2002

Human Population and Freshwater Resources: U.S. Cases and International Perspectives

Karin M. Krchnak

Victoria Dompka Markham

Nancy Thorne

Bulletin Series
Yale School of Forestry & Environmental Studies

NUMBER 107

Human Population and Freshwater Resources: U.S. Cases and International Perspectives

KARIN M. KRCHNAK, VOLUME EDITOR

VICTORIA DOMPKA MARKHAM AND NANCY THORNE,
ASSISTANT VOLUME EDITORS

JANE COPPOCK, BULLETIN SERIES EDITOR

Yale University
New Haven, Connecticut · 2002

The Yale School of Forestry & Environmental Studies *Bulletin Series*, begun in 1912, publishes faculty and student monographs, symposia, workshop proceedings, course materials, and other reports, with the goal of bringing work or events of special environmental interest taking place on the Yale University campus to the attention of a broader audience.

Copies of recent *Bulletins* are available in downloadable PDF format for no charge at the F&ES Bulletin Series webpage at www.yale.edu/environment/publications/. Printed copies of recent *Bulletins* can be ordered at the same web address. Orders can also be sent to the following:

Yale F&ES Bulletin Series
205 Prospect Street
New Haven, CT 06511
USA

Bulletin 107 was published as a cooperative effort of the Center for Environment and Population (CEP), National Wildlife Federation (NWF), Population Resource Center (PRC), the Yale School of Forestry & Environmental Studies (Yale F&ES), and the Yale Institution for Social and Policy Studies (ISPS), with the support of the University of Michigan Population Fellows Program funded by the U.S. Agency for International Development (USAID). The volume contains the proceedings of an experts' meeting held on March 22-23, 2001, at Yale University.

Volume Editor **Karin M. Krchnak**

Assistant Volume Editors **Victoria Dompka Markham and Nancy Thorne**

Bulletin Series Editor **Jane Coppock**

Bulletin Design **R. Richard Solaski**

Production **Dottie Scott, Tupos Type House; Peggy Sullivan, Sullivan Graphic Design**

Editorial Assistance **Melissa Goodall, Shafqat Hussain**

Printing **Yale University Reprographics and Imaging Services (RIS)**

Cover Design **Maura Gianakas, Yale RIS**

Paper **Mohawk Vellum, Cream White, 60 lb. text, acid free, recycled**

Bulletin Number 107
ISSN 0361-4425
CODEN BYSSDM

Contents

Acknowledgements

The editors wish to thank the following for their invaluable assistance in this project: James Gustave Speth, Dean of the Yale School of Forestry & Environmental Studies (Yale F&ES); John Wargo, Professor of Environmental Risk Analysis and Policy and Director, Environment and Health Initiative, Yale F&ES; Jane Coppock, Assistant Dean, Yale F&ES, and Editor of the *Yale F&ES Bulletin Series*; and Carol Pollard, Development Coordinator, Yale Institution for Social and Policy Studies (ISPS). The experts' meeting was sponsored by the Yale School of Forestry & Environmental Studies and the Yale Institution for Social and Policy Studies. We are grateful to the Compton Foundation, Bill and Melinda Gates Foundation, Richard and Rhoda Goldman Fund, William and Flora Hewlett Foundation, John D. and Catherine T. MacArthur Foundation, David and Lucile Packard Foundation, Summit Foundation, and the University of Michigan Population Fellows Program funded by the U.S. Agency for International Development for their generous support of this project.

Summary of Experts' Meeting on Human Population and Freshwater Resources

Held March 22-23, 2001 at Yale University

Victoria Dompka Markham, Karin M. Krchnak, and Nancy Thorne

Water may be the resource that defines the limits of sustainable development. It has no substitute, and the balance between humanity's demands and the quantity available is already precarious.

– Footprints and Milestones: Population and Environmental Change, State of World Population Report 2001, United Nations Population Fund

Only 2.5% of all water on the Earth is freshwater, and of that, 0.5% is accessible to us through ground or surface water supplies. Although water supplies are finite, the world population has grown – tripled in the past 70 years – and water-use has increased sixfold, mainly from irrigation and industrial use.[1]

The trends are particularly striking. In any given year, 54% of the available freshwater is used. If per capita consumption remains the same, in less than 25 years we could be using 70% of available freshwater as a result of population growth alone. We could use 90% of available water by 2005 if the per capita level worldwide reaches that of more developed nations.[2]

What does this mean for each of us? How will it affect our daily lives, and those of generations to come? How much do we know about how population factors affect pressures on freshwater resources in the United States and around the world? Where are the gaps in our knowledge, and what do we need to know? What can we do about it?

These questions, among others, prompted the Center for Environment and Population (CEP), National Wildlife Federation (NWF), and the Population Resource Center (PRC) to hold an experts' meeting on the relationship between human population and freshwater resources, as part of CEP's "Emerging Issues in Environment and Population Project."

The Emerging Issues Project involves a series of integrated activities including: experts' meetings and meeting reports; materials development; and, policy, media and public outreach briefings – all centered on a range of topics relating to the human population's environmental impact. The objective is to focus on what is "new and emerging" in relation to a given topic (in this case, population and freshwater), so that we can work more effectively towards achieving environmental sustainability.

Water was selected for this set of activities because it is something on which all life depends, and there is evidence that humans are altering water resources at rates, scales, and in ways never before experienced.[3] Analysis of

1 Falkenmark, M., 1994. "Population, Environment and Development: A Water Perspective." In Population, Environment and Development: Proceedings of the UN Expert Group Meeting on Population, Environment and Development, New York, New York, 20-24 January 1992. UN, 1994: 99-116.

2 United Nations, 2001. Population, Environment, and Development 2001 Wall chart. New York: Population Division, Department of Economic and Social Affairs, UN.

3 World Health Organization, 2001. Global Water Supply and Sanitation Assessment 2000 Report. Geneva: UN Educational, Scientific, and Cultural Organization.

these issues – particularly the most current scientific thinking and emerging trends in the field – is not necessarily reflected in public policies, outreach, and advocacy efforts.

Through the experts' meeting, this Yale F&ES Bulletin Series meeting report, and follow-up activities, we hope to make available good quality research and analysis that will be integrated into policies and public outreach efforts to conserve freshwater for a healthy planet.

THE EXPERTS' MEETING

The meeting on which this report is based took place on March 22 and 23, 2001 at Yale University. It was hosted by the Yale School of Forestry & Environmental Studies (Yale F&ES) and co-sponsored by the Yale University Institution for Social and Policy Studies (ISPS). James Gustave Speth, Dean of the Yale School of Forestry & Environmental Studies, gave the opening remarks. The meeting was attended by 18 participants. Yale F&ES students acted as rapporteurs. A meeting agenda can be found in the Appendix.

The Center for Environment and Population (CEP), National Wildlife Federation (NWF) and Population Resource Center (PRC) jointly convened the meeting. The organizations represented the three legs of the event: science, policy, and public outreach. CEP was responsible for bringing the best and latest scientific research to the table, PRC oversaw the U.S. and international policy links, and NWF focused on the public outreach, advocacy, and grassroots links. Together, the team of organizations was able to bring a range of expertise to the meeting, something that would have been difficult for any one of the groups to do on their own. The organizations are described in more detail at the end of this Summary.

The purpose of the Population and Freshwater working meeting was twofold:

- First, to present a sampling of the latest scientific research on the topic, in the form of case studies; and,
- Second, to determine common themes for action relating to policy, research, and public outreach.

