the genetic engineering of humans) and political and economic concerns (e.g., new forms of dependency of developing countries on the international agro-industrial system).

Lastly, the miniaturization of mechanics -- *microdynamics* -- could fundamentally alter medicine and some industrial processes (NSF, 1989). The ultimate in this direction would be *nanotechnology*, the engineering of computers, motors and machines at the molecular level. While still in the early stages of research and development, nanodevices could revolutionize medical practices, material science, computer performance and many other applications. In one sense, nanotechnology could be a dramatic continuation of the twentieth century process of dematerialization, where progressively less material input is required per unit product, and automation, where smart machines replace manual labor. In addition to its effects on products, nanotechnology -- along with other technological development -- can diminish environmental pressure and reduce labor requirements through robotization . The latter, if not linked to a general scaling back of average work loads, could radically reduce employment opportunities. In general, these productivity enhancing technologies could have a profound effect on future societies with the potential both for increasing wealth while eliminating drudgery and environmental pressure or -- if not coupled to other social and cultural changes -- for massive social displacement.

Finally, environmental degradation as a transnational process is now recognized as a cardinal phenomenon of our era, and may be considered another significant transnational driving force. International concern has grown about human impacts on the atmosphere, water resources, the bio-accumulation of toxic substances, species loss, and the degradation of ecosystems. The cumulative effects of global environmental insults cannot be known precisely, but could have significant detrimental effects on economic performance, human health, social stability, and even international security. The realization that individual countries cannot insulate themselves from global environmental impacts is changing the basis on which industrialized countries allocate foreign assistance and is stimulating a series of international discussions and treaties to abate pressures on natural systems, possibly a harbinger of new forms of global governance.

One of the first indications that water pollution is no longer a local phenomenon was the discovery in the 1960s of contamination of Antarctic ice. A number of anthropogenic activities are causing water pollution beyond local watershed boundaries: (1) fallout from atmospheric pollution due to fossil fuel burning, industrial production, mining, smelting, and agriculture, (2) groundwater pumping in coastal and semi-arid areas that causes groundwater salinization, (3) large scale deforestation, (4) damming of rivers, and (5) destruction of wetlands (Meybeck et al., 1989). Increasingly, these problems are found in rapidly growing and industrializing countries where environmental regulations are frequently non-existent or ineffective.

There are other potentially significant global-level processes affecting water issues. For example, climate change would cause significant distortions of hydrological cycles with implications for the distribution of water resources, the incidence of diseases from water-borne vectors, and the frequency and severity of storms, floods and droughts (Epstein and Sharp, 1994).

2.2 A Conventional Development Scenario for Water

As a first step in assessing water scenarios for the 21st century, we examine the implications for the future of today's driving forces, current policies and orthodox notions of development. To that end, we introduce a *Conventional Development Scenario* (CDS)[3] for global water analysis. The CDS is neither a prediction of what *will* happen nor a statement of what *should* happen. It describes the direction we are headed and the problems we may encounter -- if current patterns and driving forces are played out.

The CDS scenario is useful as a cognitive aid for understanding the constraints on business-as-usual development, and a reference for exploring the timing and scale of policy measures required for more favorable development scenarios. Though we will focus here on the water aspects of the CDS, it should be noted that the scenario was developed as a comprehensive analysis covering such issues as energy, water, food, land use, economy, etc., and the linkages among them (Raskin et al., 1996).

The guiding principles of the CDS are *evolution, convergence, and integration.* Demographic, socio-economic and technological patterns gradually evolve without significant surprises, radical technological innovations, or fundamental policy changes. Developing and transitional regions are assumed to converge gradually toward OECD economic and water practices. Ultimately, in the CDS, the world becomes progressively more integrated both economically and culturally.

The conventional development paradigm assumes that the engines for economic growth and wealth allocation are unregulated markets, private investment, and competition; population increases at mid-range projections with a continuation of rapid urbanization; industrialization progressively absorbs nations and regions on the periphery of the marketed world economy; human motives are dominated by the value of possessive individualism with material wealth the basis for the "good life"; and the nation-state survives as the central unit of governance.

[3]The phrase *business-as-usual* is widely used to refer to a future in which current patterns are projected assuming the gradual evolution of structural patterns and no significant changes in policy. We use the term *conventional development* to underscore the normative content of such a scenario, which assumes the maintenance of a set of historically contingent values, behaviors and social and political assumptions.

2.3 Regionalization

The *spatial structure* for long range global assessment requires enough resolution for exploring important global variations and trade patterns, while not exceeding the availability of data and the capacity to grasp the main contours of the global system. For purposes of this analysis, we have grouped countries into ten global regions, based on the comparability of socio-economic development and geopolitical considerations. The regional groupings and the countries included in each are displayed in Table 1.

There are many alternative ways of defining global regions, e.g., by dominant religio-cultural practices, by agro-ecological zones, by river basin, by socio-economic system. Furthermore, there is never a sharp demarcation between regions, so certain countries can arguably be moved from one region to another without doing violence to the analysis. No configurations are without conceptual complications and daunting data problems. The regional structure employed here is reasonably manageable while preserving sufficient spatial detail for the purposes of understanding major global interactions and trends.

Table 1. Regional Structure

North America	**Eastern Europe**	**Africa (contd)**	**Middle East**
USA	Albania	Reunion	Afghanistan
Canada	Bulgaria	Rwanda	Bahrain
	Czechoslovakia	Senegal	Cyprus
Western Europe	(former)	Sierra Leone	Iran
Austria	Hungary	Somalia	Iraq
Belgium	Poland	South Africa	Israel
Denmark	Romania	Sudan	Jordan
Finland		Swaziland	Kuwait
France	**Africa**	Tanzania	Lebanon
Germany (All)	Algeria	Togo	Oman
Greece	Angola	Tunisia	Qatar
Greenland	Benin	Uganda	Saudi Arabia
Iceland	Botswana	Zaire	Syria
Ireland	Burkina Faso	Zambia	United Arab Emirates
Italy	Burundi	Zimbabwe	Yemen
Luxembourg	Cameroon		
Netherlands	Central African	**Latin America**	**China +**
Norway	Republic	Argentina	China
Portugal	Chad	Bolivia	Korea, DPR
Spain	Congo	Brazil	Laos
Sweden	Egypt	Chile	Mongolia
Switzerland	Ethiopia	Colombia	Vietnam
Turkey	Gabon	Costa Rica	
United Kingdom	Gambia	Cuba	**South & South East**
Yugoslavia (former)	Ghana	Dominican Republic	**Asia**
	Guinea	Ecuador	Bangladesh
OECD Pacific	Guinea Bissau	El Salvador	Bhutan
Australia	Ivory Coast	Guatemala	Brunei
Fiji	Kenya	Guyana	Burma
Japan	Lesotho	Haiti	Hong Kong
New Zealand	Liberia	Honduras	India
	Libya	Jamaica	Indonesia
Former Soviet Union	Madagascar	Mexico	Kampuchea
(FSU)	Malawi	Nicaragua	Korea, Republic of
Former Soviet Union	Mali	Panama	Malaysia
and Baltic States	Mauritania	Paraguay	Nepal
	Mauritius	Peru	Pakistan
	Morocco	Surinam	Papua New Guinea
	Mozambique	Trinidad & Tobago	Philippines
	Namibia	Uruguay	Singapore
	Niger	Venezuela	Sri Lanka
	Nigeria		Taiwan
			Thailand

2.4 Demographic and Economic Assumptions

The CDS population and economic assumptions are compatible with the mid-range scenarios of the Intergovernmental Panel on Climate Change (IPCC, 1990a-b; IPCC, 1992a-b). The IPCC exercise included an extensive international process that involved analysts representing all regions of the world. Regional population projections for the CDS are presented in Table 2. World population approaches 10 billion by the year 2050 with most of the increase in developing regions. By contrast, population in "industrial" and "transitional" regions[4] are relatively stable in the scenario, as their share of world population decrease from about 20% to 13%.

[4]We shall sometimes use the terms "industrial" for the three OECD regions and "transitional" for the FSU and Eastern Europe regions.

Table 2. Population Projections (Millions)

Region	1990	2025	2050	Growth Rate (%/Year) 1990-2025	2025-2050
North America	277	330	322	0.5	-0.1
Western Europe	456	489	477	0.2	-0.1
OECD Pacific	145	161	157	0.3	-0.1
Former Soviet Union	289	332	349	0.4	0.2
Eastern Europe	100	115	121	0.4	0.2
Africa	640	1,519	2,204	2.5	1.5
Latin America	445	699	812	1.3	0.6
Middle East	151	384	557	2.7	1.5
China +	1,223	1,733	1,867	1.0	0.3
South & East Asia	1,564	2,634	3,214	1.5	0.8
World	5,290	8,395	10,080	1.3	0.7
Industrial	878	980	956	0.3	-0.1
Transitional	389	447	470	0.4	0.2
Developing	4,023	6,968	8,654	1.6	0.9

Source: values for 1990 from the World Bank (1993a); projections from World Bank analysis (Bulatao et al., 1989) and the United Nations (1992a).

Population projections are sensitive to the assumed trend in total fertility rate (TFR, the number of children per female) particularly in developing regions. The mid-range projection assumes that the TFR approaches the replacement rate in the mid-21st century, the value (about 2.06) at which populations become stable. If the TFR is assumed to approach 2.17 over the next century, for example, population projections would rise to about 13 billion by 2050 (Haub, 1994). Future fertility rates will depend on such factors as the character of economic development, the status of women, the degree of persistence of traditional cultural patterns, and disease incidence. In the spirit of the CDS, we assume mid-range projections that incorporate a gradual global transition to "modern" developed country population patterns and socio-economic patterns.

Current values and typical mid-range projections for economic activity are shown in Table 3, along with average annual growth rates over the periods 1990-2025 and 2025-2050. Rates of growth are seen to be somewhat more rapid in the developing regions than the industrial and transitional regions. The industrial region share of gross world product decreases -- from about 80% in 1990 to 60% in 2050.

To explore the income and equity implications of these projections, GDP per capita is reported in Table 4. Also shown are growth rates in GDP per capita, which are significantly less than total GDP growth rates in developing countries because of high population growth rates. The projections show a very gradual North-South convergence in the sense that the ratio of average GDP per capita in industrial regions to developing regions decreases from 22 to 15. However, the absolute difference in average per capita income increases substantially. Comparing industrial and developing regions, rises from about 18,000 $/capita in 1990 to 55,000 $/capita by 2050 as northern incomes soar. The conventional development world remains a profoundly inequitable one.

The GDP values are aggregate measures of economic scale. In the CDS, the composition of economic output is assumed to change with gradual changes in consumption patterns. In the OECD regions, the service sector provides an increasing share of overall economic activity, while agriculture and industrial shares decrease. In addition, the scenario captures the leveling in OECD countries of the per capita growth of material consumption over recent decades (Williams et al., 1987; Bernardini and Galli, 1993), as the subsectoral composition of industrial production changes with time. Output per capita of materials intensive industries (e.g., iron and steel, non-ferrous metals, non-metallic minerals, paper and pulp, and chemicals), is assumed to stabilize and in some cases decrease. Non-OECD regions are assumed to converge toward OECD economic structures with increasing GDP per capita. Based on these processes, the changing composition of economic activity is reflected in the CDS at two levels: among sectors (domestic, industrial, and agricultural) and among subsectors within the sectors (Raskin and Margolis, 1995).

The CDS analyses water withdrawal by economic sector: domestic, industry, and agriculture. Within each economic sector, water is analyzed by specific activity in the sector, for example sanitation end-uses in the domestic sector, paper production in the industry sector, or irrigation in the agriculture sector. For each activity, the CDS projects the level of the activity (for example, populations, value-added or crop output), and the water intensity of the activity (for example, the volume of water used per person, value-added or crop output). Multiplication of the level of activity by the water intensity gives the total of water use for each activity. The sum over all activities in each sector gives the volume of water withdrawal by sector. Please refer to Appendix 5 for a summary of technical assumptions governing sectoral water use in the CDS.

Table 3. GDP Projections (Billions US $1990)

Region	1990	2025	2050	Growth Rate (%/Year) 1990-2025	2025-2050
North America	6,040	14,884	21,063	2.6	1.4
Western Europe	7,171	15,917	23,660	2.3	1.6
OECD Pacific	3,524	8,100	11,748	2.4	1.5
Former Soviet Union	854	1,898	2,756	2.3	1.5
Eastern Europe	210	467	679	2.3	1.5
Africa	401	1,657	4,245	4.1	3.8
Latin America	994	3,018	6,038	3.2	2.8
Middle East	541	2,237	5,071	4.1	3.3
China +	451	2,698	6,391	5.2	3.5
South & East Asia	1,043	4,943	12,631	4.5	3.8
World	21,230	55,820	94,282	2.8	2.1
Industrial	16,735	38,901	56,471	2.4	1.5
Transitional	1,065	2,366	3,435	2.3	1.5
Developing	3,430	14,553	34,376	4.2	3.5

Source: values for 1990 from the World Bank (1993a); growth rates from IPCC (1992b), which are generally within the range of World Bank projections.

Table 4. GDP per Capita Projections (US $1990)

Region	1990	2025	2050	Growth Rate (%/Year) 1990-2025	2025-2050
North America	21,804	45,127	65,477	2.1	1.5
Western Europe	15,726	32,548	49,607	2.1	1.7
OECD Pacific	24,304	50,301	74,803	2.1	1.6
Former Soviet Union	2,956	5,712	7,889	1.9	1.3
Eastern Europe	2,108	4,073	5,626	1.9	1.3
Africa	626	1,091	1,926	1.6	2.3
Latin America	2,233	4,315	7,435	1.9	2.2
Middle East	3,585	5,832	9,110	1.4	1.8
China +	369	1,557	3,423	4.2	3.2
South & East Asia	667	1,877	3,930	3.0	3.0
World	4,013	6,649	9,354	1.5	1.4
Industrial	19,060	39,699	59,089	2.1	1.6
Transitional	2,738	5,292	7,308	1.9	1.3
Developing	853	2,089	3,972	2.6	2.6

Source: values for 1990 from the World Bank (1993a); growth rates from IPCC (1992b).

2.5 Summary of Scenario Results

The CDS mid-range results are based on the population and economic assumptions summarized above and on detailed sectoral and end-use analysis (summarized in Appendix 5). To examine uncertainty, we develop high and low cases to reflect the sensitivity to variation in both the scale of regional economic activity and the intensity of regional water requirements. A range of economic activities is generated by varying the mid-range CDS annual growth rate in income to 2025 by $\pm$ 10%. Then each regional income is multiplied by the regional population in 2025 to produce the range reported in Table 5.

To reflect uncertainty in water intensity, we first note that average aggregate water intensity (water/GDP) changes over time for two distinct reasons: 1) structural changes in the economy and 2) technological and management improvements in the efficiency in end-use water uses. Structural changes affect average water intensity as the composition of the economy changes among sectors and subsectors which have very different water intensities (e.g., form manufacturing to services, or from heavy to light industry). Structural changes are assumed to be invariant across the CDS's high and low cases. High and low case adjustments are applied to technological improvement by varying mid-range values. Technological improvements decrease end-use water intensities in the mid-range scenario by about 10% globally by 2025, with some variation by region (e.g., in North America the water intensity decreases 16%). The high case assumes only 90% of regional technological improvements are realized by 2025 (e.g., the decrease in water intensity in North America is 14.4%). The low case assumes that technological improvements are 10% greater than in the mid-range case (e.g., water intensities decreases in North America is 17.6%).

The assumptions for the three cases for 2025 are collected in Table 5. Annual water requirements by region are computed as the product of future water intensity and GDP. The results are summarized graphically in Figure 4. Water withdrawals by country in 1995 and in 2025 are reported in Appendices 1 and 2, respectively.

Table 5. GDP and Water Intensity by Region in 2025

REGION	Low	Mid	High
GDP (10^9 1990 US $)			
North America	13,857	14,892	16,002
Western Europe	14,809	15,916	17,103
OECD Pacific	7,536	8,099	8,703
FSU	1,776	1,896	2,024
Eastern Europe	438	468	499
Africa	1,568	1,657	1,751
Latin America	2,825	3,016	3,219
Middle East	2,134	2,240	2,351
China+	2,342	2,698	3,106
S&E Asia	4,464	4,944	5,474
WORLD	51,751	55,826	60,232
Water Intensity (liters / $)			
North America	40.8	41.5	42.2
Western Europe	19.6	19.8	20.1
OECD Pacific	17.0	17.2	17.3
FSU	255.5	258.7	261.8
Eastern Europe	174.6	177.4	180.1
Africa	152.5	153.8	155.2
Latin America	121.5	122.5	123.5
Middle East	141.4	142.5	143.6
China+	287.8	290.7	293.6
S&E Asia	328.4	330.7	333.0
WORLD	87.7	89.7	91.8

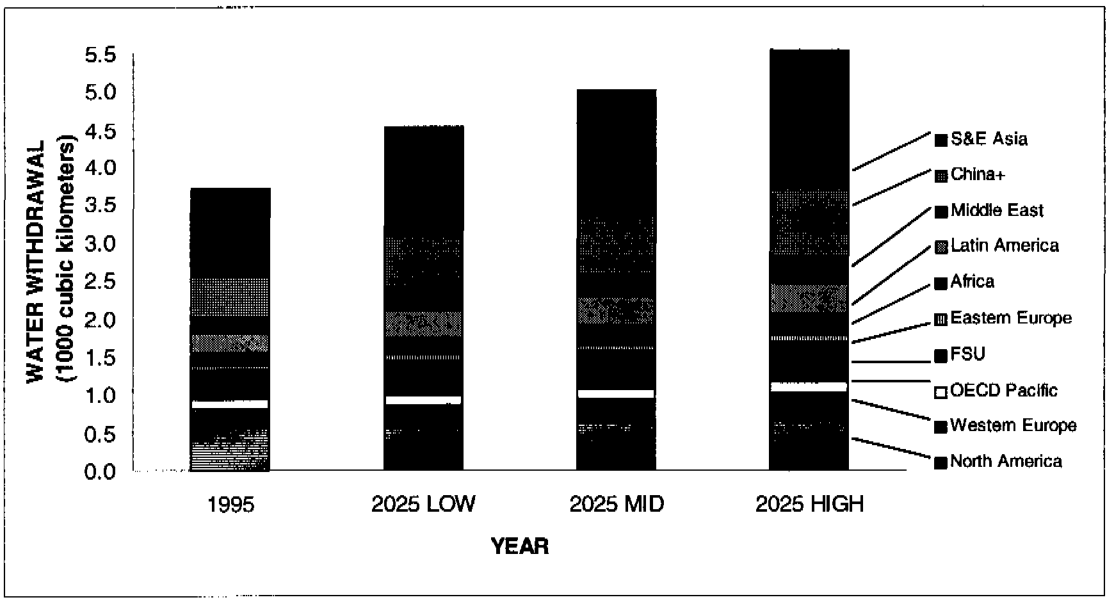

Figure 4. Global Water Withdrawal by Region, 1995-2025

In the CDS mid-range case, annual global water withdrawal grows from 3,700 cubic kilometers in 1995 to 5,000 cubic kilometers in 2025, an increase of 35%. The largest absolute increases occur in S&E Asia (493 additional cubic kilometers) and China+ (231 additional cubic kilometers). This reflects the fact that in 1995 about 31% of the global withdrawals are attributable to South & East Asia, and 15% to China+. The largest relative increases in 2025 withdrawals in the mid-range case are in Middle East (60% higher than 1995) and Africa (53% higher). More generally, the non-OECD grows by 42% while the OECD grows by 15% in the mid-range case.

