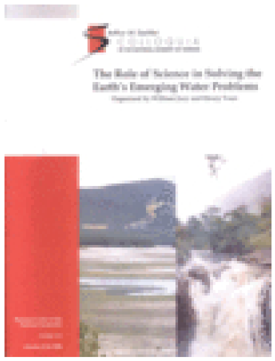

(Sackler NAS Colloquium) The Role of Science in Solving the Earth Emerging Water Problems

Organized by William Jury and Henry Vaux, National Academy of Sciences

ISBN: 0-309-65397-5, 37 pages, 8 1/2 x 11, (2005)

Arthur M. Sackler
COLLOQUIA
OF THE NATIONAL ACADEMY OF SCIENCES

The Role of Science in Solving the Earth's Emerging Water Problems

National Academy of Sciences
Washington, DC

Arthur M. Sackler, M.D.
1913–1987

Born in Brooklyn, New York, Arthur M. Sackler was educated in the arts, sciences, and humanities at New York University. These interests remained the focus of his life, as he became widely known as a scientist, art collector, and philanthropist, endowing institutions of learning and culture throughout the world.

He felt that his fundamental role was as a doctor, a vocation he decided upon at the age of four. After completing his internship and service as house physician at Lincoln Hospital in New York City, he became a resident in psychiatry at Creedmoor State Hospital. There, in the 1940s, he started research that resulted in more than 150 papers in neuroendocrinology, psychiatry, and experimental medicine. He considered his scientific research in the metabolic basis of schizophrenia his most significant contribution to science and served as editor of the *Journal of Clinical and Experimental Psychobiology* from 1950 to 1962. In 1960 he started publication of *Medical Tribune*, a weekly medical newspaper that reached over one million readers in 20 countries. He established the Laboratories for Therapeutic Research in 1938, a facility in New York for basic research that he directed until 1983.

As a generous benefactor to the causes of medicine and basic science, Arthur Sackler built and contributed to a wide range of scientific institutions: the Sackler School of Medicine established in 1972 at Tel Aviv University, Tel Aviv, Israel; the Sackler Institute of Graduate Biomedical Science at New York University, founded in 1980; the Arthur M. Sackler Science Center dedicated in 1985 at Clark University, Worcester, Massachusetts; and the Sackler School of Graduate Biomedical Sciences, established in 1980, and the Arthur M. Sackler Center for Health Communications, established in 1986, both at Tufts University, Boston, Massachusetts.

His pre-eminence in the art world is already legendary. According to his wife Jillian, one of his favorite relaxations was to visit museums and art galleries and pick out great pieces others had overlooked. His interest in art is reflected in his philanthropy; he endowed galleries at the Metropolitan Museum of Art and Princeton University, a museum at Harvard University, and the Arthur M. Sackler Gallery of Asian Art in Washington, DC. True to his oft-stated determination to create bridges between peoples, he offered to build a teaching museum in China, which Jillian made possible after his death, and in 1993 opened the Arthur M. Sackler Museum of Art and Archaeology at Peking University in Beijing.

In a world that often sees science and art as two separate cultures, Arthur Sackler saw them as inextricably related. In a speech given at the State University of New York at Stony Brook, *Some reflections on the arts, sciences and humanities,* a year before his death, he observed: "Communication is, for me, the *primum movens* of all culture. In the arts. . . I find the emotional component most moving. In science, it is the intellectual content. Both are deeply interlinked in the humanities." The Arthur M. Sackler Colloquia at the National Academy of Sciences pay tribute to this faith in communication as the prime mover of knowledge and culture.

Arthur M. Sackler COLLOQUIA OF THE NATIONAL ACADEMY OF SCIENCES

THE ROLE OF SCIENCE IN SOLVING THE EARTH'S EMERGING WATER PROBLEMS

OCTOBER 8-10, 2004

The Beckman Center, Irvine, CA

Organized by William Jury and Henry Vaux

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Cover Art

Dillon Reservoir, Colorado, during the severe drought of 2002. Photo provided by Claire McGrath, Center for Limnology, University of Colorado.

Waters of Nevis, Scotland. Photo provided by James McCutchan, Center for Limnology, University of Colorado.