OPENING REMARKS

James Gustave Speth, Dean of the Yale School of Forestry & Environmental Studies, provided the welcome and opening remarks to the working meeting. He opened by stating that water and climate change would be the two dominant issues of the next few decades in terms of environment and natural resources and took special note of the interaction between the two, remarking that the most profound effect of climate change in the short and long run will be its major impact on water resources. Dean Speth described the challenges of providing safe water for drinking, agriculture, and other purposes and stated that, in almost every environmental resource sector, we have destroyed or degraded a substantial portion of the natural resources. He urged that environmental restoration become a priority on the science and policy agenda for water as for other resource sectors. Dean Speth closed by noting that people are beginning to understand what sustainable management of water resources really is, and they are relating it to demographics, which is critical if we are to move beyond research to action.

U.S. CASE STUDIES

Moving to the more specific, experts presented five case studies from around the United States and its international borders. They included cases from the West, Midwest (Michigan), Mid-Atlantic (Chesapeake Bay area), Southeast (Florida), and Southwest-Border (Texas, Mexico). The case studies as presented at the working meeting were designed to include information on:

- Status of freshwater resources and ecosystems;
- Population and consumption factors (such as population growth rates, composition, density, movement, tourism, migration, rates of natural resource consumption and pollution) which influence freshwater resources;
- How population factors affect plant and animal species and their habitat;
- How ecosystems are affected;
- Historic and present population – water resource dynamics, and what the issues will be in the near and long term future; and,
- Suggestions for policy responses, public outreach, education and activism, including how the print and broadcast media should address the issues.

Each case study as presented at the working meeting represented quite different perspectives on the issues. Although the complete case studies are included in this *Bulletin*, some highlights include the following:

West: University of New Mexico Law Professor Denise Fort oversaw the Western Water Policy Review Advisory Commission Report, *Patterns of Demographic, Economic and Value Change in the Western U.S.: Implications for Water Use and Management*. The report showed how the rate of population growth in the Western U.S. was much faster than the rest of the country, growing at 32% in the last 25 years, while growth in the rest of the U.S. was 19%. The population is forming "urban archipelagos," with 86% of Westerners living in or near cities. Agriculture use for irrigation represents 90% of water use. The demands of the fast growing and highly concentrated populations, combined with low rainfall, have resulted in the lack of water supplies and major water management problems in many of the 17 western states. Ecological effects include species loss and endangerment; alteration of river, stream, and spring ecosystems; and imperilment of fisheries.

Southeast: Bonnie Kranzer, Senior Supervising Planner with the South Florida Water Management District and former Executive Director of the Governor's Commission for the Everglades, noted that rapid and steady growth characterize South Florida's population change. Increased urban sprawl, greater per capita land use, and increasing pressure for additional development accompany the residential growth. Reconciling the intense population pressures and development in the fragile South Florida ecosystem is the greatest challenge. Over the past 50 years, over half of the Florida Everglades has been destroyed, mainly due to massive drainage to allow human occupation in areas otherwise too wet for habitation. Dr. Kranzer pointed out that if current trends continue, there will be continued degradation of wetlands, estuaries and aquatic plant and animal life; increased water shortages for agricultural and urban use; increased flooding, and, loss or movement of groundwater well fields. The recently passed Comprehensive Everglades Restoration Plan by the U.S. Congress is seen by many as a viable means to restore the South Florida ecosystem if rigorously implemented.

Mid-Atlantic: Margaret Palmer, Professor of Biology at the University of Maryland (UM), discussed how human-induced changes to natural landscapes have been identified as one of the greatest threats to freshwater resources. She is part of an interdisciplinary team established to study and later develop predictive models for how land use change will affect stream ecology in four urban-area watersheds in suburban Maryland, northwest of Washington, DC. The team is examining the relationship between land use and stream ecosystems for the urban watersheds, and how they expect the land use to change over two decades, and the ecological consequences. They have based their work, in part, on evidence that demographic trends and human activities are such that the rate of urbanization of the landscape is increasingly rapid, and there are no signs that the pattern of increasing human alteration of landscape will slow. The effect on the ecosystems can persist for many decades and may be difficult to reverse.

Midwest: David Rankin, Vice President and Director of Programs of the Great Lakes Protection Fund, discussed how the combination of biological and chemical pollution, and landscape conversion adversely affected the Great Lakes, the largest freshwater system in the world. Mr. Rankin cited population density and rates of resource consumption as the two major population factors contributing to the lakes' degradation. Reshaping the land and rivers around the lakes, introduction of nutrients and chemical poisons, and introduction of non-native species are the three most prominent alterations that affected the lakes' ecosystems. A government-led, coordinated resource and management strategy begun in the 1960s made much progress in restoring the health of the lake system. The challenge now is to create governance systems that support its recovery over the long term.

Texas-Mexico Border: Mary E. Kelly, Executive Director of the Texas Center for Policy Studies, described how demographic trends, such as movement to urban areas and high rates of natural increase in population, characterize the overall population growth in the Texas/U.S.-Mexico border. Rapid industrialization and the rapid growth of populations in urban areas in the Río Grande River Basin have resulted in severe stress on water and wastewater infrastructures. Ms. Kelly discussed how the combined factors of high temperatures and frequent droughts, high pollutant discharge rates, inefficiencies in water use, differing national politics, and the aforementioned population dynamics, all contribute to the stress on water resources in this region.

OVERVIEWS AND OUTREACH

The meeting included experts from the international, policy, media and advocacy sectors who presented their perspectives on population and freshwater issues, including how the information can be used or conveyed in their respective fields.

International Overview: At the time of the meeting, the United Nations Population Fund (UNFPA) was preparing the new *State of the World Population 2001, Footprints and Milestones: Population and Environmental Change*. Report researcher and writer Stan Bernstein presented a global view of the issues, reviewing the status of freshwater resources on the planet, and how irrigation, industry and household use affect the resources. Mr. Bernstein pointed out that the availability of water between and within nations is often related to income. The most developed nations have, on average, higher rainfall than the lesser developed nations. To further exacerbate inequities in water availability, richer countries are better able to develop reservoirs, dams, and other technologies to capture freshwater run-off and available ground water. He said that the quality of water is far from adequate for all people: approximately 1.1 billion people do not have access to clean water worldwide, and 2.4 billion lack access to sanitation. Mr. Bernstein highlighted the challenges of gender issues, international conflict, and climatic change as relates to water resources.

Media and Public Outreach: Kathy Bonk, Executive Director of the Communications Consortium Media Center (CCMC), discussed steps needed to bring information about the population-water issue to the attention of the media and public. Her polling data indicated that pollution of drinking water and water pollution in general were top amongst the public's environmental concerns. She described how the data revealed the sectors of society that might be most open to becoming likely supporters on the issues, persuadable, and unlikely supporters. Ms. Bonk said that telling stories, general framing of the topic rather than providing details, news you can utilize with a local link, presenting solutions, and "weather stories" relating to the issue were the most effective ways to reach audiences through the media. She stressed how communicating "values," or why people care about environment and population issues, was central to success in message development on these issues. Ms. Bonk described how a strategic communications plan including positive news stories and use of editorials, op-eds, and articles are important tools in reaching the media.