The high and low case global withdrawals in 2025 are 4500 and 5500, respectively, representing a 23% and 49% increase over the 1995 value. Growth remains greater in the non-OECD where water withdrawal increases from 1995 to 2025 by 29% (low case) to 58% (high case), compared to the OECD where water withdrawal increases by 5% (low case) to 25% (high case).

Regional withdrawals disaggregated by sector are reported in Figures 5 and 6 for 1995 and mid-range case in 2025, respectively. Between 1995 and 2025, irrigation remains the dominant water end-use in developing regions, though it accounts for a decreasing fraction of total water use. Water withdrawals for industry increase in all regions in both absolute quantity and in fractional share of the total. The domestic sector (households and services) grows substantially in developing regions.

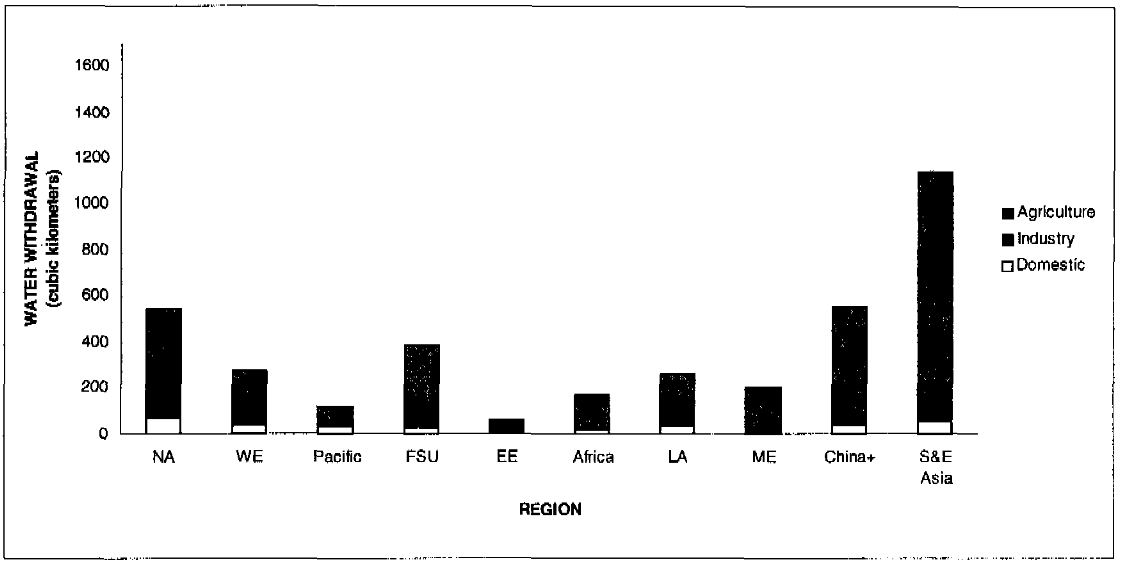

Figure 5. Water Withdrawal by Region and Sector in 1995

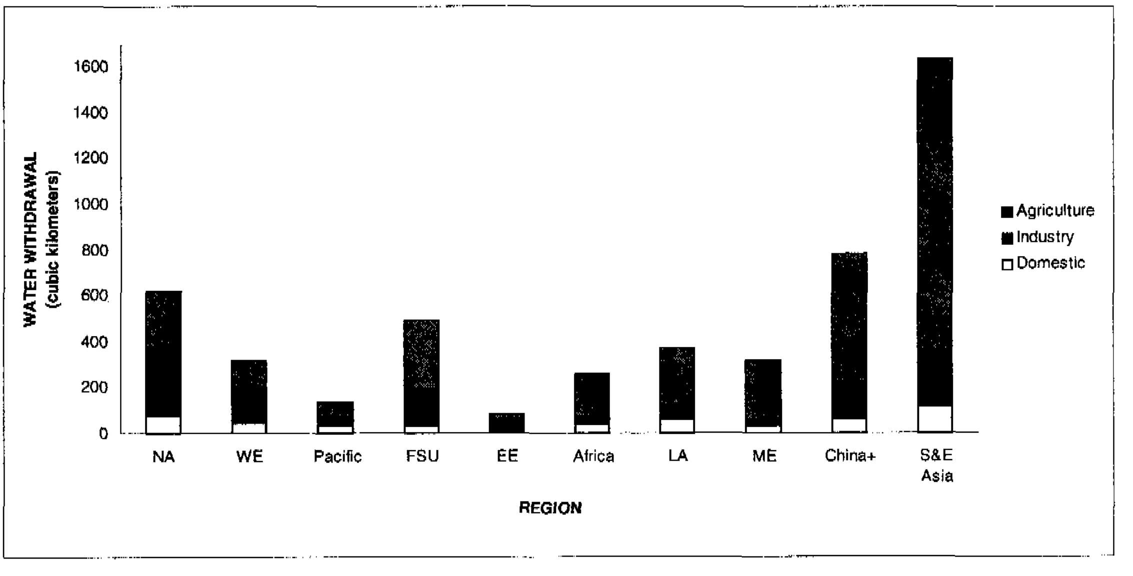

Figure 6. Water Withdrawal by Region and Sector in 2025 CDS Mid-range Case

Mid-range CDS withdrawals in 2025 represent about twelve percent of the average annual runoff of just over 42,000 km^3 (Shiklomanov, 1996). For several reasons, the sufficiency of freshwater is more problematic than might appear from gross comparisons of resources and requirements. First, most of the annual runoff is in the form of floods, leaving only about one-third, or 14,000 km^3 per year, as a steady supply (L'vovich, 1974). However, flood control measures, especially reservoir construction, can increase this supply by storing water during high flow periods for use during dry seasons. Second, surface water availability to meet withdrawal requirements is limited by competing in-stream uses. Most fundamentally, sustainable water development requires that adequate flows be maintained in rivers for the protection of river, lake, and wetland ecosystems. Third, regional averages mask the spatial and temporal variance of freshwater resource and requirement patterns.

As the competition for limited resources increases with expanding water use, water quality often deteriorates and ecosystem maintenance is compromised. In the absence of policies to address these tensions, water competition can evolve into discord between groups dependent on the same resources. Conflicts can arise between immediate and longer term needs, with the latter often the loser. Furthermore, inadequate or degraded water is a matter of life and death in developing regions where an estimated 25,000 people die daily from water-related diseases (UNEP, 1991).

The CDS results are compared to other studies in Table 6. Several global water demand projections were conducted from the 1960s to the mid-1970s, and after a hiatus again in the 1990s. The earlier studies generally projected higher withdrawals than the more recent ones. The CDS continues this trend.

Table 6. Global Water Projections

Study	World Withdrawal (km^3)	Year
Nikitopoulos (1967)	6730	2000
L'vovich (1974)	7000	2000
Falkenmark and Lindh (1974)	8380	2000
Falkenmark and Lindh (1976)	3986, 4961	2000, 2015
de Mare (1976)	6080	2000
WRI (1990)	4195-4350	2000
Shiklomanov (1993)	5190	2000
***Conventional Development Scenario* - this study**	4500, 5000, 5500	2025 (low, mid, high)

World withdrawal in 1995 is estimated at 3700 cubic kilometers.

The lower estimates of future water requirements in the CDS reflect more moderate growth rates in population and economic scale, the incorporation of an assumed shift in the structure of the economy toward less water intensive activities (such as the service sector) and continuing improvements in water use efficiency. The analysis does not simply project historic trends, but captures the changing dynamics of water use in a disaggregated analytic framework. We find that problems of water scarcity and ecosystem pressure, while not likely to be as severe as soon as suggested by earlier global projections, will nevertheless be of continuing concern in the absence of policies for sustainable water use.

We take up the question of future water stress in Part III. For better spatial resolution, we *zoom* in to the national level as the unit of analysis, introduce relevant indices of water vulnerability, and explore the implications of the CDS for water sustainability in 2025.

3 FUTURE WATER STRESS AND VULNERABILITY

The aim of this section is to examine the implications of the scenario for water sustainability to the year 2025. The regional analysis described in the previous section provided broad insight into changing water use and resource patterns in a global context. But the spatial resolution is too coarse for detailed assessment. Ideally, the analysis would be conducted at the river basin level where the relationship among water resources, human requirements and ecosystems is most direct. But a comprehensive global assessment that is built from numerous river basins would be a problematic undertaking due to the sheer scale of the effort and to the lack of a comprehensive water data base organized by basin.

Here we strike a balance between regional and local spatial scales by conducting the assessment of future water issues by zooming down from the regional to the national level, where data are available. We first introduce the criteria used for evaluating water stress, then summarize the scenario data, and finally evaluate current and emerging water stress and vulnerability by country.

3.1 Evaluation Indices

There are many factors influencing the adequacy of a nation's water system -- withdrawal requirements, ecosystem conditions, supply infrastructure, and water resources and their variability. Consequently, there is no simple way to design a single measure of water sustainability. However, progress can be made in assessing national water conditions by developing a set of relevant metrics -- variables that aim to capture key aspects of water stress, supply reliability and the economic capacity for coping with water problems. The metrics can then be combined in various way to provide planners and policy makers with simple screening measures for assessing water resource vulnerability. But it must be stressed that such indicators are only rough guides for flagging situations which require more detailed analytic and policy attention.

We wish to develop metrics of water vulnerability. The concept of resource vulnerability has been associated with the inability to sustain economic and social activity commensurate with a region's goals (Kulshreshtha, 1993). In a sustainability context, the socio-economic emphasis must be complemented by considerations ranging from the vulnerability of aquatic ecosystems to pressures due to human development. Thus, a nation may be said to be water vulnerable if its capacity both to sustain its aquatic ecosystem and to provide its population with a desired level of economic and social development, is compromised by the nature of its hydrologic system, its water resources infrastructure or its water management system.

In this analysis, five separate measures are considered for assessing aspects of a nation's water resources stress:

- *storage-to-flow ratio,* national reservoir storage capacity divided by average annual water supply, measures the capacity of water resources infrastructure to cope with water fluctuations. Higher ratios imply more resilience against floods and droughts (Fiering, 1990; Strzepek et al., 1996).
- *coefficient of variation of precipitation (COV),* the standard deviation of annual precipitation divided by the mean annual precipitation, measures the degree of

variability in annual hydrological patterns and the sensitivity of rainfed agriculture to variations in precipitation. The higher the COV, the more variable the precipitation.

- *import dependence,* the percentage of a national water supply that flows from external sources, measures the geopolitical security of national water resources. Higher percentages reflect greater vulnerability (FAO, 1995; Raskin et al., 1995); availability is dependent on developments in upstream riverine countries and the maintenance of international allocation arrangements. Also, downstream nations are subject to degradation of water quality.
- *use-to-resource ratio,* the annual water withdrawals divided by annual renewable water resources, provides an overall gauge of the average pressure on available resources and the threat to aquatic ecosystems.
- *average income,* GDP per capita, serves as a proxy for a nation's capacity to cope with water problems and uncertainties, and to deliver basic water services to its citizens

These measures are selected for their relevance to the issue of water vulnerability, and for the availability of data to quantify them both now and in the scenarios. The three variables -- storage-to-flow ratio, COV, and import dependence -- represent different aspects of water resources *reliability.* The use-to-resource ratio reflects the physical pressure on water resources, *on average.* Finally, average income recognizes that the level of vulnerability depends on economic *coping capacity.*

The Reliability Index

To reduce the complexity, we first create a composite reliability index by combining the storage-to-flow, COV, and import dependence measures. Each measure is divided into four classes and designated 1, 2, 3, or 4 denoting, respectively, *no stress, low stress, stress,* and *high stress.* The following procedure is used.

Storage-to-Flow

S/Q	> 0.6	0.3 - 0.6	0.3 - 0.2	< 0.2
Classification	1	2	3	4

Note: Fiering and Matalas (1990) and Gleick (1990) suggest that river basins with S/Q less than 0.6 are vulnerable. The further demarcations at 0.3 and 0.2 are based on review of a number of river basins globally. If a nation uses little of its available supply, storage is not an important issue. To reflect this, if the use-to-resource ratio is 0.1 or less, the S/Q classification is set to 1.

Coefficient of Variation of Precipitation

COV	< 0.06	0.06 - 0.12	0.12-0.18	> 0.18
Classification	1	2	3	4

Note: The classifications are based on a statistical analysis of national COVs for 158 nations. The distribution of COVs resembled a log-normal distribution with a mean of 0.12. The value of 0.12 was selected as the cutoff between low stress and stress, as 60% of nations were below 0.12. The breakpoints on either side were set so that 80 percent of the nations fell within class 2 and 3. The reasonableness of these breakpoints were tested by comparing the COV classifications to known conditions in various river basins.

Import Dependence

% Imported	< 15	15 - 25	25 - 50	> 50
Classification	1	2	3	4

Note: When comparing this index with the use-to-resource ratio, recall that the water "resource" in the latter index is assumed to include both domestically controlled resources and international flows.

The composite water supply *Reliability Index* is computed by adding the classification scores for storage-to-flow ratio, COV, and import dependence, then classifying the sum as follows:

Reliability Index

Composite Score	1-3	4-6	7-9	10-12
Classification	1	2	3	4

The Use-to-Resource Ratio

The *use-to-resource ratio* is an index which serves as a proxy for average water-related stress on both ecosystems and socio-economic systems. Average annual resource flows (Q) include both domestic resources and inflows from other countries. Again, four classes are defined ranging from a value of 1 for no stress to 4 for high stress.

Use-to-Resource Ratio

Withdrawal/Q	< 0.1	0.1- 0.2	0.2 - 0.4	> 0.4
Classification	1	2	3	4

Note: According to Falkenmark and Lindh (1976), Szesztay (1970), Kulshrestha (1993) and Strzepek et al. (1996), at ratios greater than 20 percent, water stress can begin to be a limiting factor on economic development. The other demarcations are based on estimates in the literature.

Coping Capacity

The *coping capacity index* breakpoints are taken at standard World Bank income classifications which are assumed to be correlated with the economic and institutional ability of countries to endure water stress, and to provide and maintain basic water services (Najlis, 1996). As with the other indices, four classes are defined ranging from a value of 1 for no stress to 4 for high stress.

Coping Capacity Index

GNP/capita	> 8625	8625 - 2786	2786 - 695	< 695
Classification	1	2	3	4

Composite Water Resources Vulnerability Indices

The indicator framework we have developed relies on three separate aspects of water stress. The *reliability index* provides the aspect of resource uncertainty due to import dependence, precipitation variability, and the capacity to weather import and hydrological fluctuations. The *use-to-resource* adds an aspect of general water stress. The *coping capacity* index is included in recognition that a nation's water vulnerability is dependent, not only on physical conditions, but the capacity to respond and manage those conditions.

Of course, a nation's water situation cannot be reduced to several simple variables, since it is often a composite of conditions in relatively autonomous river basins and dependent on many details. The indicators we have introduced must be interpreted as rough and suggestive signals of possible water stress for any specific country.

In this spirit, as a final step in developing a broad-brush picture of current and future water vulnerability, we synthesize the three indices into a *composite water resources vulnerability index.* There is no definitive theory or empirical basis for merging such incommensurate indices. Numerous mathematical procedures may be used for combining and weighting them into a common measure. Consequently, different analysts and stakeholders legitimately can weigh the variables in alternative ways. Without advancing a preference here, we offer two approaches for distilling the information into a composite vulnerability index for ease of viewing results.

Water Resources Vulnerability Index I (WRVI-I). This index weighs equally the three separate water resource stress indices: *reliability, use-to-resource, and coping capacity.* This approach assumes that the indices can compensate for one another, with a high score on one balancing a low score on another. For each nation, the classification values for each of the three stress indices are added to give a "combined score", which is then classified as follows :

Water Resources Vulnerability Index I (WRVI-I)

Combined Score	1-3	4-6	7-9	10-12
Classification	1	2	3	4

The Water Resources Vulnerability Index II (WRVI-II). In this formulation of the composite vulnerability index, the *WRVI-II* is set equal to the maximum value of the three individual stress indices -- *reliability, use-to-resource, and coping capacity.* In other words, if any of the three variables has a value of 4, the *WRVI-II* is set at 4; if the highest value of the variables is 3, the *WRVI-II* is 3, and so on. This approach provides a stronger signal of vulnerability by assuming that a nation is vulnerable if it is vulnerable in any of the separate dimensions.

3.2 Data Sources

The next step is to apply this evaluation framework at country and regional levels. We consider conditions in two years -- 1995 and 2025. For 2025, we use the results of the three *Conventional Development Scenario* cases (low, mid-range, high) introduced in Section II. We explore also the sensitivity of the results to variations in hydrological patterns that might be induced by climate change.

To conduct this analysis, country-level data for each of the basic indices are required. The data for 1995 is shown in Appendix 1. Withdrawal and supply data are drawn from recent compilations conducted for the Comprehensive Freshwater Assessment (Najlis, 1996; Shiklomanov, 1996). Reservoir storage data are from the World Register of Dams (ICOLD, 1988; Strzepek et al., 1996), which cover over 20,000 reservoirs (including those under construction) in over 100 countries through 1988 (note that reservoir construction has declined sharply since the survey). For countries with no information, it is assumed that there are no major storage reservoirs.

The annual coefficient of variation (COV), the standard deviation divided by the mean, of national precipitation is based on 1 degree gridded values of annual mean and standard deviation (Legates and Willmott, 1990), interpolated to 0.5 degree grids and averaged for each country.

Conventional Development Scenario results for national water requirements in 2025 for the low, mid-range, and high cases are based on regional growth rates (see Appendix 2). Future national-level incomes in the three scenario cases are also based on the regional growth rates. Lacking a basis for projecting storage changes, it is assumed that no new reservoir capacity is added in the next 30 years. While this will certainly not be the case, only a few large reservoirs are now under construction, and new projects will take many years to design, to construct, and to pass environmental and local concerns. For most nations, additional storage capacity is unlikely to change the storage-to-flow (S/Q) classification. In the standard scenario, hydrology is not subject to climate change impacts, so the COV and water supply data for 2025 are the same as for 1995.

Finally, an analysis of sensitivity to climate change was conducted. Based on CDS assumptions, annual greenhouse gas emissions to the year 2025 were read into two different global climate models. The Max Plank Institute (MPI) and the Goddard Fluid Dynamics Laboratory (GFDL) general circulation models were run in a transient mode and estimates of changes in temperature and precipitation over a global grid were produced for the 2030 decadal average. These changes in temperature and precipitation were then used as input to a model of annual river runoff, and changes in national water supply were computed (Yates and Strzepek, 1996). The GFDL results show a 2.5 percent increase in global runoff with 73 nations having a decrease in flow and 85 nations having an increase. The MPI results show a 5.3 percent increase in global runoff with 70 nations having decreases and 88 countries having increases in runoff.

3.3 Evaluation of Future Water Problems

With this information, we are able to apply the evaluation framework at the national level. The full results of the classification procedure are collected for each country in Appendix 3, for each of the three water stress indices, and in Appendix 4, for the two composite water vulnerability indices. To gain insight into these results, we begin with a global summary. Table 7 presents the distribution of countries and populations for each of the three stress indices broken down by classification for 1995, and for 2025 under various scenario conditions.