Arthur M. Sackler COLLOQUIA OF THE NATIONAL ACADEMY OF SCIENCES

THE ROLE OF SCIENCE IN SOLVING THE EARTH'S EMERGING WATER PROBLEMS

October 8-10, 2004
Beckman Center of the National Academies
100 Academy Drive, Auditorium
Irvine, California

Organized by William Jury and Henry Vaux

PROGRAM

Friday, October 8

6:00-8:00 pm Registration and Welcome Reception (Hyatt Newporter – Plaza Arbor)

Saturday, October 9

7:45 am and
8:00 am Buses Depart Hyatt Newporter to Beckman Center

8:00 am Breakfast

Introductory Remarks

9:00 am Henry Vaux and William Jury

Session I: Water Problems from a Global Perspective

9:15 am Malin Falkenmark (Stockholm International Water Institute), *Global Problems of Water Scarcity and Conflict*

10:00 am Michael Dettinger (U.S. Geological Survey and Climate Research Division/ Scripps Institution of Oceanography), *The Implications of Global Change for the World's Water Resources*

10:45 am Break

11:00 am Pat Brezonik (University of Minnesota), *Global Water Quality: Implications for Supply and Health*

11:45 am Alexander Zehnder (Board of the Swiss Federal Institutes of Technology), *Feeding a More Populous World*

12:30 pm Lunch

Session II: Water and the Environment

2:00 pm	William Lewis (University of Colorado), *Evaluating the Importance of Aquatic Ecosystems*
2:45 pm	Barbara Bedford (Cornell University), *Recent and Prospective Scientific Advances in Aquatic and Terrestrial Ecology*
3:30 pm	Break
3:45 pm	Will Graf (University of South Carolina), *Science for Water Development and Wildlife Preservation*
4:30 pm	Elías Fereres (University of Cordoba, Spanish Academy of Engineering), *The Increasing Importance of the Agricultural/Environmental Tradeoff in Managing Water Resources*
5:30 pm	Poster Session and Reception
7:00 pm	Dinner
8:45 pm and 9:00 pm	Buses Depart Beckman Center for Hyatt Newporter

Sunday, October 10

7:45 am and 8:00 am	Buses Depart Hyatt Newporter to Beckman Center
8:00 am	Breakfast

Session III: New Perspectives in Water Management

9:00 am	Alessandro Palmieri (World Bank), *The Prospects and Problems of Storage*
9:45 am	Rhodes Trussell (Trussell Technologies), *The Prospects for Emerging Water Technology*
10:30 am	Break
10:45 am	Frank Rijsberman (International Water Management Institute), *Soft Path Technologies for the Developing World*
11:30 am	Richard Evans (Sinclair-Knight-Mertz), *Groundwater Resource Management Challenges in North China*
12:15 pm	Lunch

Session IV: The Importance of Water Institutions

2:00 pm	Helen Ingram (University of California, Irvine), *The Importance of Institutions and Policy in Resolving Global and Regional Water Scarcity*

2:45 pm	Steve McCaffrey (University of the Pacific McGeorge School of Law), *The Role of International Law*
3:15 pm	General Discussion and Questions
4:00 pm and 4:15 pm	Buses Depart Beckman Center for Hyatt Newporter and Orange County Airport

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Arthur M. Sackler COLLOQUIA OF THE NATIONAL ACADEMY OF SCIENCES

THE ROLE OF SCIENCE IN SOLVING THE EARTH'S EMERGING WATER PROBLEMS
October 8-10, 2004

PRESENTATION

ABSTRACTS

Global Problems of Water Scarcity and Conflict

Malin Falkenmark
Stockholm International Water Institute

Water is the bloodstream of both the biosphere and society. It is per definition scarce in the semiarid region - a region housing many of the poor and hunger-prone countries - in the sense that most of the rain evaporates. This complicates socioeconomic development greatly unless exogenous water is brought by large rivers, by water transfers or by food import (virtual water import).

Water security has four key dimensions: security for societal supply and crop production; security from effects of water-related hazards and from impacts of water's functions as a hidden destroyer. Therefore, water resources management may be thought of in terms of three different perspectives: secure water for societal needs and food production - avoid problems related to water-related hazards and side effects of human activities generated by the hidden destroyer functions, and foresee predictable problems related to driving forces at work.

Water scarcity may have several alternative origins. It may be distinguished according to the causing phenomenon: A. intraannual variability (dry spells, seasonality); B. interannual variability (drought years); C. soil deficiencies (infiltrability, water holding capacity); D. limited runoff generation. It may also be seen from different perspectives: scarcity for plants (green water scarcity) as opposed to scarcity for society (blue water scarcity). Blue water scarcity may - besides natural factors - also be related to societal factors like water use, distinguishing scarcity related to technical limitations (mobilisation constraints) as opposed to demographic limitations (water crowding), but may also be caused by pollution, reducing the usability of available water.

Society's deep going water dependence involves many possibilities for conflicts of interest: between upstreamers and downstreamers, and between humans and nature; conflicts may arise around quantity, quality as well as management structures. In a long-term perspective, all these conflicts of interest can be foreseen to escalate due to continuing population growth, especially as food needs can be translated into green water entitlements, and demographic change will cause escalating upstream/downstream conflicts of interest.