Policy and Decision Makers: The U.S. Department of State Office of Population's Director Margaret Pollack discussed America's foreign policy, the use of family planning and reproductive health as an important public health intervention, and environmental linkages. She stated that U.S. international population policy is based on the premise that achieving a healthy and sustainable world is vital to U.S. foreign policy interests. Ms. Pollack said that U.S. foreign assistance is focused on reducing the challenges of a growing population to the environment. She also noted several U.S. Agency for International Development (USAID) programs linking population to the environment, including the Honduran-based "Farm Management Plan" involving rural families' sustainable management of natural resources, the University of Michigan Population and Environment Fellows Program, and the Environmental Health Project in Madagascar.

Advocacy and Grassroots: Pamela Goddard, NWF's Senior Grassroots Outreach Manager, presented the view that although public opinion polling demonstrated that there is much interest in clean water issues, the public has not yet made the explicit connection between water quality, quantity, and population pressures. She said that although polls show people care about clean water, this does not necessarily translate into action. Ms. Goddard suggested that what is needed is to educate the public about the connections between water quality, quantity, and various population pressures, and how they personally are affected by water-related problems. She said credible spokespersons were needed to bring the topic to the forefront in the media, and more media coverage was necessary to increase the level of understanding people have of the issues so they may eventually take action.

Yale F&ES Commentary: During the meeting, Dr. Wargo, Professor of Environmental Risk Analysis and Policy and Director of the Environment and Health Initiative at the Yale School of Forestry & Environmental Studies, highlighted several important overarching issues. First, he noted that he was increasingly pessimistic about "top-down" institutional strategies, and stressed the need for "bottom-up approaches," including improving environmental and scientific literacy, encouraging individuals to think differently about their own involvement and approach to the environment, and motivating people to think of the ecological system as a whole.

Second, Dr. Wargo observed that we are not getting information on current approaches to environmental issues through to people. He pointed out: "...People have over 400 chemicals in their bodies that did not exist prior to 1900. We need a different approach to address these kinds of new problems, approaches that we are not currently using." He said it is necessary to respond to the complexity of the issues by thinking of them strategically, to try and "reframe the nature of the problem." For example, he commented that we should be looking at land use and its connection to watersheds, water-related species loss, and human health effects, as a whole. He noted that much has to do with the "invisibility of the threat – when you eat swordfish, for example, you cannot taste the mercury, but it is there."

Third, Dr. Wargo pointed out that water scarcity is driven by many factors with population growth being one of them. In addition, water is being contaminated by chemicals to a greater degree than previously understood and that this contamination is a serious threat to human health and biodiversity. There are important equity issues to consider, as water is not distributed equally throughout the world. Pollution is also more prevalent in some areas of the world and, thus health threats differ across regions. Dr. Wargo commented that many of the "at risk water-related ecosystems" are not being managed effectively or at all. For example, there is no agreement between Israel and Jordan on how to manage water. He emphasized that we need to determine what information is required to inform various target audiences, and how to respond with the best solutions. Finally, Dr. Wargo noted that the case studies presented as part of the meeting are an excellent start in providing some viable solutions to address the world's water issues.

COMMON THEMES, POLICY RESPONSES AND PUBLIC OUTREACH

The working meeting's case studies and other presentations provided a wealth of information and insights on how human actions and other dynamics affect freshwater resources. These are best brought out in the presentations as they appear in this Volume. In addition, a number of common themes emerged from the meeting. They provide an excellent reference on how to approach the issues in general, and in the policy, research, advocacy, and public education sectors. A sampling of the themes appears below:

General

- Approach the issues with the concept of "connectivity," using the whole ecosystem as a central theme;
- Show tangible benefits from making the ecosystem connections, from watershed and water source, to land, biodiversity, plant and animal species' habitat, "services" provided, humans, food on the table, health, and so on;
- Present the issues and /or problems with viable, proven solutions and lessons learned;
- Develop and use "indicators" of "water health;"
- So people get the whole big picture and context in which water issues occur, frame the issues globally, then go to regional, national, local, community, and individual levels, using specific case studies to illustrate points at all levels; and,
- Focus on the individual's responsibility towards and stewardship with water resources and ecosystems.

Land Use Development

- A better understanding is needed on the environmental effects of land use development patterns, as well as when policy instruments are effective in relation to land use development and watershed impacts; and,
- Land use patterns, whether they be "smart growth" or "uncontrolled sprawl," will generally have a dramatic affect on stream ecosystems.

Local to Global Issues

- Pollution from the local to global atmosphere affects water quality. This includes pollution from coal-fired power plants and the use of airborne pesticides that enter the water. This points to the need for global as well as local resource management.

Research Needs

- Better data on water use patterns, water availability and environmental water needs is needed, and should be made widely available to the public and professionals alike;
- Research is needed on instream flow required to maintain healthy aquatic ecosystems and riparian habitats; and,
- A scientific research agenda is needed on the land connections to water, and vice versa, and on the gaps of what is not known, what is known, what needs to be known on water and population pressures.

Management

- Water conservation in the agricultural and municipal sectors, including application of more "water-use efficiency," can play a major role in saving on water supplies;
- Future water demands must be met by a combination of factors, including: greater water use efficiency; better responses to environmental stimuli such as rain and drought; better pricing policies; and additional, different water sources, such as reservoirs and wastewater re-use;
- Use dynamic rather than static measures for assessment and management;
- Need modernization of the legal, administrative, and governing systems for water management;
- Water management must be done at the local as well as global level, because pollution comes from all levels. For example, biological pollution in the form of invasive species can be carried to the U.S. on international commercial ships to U.S. waterways, and can come from local sources; and,
- To restore degraded water systems, natural flow regimes to tributaries and coastal lake areas need to be reinstated.

Policy

- Sustainability needs to be put at the center of water policies. Current policies reflect separate, unconnected management approaches for irrigation, household, and industrial use;
- Ecological functions of rivers and other freshwater ecosystems are not, for the most part, currently taken into account in public policy and need to be;
- When watersheds are threatened by development, setting aside areas for protection from further development has been a successful policy option;
- Where cross-U.S. border issues apply, there should be binational policy frameworks for addressing water issues;
- Economic factors like subsidies and water pricing, are often hidden causes of water problems; and,
- Often an area's economy exacerbates its environmental problems, with expanding agricultural, commercial and tourism sectors. A good approach is to reconcile these needs by making water a "draw" or "currency" so as to support the economy, however in a way which is sustainable for the water systems.

Public Outreach

- There must be a concerted effort on the part of water management agencies and non-government organizations (NGOs) to build broader public awareness of water scarcity and water policy issues;
- Educating the public about the environmental affects of urban sprawl and people's individual actions are key ingredients to successful watershed management and stream protection; and,
- There is a need to focus on state governments in conjunction with local groups for action on the issues.

Future Issues

- Water may become central to international conflicts as more and more pressure is placed on increasingly scarce or degraded water resources;
- Technological fixes, such as desalination, are proving too difficult to count on to increase future freshwater supplies; and,
- Climate change may have increasing affects on water resources, influencing rainfall patterns, sea level rise, and increased incidence and severity of major weather events such as storms, thus affecting human settlement patterns along coastal and other areas.

Follow-up Activities

A number of follow-up activities based on the Population and Freshwater Experts' Meeting held at Yale University are planned for 2001-2002. Among them are: production and broad dissemination of the working meeting proceedings as part of this working meeting report; reporting on the working meeting in CEP, NWF and PRC venues such as web sites and publications; and, development, distribution, and use of the materials based on the meeting, for policy makers in the U.S. Congress and at the state level, and for NWF's network of grassroots activists.