Considering first the *reliability index*, we see from Table 7 that the number of countries in each of the stress classifications does not vary much across 2025 scenarios, nor between 1995 and 2025. However, due to population growth, the number of people in countries under reliability stress conditions (classifications 3 and 4) is likely to grow substantially, from 3.5 billion in 1995 to about 5.3 billion in 2025, or about 63% of the world's people. That many more people may be at risk to droughts and floods. Figure 7 and 8 shows that this type of stress is found primarily in Asia, North Africa and the Middle East, and that is where the problem will grow in the future. Figure 17 shows a geographical view by country. The problem results from large variability of precipitation, inadequate storage to buffer this variability and/or high import dependence. In many cases, this stress can be addressed by building storage, but this can require large capital outlays, be environmentally costly, and in some cases, prohibited by topography.

Turning to the *use-to-resource ratio*, we see from Table 7 that the number of countries in stress classifications 3 and 4 is likely to increase in the scenarios, even in the low-range case. For the CDS mid-range, the number of countries under stress grows from 41 in 1995 to 53 in 2025. In terms of population, the number living in such countries grows substantially, from 1.9 billion to about 5.3 billion, an increase of some 3.4 billion. The population in stress conditions as a percentage of total world population rises from about 34% to 63%. Affected populations are concentrated in China, Central Asia, the Indian Sub-continent, the Middle East and North Africa (see Figures 9 and 10). These nations are posed with the challenge of economic development, while investing heavily in water infrastructure and protecting their aquatic ecosystems. Figure 18 shows a geographical view by country.

The coping capacity index in Table 7 shows that, consistent with the robust economic growth assumptions of the *Conventional Development Scenarios*, the number of countries under stress (classifications 3 and 4) decrease from 112 in 1995 to about 85 in 2025. This follows from the assumed greater capacity to deliver water services to their citizens and provide a resilient infrastructure in the face of heightened physical pressure on water resources and environments. However, because population growth is most rapid in the poorer countries, the number of people in the low income classifications actually increases, from 4.4 billion in 1995 to 5.9 billion in 2025, some 70% of the world's people. Despite the assumed economic progress, serious poverty persists, including most of Africa and Asia (Figure 11 and 12). Figure 19 shows a geographical view by country.

Table 7. Stress Classification Distribution by Country and Population

		Number of Countries			Population (millions)		
	classification	reliability	use/resource	coping	reliability	use/resource	coping
1995							
	1	16	98	27	147	1,693	830
	2	76	21	21	2,025	2,068	484
	3	57	22	54	3,283	1,462	1,180
	4	11	19	58	241	474	3,203
2025							
CDS LOW							
	1	15	95	34	251	2,623	1,096
	2	77	14	33	3,004	640	1,257
	3	56	26	56	4,691	4,049	3,173
	4	12	25	37	449	1,083	2,870
CDS MID-RANGE							
	1	15	90	35	251	2,454	1,097
	2	73	17	39	2,854	639	1,421
	3	59	27	53	4,822	2,762	4,506
	4	13	26	33	469	2,540	1,371
CDS HIGH							
	1	15	90	37	251	2,454	1,140
	2	73	12	38	2,854	360	1,385
	3	59	27	52	4,822	2,926	4,500
	4	13	31	33	469	2,656	1,371
CDS MID-RANGE (climate change MPI)							
	1	15	89	35	251	2,455	1,097
	2	72	17	39	2,792	710	1,421
	3	59	27	53	4,877	4,127	4,506
	4	14	27	33	476	1,104	1,371
CDS MID-RANGE (climate change GFDL)							
	1	15	90	35	251	2,478	1,097
	2	74	17	39	2,885	714	1,421
	3	57	27	53	4,784	4,114	4,506
	4	14	26	33	476	1,090	1,371

1 = no stress
2 = low stress
3 = stress
4 = high stress

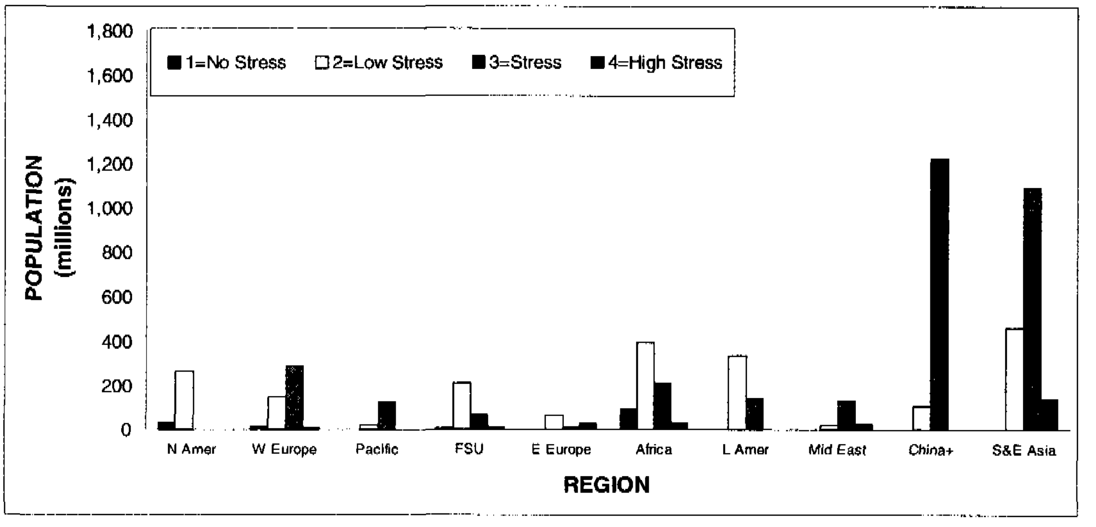

Figure 7. Reliability Index by Region for 1995: Population in Each Classification

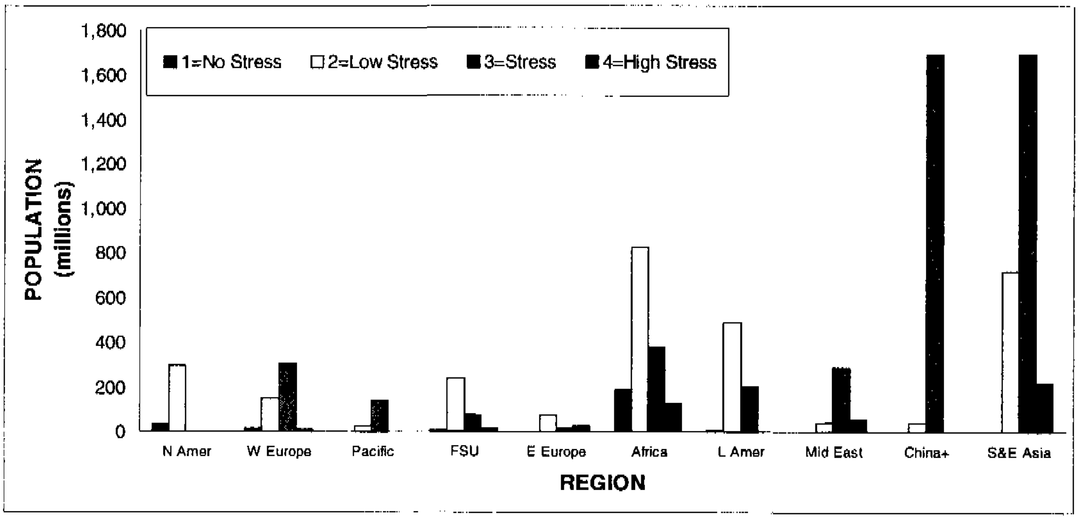

Figure 8. Reliability Index by Region for 2025: Population in Each Classification

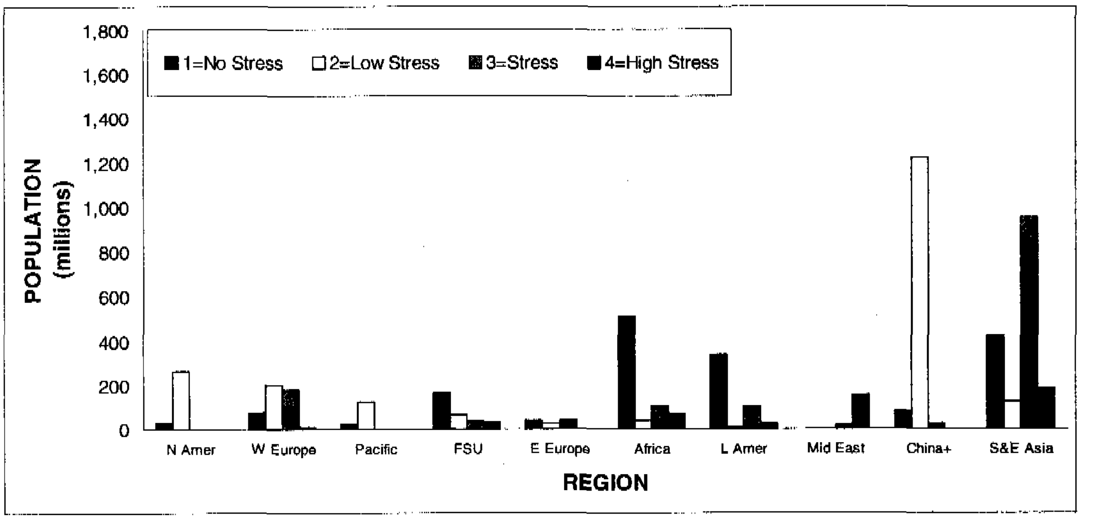

Figure 9. Use-to-Resource Index by Region for 1995: Population in Each Classification

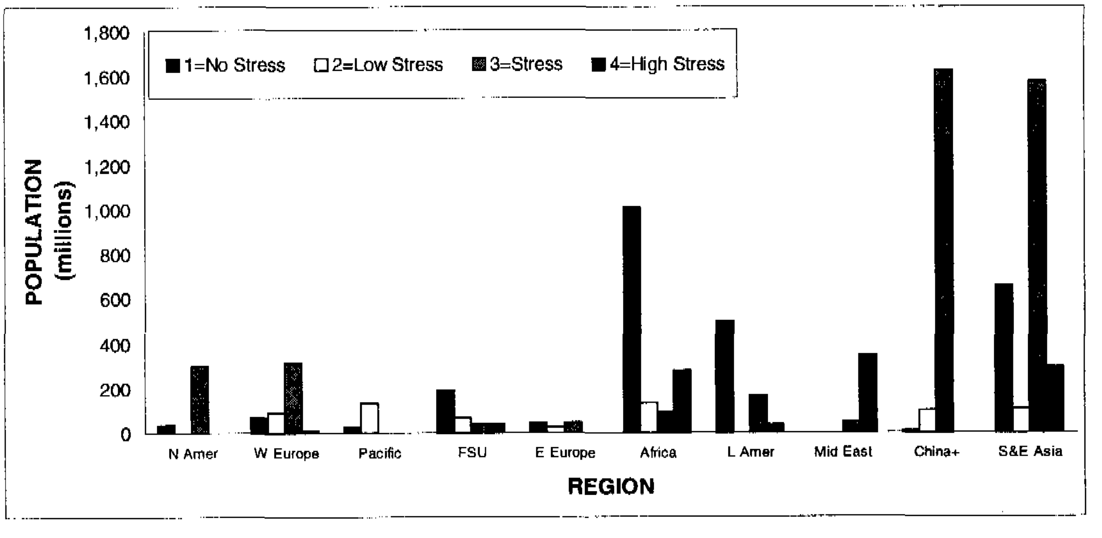

Figure 10. Use-to-Resource Index by Region for 2025: Population in Each Classification

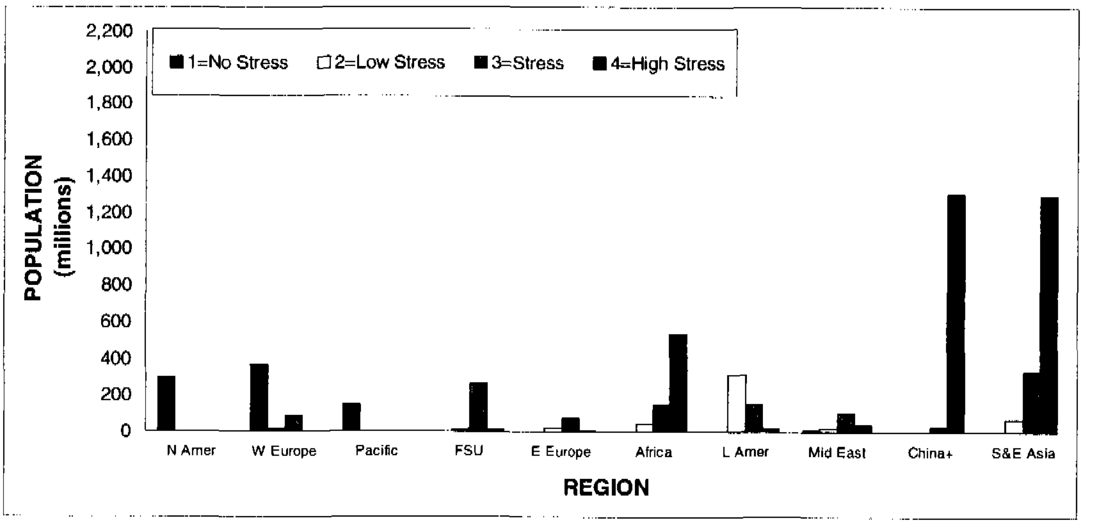

Figure 11. Coping Index by Region for 1995: Population in Each Classification

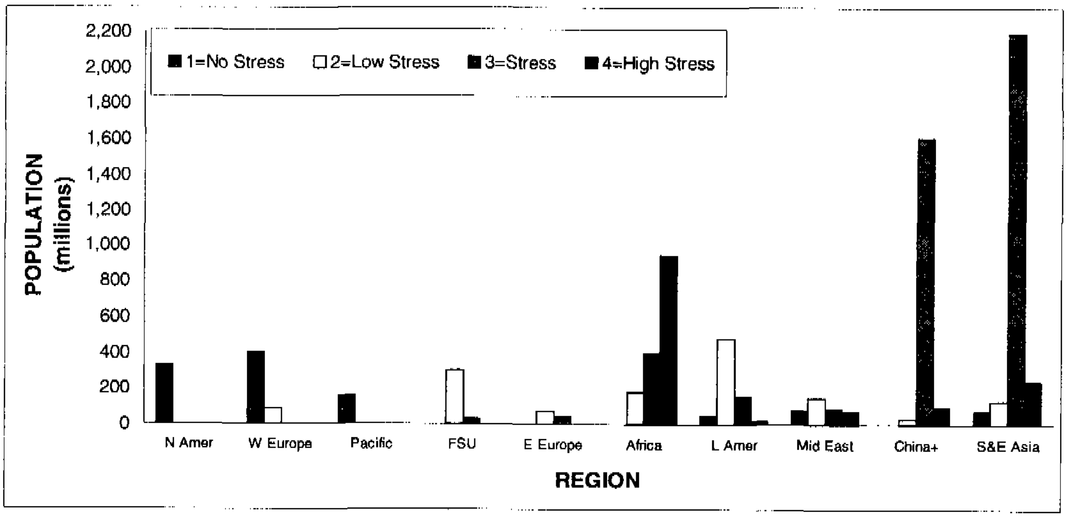

Figure 12. Coping Index by Region for 2025: Population in Each Classification

In an effort to convey a simple "bottom line" result, we turn to the two composite *water resource vulnerability indices* introduced in Section III-A. Recall that the first composite index adds the three stress indices (WRVI-I) and the second takes the maximum value of the three indices across the indices (WRVI-II). The results are shown in Table 8.

Focusing on WRVI-I, we see that the number of countries in stress (classifications 3 and 4) decreases from 100 in 1995 to about 89 to 92 in 2025 depending on the scenario variation. This is because the improvement in *coping capacity* (income growth) compensates for greater resource stress. This formulation of the composite index might appeal to those whose world view includes optimism about the possibility for substitutability of built capital for natural capital and about the capacity for economic growth alone to address adequately resource and environmental problems. However, even in this optimistic view, we see from Table 8 that the number of people classified as stressed grows from about 4.2 billion in 1995 to about 6.2 billion in 2025. The problem is illustrated in Figures 13 and 14 which suggest the increase of water resource vulnerability in developing regions.

Turning now to the second *water resources vulnerability index* (WRVI-II), Table 8 shows that more countries and people are classified as vulnerable than was the case for WRVI-I. The number so classified grows from about 5.1 billion in 1995 to about 7.6 billion in 2025. Fully 90% of the world's population is reported as vulnerable in 2025, with nearly 50% highly vulnerable. The regional patterns are displayed in Figures 15 and 16 showing that Africa, China+ and the Middle East account for most of the stressed population in both 1995 and 2025. However, the USA and much of Latin America now become vulnerable under the WRVI-II formulation. The higher estimates are a result of the construction of WRVI-II in which vulnerability in any single index is treated as determinative of overall vulnerability. In contrast, to WRVI-I, this second formulation might appeal to those with a world view which is pessimistic about the substitutability of built capital for natural capital, and sees vulnerability as being related to the weakest link in the chain of environmental pressure, resource reliability, and development.