The fact that water is finite makes a shift in thinking essential by moving focus from mobilising more blue water and willful neglect of escalating water pollution towards more productive use of water by minimising losses, blue as well as green; towards reducing per capita blue water needs; and towards an active water pollution abatement. A challenging component of a successful water resources management will have to be a catchment-based orchestrating of partly incompatible water imperatives, paying due attention to both human needs, water availability, land use and ecosystem requirements.

To make all this possible, Academia will have to better live up to expectations by addressing a set of surviving failures: retarded conceptual development, widespread myths, mental barriers and dichotomies, sanctioned discourses and skewed debates. Sustainability science has to be reevaluated to properly incorporate key roles that water plays for environmental, social and economic resilience.

Feeding a More Populous World

Alexander J.B. Zehnder
Board of the Swiss Federal Institutes of Technology

The main consumer of fresh water is agriculture, using approximately 80 percent of the total world water withdrawal. Long term experience shows that the per capita consumption of fresh water in industrialized countries lies around 1500 to 1700 cubic meter per year. These numbers could be verified by analyzing fresh water supply and amount of food imported by countries with limited amount of water available. Taking into account demographic trajectories, predictions can be made of where and when on this planet water represents already a scarce resource.

With the help of importation/exportation figures and the knowledge on the average atmospheric precipitation, North African states from Morocco to Egypt and Israel were used as cases to exemplify how missing water is compensated by importing food. Extrapolation of these basic data to the year 2025, made clear that for many countries of the economic “South”, water shortage and food import will become one of the essential limits to economic growth.

Today, only about seven countries compensate to a different degree with their food export the water shortage of a growing number of other countries. The most important exporters are to be found in the industrialized “North” except for Argentina. The number of exporters will hardly change in the coming years, however the number of importing countries will increase. These countries are situated almost exclusively in the economic "South". The overriding challenge for the developing and fast industrializing countries is to keep their economic independence, despite the growing need for food imports. It is up to the industrialized “North” to allow the water deficient countries through fair trade agreements to economically optimize the use of their scarce water resources.

Evaluating the Importance of Aquatic Ecosystems

William M. Lewis, Jr.
Center for Limnology, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder

The task of evaluating the importance of a particular ecosystem or class of ecosystems falls directly on the boundary between ecological and social sciences. Some important developments relevant to this task have already occurred; these include invention and elaboration of the concepts of ecosystem services and environmental sustainability. Even so, there is no generally accepted framework for evaluating the overall importance of aquatic ecosystems. The purpose of this presentation is to describe a framework that could assimilate information from both the ecological and social sciences to produce a measure of the importance of an aquatic ecosystem or a group of aquatic ecosystems. For present purposes, importance is gauged in terms of the potential to provide ecosystem services. No attempt is made here to convert services to a monetary equivalent, although such a conversion could be added through the use of recently developed valuation methods. Aquatic ecosystems are assigned a baseline importance corresponding to their natural state. Use of an ecosystem replaces the baseline importance with importance related to use, which for present purposes include six separate sets of services. Each of these services is considered in relation to 10 different types of human influences. Response curves are drawn either on the basis of experience or theoretical considerations to show the effect of human influence across a gradient of intensity on the output of each category of service. For any specific location, services are weighted according to their potential expression at that particular site. For a given site, the importance of an aquatic ecosystem is obtained as the sum of weighted services for that site, expressed on an axis of increasing intensity of human use. Output for specific sites shows general results as follows: 1) importance measured by the model described here often is as high for sites that are aesthetically unappealing as for sites that are aesthetically appealing, 2) importance is typified by lack of substantial response to increasing human use up to some threshold, beyond which notable decline in importance begins, and 3) components of importance that are wholly or in part biotic are much more diverse in their response to human influence than other components of importance. Modeling suggests that priorities for research in support of the assessment of importance for aquatic ecosystems should focus on response thresholds for components of importance related to useful biomass and biotic composition of ecosystems.

Science for Water Development and Wildlife Preservation

William L. Graf
Department of Geography, University of South Carolina

Water and wildlife are strongly connected in the United States because the Endangered Species Act (ESA) commits the nation to prevent the extinction of wildlife, while the Clean Water Act (CLA) commits the country to restore and maintain the nation's water courses. Water development is the number one threat to species: it stresses one third of all the species listed under the ESA as threatened or endangered, while specific water management activities such as water diversion and flow disruptions affect a quarter of the listed species. Dams, by their control of flows, are the most common human controls on rivers that threaten wildlife populations by eliminating pre-dam habitats through channel shrinkage and simplification of the fluvial geomorphology. Dams also create new habitats, but they are rarely suitable for imperiled species. Restoration of rivers through dam modification, re-operation, or removal creates partly modified, partly "natural" river segments with expanded suitable habitat for many species. Experiences with dams, species impacts, and potential restoration on the Rio Grande of New Mexico (where the silvery minnow is endangered), Platte River of Nebraska (whooping crane), and Everglades of Florida (Florida panther) suggest three general contributions of science for dealing with conflicts between water development and species preservation: (1) understanding the mechanics of the environmental and social systems at issue by emphasizing hydrologic processes; (2) providing an appropriate general systems context for research by defining the pivotal role of physical integrity; and providing an effective perspective for decision-making by de-emphasizing commodity-based approaches and emphasizing systems concepts.