In addition, CEP, NWF and PRC have been invited to convene a special experts' panel session based on the Yale meeting at the American Association for the Advancement of Science's (AAAS) Annual Meeting in Boston in February 2002. The launch of the Yale *Bulletin* will be held at the AAAS Meeting. NWF and PRC will hold a briefing for students, activists and state policymakers on "Population and the South Florida Ecosystem" in 2002. The three organizations will also be using the meeting's information and recommendations to help shape the policy debate at the national and international levels at such fora as the World Summit on Sustainable Development in fall 2002, and subsequent reviews of the implementation of the 1994 International Conference on Population and Development (ICPD).

ORGANIZERS

Center for Environment and Population (CEP)

The Center for Environment and Population (CEP), a non-profit organization and project of the Tides Center, addresses the relationship between human population, resource consumption, and environmental impacts. The Center works to strengthen the scientific basis of policies and public outreach to achieve a long-term sustainable balance between people and the natural environment around the world. CEP partners with leading organizations to link science to policy and public education efforts, so as to better understand and effectively address the issues. To do this the Center and its organizational partners undertake a series of activities to: compile and assess the current knowledge and emerging trends on the issues; produce expert and research-based materials for policy makers and the public, and; conduct activities to disseminate the materials and information for policy and public outreach.

The Center has three major program areas: Emerging Issues in Environment and Population, Building New Population-Environment Leadership, and the AAAS Atlas of Population and Environment Distribution and Briefing Project. Activities center on producing science-based materials including Issues Papers, and undertaking strategic distribution and briefings based on the new materials from the local-community to international level. The Center also utilizes its CEP Experts Network to engage leading scientists and other issues-experts in policy and public outreach projects. For more information contact, Victoria Dompka Markham, CEP Director, at vmarkham@cepnet.org or visit the web site at www.cepnet.org.

National Wildlife Federation (NWF)

The National Wildlife Federation (NWF) is the nation's largest, not-for-profit, environmental education and advocacy organization with more than four million members and supporters. Its purpose is to educate, inspire, and assist individuals and organizations of diverse cultures to conserve wildlife and other natural resources and to protect the Earth's environment in order to achieve a peaceful, equitable and sustainable future. Founded in 1936 as a national group of outdoor enthusiasts, NWF is a member-supported national network of affiliated organizations and individual members throughout the United States and its territories. Combining the local knowledge and focus of its strong grassroots network with the perspective, resources, and strength of a national organization, the National Wildlife Federation generates unparalleled support for wildlife, wild places and a healthy environment.

People and Nature: Our Future is in the Balance – This statement of NWF summarizes the recognition by NWF that environmental issues are increasingly global in scope and that human demand for and use of natural resources relate to environmental deterioration worldwide. We are in danger of losing the balance between population and nature as the world's population continues to rise. NWF's strong educational focus and broad constituency of members and grassroots activists enables individuals of all ages and backgrounds to work together toward achieving a balance between people and nature. NWF's Population & Environment Program makes a significant contribution toward promoting responsible national and international action by informing people of how population growth and pressure are imperiling the wildlife and wild places that they love and how they can take action. NWF works to achieve a sustainable balance among the world's population, environmental quality, wildlife and wildlife habitat, and our finite natural resources. For more information contact, Karin Krchnak, Population & Environment Program Manager, at krchnak@nwf.org or visit the web site at www.nwf.org/population.

Population Resource Center (PRC)

The Population Resource Center's (PRC) mission is to improve public policy by promoting the inclusion of sound objective analyses of demographic data in the policy process. To achieve this goal, the Center organizes 50 to 70 programs annually that provide national, state and local policymakers with information about the effects of demographic and related social and economic change on public policy issues. For almost 30 years, the Center has organized educational briefings for government leaders on issues such as immigration, teenage pregnancy, aging, the well being of children and families, and international population growth and change. At each of these programs, we arrange for leading experts to discuss with policymakers the latest research in the field and answer specific questions about the implications of their research findings for policy.

The information gained from this experts' meeting on population and freshwater is part of a larger effort to engage and educate the public about the importance of international population issues. PRC is conducting a four-year project to promote understanding of how demographic dynamics effect economic development, the status of women, public health, and the environment. The nation's foremost sociologists, demographers, public health and environmental experts donate their time to participate in PRC's issue focused programs. The core values of PRC are nonpartisanship and objectivity. Briefing programs for federal, state and local policymakers are based on academic research. Policymakers from both political parties serve on the PRC board of directors and participate in programs as moderators and co-sponsors. For more information, contact Jane De Lung, PRC President, at Jdelung@prcnj.org or Nancy Thorne, PRC Vice President, at nthorne@prcdc.org, or visit the PRC web site at www.prcdc.org.

Water and Population in the American West

Denise D. Fort
University of New Mexico School of Law

ABSTRACT
The American West is justly famed for its sunshine and wide skies.[1] However, there is a potent combination of low rainfall and growing population in the West that ensures that water, or the lack of it, will remain another well-known feature of the region. As the number of people sharing already stressed water supplies increases, the economic, ecological, and social costs of providing water become more evident. Agriculture consumes about 90% of the water that is extracted in the West, and the transfer from agricultural to municipal and industrial uses is invariably complex. Increased water extraction has resulted in the loss of species across the western landscape. Groundwater mining is a looming crisis in the West; however, as an issue it is hidden from public consciousness and typically solved by costly water projects. The movement toward sustainability will require a reorientation of public policies to recognize the need to balance human uses with ecological functions, and to incorporate the true costs of water into decision-making. It is important that the public learns that public entities make decisions throughout the year that affect the availability and management of water supply. Issues that should be of concern to consumers include water rates, whether rivers will be tapped for municipal supplies, achievement of water quality standards, whether new development and industry will be encouraged, as well as other issues that profoundly affect the future of western rivers.

INTRODUCTION AND BACKGROUND

The amount of water available for human use is determined by the hydrological cycle. While there is a relationship between population growth and stresses on water supplies, the relationship is not linear. Increased human populations typically result in reallocation of current resources rather than the development of new water sources. Water supplies in the American West are particularly limited and, with newcomers lured by bright skies and new economic centers, population growth in the region has outstripped the rest of the country in recent years. Yet it is unlikely that a resident of a new subdivision in the American West will want for water, as a resident of a city in the developing world might. It is more likely that the water for a new subdivision will be procured at the cost of a river ecosystem or with a change in agricultural practices.

Irrigated agriculture consumes 90% of the water extracted in the region.[2] The amount of water extracted for agriculture peaked at 150 million acre feet (maf) in 1960, and declined to 139.6 maf in 1990.[3] In part, this is a reflection of a dramatic change in the nature of farming and ranching in the last half century. Trends of corporate farming and consolidation have led to larger farms, which has led to a decline from 2.7 million farms in 1969 to 1.9 million in 1992.[4] Western irrigated agricultural lands are responsible for 45% of the value of U.S. crop commodity exports.[5]

Agriculture occupies a very different place in the West's economy than it did a half century ago. The popular portrayal of the West continues to be one of running cattle, mining, and living off the land. Building on these images, lobbyists routinely represent agriculture as the mainstay of the West's economy. *However, farming, ranching, mining, and agricultural and mineral processing account for only 6% of employment in the region.*[6]

[1] For the sake of this discussion, the "West" is defined as the American states west of the 100th meridian, excluding Hawaii and Alaska. There is enormous variation within this large area, but with respect to water it is appropriate to characterize this as a region.