Table 8. Composite Index Distribution by Country and Population

	Number of Countries		Population (millions)	
classification	WRVI-I	WRVI-II	WRVI-I	WRVI-II
1995				
1	4	4	50	50
2	56	19	1,461	581
3	84	58	2,797	1,512
4	16	79	1,388	3,554
2025				
CDS LOW				
1	4	4	55	55
2	65	28	2,122	794
3	74	62	3,991	3,590
4	17	66	2,228	3,957
CDS MID-RANGE				
1	4	4	55	55
2	67	26	2,099	714
3	74	67	4,061	3,712
4	15	63	2,181	3,915
CDS HIGH				
1	4	4	55	55
2	64	25	1,843	656
3	74	63	4,279	3,654
4	18	68	2,218	4,031
CDS MID-RANGE (climate change MPI)				
1	4	4	55	55
2	66	27	2,090	730
3	73	65	5,476	5,132
4	17	64	774	2,479
CDS MID-RANGE (climate change GFDL)				
1	4	4	55	55
2	67	26	2,099	714
3	74	68	5,511	5,169
4	15	62	731	2,458

1 = no vulnerability
2 = low vulnerability
3 = vulnerability
4 = high vulnerability

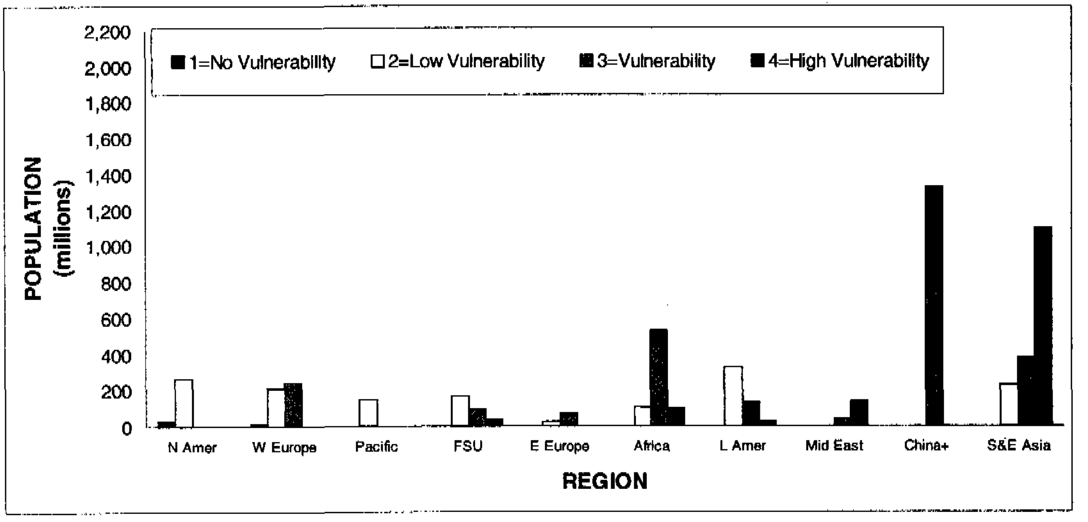

Figure 13. Water Resources Vulnerability Index I by Region for 1995: Population in Each Classification

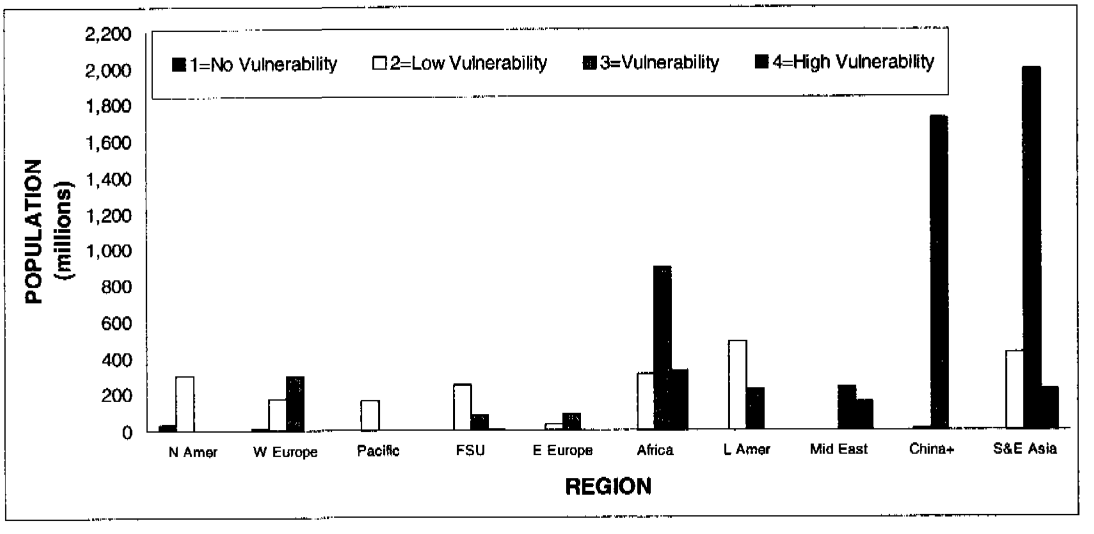

Figure 14. Water Resources Vulnerability Index I by Region for 2025: Population in Each Classification

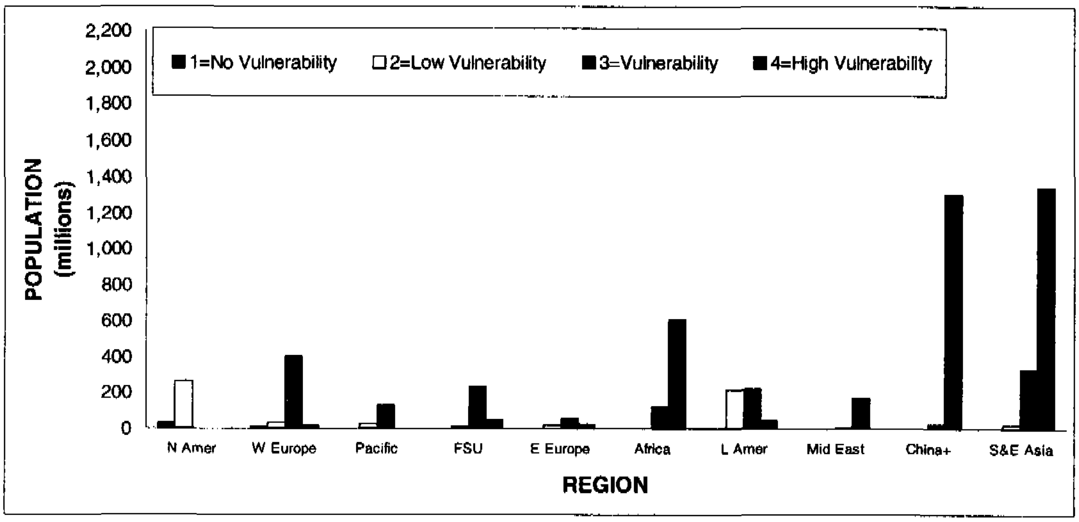

Figure 15. Water Resources Vulnerability Index II by Region for 1995: Population in Each Classification

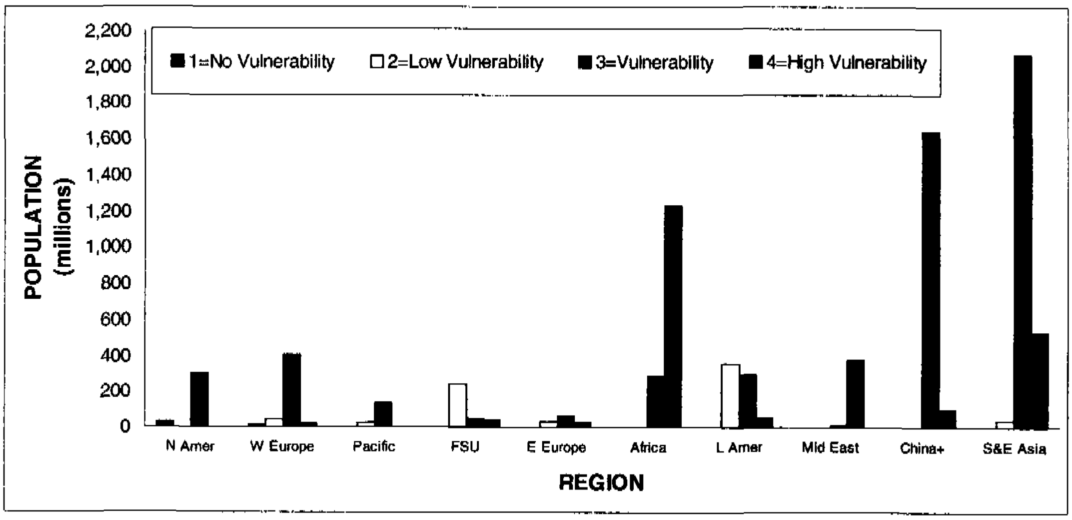

Figure 16. Water Resources Vulnerability Index II by Region for 2025: Population in Each Classification

Regarding the sensitivity to climate change, we note from the tables that national impacts tend to cancel out, producing very little change on the global scale. However, these gross average changes probably mask considerable disruption that might be induced by local shifts to wetter or drier conditions. It should be noted that the analysis here was performed for the 2030 decadal average where global temperature increase is less than 1°C. A global temperature increase of more than 2.0°C, commonly estimated for the year 2100 and beyond, would have more dramatic impacts on water supplies and irrigation requirements.

The sensitivity to economic and technical assumptions is reflected in the results for the high and low CDS cases. The low scenario shows almost no change relative to the mid-range case in populations in any of the classes for either of the indices. This is because reduced coping capacity is counteracted by reduced water use and a lower use to supply ratio. The high case shows only minor changes in coping stress, but significant changes in stress as reflected in the *use-to-resource index* due to greater water use. These changes lead to significant changes in classifications in both *water resource vulnerability indices*. However, comparing the results for the two composite indices in Table 8, we conclude that the basic findings of this study are robust against the economic, technological and climate change variations considered.

The results are displayed geographically for the year 2025 for each of the component stress indices in Figures 17 through 19. The composite *water resource vulnerability indices* are mapped in Figures 20 and 21, respectively. The pictures reflect a range of assumptions and philosophical dispositions. But in all cases considered, we can conclude that problems of water stress and vulnerability are likely to persist and grow with time. That is, unless initiatives are taken to transition away from a *Conventional Development Scenario* and toward water sustainability.

Classification

- no stress
- low stress
- stress
- high stress

Figure 17. Reliability Index for 2025

Figure 18. Use-to-Resource Index for 2025

Figure 19. Coping Capacity Index for 2025

Classification

- no stress
- low stress
- stress
- high stress

Figure 20. Water Resources Vulnerability Index I for 2025

Figure 21. Water Resources Vulnerability Index II for 2025

4. TOWARDS WATER SUSTAINABILITY

This study has examined water issues at global, regional and national levels of analysis. To examine possible conditions in the future, a long-term *Conventional Development Scenario* was introduced. The scenario incorporates commonly held assumptions on population and economic growth, progressive globalization of culture and commerce, and a gradual convergence of developing and industrial economies. A framework was developed for evaluating water stress and vulnerability today and in the future, which included a set of indices to gauge the degree of pressure on water resources, the reliability of those resources and the economic capacity to cope with water adversity. The scenario -- were it to occur -- shows persistent and serious water problems which deepen with time. A conventional picture of development includes growing stress on water resources, human health and eco-systems. Moreover, the scenario contains the seeds of continuing socio-economic problems due to the persistence of poverty, the failure to achieve global equity and the increase in local conflict over scarce water and other resources.

4.1 Policy Considerations

But no scenario is inevitable, the future is determined, at least in part, by the actions that are taken to avoid unsustainable futures. What alternative scenarios should be considered? What types of initiatives could foster water sustainability?

The task is to find a pathway to a vision of a future society which is environmentally and socially sustainable, and which can endure and flourish in a manner which respects human rights, preserves ecosystems and provides a decent life for all. This must include acting to improve human health, food security, and employment opportunities all in a context which keeps aggregate human pressures on natural resource and environmental systems within tolerance levels for sustainability.

A sustainable water vision would include initiatives for promoting the rapid development and deployment of technologies that are highly environmentally friendly. This would require a mobilization of political will to introduce programs and policies for the deployment of highly efficient end use equipment (e.g., irrigation systems, household fixtures and toilets, industrial processes), water recovery and ground-surface water conjunctive use projects, improved water system management techniques, drinking water and sanitation infrastructure, and environmental protection and reclamation activities.

The evaluation has shown a correlation of future water vulnerability to persistent poverty in developing regions, in the context of rapid population growth. To address the equity aspects of sustainability, the alternative vision would assume stronger convergence of development between poor and rich countries. Accelerated industrialization throughout the developing world is fostered by a combination of economic globalization led by transnational corporations, concerted international policy, strengthening of market and financial institutions, and open technology transfer. Aggregate consumption levels are driven higher as average per capita incomes increase. In scenarios with greater equity, it is likely that demands on water systems would increase relative to CDS levels, all else equal, due to more rapid growth in consumption and production in the populous developing regions. However, this could be offset by the effects of a greater economic capacity to deploy efficient water-use technology, less population growth and stronger institutional capacity to mange water resources better.

Beyond better technology and greater equity, one can conceive of fundamental changes in social organization and values that could contribute positively to water sustainability. For example, more dispersed settlement patterns based on communities with tighter integration of work and personal life could slow urbanization and associated water and health pressures. Population growth could moderate with the rise of the sustainability world-view, the empowerment of women and a more equitable distribution of wealth. Consumerism could be supplanted by a philosophy of voluntary simplicity which seeks a comfortable, but not profligate, level of material well-being, as society strives for a high degree of economic and social equality, again reducing water stress. Small scale technology and greater degrees of regional self-reliance could complement global infrastructures and trade.

There is a growing international consensus on the principles that should govern water policy (United Nations, 1992b; Young et. al., 1994, World Bank, 1993b). Under these principles, actions should be based on a *comprehensive analytic framework, proper valuation of water resources, environmental protection, stakeholder participation, capacity building*, and *institutional coordination and decentralization.* Though a detailed policy discussion is beyond the scope of this paper, (policy implications are taken up in Chapter 4 of the Comprehensive Freshwater Assessment), a water sector policy agenda for a transition to water sustainability would clearly seek to avert water conflict, control pollution, avoid degradation of agriculture lands, prevent drought-related crop failures and provide adequate urban water and sanitation infrastructure. These goals require appropriate management initiatives, such as water-sharing regulations, water quality policy, land fertility protection, drought-proofing technologies, and water infrastructure provision and maintenance.

More generally, as we have seen, water is part of a complex socio-ecological system that is evolving in uncertain ways. Thus, there are many factors driving problems of water provision and water resources. We have stressed that the water problem is *intersectoral* -- interacting strongly with agriculture, energy use, socio-economic development, and ecosystems -- and spatially *nested* -- having river basins which are parts of countries, which are parts of regions, which are parts of a global system.

Consequently, the chain of influences effecting water resources and use can be quite indirect. As we have argued, global drivers can have a strong influence on the economic development, environmental conditions and water requirements at national and river basin levels. Furthermore, policies that affect a range of local activities -- farming practices in agriculture, settlement patterns, energy needs and options, economic growth, demographics, etc. -- can have important implications for water, as well. For these reasons, in the transition to sustainability, water planning and policy must be comprehensive and integrated, taking into account the interplay between water and other factors both now and in future scenarios.

4.2 The Transition to Water Sustainability: A Vision[5]

As we have seen, under conventional development conditions, the world of the future is likely to require a share of the Earth's limited renewable fresh water that is even larger than today's. This water will come at an increasing financial and ecological price. The *Conventional Development Scenario*, with the nagging water supply and environmental problems identified above, is not inevitable. The future is uncertain, unpredictable, and complex -- and dependent on human choices yet to be made.

But we know where we are today with millions dying every year from water-related diseases, the destruction of aquatic ecosystems and fisheries worldwide, growing political disputes over water that crosses political borders, and increasing competition for water in water-short regions. The CDS examines a future based on present policies and institutions, the gradual evolution of technological trends, and conventional assumptions on population growth and economic development. As we have seen in Section III, under these conditions, many areas of the world will continue to face water stress, billions of people will be unserved or underserved by basic water services, and the natural environment will continue to suffer.

Conventional development visions follow a road toward a future that looks much like today, a road that many would not elect to take if there were a choice. We *do* have a choice. We can choose a different path and a different future. But we must make that choice soon, for every day we delay, moves us further in the wrong direction.

Many alternative futures can be imagined. Some representing far worse socio-economic and environmental conditions than envisioned in the CDS, others far more favorable (Gallopin et al., 1996). Unless we visualize where we want to be, it will not be possible to craft the policies and institutions -- and to apply the technologies and tools -- that will take us there. And once having described a future, there can be no guarantee we can ever attain it. In the end, a vision is not a prediction. It is a story about the directions the future can take. Here is one vision of a transition to water sustainability.

It is the year 2050. The population of the earth has reached nearly 10 billion and is stabilizing. Major efforts have been undertaken to restore the environment for the sustainable development of humankind at a decent quality of life. In particular, these efforts have focused on fresh water, recognized as an essential renewable resource.

Beginning in the 1990s, a series of major international water conferences and meetings refocused global attention on freshwater issues, particularly the human suffering resulting from the lack of access to basic water supplies, inadequate availability of sanitation services, and the growing threats to global food sufficiency due to declining per-capita irrigated land and grain production. At the same time, political conflicts over shared international rivers and watercourses raised the issue of environmental security to the highest political levels. Last but not least, the relationship between freshwater resources and long-term ecosystem health was increasingly highlighted.

By the end of the 1990s, progress had been made toward identifying a series of explicit goals and principles to guide long-term water planning and management.

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[5] This section is drawn from Gleick (1996).

Building on the Mar del Plata, Dublin, and UNCED Agenda 21 principles, these goals have often been modified and refined in the intervening decades, but they mark the first explicit attempt to integrate water resources supply, use, and management in a truly sustainable way.

As a top international priority, basic human needs for water were identified and have at last been largely met. At the Earth Summit of 2002, "Universal Access" programs (for water, food, telecommunications, education, and health service) were adopted by all nations, and access to clean water was made a top and permanent priority. Governments, aid agencies, private corporations, and non-governmental organizations joined forces in the Global Water Partnership to meet the goal of providing this basic need universally with a flexible and varied combination of technologies and institutions. By 2025, 95 percent of the global population had access to a basic water requirement for drinking, sanitation services, cleaning, and food preparation. The financial cost of meeting these basic needs has proven to be modest and far outweighed by vast savings in health costs, improvements in worker productivity, and the freeing up of time for women and children for educational, commercial, and community activities.

At the same time, domestic water use in the developed world has become much more efficient and equitably allocated. The efficiency improvements begun in the late 1990s to cope with droughts, and to avoid the need for expensive and controversial new supplies, have been extended to all reaches of domestic life. Total municipal supplies are widely supplemented by extensive use of reclaimed urban wastewater for non-potable uses and inexpensive water efficiency equipment is widely available.

Advocates of desalination believe that large-scale cost-effective systems are just a decade or two away. The price has dropped substantially due to the availability of inexpensive photovoltaic systems, but capital construction and maintenance costs remain above the costs of demand management programs in most regions. In arid rural coastal areas lacking municipal water infrastructure, basic needs are being met by small modular solar desalination systems. More widespread solar desalination is practiced in arid coastal countries where water-use efficiency is high, water availability is low, investment capital is available, and solar energy is abundant, particularly in the Persian Gulf and North Africa.

Water-related diseases are being conquered. The international effort to meet the basic water requirements of all people, combined with effective education about sanitation practices and wide improvements in access and quality of medical care, have greatly reduced both the prevalence and severity of human suffering from water-related diseases. Guinea worm was the first water-related disease to be eliminated, around the turn of the century. Attention then turned to schistosomiasis and trachoma, both of which were completely eradicated by 2030. The incidence of childhood diarrhea has also been drastically reduced as the sources have been identified and attacked and as treatment has become universally available. Cholera has been brought under control after the seventh (1991 to 2003) and eighth (2009 to 2016) great pandemics. Malaria and typhoid, which have expanded in range, still plague certain regions, but biological controls of disease vectors are making inroads on the drug-resistant strains prevalent during the early part of the century. The links between a variety of cancers and chemical contamination of water in the heavily industrialized nations continue to be discovered, but new methods for preventing such contamination and for cleaning up contaminated waters are reducing health risks.

The spread of cryptosporidium and new strains of bacteria throughout North America, Japan, and Europe was halted by 2020 through the wider application of a combination of watershed protection policies and effective large-scale filtration technology. At the height of the worst urban outbreaks, an enormous demand for bottled water and home water-purification systems developed in the richer markets. This market has now largely disappeared and most large cities now send samples of their drinking water to the annual taste-testing competition held every summer at the famous Stockholm Water Festival in an effort to win the prestigious annual prize for the best-tasting urban drinking water on each continent.

Serious water-related conflicts are now regularly resolved in formal negotiations. The early part of the 21st century saw a series of minor and major water-related conflicts. After the military skirmishes between Hungary and Slovakia across the Danube, the more serious intra-regional conflicts in India and southern Asia over the Cauvery, Narmada, Ganges, and Mekong rivers, and the intentional contamination of shared groundwater aquifers on the border between the United States and Mexico, new international water tribunals were set up to hear and mediate disputes. By 2010, however, unresolved disputes in southern Africa over the development of regional rivers and the bombings of both Turkish and Syrian dams on the Euphrates led to a widely attended international diplomatic Congress, at which binding principles of conflict resolution and negotiation were accepted.

In the years following the Congress, formal treaties and river basin commissions were put in place for nearly all of the world's major shared rivers. The New Nile River Treaty of 2017, for example, has been signed by all 14 nations of the Nile Basin and includes provisions for sharing both water and water experts. These treaties also include allocation agreements during droughts and floods, provisions for formal negotiations of disputes, and a sharing of responsibility for environmental and ecological protections. Upon request, United Nation hydrologists and environmental scientists help to monitor water treaties remotely using on-site survey equipment and the orbiting "Hydra" satellite system, which provides real-time observations of water conditions everywhere on the Earth.