The Increasing Importance of the Agricultural/Environmental Tradeoff in Managing Water Resources

Elías Fereres
Royal Academy of Engineering of Spain and University of Cordoba

As the world population has expanded in the last century, human activities have increasingly affected the hydrologic cycle of terrestrial and freshwater ecosystems, often with negative consequences. Of all activities, agriculture is by far the one that uses the most of the renewable water resources. Furthermore, a good fraction of agricultural use is consumptive, while most urban and industrial uses are basically not consumptive. Recent intensification of agriculture in response to the increased demand for food, has raised the risk of deteriorating the quality of the water not used consumptively that returns to the system. Thus, at the basin scale, agriculture is the activity that impacts the most on the availability and on the quality of water in nature.

While food production in rainfed agriculture and grasslands primarily affects the quality of the return flows to the environment, the competition for water between food production and nature is centered around irrigated agriculture for a number of reasons. First, irrigation developments occur in regions of scarce water resources. The substantial crop water requirements under irrigation usually represent the lion’s share of such resources, leaving limited volumes for other sectors. Finally, the storage and diversion facilities that form the basis of irrigated agriculture cause fundamental changes in river hydrology and in the landscape, changes that have deep effects on ecosystems and that are increasingly challenged by segments of society. It is therefore not surprising that there is often confrontation between these two sectors, irrigation and environment, in the management of water resources around the world. Lack of understanding of the benefits and costs of the tradeoffs involved and inflexibility on both sides are at the root of these multidimensional conflicts of difficult resolution.

Recent concerns on global water scarcity have given way to a number of assessments of irrigation and environmental requirements at the global scale that will be reviewed here. Global assessments have limited validity because of the poor quality of much of the data and because site specificity is crucial in determining, not only the technical issues but the socio-economic, institutional and cultural issues that so strongly influence the management of water. It is more desirable to carry out this work at the regional, or preferably the basin or sub-basin scales, and to include forecasting uncertainties and climate extremes in scenario assessments. It is particularly important to develop management strategies for situations of water scarcity created by either increased water demands from sectors of higher priority (e.g., urbanization) or by periodic droughts. Under such conditions the relevant questions should focus on: a) How much water can irrigated agriculture give up/contribute?; b) How much water does the environment need?; and, c) What are the societal perceptions of the tradeoffs between the two sectors?. The presentation will discuss new technological options that are or will soon be available to provide answers to the above questions within an adaptive management framework of basin water resources aimed at making irrigated agriculture and nature needs compatible.

The Prospects for Emerging Water Technology

R. Rhodes Trussell
Trussell Technologies, Inc.

This talk will review where we have been in water treatment, it will suggest where we will be going in the near future and it will speculate on what water treatment strategies and issues will look like in the next generation and beyond.

In the early 19th century the development of the world's largest cities began to reach the point where epidemics of water borne disease had become the biggest risk to life for people living there. Engineers and scientists responsible for safe public water supply took several actions to control waterborne disease. These include: 1) Finding a source of water that has never been exposed to human excrement, 2) Using continuously pressurized water systems, 3) to "repurify" a contaminated supply via water treatment and 4) the use of bacterial indicators to test water and find fecal contamination. Simultaneous compliance with the first two principles is sufficient to control classical waterborne disease. Many U.S. cities gained protection this way, including; Los Angeles, New York, Boston, San Francisco, Oakland, Seattle, and Portland. But, from the beginning, many cities were not able to get a protected water source. As a result, the third and fourth principles also become important.

As a result of these actions, by the middle of the 20th Century, classical waterborne disease had been eliminated in the developed world. Because this effort requires a substantial investment in infrastructure, waterborne disease remained a chief cause of death in the undeveloped world. In fact, from the middle of the 20th Century and on, safe drinking water has been a major distinguishing characteristic dividing the developed and undeveloped worlds.

In the developed world membrane technology will become an increasingly important part of treatment technology. At the same time concern about the deterioration of water quality in distribution systems will increase and pharmaceuticals and personal care products will become issues.

Where the undeveloped world is concerned the situation is quite different. There the problem can be broken in two parts:1) A need for the development of infrastructure, 2) A lack of water altogether. Where is adequate and infrastructure is the problem often the second principle (continuous pressure) is the most common problem. Where water shortage is severe progress is inhibited by demands from the developed world that the developing world use more environmental sensitivity than was used in earlier times. Progress may require the development of sanitation technologies that are not as water intensive, such as 1) decentralized waste treatment, 2) Grey-water recycling, 3) Low water sanitation systems.