[2] Western Water Policy Review Advisory Commission. 1992. *Water in the West: the Challenge for the Next Century*. Denver, Colorado: 2-24.

[3] *Ibid*: 2-22, 2-23, fig. 2-10.

[4] *Ibid*, 2-19.

[5] *Ibid*, 2-18 and 2-19.

[6] *Ibid*, 2-18.

The federal government and tribal governments play unique roles in the West. The Bureau of Reclamation and the Corps of Engineers built storage and hydropower facilities across the West, enabling agricultural and then industrial development. The era of building large-scale dams is now at an end, but these agencies still operate and maintain these facilities, ensuring a federal presence on western rivers.[7] Further, the Endangered Species Act has thrust the responsibility of managing most major western rivers onto the U.S. Fish and Wildlife Service and the U.S. Department of the Interior. The Corps of Engineers, in its role as operator of dams, struggles against the Bureau of Reclamation for dominion through flood control construction projects and through other river-related functions. Finally, tribal governments hold large, but unquantified claims to western rivers, and the federal government has a fiduciary relationship to these governments.

State governments typically administer water rights in western states. These rights are based on the prior appropriation doctrine, which was developed in response to the aridity of the West. Under this doctrine, the basis for claims was the "beneficial use" of water, so it has been difficult to reconcile the protection of instream flows with this fundamental tenet of western water law. State governments aggressively assert their sole control over water, but the reality is that power is shared among many authorities. Many of the water rights that were established under the prior appropriation doctrine came into existence when stagecoaches were crossing the West. In fact, it is common for current adjudications to involve rights that were established a century earlier. Under the *Winter's*[8] doctrine, tribal rights will be even older. Although water rights can be transferred or sold in many states, historical patterns still weigh heavily.

Finally, municipal governments, urban water districts, and other substate entities are growing in importance as population booms in the West. By imposing charges for water, they become formidable competitors where there are water markets. These authorities are inextricably linked to the other entities involved with western water. For example, a California municipality might be directly affected by the Colorado River compact as well as the actions of the Secretary of the Interior, tribes, other western states, and other municipalities. However, these groups have been less dependent on federal funding, and are therefore somewhat more independent of federal decision-making than agricultural interests. In the West, the adage is that "water flows uphill to money," which has certainly been confirmed by the vigorous expansion of western cities.

MAJOR ISSUES

The major issue in western water is the effect of population increases on water resources. Expanding populations exacerbate the stresses that are already being felt in the system, and test whether society will be able to find water solutions that provide for long-term sustainability in the West. Water stresses in the West stem from a variety of causes:

[7] The demand for new storage facilities may result in some additional dams, off-stream reservoirs, groundwater recharge or desalinization facilities, but most of the sites for large-scale dams have already been used. The federal government's role in providing these additional storage facilities is an open question.

[8] *Winters v. United States*, 207 U.S. 564 (1908).

In the West, the adage is that "water flows uphill to money," which has certainly been confirmed by the vigorous expansion of western cities.…The major issue in western water is the effect of population increases on water resources.

(1) Rivers have been developed without regard for their ecological functions, resulting in threats of species extinction;
(2) Most rivers are fully allocated, so that it is hard to find water for environmental and ecological uses;
(3) Groundwater is being mined in some regions – when these sources are exhausted, new supplies will be sought;
(4) Water prices do not reflect the value of water, which means that consumers are making decisions without full understanding of the implications of their choices; and
(5) Water quality has been impaired, which has affected water supplies, therefore constraining water uses.

The population of the West grew by 32% during the last twenty-five years, compared to 19% in the country as a whole.[9] An interesting challenge to the myth of the wide-open western life is that 86% of all westerners live in or near cities.[10] Eight of the ten fastest growing cities in the United States are in the West,[11] which is evidenced by the overall development pattern towards a number of large cities dubbed "urban archipelagos."[12] These cities include Boise, Salt Lake City, Spokane, Denver, Colorado Springs, Las Vegas, Sacramento, Eugene, El Paso, Dallas, Albuquerque, Tucson, Phoenix, and Missoula.[13]

The U.S. Geological Survey (USGS) has chronicled the withdrawal and consumption of water in the West. In 1960, withdrawals in the West totaled 135 maf, compared with 179 maf in 1990.[14] During that same timeframe, agricultural withdrawals declined as a percentage of the whole from 86% to 78%, with increases in the relative shares of thermoelectric and domestic consumption.[15] A report to the Western Water Policy Review Advisory Commission asserts that all "withdrawals in the 19 western states appear to have stabilized"[16] and this is borne out by the USGS projections for increases in demand. Over a 30-year period, from 1990 to 2020, the population of the West is projected to increase by 51%, but the demand for water is projected to increase by only about 5%.[17] However, the USGS has suggested caution regarding the reliability of water use projections in another context: "The projections by these agencies and commissions vary greatly, reflecting the availability of reliable data and reflecting different assumptions for population growth, economic conditions, energy-resources development, and environmental regulations."[18]

The ecosystems of rivers, streams, springs, and other bodies of water have been drastically altered by water development in the West. The causes and result of river disruption were succinctly summarized in a 1998 article:

> Little debate occurs among fisheries professionals about the causes of imperilment and extinction of southwestern fishes. Most frequently mentioned causes are construction of dams, loss of physical habitat, habitat degradation, chemical pollution, overexploitation, and introduction of nonindigenous species. Dam construction and regulation probably had the greatest adverse effect on native fishes of

[9] Case, Pamela J., and Alward, Gregory S., 1997. *Patterns of Demographic, Economic and Value Change in the Western United States: Implications for Water Use and Management.* The Western Water Policy Review Advisory Commission, Springfield, Virginia: 7.

[10] *Ibid.*

[11] Riebsame, William E., with James L. Wescoat and Peter Morrisette. 1997. *Western Land Use Trends and Policy: Implications for Water Resources.* The Western Water Policy Review Advisory Commission, Denver, Colorado.

[12] Western Water Policy Review Advisory Commission. 1992. *Water in the West: the Challenge for the Next Century.* Denver, Colorado: 2-15; See also, Tarlock, Dan A. 1999. Growth Management and Western Water Law: From Urban Oases To Archipelagos in *Hastings West-Northwest Journal of Environmental Law and Policy Winter.* 163-201.

[13] *Water in the West: the Challenge for the Next Century.* Western Water Policy Review Advisory Commission, Denver, Colorado (1998) at 2-15.

[14] *Water in the West: the Challenge for the Next Century.* Western Water Policy Review Advisory Commission, Denver, Colorado (1998) at 2-23, figure 2-10. Solley, W.B., Pierce, R.R., Pearlman, H.A., 1998. Estimating Water Use in the United States. *Water in the West: the Challenge for the Next Century.* 2-23.

[15] *Ibid.*

[16] Western Water Policy Review Advisory Commission. 1992. *Water in the West: the Challenge for the Next Century.* Denver, Colorado: 2-21.

[17] Western Water Policy Review Advisory Commission. 1992. *Water in the West: the Challenge for the Next Century.* Denver, Colorado: 2-22. (Demand here probably means actual withdrawals.)