The Middle East -- a region thought by many to be the most vulnerable to water-related conflicts -- has turned out to be a model for regional cooperation and water sharing. Effective joint basin management commissions, first set up between Israel and Jordan in the treaty of 1994 over the Jordan River, have now been established for the Tigris, Euphrates, and Orontes rivers. After sporadic conflict over dam projects on the Euphrates River, international negotiators helped Turkey, Syria, and Iraq work out a sharing arrangement that equitably distributed both the benefits and the costs of river developments. A water-sharing agreement has been worked out between the Israelis and the Palestinians over groundwater aquifers in the West Bank.

Basic ecosystems water needs are being identified and met. The mass extinction in the Aral Sea and Lake Victoria in the 1980s and 1990s and in the Yangtze and Mekong rivers in the 2010s, combined with widespread extinction in other aquatic systems, led to the adoption of national and international actions to protect ecosystems. Since 2025, the number and types of internationally threatened and endangered aquatic species have begun to diminish following implementation of comprehensive minimum environmental water commitments, international agreements on species protection and management, and the identification and protection of critical habitats around the world. All international aid and development projects now include explicit ecosystem protection and management components.

Restoration efforts are also well underway in coastal and inland wetlands around the world following the collapse of coastal fisheries in Asia, the North Atlantic, the Gulf of Mexico, and along the coastline of western Africa. International delta protection agreements are in place for the Mekong, the Nile, the Niger, the Zambesi, the Ganges/Brahmaputra, the Colorado, and dozens of other international rivers. The loss of wetlands has been stopped, and innovative management is now actually creating new wetlands at the mouth of many of the largest rivers in the world. The Mississippi River delta has begun to expand rapidly following a plan designed to give in to the river's natural inclinations to meander.

Regional monitoring programs are keeping exotic species invasions to a minimum and international teams of ecologists are working to eliminate invasions that have successfully taken hold. The zebra mussel still clogs waterways in North America, but the water hyacinth is being defeated in Africa. The sea lamprey, accidentally introduced into the Great Lakes region of the United States and Canada was unintentionally wiped out by commercial over fishing in the 2010. It had been identified as a delicacy in the late 1990s and widely exported to Europe and Asia for over a decade.

Following the 2015 agreement among the six nations sharing the Aral Sea basin, flows of the Amu Darya and Syr Darya Rivers into the Sea have reached their highest levels in half a century. The agreement instituted effective joint water management among the parties, a substantial reduction in cotton production in the region, and vast improvements in irrigation efficiency. The surface area of the Aral Sea is now approximately 55,000 square kilometers, an increase of nearly 30 percent since the 1990s, but still more than 10,000 square kilometers below natural levels. The devastating health problems suffered by the regions inhabitants from the 1980s through the early part of the 21st century are abating, and work is underway to restore a fishery in the Sea.

Agricultural water is now efficiently used and allocated. One of the greatest concerns facing the world in the early part of the 21st century was the challenge of producing food for the world's billions. Shortfalls of grain began to appear in the first decade of the new millennium as major nations such as China began to make large purchases on the international markets. By 2012, China, India, Nigeria, Indonesia, Egypt, and Bangladesh were competing in world markets for grain, while traditional exporters such as Argentina, Australia, Canada, and the United States had cut back on export volumes to meet internal and regional needs. Saudi Arabia, a major wheat exporter in the 1980s and 1990s, saw its agricultural exports collapse after groundwater overdraft depleted or permanently damaged its fossil aquifers.

Between 2012 and 2018, the simultaneous great droughts in North American, Chinese, and Indian led to the reappearance of famines in Africa and southern Asia, as well as extremely high food prices in the United States and Canada. Food riots in the winter of 2017 in the USA and seven European countries forced a re-evaluation of food and water policies, the elimination of water subsidies, widespread improvements in irrigation efficiency, and substantial shifts in cropping patterns.

By 2020, the return of the rains and the new policy changes began to reduce pressures and to increase the nutritional status of the world's poorest inhabitants. In particular, the enormous regional disparities in diet evident at the end of the 20th century began to close, as the large-scale consumption of meat in the industrialized world decreased. A rapid drop in beef and lamb consumption, driven by higher prices, the public health disasters in Great Britain, the EC, Japan, and the United States attributed to contaminated meat, better education about the adverse health effects of eating meat, and new policies on land management, has freed up substantial quantities of land, irrigation capacity, and grain and cereal crops for direct human consumption.

At the same time, new varieties of rainfed crops began to appear on the market. These genetically improved crops have substantially increased yields from rainfed lands, which remain the majority of all agricultural land. A renewed interest in traditional farming techniques in semi-arid regions combined with inexpensive high-tech water monitoring equipment and new crop varieties has encouraged a rethinking of agricultural aid policies, improved production without new irrigation requirements, and resulted in great demand for farming advice from experts in developing countries.

On irrigated lands, overall irrigation efficiency has improved dramatically with the universal adoption of high-efficiency sprinklers and drip irrigation on appropriate crops and lands. Water-use efficiency has also improved due to advances in sensor and computer technology that permit farmers to inexpensively and accurately monitor soil moisture and to apply water only when needed. Many farmers are now tied directly into regional weather forecasting centers that help avoid unnecessary irrigation prior to natural precipitation. The trend away from pesticide and herbicide use, and toward integrated pest management and the use of innovative ground cover, has further reduced overall irrigation requirements while maintaining high yields, soil fertility, and water quality.

In many arid countries, limited but highly efficient agricultural production is still maintained with high-quality reclaimed urban wastewater. Middle East water experts, who pioneered this approach, are in high demand in many parts of Africa, Asia, and Latin America as countries make an effort to maximize their use of this under-utilized resource.

By 2030, great improvements in food distribution and storage permitted countries to rely more on international markets and have reduced the impacts of severe droughts and other forms of climatic variability. Water trading among market sectors is common, reflecting a greater emphasis on economic mechanisms to meet water needs. Communities have a major say in water trading, however, and the price of water reflects community and environmental values, as well as purely market values.

A new focus on global food sufficiency has replaced the old nationalistic concept of food security, which led many countries in arid and semi-arid regions to overdraft fossil groundwater and invest in unsustainable irrigation projects during the late 1900s. International development efforts have refocused on non-agricultural developments in water-short countries, such as industrial and commercial activities. These activities provide sufficient capital to permit food-buying nations to meet food shortfalls on the international market. No country in the world is completely food self-sufficient, yet the world as a whole maintains adequate food production and storage. Average populations in all regions now receive the minimum recommended number of calories, though pockets of malnourishment still remain.

Among the unresolved problems of the 21st century is the question of how best to address the impacts of the greenhouse effect. All efforts at rational water management continue to be complicated by the effects of global climate change. Global warming was recognized by the scientific community in the 1980s and 1990s, but it was not seriously acknowledged by politicians until well after 2000, at which point it was too late to prevent many major impacts.

Climatic changes have had particularly severe effects on regional water resources management. Rainfall patterns have changed, the frequency and intensity of storms has increased in many places, and reservoirs and municipal water supply systems designed for one set of conditions have had to be redesigned or managed for quite different conditions. One positive outcome has been the training of a whole new generation of water managers much more comfortable with the concepts of operational flexibility and resilient water management, rather than relying on the traditional approach of using past trends to forecast future conditions.

Despite these remaining uncertainties and the continuing challenges facing water managers and planners everywhere, the wide sharing of water data and information on successful management strategies and the great improvements since the late 1990s have led to a spirit of international cooperation throughout the world's water community. The enormous efforts of the past several decades have led to the feeling that the worst threats to global and regional stability from water problems are finally behind us and that sustainable water management will be a permanent fixture throughout the world.

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APPENDIX 1: CURRENT DATA

Country	1995					
	GDP/cap. (1994 $)	Withdrawal	Supply	Storage	Imports (% supply)	Coeff. of Variation
		(10^6 cubic meters)				
N AMERICA						
Canada	19,510	47,246	2,901,000	791,916	2	0.05
USA	25,880	492,259	2,478,000	898,000	1	0.05
W EUROPE						
Austria	24,630	2,424	90,300	2,491	38	0.19
Belgium	22,870	9,237	12,500	171	33	0.10
Bosnia/Herze	1,500	1,354	265,000	n.a.	43	0.15
Croatia	2,000	1,760	265,000	n.a.	43	0.12
Denmark	27,970	1,210	13,000	29	15	0.06
Finland	18,850	2,243	113,000	18,880	3	0.04
France	23,420	38,570	198,000	12,642	9	0.10
Germany	25,580	47,303	171,000	2,582	44	0.11
Greece	7,700	7,109	58,700	11,450	23	0.11
Iceland	24,630	167	168,000	1,464	0	0.17
Ireland	13,530	808	50,000	941	6	0.09
Italy	19,300	56,362	167,000	11,095	5	0.16
Macedonia	820	847	265,000	n.a.	43	0.13
Netherlands	22,010	8,039	90,000	9,366	89	0.03
Norway	26,390	2,077	392,000	6,380	2	0.12
Portugal	9,320	7,257	69,600	7,744	45	0.16
Slovenia	6,490	762	265,000	n.a.	43	0.11
Spain	13,440	30,968	111,300	54,612	1	0.15
Sweden	23,530	2,990	180,000	21,435	2	0.06
Switzerland	35,760	1,146	50,000	n.a.	15	0.19
Turkey	2,500	36,237	193,100	179,816	4	0.11
UK	18,340	11,929	71,000	8,207	0	0.10
Yugoslavia	2,000	4,248	265,000	508,269	43	0.12
PACIFIC						
Australia	18,000	27,312	343,000	92,274	0	0.06
Fiji	2,250	33	28,600	153	0	0.19
Japan	34,630	91,945	547,000	88,176	0	0.12
New Zealand	13,350	1,992	327,000	22,729	0	0.19
FSU						
Armenia	660	4,109	13,300	n.a.	16	0.06
Azerbaijan	730	17,061	33,000	n.a.	61	0.06
Belarus	2,870	2,979	73,800	n.a.	29	0.02
Estonia	3,080	3,220	17,600	n.a.	27	0.07
Georgia	580	4,054	65,200	n.a.	12	0.06

See text for data sources.

Country	1995 GDP/cap. (1994 $)	Withdrawal (10^6 cubic meters)	Supply	Storage	Imports (% supply)	Coeff. of Variation
Kazakhstan	1,560	44,138	169,400	n.a.	33	0.07
Kyrgyztan	850	12,953	61,700	n.a.	0	0.15
Latvia	2,010	673	34,000	n.a.	49	0.02
Lithuania	1,320	4,416	24,200	n.a.	43	0.02
Moldova	1,060	3,787	13,700	n.a.	83	0.04
Russia	2,340	116,422	4,498,000	n.a.	5	0.06
Tajikistan	470	14,950	101,300	n.a.	47	0.02
Turkmenistan	1,000	26,186	72,000	n.a.	96	0.12
Ukraine	2,210	34,623	231,000	n.a.	15	0.04
Uzbekistan	970	91,842	129,600	n.a.	76	0.08
E EUROPE						
Albania	380	356	21,300	5,049	53	0.15
Bulgaria	1,250	13,576	205,000	7,689	91	0.12
Czech Rep.	3,200	2,727	58,200	4,394	0	0.09
Hungary	3,840	6,678	120,000	21	95	0.05
Poland	2,410	12,349	56,200	2,824	12	0.05
Romania	1,270	25,173	208,000	12,569	82	0.08
Slovakia	1,950	1,818	30,800	n.a.	0	0.14
AFRICA						
Algeria	1,650	5,042	14,300	7,959	3	0.14
Angola	900	628	184,000	10,757	0	0.07
Benin	370	154	25,800	1,734	60	0.06
Botswana	2,800	120	14,700	155	80	0.07
Burkina Faso	300	412	17,500	2,003	0	0.06
Burundi	160	127	3,600	0	0	0.09
Cameroon	680	500	268,000	13,526	0	0.05
Cape Verde	930	30	300	0	0	0.12
CAR	370	85	141,000	0	0	0.03
Chad	180	218	43,000	0	65	0.11
Comoros	510	13	1,020	0	0	0.09
Congo	620	51	832,000	44	73	0.04
Cote d'Ivoire	610	941	77,700	37,219	1	0.05
Djibouti	780	11	2,300	0	87	0.23
Egypt	720	55,432	68,500	174,535	97	0.44
Eq. Guinea	430	12	30,000	0	0	0.07
Eritrea	100	240	8,800	0	68	0.19
Ethiopia	100	2,156	110,000	914	0	0.12
Gabon	3,880	78	164,000	220	0	0.04
Gambia	330	36	8,000	0	63	0.11
Ghana	410	325	53,200	296,113	43	0.06
Guinea	520	936	226,000	241	0	0.08

Country	1995 GDP/cap. (1994 $)	Withdrawal (10^6 cubic meters)	Supply	Storage	Imports (% supply)	Coeff. of Variation
Guinea-Bissau	240	22	27,000	0	41	0.13
Kenya	250	2,454	30,200	2,357	33	0.14
Lesotho	720	62	5,200	7	0	0.11
Liberia	500	168	232,000	0	14	0.11
Libya	1,000	4,751	600	336	0	0.26
Madagascar	200	23,135	337,000	425	0	0.09
Malawi	170	971	18,700	3	6	0.12
Mali	250	1,746	100,000	13,440	40	0.13
Mauritania	480	1,851	11,400	0	96	0.14
Mauritius	3,150	390	2,200	56	0	0.09
Morocco	1,140	11,540	30,000	0	0	0.20
Mozambique	90	655	216,000	8,072	54	0.07
Namibia	1,970	278	45,500	632	86	0.14
Niger	230	628	32,500	0	89	0.14
Nigeria	280	4,648	280,000	41,338	21	0.07
Rwanda	80	809	6,300	0	0	0.10
Senegal	600	1,702	39,400	11,520	33	0.12
Sierra Leone	160	445	160,000	22	0	0.09
Somalia	300	914	13,500	0	56	0.15
South Africa	3,040	14,890	50,000	28,689	10	0.11
Sudan	300	17,800	154,000	3	77	0.14
Swaziland	1,100	758	4,500	250	42	0.14
Tanzania	140	1,193	89,000	1,135	10	0.08
Togo	320	115	12,000	1,711	4	0.07
Tunisia	1,790	3,391	9,000	2,685	44	0.18
Uganda	190	217	66,000	200	41	0.08
Zaire	300	422	1,019,000	53	8	0.04
Zambia	350	1,759	116,000	208	31	0.04
Zimbabwe	500	1,527	20,000	165,021	30	0.06
L AMERICA						
Argentina	8,110	35,812	994,000	123,699	30	0.12
Bolivia	770	1,557	300,000	0	0	0.11
Brazil	2,970	46,856	6,950,000	706,259	25	0.04
Chile	3,520	23,203	468,000	7,777	0	0.27
Colombia	1,670	6,031	1,070,000	9,965	0	0.13
Costa Rica	2,400	1,464	95,000	2,226	0	0.18
Cuba	800	9,585	34,500	1,618	0	0.07
Dominican R.	1,330	3,483	20,000	2,226	0	0.16
Ecuador	1,280	6,677	314,000	7,025	0	0.24
El Salvador	1,360	1,084	19,000	174	0	0.08
Guatemala	1,200	1,501	116,000	460	0	0.26
Guyana	530	1,501	241,000	0	0	0.09

See text for data sources.

Country	1995					
	GDP/cap. (1994 $)	Withdrawal (10^6 cubic meters)	Supply	Storage	Imports (% supply)	Coeff. of Variation
Haiti	230	47	11,000	0	0	0.16
Honduras	600	1,656	63,400	11,353	13	0.15
Jamaica	1,540	414	8,300	220	0	0.18
Mexico	4,180	84,209	357,400	101,458	0	0.13
Nicaragua	340	1,688	175,000	460	0	0.13
Panama	2,580	1,975	144,000	5,314	0	0.12
Paraguay	1,580	541	314,000	33,290	70	0.05
Peru	2,110	18,726	40,000	3,854	0	0.22
Suriname	860	518	200,000	20	0	0.04
Trinidad/Tob.	3,740	163	5,100	48	0	0.05
Uruguay	4,660	4,325	124,000	17,345	52	0.09
Venezuela	2,760	4,446	1,317,000	163,757	35	0.11
MID EAST						
Afghanistan	300	35,704	50,000	3,158	0	0.13
Bahrain	7,460	334	290	0	0	0.10
Iran	2,000	85,608	117,500	16,364	0	0.13
Iraq	1,000	52,259	109,200	69,683	60	0.12
Israel	14,530	2,277	2,200	0	23	0.29
Jordan	14,440	907	1,700	83	24	0.30
Kuwait	19,420	472	758	0	0	0.10
Lebanon	1,500	1,178	5,600	0	11	0.40
Oman	5,140	524	2,103	0	0	0.21
Qatar	12,820	226	195	0	0	0.02
Saudi Arabia	7,050	5,092	8,760	3,039	0	0.10
Syria	1,346	10,907	53,700	327	52	0.18
UAE	21,430	657	797	0	0	0.06
Yemen	280	3,397	4,902	0	0	0.24
CHINA+						
China	530	504,315	2,800,000	279,122	0	0.11
Korea (DPR)	1,000	16,407	67,000	34,286	0	0.08
Laos	320	1,260	270,000	7,400	0	0.09
Mongolia	300	657	24,600	0	0	0.08
Viet Nam	200	30,851	376,000	165	0	0.10
S & E ASIA						
Bangladesh	220	26,467	2,357,000	6,501	42	0.11
Bhutan	400	23	95,000	311	0	0.35
Cambodia	230	660	498,100	237	82	0.12
India	320	607,227	2,085,000	267,357	11	0.10
Indonesia	880	83,061	2,530,000	14,249	0	0.07
Korea (Rep.)	8,260	29,558	66,100	14,153	0	0.07

	1995					
	GDP/cap.	Withdrawal	Supply	Storage	Imports	Coeff. of
Country	(1994 $)	(10^6 cubic meters)			(% supply)	Variation
Malaysia	3,480	13,058	456,000	23,640	0	0.08
Myanmar	660	4,694	1,082,000	2,324	0	0.13
Nepal	200	3,284	170,000	145	0	0.15
Pakistan	430	278,844	468,000	22,981	36	0.13
Papua/NG	1,240	120	801,000	33	0	0.10
Philippines	950	49,035	323,000	7,088	0	0.12
Singapore	22,500	211	600	75	0	0.08
Sri Lanka	640	10,410	43,200	6,272	0	0.20
Thailand	2,410	35,042	179,000	58,660	39	0.10

See text for data sources.