Soft Path Water Technologies for the Developing World

Frank R Rijsberman
International Water Management Institute, Colombo, Sri Lanka

The traditional, engineering response to water scarcity has been to construct infrastructure, particularly dams, to increase human control over water resources and make a larger share of the total renewable resources available for human use. While that approach has, by and large, been successful in producing its primary output, cheap food, and has provided water supply and sanitation to large numbers of people, the flip side is also clear. Many people do not have access to safe and affordable water supply, despite enormous investments, close to half the world population lacks access to sanitation, many rural poor do not have access to water for productive purposes, groundwater levels in key aquifers are falling rapidly, many rivers are no longer reaching the sea, etc. etc.

Some well-known water authors such as Sandra Postel and Peter Gleick have questioned the sustainability of the water economy if it is not transformed in a significant way. Postel proposes a shift towards higher productivity in agriculture through decentralized micro-irrigation. Gleick discusses what he, after Lovins, calls the “soft path for water” – in essence a focus on the improvement of the overall productivity of water rather than seeking new supplies. According to Gleick the trends towards a less water-intensive economy can already be observed in the US. The US economic productivity of water was relatively constant from 1900 to 1970, at US$6.50 of gross domestic product per cubic meter of water withdrawn, and has subsequently risen dramatically to about US$15; total withdrawals at a national scale have stabilized and the use per capita has fallen.

Key “Soft Path Technologies” for the developing world are:
1. community-managed low-cost water supply and sanitation technologies; and
2. small-scale water technologies for livelihoods in agriculture.

Low-cost water supply implies standpipes and low-cost sanitation refers to latrines (ventilated, improved) in rural areas and to low-cost sewerage in urban areas. Communities ought to be involved in the design, implementation and management of the systems, and contribute labor to reduce capital costs. Investment in infrastructure is linked to hygiene education, as part of a social marketing effort, and combined with micro-credit programs that increase the ability of the poor to pay (part of) the investment costs. Low cost sanitation for rural populations consists essentially of pit latrines, costing US$30-60 per capita in initial investment. Low cost sanitation for dense urban areas, where latrines are not an option, may consist of septic tanks or shallow, small-bore sewerage combined with low cost treatment, costing US$60-140 per capita in initial investment, with so-called simplified or condominial sewer costs starting as low as US$30/capita.

There has been an upsurge in the adoption of water technologies for smallholders such as low-cost small electric and diesel pumps, manual devices such as treadle pumps, bucket and drip lines, sustainable land management practices such as low or zero-till agriculture, supplemental irrigation, deficit irrigation, groundwater recharge and rainwater water harvesting systems.

Drip irrigation is promoted to help farmers in water scarce areas. The advantages of drip systems are that they minimize water losses and increase yields. Drip can increase yields from 20% to 70%, while water savings are reported up to 60% over flood irrigation. Cheap, small scale bucket-and-drip kits (e.g. Chapin bucket-kits in Kenya) have been developed for vegetable cultivation on small plots that do have potential for poor smallholders. The cost of each drip kit promoted by IDE in the mountain range of Nepal is US$13, with a life cycle of 3 years, adequate for irrigation of 125 square meters. The total net benefits, subtracting all costs except labor, obtained by each farm household were US$210 per 1000 M^2 per year by growing two crops of cauliflower and cucumber. In India, the 'Pepsee' kit, a locally developed "disposable" micro-irrigation kit made of low-grade plastic tubes was introduced in 1998-99. The initial investment in a Pepsee system to irrigate an acre of cotton is estimated to be US$ 93 which is about half the investment required for micro-tubes and nearly 25% of the capital required for more conventional drip.

The treadle pump is a foot-operated device that uses bamboo or flexible pipe for suction to pump water from shallow aquifers or surface water bodies. Since it can be attached to a flexible hose, a treadle pump is useful for lifting water at shallow depths from ponds, tanks, canals or catchment basins, tubewells and other sources up to a maximum height of 7 meters. It performs best at a pumping head of 3.0-3.5 m, delivering 1.0-1.2 l/s. IWMI research found that treadle pump technology has had a significant impact in improving the livelihoods of the poor in eastern India, the Nepal Terai and Bangladesh, South Asia's, so-called "poverty square". The treadle pump costs from US$12-30 up to US$100-150, is easy to install, operate and maintain and has no fuel costs. The labor-intensive treadle pump self-selects the poor that have under-utilized time to work the pumps. Farmers using treadle pump technology see an average increase of US$ 100 per year in annual net income with gross incomes of US$300-400 per acre quite common. IDE estimates to have sold 1.3 million pumps since the mid-1980s in Bangladesh, and 200,000 in eastern India and the Nepal Terai since the mid-1990s and indicates that, eastern India and the Nepal Terai have an ultimate market potential for some 10 million treadle pumps.