> southwestern rivers, while the effects of excessive groundwater pumping have imperiled many spring systems and their associated fauna. The number of nonindigenous fish species in the Southwest is considerable: Arizona has 71 species; New Mexico, 75 species; Utah, 55 species; and Texas, 96 species.
>
> As a whole, fishes in the western United States are clearly more imperiled than those in the eastern United States. More than half of the fishes listed as endangered or threatened by the U.S. Fish and Wildlife Service, or being considered for such listing, occur west of the Continental Divide. The commonly observed pattern is the disappearance of the most sensitive fishes, followed by the collapse of whole fish faunas in major western river basins. If current efforts directed at recovery of native western fishes are not continued and successful, we could witness the disappearance of most of the region's endemic fish fauna.[19]

Water in the western United States will also be affected by global climate change. Although the exact nature of the impact is not known with certitude, the following is a projection of the potential effect of climate change on water in the southwest:

> Since most of the water supply in the West comes from melting snow during the spring and early summer, changes in storm tracks, in the proportion of precipitation that falls as snow during a water year (October-September), and in seasonality and vertical temperature lapse rates are likely to result in an earlier melt season, diminished snowpack, increased evaporative losses, and lower runoff. Obviously, this translates to less water being available for storage within the network of western reservoirs.[20]

The issues relating to population and freshwater resources will intensify in the short term. As a non-geographer, my impression is that the new West, the West of the great urban archipelagos, has developed without regard to where water is naturally abundant, or perhaps in inverse ratio to abundance. No one who has been to the desert cities of Las Vegas or Phoenix could discern the ecological rationale for their display of water abundance. This is for the poets and artists to interpret. The assumption behind this growth is that agricultural water supplies are more than sufficient to provide for urban uses and that technological fixes such as piped water, desalinization, and recycling will provide water into the only future that is relevant to the present.

There is a choice as to how natural systems are treated as this growth occurs. Environmental awareness has resulted in a virtual about-face in the Bureau of Reclamation, as well as in much of the Corps of Engineers. State agencies in the West have been slower to embrace the need for balance in water management, but the momentum is towards more tempered treatment of the environment. Protection and restoration of natural systems is possible, even with the new

[18] United States Geological Survey, Estimated use of water in the United States in 1990; Trends in Water Use, 1950-1990. http://water.usgs.gov/watuse/wutrends.html. *Estimated use of water in the United States in 1990; Trends in Water Use, 1950-1990* (visited February 6, 2001) http://water.usgs.gov/watuse/wutrends.html.

[19] Bogan, Michael A. 1998. Changing Landscapes of the Middle Rio Grande in *Status and Trends of the Nation's Biological Resources*, 2: 562-563.

[20] Diaz, Henry F. and Craig A. Anderson. 1995. Precipitation Trends And Water Consumption Related To Population In The Southwestern United States: A Reassessment in *Water Resources Research,* 31: 713-720.

…the West of the great urban archipelagos has developed without regard to where water is naturally abundant, or perhaps in inverse ratio to abundance. No one who has been to the desert cities of Las Vegas or Phoenix could discern the ecological rationale for their display of water abundance. This is for the poets and artists to interpret.

population, climate, and supply stresses. However, it is not ensured, as discussed below.

POLICY RECOMMENDATIONS

Sustainability should be at the center of western water policy. Instead, the current policies reflect the exigencies of developing water for irrigation, power, and the cities of the West. This is compounded by bureaucratic competition and conflicting mandates. The posture of western state water administrators tends to reflect the time-honored policies of these bureaucracies more than it does contemporary public opinion. Polling shows broad support for environmental expenditures and controls, but from the statements of some western water officials, one might think that "the public" is comprised entirely of irrigators. This discrepancy is frustrating to environmentalists, but common in the West with respect to resource development issues, where the "old West" maintains its purchase in political offices. The imperatives of the natural world have found little hold in western water policy, and the results of that denial are visible in virtually every western river system.

Sustainability should be at the center of western water policy. Instead, the current policies reflect the exigencies of developing water for irrigation, power, and the cities of the West...The imperatives of the natural world have found little hold in western water policy, and the results of that denial are visible in virtually every western river system.

Natural systems are a key aspect of sustainability. Although the Endangered Species Act (ESA) has led to restoration efforts on some stretches of western rivers, public policy does not generally encompass protection of the ecological functions of rivers. At the national level, legislation has been reintroduced to limit the effect of the ESA on western water allocation decisions, reaffirming the preeminence of state allocation schemes.[21] The effect of this legislation, if adopted, would likely be the eventual dissolution of the initiatives to balance ESA concerns with water allocation on rivers throughout the West. In contrast, legislation to further sustainability would provide for a national restoration initiative, as called for by the Western Water Policy Review Advisory Commission's Report, *Water in the West.*

[21] S. 446, 107th Cong. (2001).

Subsidies and failure to recover the full cost of water extraction and distribution are shaping water policy at all levels of government. Within this context, the key issues are regulation of groundwater mining, assessment of appropriate water charges, and poorly placed development. Of equal importance is designating water for environmental purposes, such as fisheries, channel scouring, riparian vegetation, aesthetic purposes, and recreational uses. The western states impose taxes on the severance of minerals, oil, and gas to pay for required infrastructure and societal needs, and a similar system could be established to secure water for environmental uses (with appropriate measures to protect low-income consumers). The costs imposed by charges on water transfers and water withdrawals, and other types of water development, would engender better water policy decision-making by increasing the portion of the financial burden allotted to the consumer.

Water quality in the West will only be protected when the interrelationship between water quality and allocation is incorporated into our systems. Because water supply is limited in the West, there is often a direct relationship between flows and chemical parameters of water quality. Additionally, the protection of habitat and biodiversity is more likely to be dependent on hydrology than water quality. The Clean Water Act was originally intended to protect all of these values, without distinction as to the causes of their impairment. Non-point source pollution is a challenge to water quality throughout the country. Recent policies from the Environmental Protection Agency (EPA) have emphasized a watershed approach, and citizens are rallying to protect many rivers and streams. Nonetheless, without regulation of some sort, the prospects for achieving compliance with stream standards are dim. Congress recently attempted to suspend EPA regulations by implementing the Total Maximum Daily Loads program, which was the product of litigation against recalcitrant states and the EPA. Federal and state policies should ensure that no class of dischargers is exempted from the Clean Water Act.

PUBLIC EDUCATION AND MEDIA INVOLVEMENT

Western newspapers are full of water stories, because conflict lends itself well to media coverage. A quick review of local papers reveals stories about housing developments seeking water supplies, wells that must be abandoned because of contamination, interstate and tribal conflicts, flood damage and droughts, Endangered Species Act litigation, and state appropriations for water development. Television and radio stations devote less space to these stories. However, polling shows that westerners are keenly aware of water issues, which is a hopeful indicator of the environmental awareness of the American public.

What is missing from these stories is the identification of the policy choices that have led to these conflicts. Also lacking is information about the right of private citizens to become involved in these decisions. Public participation in water management is frequently portrayed as being limited to conservation. However, while conservation is a worthy endeavor, it is not sufficient. The media and the public should be enlightened as to the more fundamental moments in which water policy is shaped.