APPENDIX 2: SCENARIO RESULTS FOR 2025

Country	Conventional Development Scenario for 2025					
	GDP/person (1990 US $)			Withdrawal (10^6 cubic meters)		
	LOW	MID	HIGH	LOW	MID	HIGH
N AMERICA						
Canada	32,459	34,884	37,485	49,559	54,127	59,094
USA	43,057	46,274	49,724	516,358	563,962	615,707
W EUROPE						
Austria	44,075	47,369	50,901	2,554	2,781	3,026
Belgium	40,926	43,984	47,264	9,735	10,597	11,532
Bosnia/Herze	2,684	2,885	3,100	1,427	1,554	1,691
Croatia	3,579	3,846	4,133	1,855	2,019	2,197
Denmark	50,052	53,792	57,803	1,275	1,388	1,510
Finland	33,732	36,253	38,956	2,363	2,573	2,800
France	41,910	45,042	48,400	40,649	44,249	48,152
Germany	45,775	49,196	52,864	49,852	54,267	59,054
Greece	13,779	14,809	15,913	7,492	8,156	8,876
Iceland	44,075	47,369	50,901	176	191	208
Ireland	24,212	26,021	27,961	852	927	1,009
Italy	34,537	37,118	39,886	59,399	64,659	70,364
Macedonia	1,467	1,577	1,695	893	972	1,057
Netherlands	39,387	42,330	45,486	8,472	9,222	10,036
Norway	47,225	50,754	54,538	2,188	2,382	2,592
Portugal	16,678	17,924	19,261	7,648	8,325	9,060
Slovenia	11,614	12,482	13,412	803	874	951
Spain	24,051	25,848	27,775	32,637	35,527	38,662
Sweden	42,107	45,253	48,628	3,151	3,431	3,733
Switzerland	62,465	67,133	72,139	1,207	1,314	1,430
Turkey	4,474	4,808	5,167	38,189	41,571	45,239
UK	32,819	35,272	37,902	12,572	13,685	14,892
Yugoslavia	3,579	3,846	4,133	4,477	4,873	5,303
PACIFIC						
Australia	26,408	28,382	30,498	28,913	31,293	33,864
Fiji	3,301	3,548	3,812	35	38	41
Japan	50,806	54,603	58,675	97,334	105,349	114,001
New Zealand	19,586	21,050	22,620	2,109	2,282	2,470
FSU						
Armenia	1,789	1,909	2,038	4,890	5,284	5,709
Azerbaijan	1,978	2,112	2,254	20,303	21,940	23,702
Belarus	7,777	8,303	8,862	3,545	3,831	4,139
Estonia	8,347	8,910	9,510	3,832	4,141	4,473
Georgia	1,572	1,678	1,791	4,825	5,213	5,632

	Conventional Development Scenario for 2025					
	GDP/person (1990 US $)			Withdrawal (10^6 cubic meters)		
Country	LOW	MID	HIGH	LOW	MID	HIGH
Kazakhstan	4,227	4,513	4,817	52,523	56,758	61,318
Kyrgyztan	2,303	2,459	2,625	15,414	16,657	17,995
Latvia	5,447	5,815	6,206	800	865	934
Lithuania	3,577	3,819	4,076	5,254	5,678	6,134
Moldova	2,873	3,066	3,273	4,507	4,870	5,261
Russia	6,341	6,769	7,225	138,541	149,711	161,738
Tajikistan	1,274	1,360	1,451	17,790	19,225	20,769
Turkmenistan	2,710	2,893	3,088	31,161	33,673	36,378
Ukraine	5,989	6,393	6,824	41,201	44,523	48,100
Uzbekistan	2,629	2,806	2,995	109,291	118,103	127,590
E EUROPE						
Albania	665	710	758	435	471	511
Bulgaria	2,189	2,336	2,493	16,585	17,980	19,484
Czech Rep.	5,603	5,980	6,382	3,331	3,611	3,913
Hungary	6,724	7,176	7,658	8,158	8,844	9,584
Poland	4,220	4,504	4,806	15,086	16,354	17,723
Romania	2,224	2,373	2,533	30,752	33,337	36,127
Slovakia	3,414	3,644	3,889	2,220	2,407	2,609
AFRICA						
Algeria	2,767	2,924	3,089	7,230	7,706	8,212
Angola	1,509	1,595	1,685	900	960	1,023
Benin	621	656	693	221	236	251
Botswana	4,696	4,962	5,242	172	184	196
Burkina Faso	503	532	562	591	629	671
Burundi	268	284	300	181	193	206
Cameroon	1,141	1,205	1,273	717	764	814
Cape Verde	1,560	1,648	1,741	43	46	49
CAR	621	656	693	122	130	139
Chad	302	319	337	312	333	354
Comoros	855	904	955	19	20	22
Congo	1,040	1,099	1,161	73	77	82
Cote d'Ivoire	1,023	1,081	1,142	1,350	1,439	1,533
Djibouti	1,308	1,382	1,460	16	17	18
Egypt	1,208	1,276	1,348	79,487	84,718	90,278
Eq. Guinea	721	762	805	17	19	20
Eritrea	168	177	187	344	366	390
Ethiopia	168	177	187	3,092	3,296	3,512
Gabon	6,508	6,876	7,264	112	119	127
Gambia	553	585	618	52	56	59
Ghana	688	727	768	466	497	530
Guinea	872	922	974	1,343	1,431	1,525

See text for data sources.

	Conventional Development Scenario for 2025					
	GDP/person (1990 US $)			Withdrawal (10^6 cubic meters)		
Country	LOW	MID	HIGH	LOW	MID	HIGH
Guinea-Bissau	403	425	449	31	33	35
Kenya	419	443	468	3,518	3,750	3,996
Lesotho	1,208	1,276	1,348	89	95	101
Liberia	839	886	936	241	257	274
Libya	1,677	1,772	1,872	6,813	7,261	7,738
Madagascar	335	354	374	33,174	35,357	37,678
Malawi	285	301	318	1,392	1,484	1,581
Mali	419	443	468	2,504	2,668	2,844
Mauritania	805	851	899	2,654	2,828	3,014
Mauritius	5,283	5,582	5,898	560	596	636
Morocco	1,912	2,020	2,134	16,548	17,637	18,794
Mozambique	151	159	169	939	1,000	1,066
Namibia	3,304	3,491	3,688	398	424	452
Niger	386	408	431	901	960	1,023
Nigeria	470	496	524	6,664	7,103	7,569
Rwanda	134	142	150	1,160	1,237	1,318
Senegal	1,006	1,063	1,123	2,440	2,601	2,771
Sierra Leone	268	284	300	638	680	725
Somalia	503	532	562	1,311	1,397	1,489
South Africa	5,099	5,387	5,692	21,351	22,756	24,249
Sudan	503	532	562	25,524	27,204	28,989
Swaziland	1,845	1,949	2,059	1,088	1,159	1,235
Tanzania	235	248	262	1,710	1,823	1,943
Togo	537	567	599	165	176	188
Tunisia	3,002	3,172	3,351	4,863	5,183	5,523
Uganda	319	337	356	311	331	353
Zaire	503	532	562	605	645	688
Zambia	587	620	655	2,522	2,688	2,864
Zimbabwe	839	886	936	2,190	2,334	2,487
L AMERICA						
Argentina	10,494	11,202	11,957	47,768	51,399	55,295
Bolivia	996	1,064	1,135	2,076	2,234	2,403
Brazil	3,843	4,102	4,379	62,498	67,249	72,347
Chile	4,555	4,862	5,190	30,949	33,301	35,826
Colombia	2,161	2,307	2,462	8,045	8,656	9,313
Costa Rica	3,106	3,315	3,538	1,953	2,101	2,260
Cuba	1,035	1,105	1,179	12,784	13,756	14,799
Dominican R	1,721	1,837	1,961	4,646	4,999	5,379
Ecuador	1,656	1,768	1,887	8,906	9,583	10,309
El Salvador	1,760	1,879	2,005	1,446	1,556	1,674
Guatemala	1,553	1,658	1,769	2,002	2,155	2,318
Guyana	686	732	781	2,003	2,155	2,318

	Conventional Development Scenario for 2025					
	GDP/person (1990 US $)			Withdrawal (10^6 cubic meters)		
Country	LOW	MID	HIGH	LOW	MID	HIGH
Haiti	298	318	339	63	67	73
Honduras	776	829	885	2,209	2,377	2,557
Jamaica	1,993	2,127	2,270	552	594	639
Mexico	5,409	5,774	6,163	112,323	120,860	130,022
Nicaragua	440	470	501	2,252	2,423	2,607
Panama	3,339	3,564	3,804	2,634	2,834	3,049
Paraguay	2,045	2,182	2,329	721	776	835
Peru	2,730	2,915	3,111	24,978	26,876	28,914
Suriname	1,113	1,188	1,268	691	744	800
Trinidad/Tob.	4,840	5,166	5,514	217	233	251
Uruguay	6,030	6,437	6,870	5,769	6,207	6,678
Venezuela	3,571	3,812	4,069	5,930	6,381	6,864
MID EAST						
Afghanistan	515	540	567	53,981	57,105	60,402
Bahrain	12,804	13,439	14,106	505	534	565
Iran	3,433	3,603	3,782	129,430	136,921	144,827
Iraq	1,716	1,802	1,891	79,011	83,584	88,410
Israel	24,938	26,176	27,474	3,443	3,642	3,852
Jordan	24,784	26,014	27,303	1,371	1,450	1,534
Kuwait	33,331	34,986	36,720	714	755	799
Lebanon	2,575	2,702	2,836	1,781	1,884	1,992
Oman	8,822	9,260	9,719	792	838	886
Qatar	22,004	23,096	24,240	342	362	382
Saudi Arabia	12,100	12,701	13,330	7,698	8,144	8,614
Syria	2,310	2,425	2,545	16,490	17,444	18,452
UAE	36,781	38,607	40,520	994	1,052	1,112
Yemen	481	504	529	5,136	5,434	5,748
CHINA+						
China	1,381	1,591	1,831	614,242	714,590	830,777
Korea (DPR)	2,605	3,001	3,455	19,983	23,247	27,027
Laos	834	960	1,106	1,535	1,785	2,076
Mongolia	782	900	1,036	800	931	1,083
Viet Nam	521	600	691	37,576	43,714	50,822
S & E ASIA						
Bangladesh	475	526	583	33,987	37,903	42,256
Bhutan	864	957	1,060	29	32	36
Cambodia	497	550	609	848	945	1,054
India	691	766	848	779,736	869,589	969,462
Indonesia	1,901	2,105	2,331	106,659	118,949	132,611
Korea (Rep.)	17,844	19,762	21,880	37,956	42,330	47,191

See text for data sources.

	Conventional Development Scenario for 2025					
	GDP/person (1990 US $)			Withdrawal (10^6 cubic meters)		
Country	LOW	MID	HIGH	LOW	MID	HIGH
Malaysia	7,518	8,326	9,218	16,768	18,700	20,848
Myanmar	1,426	1,579	1,748	6,027	6,722	7,494
Nepal	432	478	530	4,217	4,703	5,243
Pakistan	929	1,029	1,139	358,061	399,323	445,185
Papua/NG	2,679	2,967	3,285	153	171	191
Philippines	2,052	2,273	2,516	62,966	70,222	78,287
Singapore	48,605	53,831	59,601	271	302	337
Sri Lanka	1,383	1,531	1,695	13,368	14,908	16,621
Thailand	5,206	5,766	6,384	44,997	50,183	55,946

APPENDIX 3: STRESS INDICES BY COUNTRY

	1995			Conventional Development Scenario (CDS) for 2025									CDS - MID case with climate change					
				LOW			MID			HIGH			MPI			GDFL		
Country	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc
N AMERICA																		
Canada	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
USA	2	2	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1
W EUROPE																		
Austria	3	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3	1	1
Belgium	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1
Bosnia/Herze	3	1	3	3	1	3	3	1	2	3	1	2	3	1	2	3	1	2
Croatia	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Denmark	2	1	1	2	1	1	3	2	1	3	2	1	3	2	1	3	2	1
Finland	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
France	3	2	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1
Germany	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1
Greece	3	2	2	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1
Iceland	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
Ireland	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
Italy	3	3	1	3	3	1	3	3	1	3	4	1	3	3	1	3	3	1
Macedonia	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
Netherlands	2	1	1	2	1	1	3	2	1	3	2	1	2	1	1	3	2	1
Norway	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
Portugal	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1
Slovenia	2	1	2	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
Spain	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1
Sweden	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Switzerland	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Turkey	2	2	3	2	2	2	2	3	2	2	3	2	2	3	2	2	3	2
UK	3	2	1	3	2	1	3	2	1	3	3	1	3	2	1	3	2	1
Yugoslavia	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
PACIFIC																		
Australia	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
Fiji	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Japan	3	2	1	3	2	1	3	2	1	3	3	1	3	2	1	3	2	1
New Zealand	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
FSU																		
Armenia	3	3	4	3	3	3	3	3	3	3	4	3	3	3	3	3	3	3

ri = *reliability index*, u/r = *use-to-resource ratio index*, cc = *coping capacity index*.
1= no stress, ... , 4 = high stress. See text in section III for discussion of indices.
MPI = Max Plank Institute method, GFDL = Goddard Fluid Dynamics Laboratory method.

	1995			Conventional Development Scenario (CDS) for 2025									CDS - MID case with climate change					
				LOW			MID			HIGH			MPI			GDFL		
Country	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc
Azerbaijan	4	4	3	4	4	3	4	4	3	4	4	3	4	4	3	4	4	3
Belarus	2	1	2	2	1	2	2	1	2	2	1	1	2	1	2	2	1	2
Estonia	3	2	2	3	3	2	3	3	1	3	3	1	3	3	1	3	3	1
Georgia	1	1	4	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3
Kazakhstan	3	3	3	3	3	2	3	3	2	3	3	2	3	3	2	3	3	2
Kyrgyztan	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Latvia	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Lithuania	4	2	3	4	3	2	4	3	2	4	3	2	4	3	2	4	3	2
Moldova	3	3	3	3	3	2	3	3	2	3	3	2	3	3	2	3	3	2
Russia	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Tajikistan	3	2	4	3	2	3	3	2	3	3	3	3	3	2	3	3	2	3
Turkmenistan	3	3	3	3	4	3	3	4	2	3	4	2	3	4	2	3	4	2
Ukraine	2	2	3	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2
Uzbekistan	3	4	3	3	4	3	3	4	2	3	4	2	3	4	2	3	4	2
<u>E EUROPE</u>																		
Albania	3	1	4	3	1	4	3	1	3	3	1	3	3	1	3	3	1	3
Bulgaria	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
Czech Rep.	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Hungary	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Poland	2	3	3	2	3	2	2	3	2	2	3	2	2	3	2	2	3	2
Romania	4	2	3	4	2	3	4	2	3	4	2	3	4	3	3	4	2	3
Slovakia	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
<u>AFRICA</u>																		
Algeria	2	3	3	2	4	3	2	4	2	2	4	2	2	4	2	2	4	2
Angola	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Benin	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Botswana	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2
Burkina Faso	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4
Burundi	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Cameroon	1	1	4	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3
Cape Verde	1	1	3	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3
CAR	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4
Chad	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4
Comoros	1	1	4	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3
Congo	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Cote d'Ivoire	1	1	4	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3
Djibouti	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
Egypt	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3
Eq. Guinea	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Eritrea	3	1	4	3	1	4	3	1	4	3	1	4	4	3	4	4	4	4

	1995			Conventional Development Scenario (CDS) for 2025									CDS - MID case with climate change					
				LOW			MID			HIGH			MPI			GDFL		
Country	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc
Ethiopia	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Gabon	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2
Gambia	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4
Ghana	2	1	4	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3
Guinea	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Guinea-Bissau	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4
Kenya	3	1	4	4	2	4	4	2	4	4	2	4	4	2	4	4	2	4
Lesotho	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3
Liberia	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Libya	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3
Madagascar	2	1	4	2	1	4	3	2	4	3	2	4	3	2	4	2	1	4
Malawi	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Mali	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4
Mauritania	4	2	4	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3
Mauritius	2	2	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3	2
Morocco	3	3	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3
Mozambique	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4
Namibia	3	1	3	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2
Niger	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4
Nigeria	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Rwanda	3	2	4	3	2	4	3	2	4	3	3	4	3	2	4	3	2	4
Senegal	3	1	4	3	1	3	3	1	3	3	1	3	3	1	3	3	1	3
Sierra Leone	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Somalia	3	1	4	3	1	4	4	2	4	4	2	4	4	2	4	4	2	4
South Africa	2	3	2	2	4	2	2	4	2	2	4	2	2	4	2	2	4	2
Sudan	4	2	4	4	2	4	4	2	4	4	2	4	4	2	4	4	2	4
Swaziland	4	2	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3
Tanzania	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Togo	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Tunisia	3	3	3	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2
Uganda	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Zaire	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4	1	1	4
Zambia	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Zimbabwe	2	1	4	2	2	3	2	2	3	2	2	3	2	2	3	2	2	3
L AMERICA																		
Argentina	2	1	2	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1
Bolivia	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Brazil	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2

ri = *reliability index*, u/r = *use-to-resource ratio index*, cc = *coping capacity index*.
1= no stress, ... , 4 = high stress. See text in section III for discussion of indices.
MPI = Max Plank Institute method, GFDL = Goddard Fluid Dynamics Laboratory method.

	1995			Conventional Development Scenario (CDS) for 2025									CDS - MID case with climate change					
				LOW			MID			HIGH			MPI			GDFL		
Country	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc
Chile	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Colombia	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Costa Rica	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Cuba	3	3	3	3	3	3	3	3	3	3	4	3	3	4	3	3	3	3
Dominican R.	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Ecuador	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
El Salvador	2	1	3	2	1	3	2	1	3	2	1	3	3	2	3	2	1	3
Guatemala	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Guyana	2	1	4	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3
Haiti	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Honduras	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Jamaica	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Mexico	3	3	2	3	3	2	3	3	2	3	3	2	3	3	2	3	3	2
Nicaragua	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Panama	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
Paraguay	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Peru	3	4	3	3	4	3	3	4	2	3	4	2	3	4	2	3	4	2
Suriname	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3	1	1	3
Trinidad/Tob.	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2	1	1	2
Uruguay	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2
Venezuela	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2	2	1	2
MID EAST																		
Afghanistan	3	4	4	3	4	4	3	4	4	3	4	4	3	4	4	3	4	4
Bahrain	2	4	2	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1
Iran	3	4	3	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2
Iraq	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3
Israel	4	4	1	4	4	1	4	4	1	4	4	1	4	4	1	4	4	1
Jordan	4	4	1	4	4	1	4	4	1	4	4	1	4	4	1	4	4	1
Kuwait	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1
Lebanon	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3
Oman	3	3	2	3	3	1	3	3	1	3	4	1	3	4	1	3	3	1
Qatar	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1
Saudi Arabia	2	4	2	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1
Syria	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3	4	3	3
UAE	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1
Yemen	3	4	4	3	4	4	3	4	4	3	4	4	3	4	4	3	4	4
CHINA+																		
China	3	2	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Korea (DPR)	2	3	3	2	3	3	2	3	2	2	4	2	2	3	2	2	3	2
Laos	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3

Country	1995			Conventional Development Scenario (CDS) for 2025									CDS - MID case with climate change					
				LOW			MID			HIGH			MPI			GDFL		
	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc	ri	u/r	cc
Mongolia	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Viet Nam	2	1	4	2	1	4	3	2	4	3	2	4	3	2	4	3	2	4
S & E ASIA																		
Bangladesh	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Bhutan	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Cambodia	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4	3	1	4
India	3	3	4	3	3	4	3	4	3	3	4	3	3	3	3	3	3	3
Indonesia	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Korea (Rep.)	2	4	2	2	4	1	2	4	1	2	4	1	3	4	1	2	4	1
Malaysia	2	1	2	2	1	2	2	1	2	2	1	1	2	1	2	2	1	2
Myanmar	2	1	4	2	1	3	2	1	3	2	1	3	2	1	3	2	1	3
Nepal	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4	2	1	4
Pakistan	4	4	4	4	4	3	4	4	3	4	4	3	4	4	3	4	4	3
Papua/NG	2	1	3	2	1	3	2	1	2	2	1	2	2	1	2	2	1	2
Philippines	3	2	3	3	2	3	3	3	3	3	3	3	3	2	3	3	2	3
Singapore	2	3	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1
Sri Lanka	3	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Thailand	3	2	3	3	3	2	3	3	2	3	3	2	3	3	2	3	3	2

ri = *reliability index*, u/r = *use-to-resource ratio index*, cc = *coping capacity index*.
1= no stress, ... , 4 = high stress. See text in section III for discussion of indices.
MPI = Max Plank Institute method, GFDL = Goddard Fluid Dynamics Laboratory method.