Rainwater harvesting refers to a host of small scale technologies that aim to conserve rainfall, either in the field directly, or in small structures. Actively promoted by NGOs and civil society organizations in India, the rainwater harvesting technologies have seen astounding adoption rates, up to several hundred thousand villages over several years in parts of India. Since these technologies are evolved by local NGOs or 'barefoot hydrologists' to suit each socio-ecological context, one finds enormous variety in type, scale, costs, benefits, adoption rates and management approaches. Technologies range from farm ponds to individual check dams or tanks benefiting a section of a village to a network of check dams built by a basin or sub-basin community. Construction costs range from US$ 0.4-0.5/m^3 of water storage for earthen structures or the so called 5% technology popular in east-Indian plateau and US$ 0.7-0.9/m^3 when bricks, cement and concrete structures are involved. Some of the larger structures can support some winter crop irrigation; however, the key benefit that drives India's rural communities to invest in these is to ensure one or two life-saving irrigations to the main monsoon crop during the frequent dry spells that ruin standing crops.

Groundwater Resource Management Challenges in North China

Richard Evans
Sinclair Knight Merz

Major groundwater development in the North China Plain, which commenced in the 1960s, has been a key factor in the huge economic growth of China and the achievement of self sufficiency in food production. This is one of the world's largest aquifer systems and supports an enormous exploitation of groundwater which has reaped large socio-economic benefits in terms of grain production, farming employment and rural poverty alleviation, together with urban and industrial water supply provision.

This has however produced major and continuing groundwater level decline and many associated problems: hundreds of thousands of dry wells, sea water intrusion, land subsidence over vast areas and groundwater salinisation. Groundwater levels continue to fall over large areas. This is a potentially disastrous problem, as at the current rate of extraction the groundwater resource will only last for several decades more. This paper focuses upon the hydrogeologic and socio-economic aspects of these groundwater resource issues, and identifies strategies to improve groundwater resource sustainability.

In relation to groundwater management, both supply side and demand side measures have been evaluated. Demand side measures, principally more efficient irrigation leading to "real water savings", is considered to be the only realistic option. Engineering, agronomic and planning measures are required to achieve real water savings. The broad scale adoption of this strategy will be dependent upon comprehensive water management at both national ("top down") and local ("bottom up") scales. The roles of the many levels of water managers need to be redefined and focused to achieve "real water savings" without a major reduction in agricultural production. The strategy has many components, including the defining of groundwater management areas and associated target yields ("sustainable" yields), an improved licensing and allocation system, institutional reforms, programs to address groundwater pollution, increased artificial recharge, metering and monitoring, price increases and community education. The implementation of the total strategy will require a huge effort. Nonetheless the principal focus must be agricultural water savings resulting in significantly reduced groundwater pumping and not an expansion in irrigation area or industrial groundwater.

The Importance of Institutions and Policy in Resolving Global and Regional Water Scarcity

Helen Ingram
University of California at Irvine

In the 21st Century the largest impediments to adequate water supplies are institutions and public policies. It is generally agreed that the point of diminishing returns has been reached in terms the development of water supplies through large-scale infrastructure projects involving dams, and reservoir storage. There is little alternative to better management of existing supplies. Moreover, there are glaring difficulties with contemporary water institutions that are readily identifiable and clearly need correction. Perverse incentives for wasting waters persist. Existing institutions are biased toward narrow interests, and they artificially separate the characteristics of water (quality, quantity, surface and groundwater) as well as fragmenting administration over natural geographies of watersheds and river basins.

Social scientists have been quick to criticize the shortcomings of water institutions, but slow to recognize progressive changes are happening. The theme of this presentation is that significant progress has been made in institutional modifications responsive to contemporary water realities. Current institutional trends are toward centralization of rules and standards, and decentralization of implementation. Greater economic discipline through markets coexists with stronger governance involving public/private partnerships and an enlarged role for nongovernmental organizations. Changing institutions recognize a wider range of values as legitimate.

Water is a place -based resource, with enormous variations in institutional requirements from one location to another. Even so, there is a growing consensus at the highest levels of government, international and national, that some values and physical realities need to be recognized everywhere. The paper traces the influence of broad and general standards and regulations including the European Union Water Framework Directive and the United States' Endangered Species Act upon emergent regional water management institutions. The international Commission for the Protection of the Danube and the California Bay-Delta Authority provide examples.

Both private and public water institutions take on new forma and roles. Markets have made inroads as institutional innovations, but not in the pure form advocated by most economists. Sales to governmental entities rather than private entities predominate. The example of the Environmental Water Account in California is explored. Non-governmental organizations have gained in power and influence and are largely responsible for many institutional changes. Implementation of water policies now often includes such organizations not just in advising but also in delivery of service. Very importantly, the multiple meanings and values associated with water are more equitably recognized.