That said, from the record of public involvement at the time of decision-making, one would have to conclude that policy makers view the development of water policy as too important to be left to the public. An example of this is the process by which federal agencies procure funding for projects in western states. The President's budget recommendations are secret until they are released to Congress. While there may be Congressional hearings regarding water policy, the first notice that citizens of a state have of a new federal project may be when their Congress member announces new appropriations for the district. The term "iron triangle" describes the relationship among state water administrators, local agency officials, and powerful Congressional appropriators. These relationships have resulted in water projects across the West that arguably may have served broad public interests, but did not result from broad public involvement. Because of environmental and administrative revolutions in public participation, more avenues for public involvement have become

Subsidies and failure to recover the full cost of water extraction and distribution are shaping water policy at all levels of government. Within this context, the key issues are regulation of groundwater mining, assessment of appropriate water charges, and poorly placed development. Of equal importance is designating water for environmental purposes…

The western states impose taxes on the severance of minerals, oil, and gas to pay for required infrastructure and societal needs, and a similar system could be established to secure water for environmental uses (with appropriate measures to protect low-income consumers).

available. Environmentalists, tribal governments, and other outsiders are now able to influence policy. Nonexperts, however, have limited opportunities to shape these policies. Ballot initiatives, bond issues, and water rate hikes may be the only forms in which water questions are posed to a larger public.

I believe that the democracy movement will extend to western water politics. One example of this is the watershed movement, in which community members of varying ideological persuasions work with professionals from a range of agencies, attempting to remedy pollution and sometimes address water allocation issues. These voluntary entities represent a reordering of the traditional relationships, where remote regulatory authorities might control a few "point sources" of pollution, without exposing most landowners and dischargers to any regulatory or exhoratory measures. Watershed entities are voluntary, and seek to persuade citizens to participate in their endeavors. The movement is shaky, but was able to gain the support of the Clinton administration through its Clean Water Action Plan.

On a larger scale, basin management efforts, chronicled in the report of the Western Water Policy Review Advisory Commission, provide for public participation and much greater transparency where a single federal agency manages a western river. These efforts are harder to characterize than watershed management, but as used here, involve multiple levels of government and operate under federal laws guaranteeing open processes. One has only to compare the power-amassing approach of the Corps of Engineers on the Mississippi River with its relatively humble role in the California Bay-Delta, or the Columbia River, to realize how effective basin management can be in bringing federal agencies back to serving the interests of more diverse constituencies.

The planned growth or antisprawl movement also reflects a movement towards democratization of water decision-making. Because the limited water resources of the West are fully allocated, a decision to allow one type of growth is a commitment to pay the costs of providing new water through reallocation from one use to another. Once the development has occurred, one can be assured that a public entity will provide water. The effect of new development on water resources has become part of the debate over land use policies. This debate is complicated, because in some settings agriculture protects open space, provides wildlife habitat, and is part of the history of western communities. At the same time, irrigated agriculture may use more water than the subdivisions that often replace it. These factors have led to new alliances and modifications in prized positions.

CONCLUSION

Western water policies have been made with too little regard for the long-term sustainability of the people and natural resources of the region. The necessity of wise management of water is increasing daily as people crowd into the urban centers in the region's driest regions. We must increase participation in water decision-making and reorient our water policies around the challenges of living in an arid region in better harmony with nature.

The term "iron triangle" describes the relationship among state water administrators, local agency officials, and powerful Congressional appropriators. These relationships have resulted in water projects across the West that arguably may have served broad public interests, but did not result from broad public involvement...Ballot initiatives, bond issues, and water rate hikes may be the only forms in which water questions are posed to a larger public.

I believe that the democracy movement will extend to western water politics. One example of this is the watershed movement... On a larger scale, basin management efforts provide for public participation and much greater transparency where a single federal agency manages a western river.

DENISE D. FORT is on the faculty of the University of New Mexico School of Law, where she teaches Environmental Law and other subjects. Her work addresses water policy, river restoration, and environmental federalism. She holds an undergraduate degree from John's College (Annapolis and Santa Fe, New Mexico) and a J.D. from the Catholic University of America School of Law.

Professor Fort has extensive experience in environmental and natural resources law and policy. She was the Chair of the Western Water Policy Review Advisory Commission, a U.S. Presidential Commission that prepared a seminal report on western water policy concerns. Prior to her appointment at the Law School, Professor Fort served as Director of the State of New Mexico's Environmental Improvement Division, as the Governor's representative to the National Governors Association, as an environmental attorney with New Mexico Public Interest Research Group (PIRG) and Southwest Research and Information Center, as Executive Director of Citizens for a Better Environment (CA), and in other capacities concerned with environmental and natural resource matters. She writes extensively about water policy and was a member of the National Academy of Science (NAS) National Research Council's (NRC) Water, Science, and Technology Board.

Professor Denise Fort, The University of New Mexico School of Law, 1117 Stanford NE, Albuquerque, NM 87131
fortde@law.unm.edu

The Human Context for Everglades Restoration: The South Florida Case Study

Bonnie Kranzer, Ph.D., AICP, South Florida Water Management District and
Former Executive Director, Governor's Commission for the Everglades

ABSTRACT
The South Florida ecosystem has experienced severe degradation over the past century. Beginning with intensive drainage efforts and compounded by dramatic population increases and agricultural activities, the Everglades has suffered drastic changes to its life-blood, namely, water quantity, quality, timing, and distribution. The Comprehensive Everglades Restoration Plan, recently approved by the U.S. Congress, will attempt to restore the functions of the natural system, while providing for the water-related needs of the region. This paper describes the historical water management alterations to the Everglades system and examines the specific effects of these alternations on the natural landscape. An in-depth review of the population, demographic, and economic characteristics of the region follows, so that an understanding of the interconnectivity of the human and natural system is established. Specific ramifications of population and economic growth on land use, water use, and flood control are examined. Through discussion of these ramifications, challenges and opportunities in light of the Comprehensive Everglades Restoration Plan are drawn. Overall, the Plan is a win-win for all systems, yet current consumption and land use patterns will need to be monitored in order for a successful restoration effort to coincide with compatible South Florida human demands.

INTRODUCTION

The lure of South Florida! Its cozy fishing villages, the seductive sights and sounds of Miami's South Beach, the reef system and lifestyles of the Florida Keys, the world class fishing in Lake Okeechobee, Disney World in the Orlando/Kissimmee region, busy agricultural towns of Clewiston, Belle Glade and Immokalee, the tranquil gulf coast towns of Ft. Myers and Naples and their beautiful off shore islands of Captiva and Sanibel, Everglades National Park, The Florida Keys National Marine Sanctuary, and the burgeoning cities of Miami, Fort Lauderdale and West Palm Beach – all are pieces of the magnet that has lured people of all ages, incomes, and cultures to its confines (Figure 1). The greater Everglades area begins in the southern Orlando suburbs and extends approximately 370 miles southward through the Florida Keys. Its east-west extent of 130 miles is defined by the coastal boundaries of the Atlantic Ocean and the Gulf of Mexico. Over the past fifty years, more than half of the original Everglades has been destroyed. Current trends forecast continued loss of uplands; degradation of wetlands, estuaries and aquatic life; increased water shortages for agricultural and urban uses; increased flooding; and loss or movement of wellfields – all revolving around a dwindling supply of "inexpensive" or "traditional" water supplies.

Over the past fifty years, more than half of the original Everglades has been destroyed.