APPENDIX 4: COMPOSITE INDICES BY COUNTRY

	1995		Conventional Development Scenario(CDS) for 2025						CDS - MID case with climate change			
			LOW		MID		HIGH		MPI		GDFL	
Country	I	II	I	II	I	II	I	II	I	II	I	II
N AMERICA												
Canada	1	1	1	1	1	1	1	1	1	1	1	1
USA	2	2	2	3	2	3	2	3	2	3	2	3
W EUROPE												
Austria	2	3	2	3	2	3	2	3	2	3	2	3
Belgium	3	4	3	4	3	4	3	4	3	4	3	4
Bosnia/Herze	3	3	3	3	2	3	2	3	2	3	2	3
Croatia	2	3	2	2	2	2	2	2	2	2	2	2
Denmark	2	2	2	2	2	3	2	3	2	3	2	3
Finland	1	1	1	1	1	1	1	1	1	1	1	1
France	2	3	3	3	3	3	3	3	3	3	3	3
Germany	3	3	3	3	3	3	3	3	3	3	3	3
Greece	3	3	2	3	2	3	2	3	2	3	2	3
Iceland	2	2	2	2	2	2	2	2	2	2	2	2
Ireland	2	2	2	2	2	2	2	2	2	2	2	2
Italy	3	3	3	3	3	3	3	4	3	3	3	3
Macedonia	3	3	3	3	3	3	3	3	3	3	3	3
Netherlands	2	2	2	2	2	3	2	3	2	2	2	3
Norway	2	2	2	2	2	2	2	2	2	2	2	2
Portugal	3	4	3	4	3	4	3	4	3	4	3	4
Slovenia	2	2	2	2	2	2	2	2	2	2	2	2
Spain	2	3	2	3	2	3	2	3	2	3	2	3
Sweden	1	1	1	1	1	1	1	1	1	1	1	1
Switzerland	1	1	1	1	1	1	1	1	1	1	1	1
Turkey	3	3	2	2	3	3	3	3	3	3	3	3
UK	2	3	2	3	2	3	3	3	2	3	2	3
Yugoslavia	2	3	2	2	2	2	2	2	2	2	2	2
PACIFIC												
Australia	2	2	2	2	2	2	2	2	2	2	2	2
Fiji	2	3	2	2	2	2	2	2	2	2	2	2
Japan	2	3	2	3	2	3	3	3	2	3	2	3
New Zealand	2	2	2	2	2	2	2	2	2	2	2	2
FSU												
Armenia	4	4	3	3	3	3	4	4	3	3	3	3
Azerbaijan	4	4	4	4	4	4	4	4	4	4	4	4
Belarus	2	2	2	2	2	2	2	2	2	2	2	2
Estonia	3	3	3	3	3	3	3	3	3	3	3	3

Country	1995 I	1995 II	CDS for 2025 LOW I	LOW II	MID I	MID II	HIGH I	HIGH II	CDS - MID case with climate change MPI I	MPI II	GDFL I	GDFL II
Georgia	2	4	2	3	2	3	2	3	2	3	2	3
Kazakhstan	3	3	3	3	3	3	3	3	3	3	3	3
Kyrgyztan	3	3	3	3	3	3	3	3	3	3	3	3
Latvia	2	3	2	2	2	2	2	2	2	2	2	2
Lithuania	3	4	3	4	3	4	3	4	3	4	3	4
Moldova	3	3	3	3	3	3	3	3	3	3	3	3
Russia	2	3	2	2	2	2	2	2	2	2	2	2
Tajikistan	3	4	3	3	3	3	3	3	3	3	3	3
Turkmenistan	3	3	4	4	3	4	3	4	3	4	3	4
Ukraine	3	3	2	2	2	2	3	3	2	2	2	2
Uzbekistan	4	4	4	4	3	4	3	4	3	4	3	4
E EUROPE												
Albania	3	4	3	4	3	3	3	3	3	3	3	3
Bulgaria	3	3	3	3	3	3	3	3	3	3	3	3
Czech Rep.	2	2	2	2	2	2	2	2	2	2	2	2
Hungary	2	2	2	2	2	2	2	2	2	2	2	2
Poland	3	3	3	3	3	3	3	3	3	3	3	3
Romania	3	4	3	4	3	4	3	4	4	4	3	4
Slovakia	2	3	2	2	2	2	2	2	2	2	2	2
AFRICA												
Algeria	3	3	3	4	3	4	3	4	3	4	3	4
Angola	2	3	2	3	2	3	2	3	2	3	2	3
Benin	3	4	3	4	3	4	3	4	3	4	3	4
Botswana	2	3	2	3	2	3	2	3	2	3	2	3
Burkina Faso	2	4	2	4	2	4	2	4	2	4	2	4
Burundi	3	4	3	4	3	4	3	4	3	4	3	4
Cameroon	2	4	2	3	2	3	2	3	2	3	2	3
Cape Verde	2	3	3	3	3	3	3	3	3	3	3	3
CAR	2	4	2	4	2	4	2	4	2	4	2	4
Chad	3	4	3	4	3	4	3	4	3	4	3	4
Comoros	2	4	2	3	2	3	2	3	2	3	2	3
Congo	3	4	2	3	2	3	2	3	2	3	2	3
Cote d'Ivoire	2	4	2	3	2	3	2	3	2	3	2	3
Djibouti	3	3	3	3	3	3	3	3	3	3	3	3
Egypt	4	4	4	4	4	4	4	4	4	4	4	4
Eq. Guinea	3	4	2	3	2	3	2	3	2	3	2	3
Eritrea	3	4	3	4	3	4	3	4	4	4	4	4

I = Water Resources Vulnerability Index - I. II = Water Resources Vulnerability Index - II.
1 = no vulnerability, ... , 4 = high vulnerability. See text in section III for discussion of indices.
MPI = Max Plank Institute method, GFDL = Goddard Fluid Dynamics Laboratory method.

	1995		Conventional Development Scenario(CDS) for 2025						CDS - MID case with climate change			
			LOW		MID		HIGH		MPI		GDFL	
Country	I	II	I	II	I	II	I	II	I	II	I	II
Ethiopia	3	4	3	4	3	4	3	4	3	4	3	4
Gabon	2	2	2	2	2	2	2	2	2	2	2	2
Gambia	3	4	3	4	3	4	3	4	3	4	3	4
Ghana	3	4	3	4	2	3	2	3	2	3	2	3
Guinea	3	4	2	3	2	3	2	3	2	3	2	3
Guinea-Bissau	3	4	3	4	3	4	3	4	3	4	3	4
Kenya	3	4	4	4	4	4	4	4	4	4	4	4
Lesotho	2	3	2	3	2	3	2	3	2	3	2	3
Liberia	3	4	2	3	2	3	2	3	2	3	2	3
Libya	4	4	4	4	4	4	4	4	4	4	4	4
Madagascar	3	4	3	4	3	4	3	4	3	4	3	4
Malawi	3	4	3	4	3	4	3	4	3	4	3	4
Mali	3	4	3	4	3	4	3	4	3	4	3	4
Mauritania	4	4	4	4	4	4	4	4	4	4	4	4
Mauritius	2	2	3	3	3	3	3	3	3	3	3	3
Morocco	3	3	4	4	4	4	4	4	4	4	4	4
Mozambique	3	4	3	4	3	4	3	4	3	4	3	4
Namibia	3	3	2	3	2	3	2	3	2	3	2	3
Niger	3	4	3	4	3	4	3	4	3	4	3	4
Nigeria	3	4	3	4	3	4	3	4	3	4	3	4
Rwanda	3	4	3	4	3	4	4	4	3	4	3	4
Senegal	3	4	3	3	3	3	3	3	3	3	3	3
Sierra Leone	3	4	3	4	3	4	3	4	3	4	3	4
Somalia	3	4	3	4	4	4	4	4	4	4	4	4
South Africa	3	3	3	4	3	4	3	4	3	4	3	4
Sudan	4	4	4	4	4	4	4	4	4	4	4	4
Swaziland	3	4	4	4	4	4	4	4	4	4	4	4
Tanzania	3	4	3	4	3	4	3	4	3	4	3	4
Togo	3	4	3	4	3	4	3	4	3	4	3	4
Tunisia	3	3	3	4	3	4	3	4	3	4	3	4
Uganda	3	4	3	4	3	4	3	4	3	4	3	4
Zaire	2	4	2	4	2	4	2	4	2	4	2	4
Zambia	3	4	3	4	3	4	3	4	3	4	3	4
Zimbabwe	3	4	3	3	3	3	3	3	3	3	3	3
L AMERICA												
Argentina	2	2	2	2	2	2	2	2	2	2	2	2
Bolivia	2	3	2	3	2	3	2	3	2	3	2	3
Brazil	2	2	2	2	2	2	2	2	2	2	2	2
Chile	2	2	2	2	2	2	2	2	2	2	2	2
Colombia	2	3	2	3	2	3	2	3	2	3	2	3
Costa Rica	2	3	2	2	2	2	2	2	2	2	2	2

	1995		Conventional Development Scenario(CDS) for 2025						CDS - MID case with climate change			
			LOW		MID		HIGH		MPI		GDFL	
Country	I	II	I	II	I	II	I	II	I	II	I	II
Cuba	3	3	3	3	3	3	4	4	4	4	3	3
Dominican R.	3	3	3	3	3	3	3	3	3	3	3	3
Ecuador	2	3	2	3	2	3	2	3	2	3	2	3
El Salvador	2	3	2	3	2	3	2	3	3	3	2	3
Guatemala	2	3	2	3	2	3	2	3	2	3	2	3
Guyana	3	4	3	4	2	3	2	3	2	3	2	3
Haiti	3	4	3	4	3	4	3	4	3	4	3	4
Honduras	3	4	2	3	2	3	2	3	2	3	2	3
Jamaica	2	3	2	3	2	3	2	3	2	3	2	3
Mexico	3	3	3	3	3	3	3	3	3	3	3	3
Nicaragua	3	4	3	4	3	4	3	4	3	4	3	4
Panama	2	3	2	2	2	2	2	2	2	2	2	2
Paraguay	2	3	2	3	2	3	2	3	2	3	2	3
Peru	4	4	4	4	3	4	3	4	3	4	3	4
Suriname	2	3	2	3	2	3	2	3	2	3	2	3
Trinidad/Tob.	2	2	2	2	2	2	2	2	2	2	2	2
Uruguay	2	3	2	3	2	3	2	3	2	3	2	3
Venezuela	2	3	2	2	2	2	2	2	2	2	2	2
MID EAST												
Afghanistan	4	4	4	4	4	4	4	4	4	4	4	4
Bahrain	3	4	3	4	3	4	3	4	3	4	3	4
Iran	4	4	3	4	3	4	3	4	3	4	3	4
Iraq	4	4	4	4	4	4	4	4	4	4	4	4
Israel	3	4	3	4	3	4	3	4	3	4	3	4
Jordan	3	4	3	4	3	4	3	4	3	4	3	4
Kuwait	3	4	3	4	3	4	3	4	3	4	3	4
Lebanon	3	3	3	3	3	3	3	3	3	3	3	3
Oman	3	3	3	3	3	3	3	4	3	4	3	3
Qatar	3	4	3	4	3	4	3	4	3	4	3	4
Saudi Arabia	3	4	3	4	3	4	3	4	3	4	3	4
Syria	4	4	4	4	4	4	4	4	4	4	4	4
UAE	3	4	3	4	3	4	3	4	3	4	3	4
Yemen	4	4	4	4	4	4	4	4	4	4	4	4
CHINA+												
China	3	4	3	3	3	3	3	3	3	3	3	3
Korea (DPR)	3	3	3	3	3	3	3	4	3	3	3	3
Laos	3	4	2	3	2	3	2	3	2	3	2	3

I = Water Resources Vulnerability Index - I. II = Water Resources Vulnerability Index - II.
1 = no vulnerability, ... , 4 = high vulnerability. See text in section III for discussion of indices.
MPI = Max Plank Institute method, GFDL = Goddard Fluid Dynamics Laboratory method.

	1995		Conventional Development Scenario(CDS) for 2025						CDS - MID case with climate change			
			LOW		MID		HIGH		MPI		GDFL	
Country	I	II	I	II	I	II	I	II	I	II	I	II
Mongolia	3	4	2	3	2	3	2	3	2	3	2	3
Viet Nam	3	4	3	4	3	4	3	4	3	4	3	4
<u>S & E ASIA</u>												
Bangladesh	3	4	3	4	3	4	3	4	3	4	3	4
Bhutan	3	4	2	3	2	3	2	3	2	3	2	3
Cambodia	3	4	3	4	3	4	3	4	3	4	3	4
India	4	4	4	4	4	4	4	4	3	3	3	3
Indonesia	2	3	2	3	2	3	2	3	2	3	2	3
Korea (Rep.)	3	4	3	4	3	4	3	4	3	4	3	4
Malaysia	2	2	2	2	2	2	2	2	2	2	2	2
Myanmar	3	4	2	3	2	3	2	3	2	3	2	3
Nepal	3	4	3	4	3	4	3	4	3	4	3	4
Pakistan	4	4	4	4	4	4	4	4	4	4	4	4
Papua/NG	2	3	2	3	2	2	2	2	2	2	2	2
Philippines	3	3	3	3	3	3	3	3	3	3	3	3
Singapore	2	3	3	4	3	4	3	4	3	4	3	4
Sri Lanka	4	4	3	3	3	3	3	3	3	3	3	3
Thailand	3	3	3	3	3	3	3	3	3	3	3	3

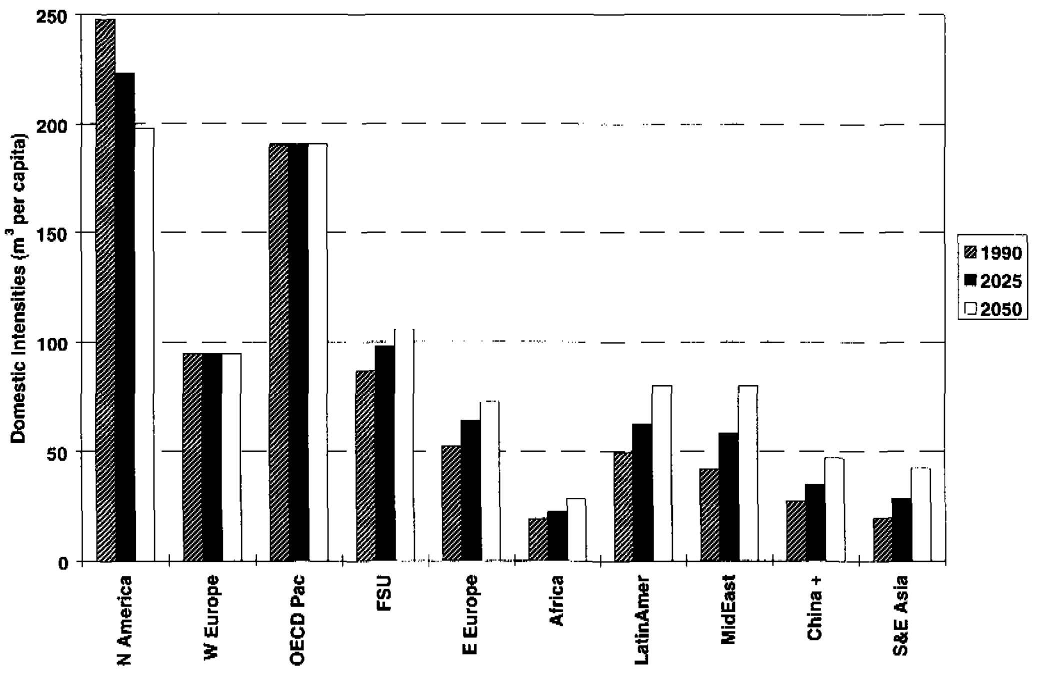
APPENDIX 5: NOTES ON *CONVENTIONAL DEVELOPMENT SCENARIO* ASSUMPTIONS

The CDS builds up water requirements at the regional level in as much detail as current data permits. Disaggregation of the analysis puts emphasis on the development assumptions underlying the scenario -- the character of the economy, household water service, power production, irrigation, etc. -- and the technologies that might be used to transmit and use water. Unlike aggregate methods, the disaggregated approach can pick up changes in the patterns of water use, in the composition of economic activity and in technology.

The population and macro-economic assumptions governing the scenario are presented in Section II. In this Appendix, we summarize the *sectoral* assumptions underlying the CDS. For more details, see Raskin et al. (1995).

We begin with the *domestic* sector which, in comprehensive global tabulations, is taken to include water use in households and in the service sector. Water is used in households for consumption, toilets, dish washing, bathing, cleaning, and outdoor use (e.g., lawn watering, car washing, decorative uses). The service sector includes such water intensive establishments as restaurants, cleaners, hotels, and hospitals. Data limitations require that we aggregate over these diverse activities. Domestic water requirements are described as the product of two factors: population and water intensity. In this case, water intensity is defined as water use per person. Domestic water intensities in a given region reflect many factors, for example, income levels, water infrastructure, technology, and water availability. CDS intensities are presented in Figure 22. This reflects continued improvement in water use efficiency from recent years in OECD regions. In the non-OECD regions, patterns are assumed to converge toward OECD values as incomes grow.

Domestic water withdrawals are computed by multiplying these intensities by the population assumptions in the scenario (described in Section II-D). The results are shown in Figure 23. Water use in the OECD regions changes little since population growth is slow and water intensities either decrease somewhat or are steady; however, the other regions show large increases. Burgeoning populations and economies are projected to drive domestic withdrawals in South and Southeast Asia in 2050 to almost five times the 1990 value, while in China+, withdrawals grow by almost a factor of three. From 1990, annual global domestic withdrawals increase by 60% in 2025 and by more than 100% in 2025.



Source: Raskin et al. (1995).

Figure 22. Domestic Intensities in the CDS

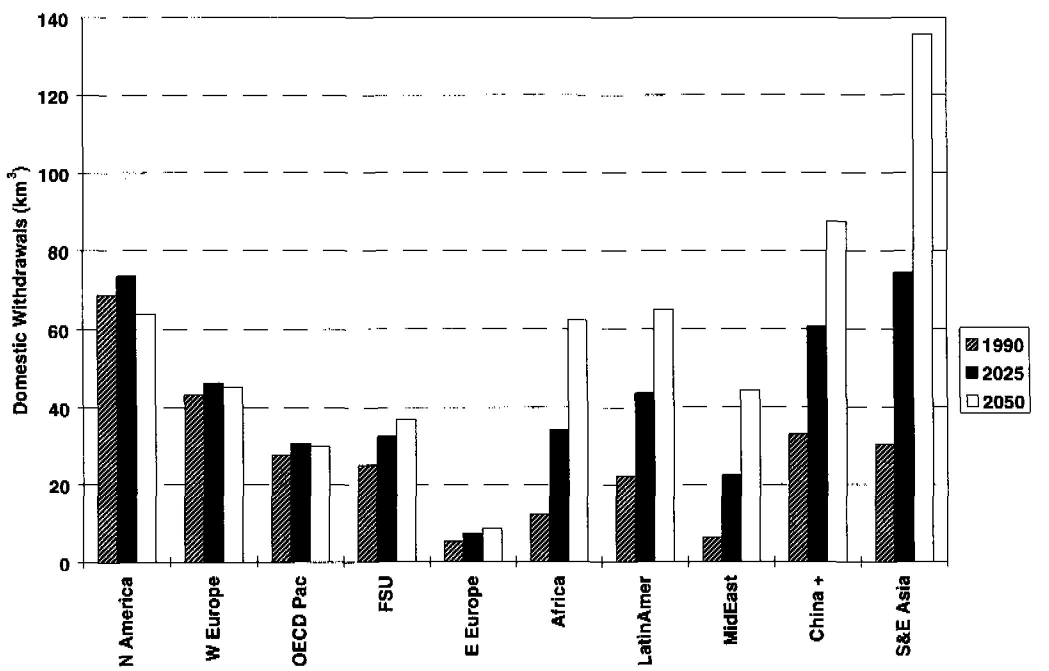


Figure 23. Domestic Withdrawals in the CDS

The industrial sector accounts for approximately 22% of current global fresh water withdrawals. In addition to standard industrial activities (manufacturing, mining, quarrying, and construction) industry data also includes energy sector uses (thermoelectric generation and petroleum refining). This broad grouping masks differing development and technological patterns across industrial subsectors and regions. In the scenario, manufacturing, refining, and thermoelectric generation are treated separately.