The Role of International Law

Stephen C. McCaffrey
University of the Pacific, McGeorge School of Law

Some 60% of global river flows pass through the world's 263 international drainage basins and supply around 40% of the planet's population. Growing scarcity of this vital natural resource, coupled with the fact that so much of it is shared by two or more countries, produces an obvious potential for competition and conflict, but also for cooperation to enhance efficiencies and even water supply.

This presentation will address the role of international law in the field of shared freshwater resources through four case studies, ranging from a dispute between the United States and Mexico over the Rio Grande in the late 19th century to the present situation as between the Israelis and Palestinians in relation to shared groundwater and the Jordan River.

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October 8-10, 2004

Poster Session

1. Familigietti, Jay, *University of California, Irvine*, D. Alsdord, *University of California, Los Angeles* and D. Lettenmaier, *University of Washington*; **Satellite Observation of Global Surface Waters**.

2. Hidalgo, Hugo, D.R. Cayan and M.D. Dettinger, *Scripps Institute of Oceanography;* **Low Frequency Drought Variability in the Western US: Paleoclimatic Indicators and GCM Projections**.

3. Lettenmaier, Dennis, *University of Washington, Charles J. Vorosmarty, University of New Hampshire, and Robert Naiman, University of Washington;* **The Global Water System Project**: **Understanding the Implications of Human Manipulation of the Global Water Cycle**.

4. McGrath, Claire and W.M. Lewis, *University of Colorado;* **Foodweb Interactions of native and Non-native Trout in Rocky Mountain Streams - a Field Test of Competition and Predation**.

5-9. McMahon, James E., *Lawrence Berkeley National Laboratory;* **The Energy-Water Nexus**. (Posters 5-9).

10. Sanden, Blake, *University of California Cooperative Extension;* **Ag Water Use Efficiency and Irrigation Scheduling in the Southern San Joaquin Valley**.

11. Wu, Laosheng and Christine French, *University of California, Riverside;* **Public Perceptions of Water Issues in California**.

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Arthur M. Sackler COLLOQUIA OF THE NATIONAL ACADEMY OF SCIENCES

THE ROLE OF SCIENCE IN SOLVING THE EARTH'S EMERGING WATER PROBLEMS
October 8-10, 2004

POSTER

ABSTRACTS

Satellite Observation of Global Surface Waters

J. Famiglietti, Dept. of Earth System Science, University of California, Irvine;
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River discharge as well as lake and wetland storage of water are critical elements of land surface hydrology and are critically important to human populations, yet they are poorly observed globally and the prospects for improvement from in-situ networks are bleak. Furthermore, off-river-channel environments, such as wetlands, floodplains are increasingly recognized for their important roles in delaying continental runoff, in biogeochemical cycling of waterborne constituents, and in trace gas exchange with the atmosphere, but the dynamics of water stored in these environments are not generally observed because flow is diffusive (non-channelized). Satellite measurements may enable hydrologists to move beyond the point-based observations provided by gauge networks to basin-wide measurements of discharge and storage, and to better understand the storage of water globally, and its dynamics. Here, some of the existing satellite-based measurements of discharge and changes in storage (e.g., SAR imagery, Altimetry, SRTM, Interferometric SAR and GRACE) are outlined along with their drawbacks. Some new methods, such as radar altimetry and Interferometric Altimetry, to remotely monitor the streamflow and changes in terrestrial surface water storage are proposed. These new techniques will provide measurements that will enable a better understanding of the land surface branch of the global hydrologic cycle, will aid in the prediction of the consequences of global change, and will be useful in water resources management. Also, the roles of wetlands, lakes, and rivers in biogeochemical cycling will be better understood using these new measurements. Finally, improved global measurements of surface water will help in obtaining better parameterizations for climate and hydrologic models.

Low Frequency Drought Variability in the Western US: Paleoclimatic Indicators and GCM Projections

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Low-frequency hydrologic variations of the western US for the past 500 years contained in gridded tree-ring reconstructions of Palmer Drought Severity Index (PDSI), were compared to PDSI projections under climate change scenarios calculated from the output of general circulation models (GCMs). Tree-ring results suggest that bidecadal and pentadecadal PDSI oscillations have been a common feature of the climate of the western US at least for the past 500 years. These variations are though to be related to similar low-frequency climate variations from the Pacific and Atlantic Ocean basins. Future PDSI projections computed from the GCM estimates of precipitation and temperature, also contain significant multidecadal variations, as well as significant negative trends. Although precipitation exhibits very little trend in many of the GCM projections for the western US, warming temperatures will drive PDSI into the dry category more frequently in the future according to the GCM data. Regional structure and change of precipitation is inconsistent across models. However, warmer climate alone will produce more frequent scarcity of water availability.