Manufacturing water intensity trends depend on assumptions on use efficiency (e.g., degree of on-site water recycling), processes employed, and product mix. In the OECD regions, the rising share of the less water-intensive manufacturing sectors in itself lowers aggregate manufacturing water intensity. This is traced to the stable per capita output of traditional heavy industries such as iron and steel, non-ferrous metals, paper and pulp and chemicals (Raskin and Margolis, 1995). Consequently, the mix of manufacturing output shifts toward less water intensive subsectors, thereby lowering the aggregate manufacturing water intensity. Increasing efficiency and the changing mix of industrial activities are reflected in the CDS manufacturing intensities shown in Figure 24. Manufacturing practices in the non-OECD regions are assumed to converge toward those in the OECD regions as incomes rise.

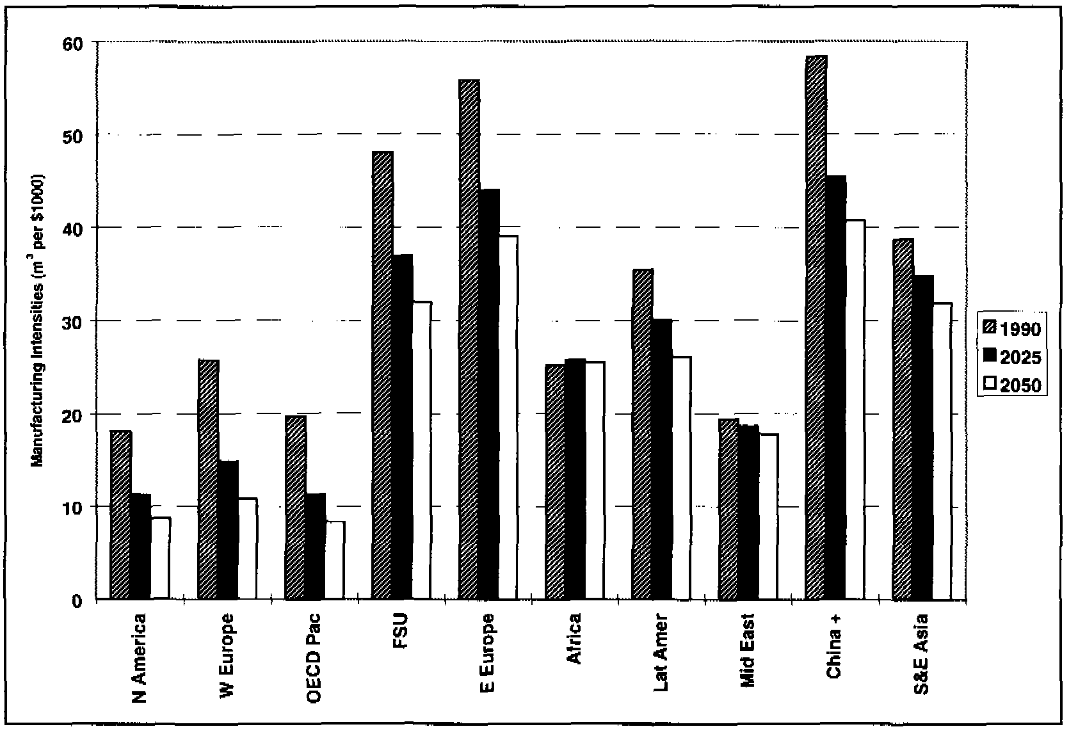


Figure 24. Manufacturing Water Intensities in the CDS

Combining activity and intensity figures, we arrive at the manufacturing water withdrawal scenario shown in Figure 25. Globally, annual water withdrawals in the sector increase by 2050 to nearly triple the 1990 value. Regional variations are due to the interplay of region-specific assumptions about industrial scale, structure and water intensity, as outlined in Section II. The dramatic growth in developing regions is particularly striking. For example, the combined withdrawals of China+ and South and East Asia rises to a level greater than the world total in 1990. These increases in manufacturing water withdrawals are despite considerable decreases in water intensities during the scenario. Water withdrawal for manufacturing is added to water withdrawal for petroleum refining and thermoelectric generation to produce the total water withdrawal in the industry sector.

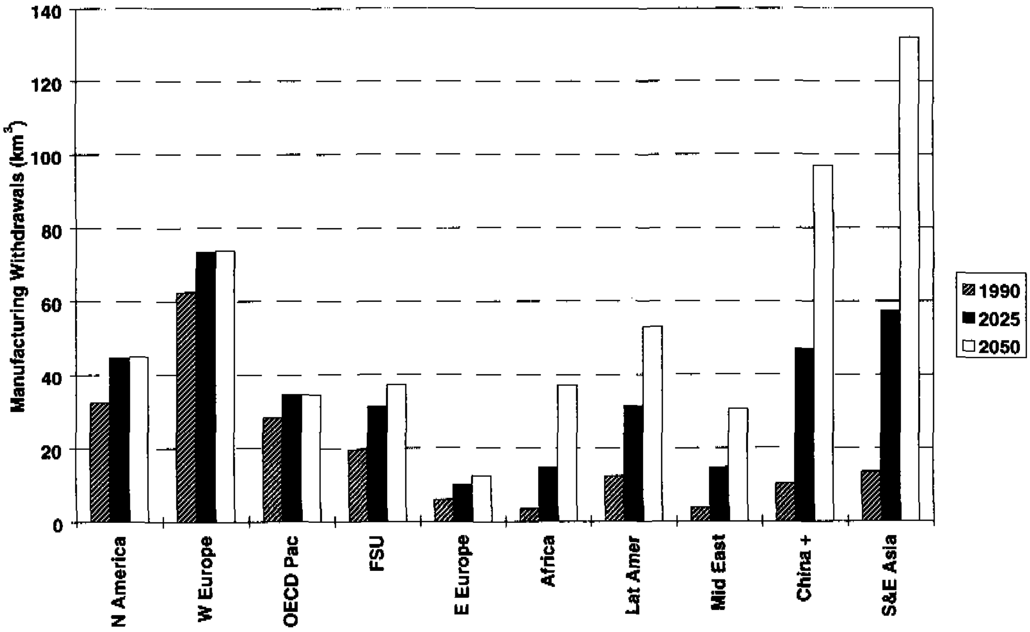


Figure 25. Manufacturing Withdrawals in the CDS

Nearly 70% of current global fresh water withdrawals are for agricultural applications, primarily for irrigation. Irrigated agriculture contributes about one-third of global crop production (Kendall and Pimentel, 1994). Roughly 16% of the world's cultivated land is currently under irrigation, with yields typically much higher than for rain-fed agriculture. For example, in the United States irrigated farming yields averages about four times those of rain-fed farms (Bajwa et al., 1987).

Table 9 shows the CDS assumptions on expansion of irrigated land area to the year 2050 (Leach, 1995). In Table 9, *irrigated land area* refers to any land that is in the irrigated agricultural system (including fallow) during the course of a year. The *cropping intensity* refers to the average number of harvests per year on the irrigated land area. For example, land that is harvested on alternate years has a cropping intensity of 0.5. Figure 26 shows the CDS assumptions for increases in cropping intensities. The *harvested area* is the irrigated land area times the cropping intensity. For example, if one hectare is harvested two times per year, then its harvested area is 2 hectares.

Irrigation water intensities, defined as withdrawals per harvested area, depend on a number of interacting factors. These include crop mix, land quality, weather conditions, irrigation methods, management practices, non-water inputs, relative prices of water and crops, and yield response to irrigation. Figure 27 illustrates the relationship between yield response and water intensity of irrigated agriculture. Different curves are shown for different levels of non-water inputs. The crop yields in the conventional development scenario increase for two reasons: 1) there is increase in water intensity, and 2) there is improvement in non-water agricultural inputs such as management practices, chemical application, and bio-engineered crop varieties. Empirical estimates for the increase in yield associated with an increase in water intensity were drawn from Heady and Hexem (1978). By 2025, the increase in intensities of both water and non-water inputs means that annual irrigated water use would have to increase by approximately 30% relative to current practices in order for annual crop production to double.

These increases in irrigated water requirements are offset partially in the scenario by an increase in the fraction of applied water that is used in plant uptake. While the potential for more water efficient irrigation practices is significant, implementation generally requires increased capital investments. Given the limited capital available for such investments, especially in developing countries, it is unlikely that the full technical potential will be achieved under conventional development assumptions. The CDS assumes 8% efficiency increase from 1990 to 2025.

Combining these factors, we arrive at the CDS irrigation intensities displayed in Figure 28. Multiplying the irrigated land area times the cropping intensities times the water intensities, we arrive at the irrigation water withdrawal scenario shown in Figure 29.

Table 9. Irrigated Land Area in the CDS (million hectares)

				Growth Rate (%/year)	
Region	**1990**	**2025**	**2050**	**1990-2025**	**2025-2050**
North America	19	20	21	0.1	0.2
Western Europe	18	20	21	0.3	0.3
OECD Pacific	5	6	6	0.3	0.1
FSU	21	23	25	0.3	0.3
Eastern Europe	6	6	7	0.3	0.2
Africa	11	12	13	0.3	0.2
Latin America	16	18	20	0.4	0.3
Middle East	13	15	16	0.4	0.2
China +	49	54	57	0.3	0.2
S&E Asia	80	92	96	0.4	0.2
World	237	265	281	0.3	0.2

Source: Values for 1990 from FAO (1992), scenario assumptions from Leach (1995).

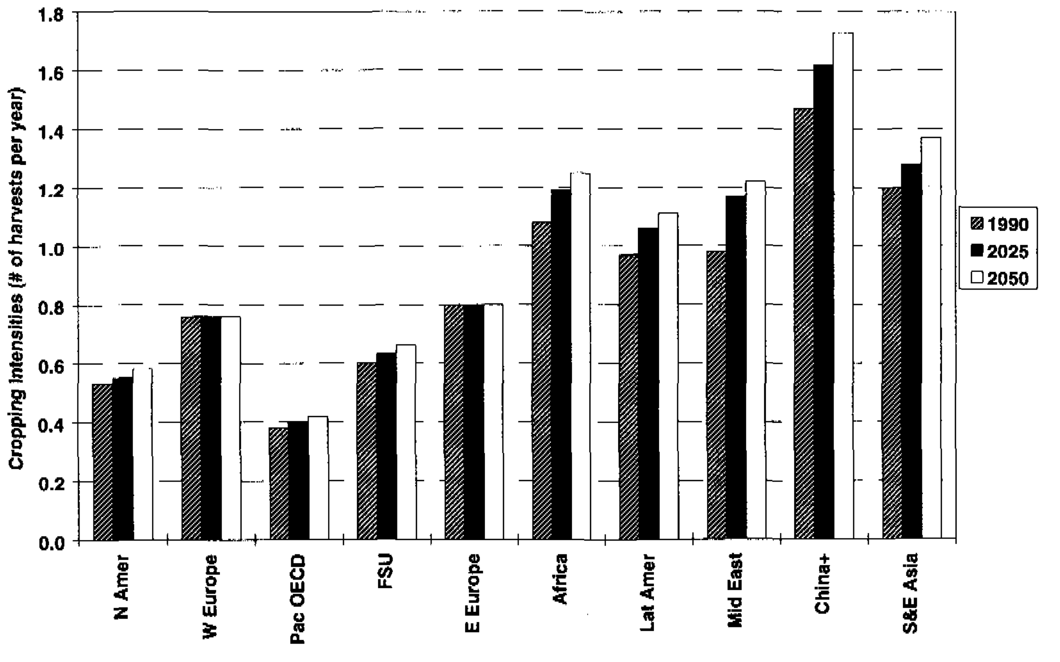


Figure 26. Cropping Intensities in the CDS

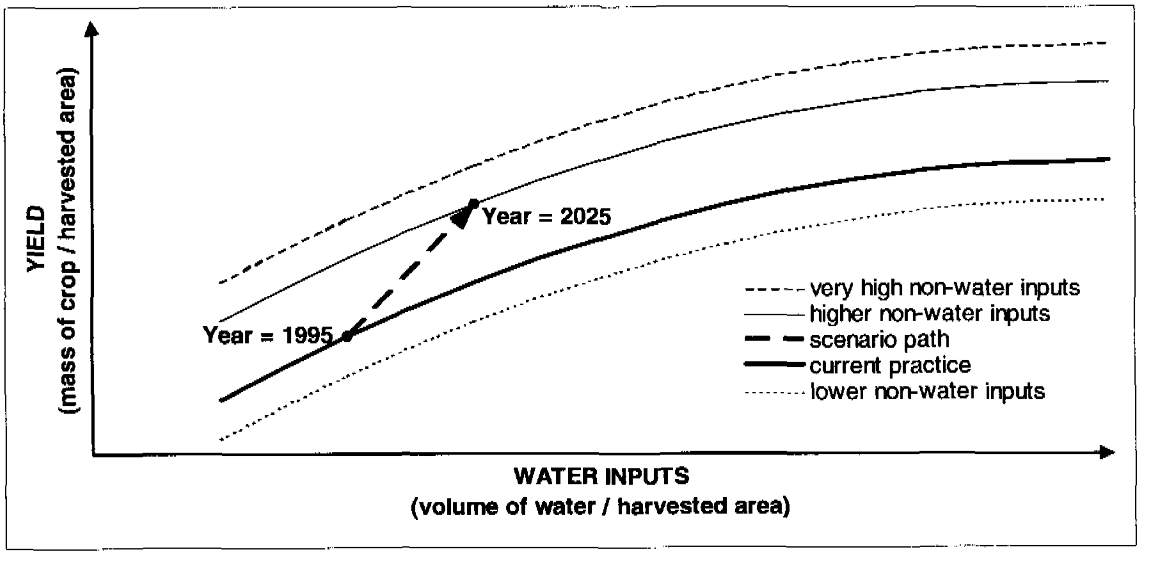


Figure 27. Yield Response to Water and Non-Water Inputs

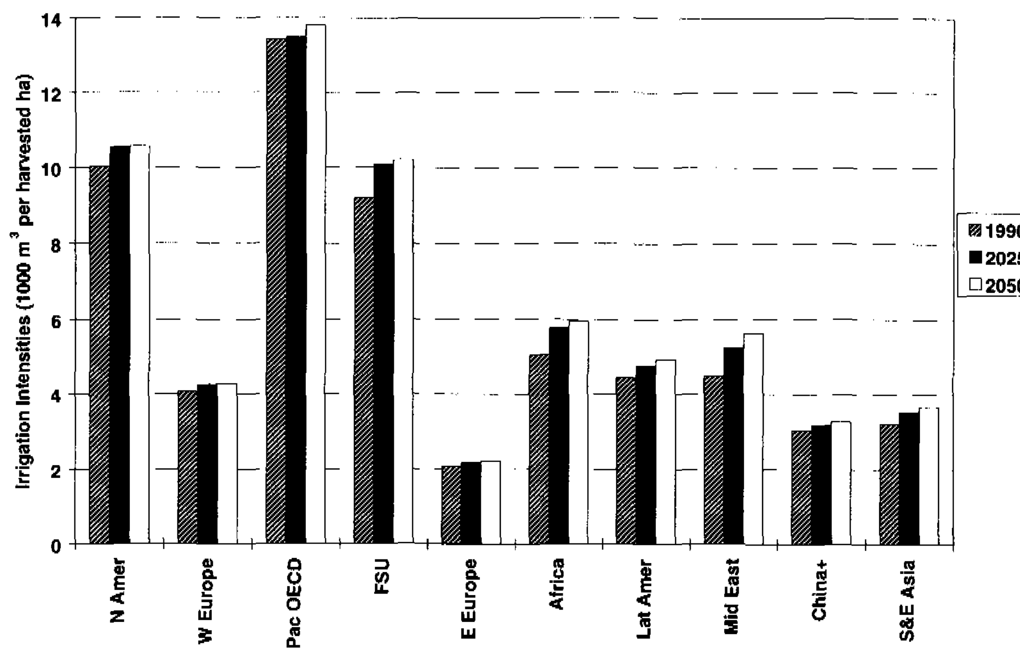


Figure 28. Irrigation Water Intensities in the CDS

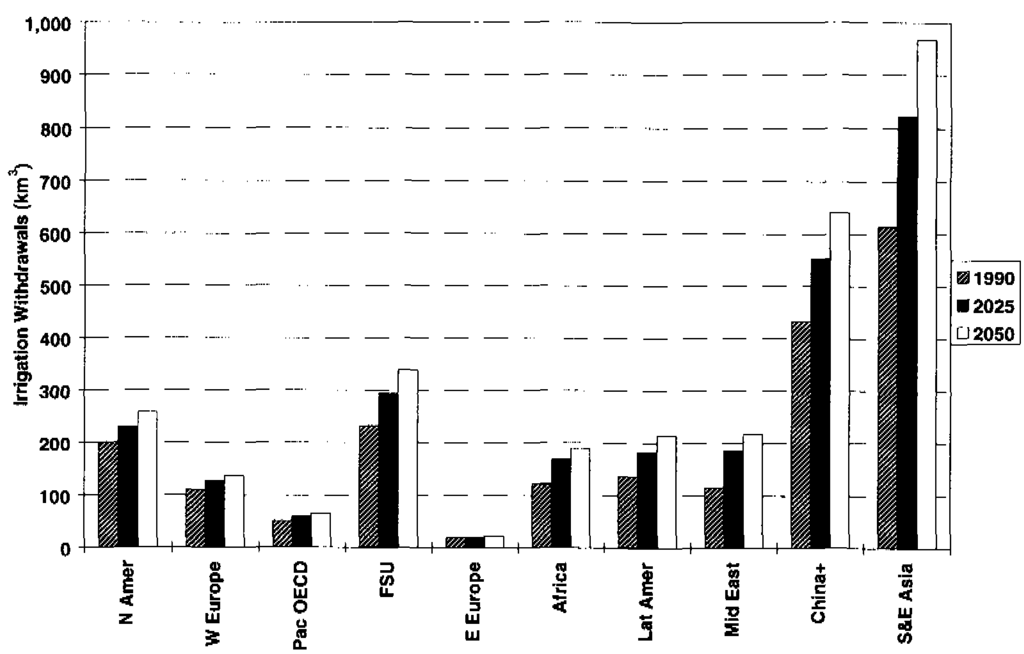


Figure 29. Irrigation Water Withdrawals in the CDS

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