The Global Water System Project: Understanding the Implications of Human Manipulation of the Global Water Cycle

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The water cycle figures prominently in the study of global change. In addition to greenhouse warming and concerns about an accelerated hydrologic cycle, several other anthropogenic factors interact with the water system to produce potentially global-scale effects. Prominent among these are widespread land cover change, urbanization, reservoir construction, irrigated agriculture, destruction of aquatic habitat, and pollution. A rich history of research at the local scale demonstrates the clear impact of such factors on the environment. Evidence now shows that humans are rapidly embedding themselves in the basic character of the water cycle over much broader domains. The collective significance of such a transformation of a basic element of the Earth system remains fundamentally unknown. This presentation summarizes a new project launched as part of the Earth System Science Partnership (ESSP) of the Global Environmental Change Programs (Diversitas, IGBP, IHDP, WCRP) that will study these water cycle changes. The aim of the GWSP is to catalyze our understanding of the dynamics of water in the Earth system, the unique role that humans play in the hydrologic cycle and reciprocal interactions between the biogeophysical and human components of the coupled system. A major emphasis of GWSP is on interactions, feedbacks, and thresholds, necessitating a balanced consideration of all factors at play: physical, chemical, biological, and societal. The GWSP is the product of contributions made by a broad cross-section of the water science and assessment community, with more than 150 contributors to a series of planning meetings, science scoping documents, and a recent Open Science Conference (October 2003; Portsmouth, NH). This poster reviews the scientific rationale for the initiative, presents the Project's motivating science questions, and describes the emerging agenda for study.

Foodweb Interactions of Native and Non-Native Trout in Rocky Mountain Streams – A Field Test Of Competition and Predation

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The greenback cutthroat trout *(Oncorhynchus clarki stomias)* is listed as a threatened subspecies under the U.S. Endangered Species Act. Restoration efforts during the past 30 years have focused on stocking suitable habitat with hatchery-reared greenback cutthroat trout. However, non-native brook trout *(Salvelinus fontinalis)* continue to displace native cutthroat trout in many areas. In the past, researchers have suggested that displacement of cutthroat trout by brook trout is a result of resource competition, but competition has not been investigated directly in field studies. We documented population dynamics and feeding ecology of greenback cutthroat trout and brook trout at 10 stream sites in the Rocky Mountains. Analysis of population, body condition, stomach content, and stable isotope data were used to determine if competition for food or predation were occurring. Results indicate that brook trout decrease the survival of young greenback cutthroat trout, and that interspecific competition for food among adult trout is not the mechanism for displacement of greenback cutthroat trout. Brook trout predation on cutthroat trout was observed at low rates and does not appear to account for population declines of cutthroat trout. Describing the mechanisms of species invasion contributes to more effective management of native species; however, the greenback cutthroat trout – brook trout system suggests that mechanisms of invasion can be subtle and difficult to identify.

The Energy-Water Nexus

James E. McMahon
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(A presentation by USDOE multi-program laboratories)

Two critical infrastructures – water and energy - are inextricably linked. Significant quantities of freshwater are withdrawn by thermal power plants producing electricity; conversely, energy is required for drawing, transporting, treating and using water and for processing wastewater. Problems are already emerging in water and energy supplies in diverse locations and future trends in population and possibly climate are expected to exacerbate these problems. Scientific and technological approaches that will help characterize and address these problems include:

- Assessment, prediction and decision support
- Basic science (e.g., data and methods for evaluation of multi-scale interdependence of water cycle variability, water quality and energy production and use)
- Technological innovation
- Implementation and technology transfer

Public Perceptions of Water Issues in California

Laosheng Wu and Christine French
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At the start of the Southwest States and Pacific Islands Regional Water Quality Program in 2002, a need to assess state and regional priorities was identified. A public survey was chosen as a tool to help reach that end. A 37-question survey was adapted by the Program Team from a similar survey used in the Pacific Northwest. One version of the survey was mailed to randomly selected residents in Arizona, California, Hawaii, and Nevada. Another version was slightly modified and conducted orally in the Pacific Islands. In California, 988 surveys were returned from 2000 sent for a response rate of 49%. Based on information gathered from the survey, key areas in need of outreach efforts were identified. Clean drinking water is the most important water issue in California and the region according to the survey. Several questions asked respondents to rate the importance of clean drinking water either on its own, or in relation to other issues, and it consistently rose to the top as the most important issue. Other high priority issues identified for California are watershed management and water conservation. This knowledge, combined with information on how residents view themselves and the environment, will help public educators in California and the region craft appropriate and effective learning opportunities for specific demographic groups and the public in general.

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THE ROLE OF SCIENCE IN SOLVING THE EARTH'S EMERGING WATER PROBLEMS

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