South Florida is a low-lying flat plain, replete with rainfall, rivaling most tropical climates, but increased demands on the water resources have resulted in a mismatch – not enough water in the right place, time, quality or quantity to satisfy the needs of the natural system as well as those of its citizenry. Water is the key to restoring the Everglades system. More efficient use of existing water supplies, modifications to the operation of the existing infrastructure, retention of water lost from the present system, and increased water storage are key

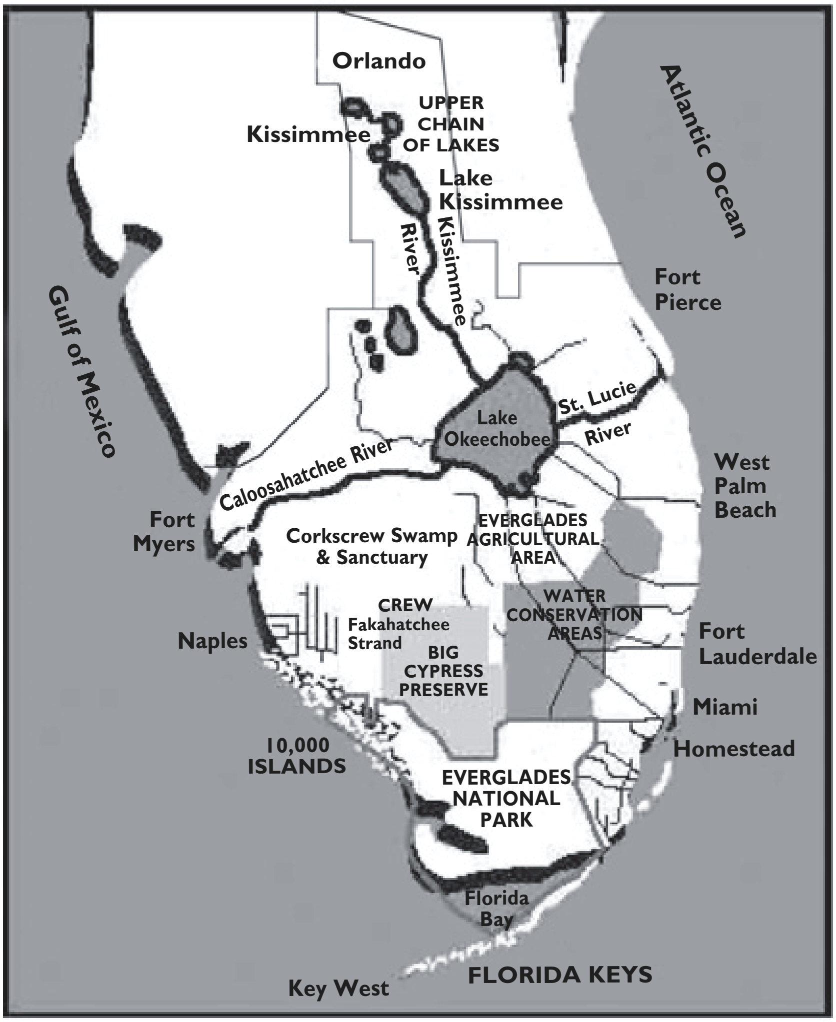


Figure 1 South Florida, showing boundary of South Florida Water Management District (SFWMD). Source: SFWMD.

objectives. The Central and Southern Florida Flood Control (C&SF) Project, authorized in 1948, provided the initial and extensive flood control and water supply system needed for the rapidly growing region. The region's growth, enabled by the drainage system, impacted the natural environment and forever changed the landscape of South Florida. Subsequent and dramatic population increases and concomitant land use changes further altered the natural system and compounded the urban and agricultural demands on the system, not just for water supply but for flood protection.

The Comprehensive Everglades Restoration Plan (CERP), approved by Congress (2000) and the State of Florida (1999), will restore the South Florida ecosystem while providing for the other water-related needs of the region, including urban and agricultural water supply and flood protection. It will cost approximately $7.8 billion over almost three decades of construction, with additional decades of operation and maintenance, aimed at benefiting all users.

The Comprehensive Everglades Restoration Plan (CERP), approved by Congress (2000) and the State of Florida (1999), will restore the South Florida ecosystem while providing for the other water-related needs of the region, including urban and agricultural water supply and flood protection. It will cost approximately $7.8 billion over almost three decades of construction...

The CERP is the opportunity to reconcile the conflicting needs of the natural environment and its human demands. While it is acknowledged that the natural system must be restored, the socio-economic needs of the region must also be wholly assessed and integrated into the complex plan. In his Inaugural Address, Governor Jeb Bush noted that, "[w]hile our cities have grown larger, our communities have grown weaker and our natural treasures more exposed to harm (1/5/99)." Aptly stated by Vice President Al Gore in 1997, "[i]n Florida, the environment is the economy." In Florida it is not possible to choose either a healthy environment or a strong economy. In South Florida the two are inseparable.

BACKGROUND – THE SOUTH FLORIDA ECOSYSTEM

The South Florida ecosystem is a complex network of interconnected fresh-water lakes, rivers, marshes, sloughs, ponds, prairies, forests and estuaries covering over 18,000 square miles from the northern Kissimmee River Basin and Lake Okeechobee south through the coral reefs adjacent to the Florida Keys, and from the Caloosahatchee River estuary located on the southwest coast to the St. Lucie River estuary on the east coast (Figure 2). The area is home to almost 7 million people and includes all or part of 16 counties.

While it is acknowledged that the natural system must be restored, the socio-economic needs of the region must also be wholly assessed and integrated into the complex plan.

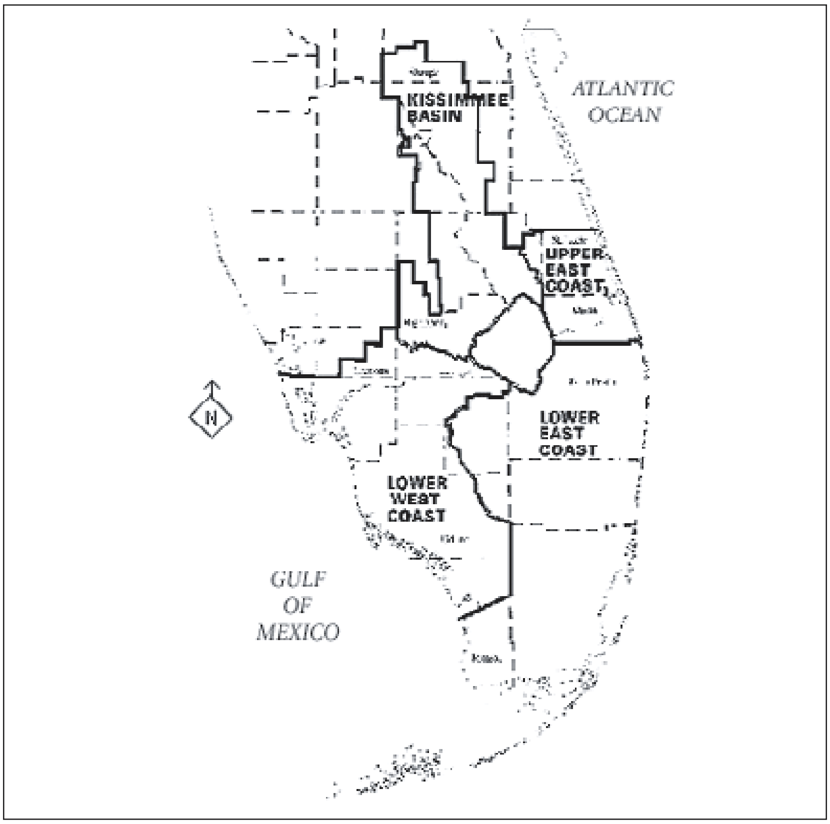


Figure 2 South Florida Water Supply Planning Regions. Population (1999): Kissimmee, 385,000; Lower West Coast, 700,000; Upper East Coast, 316,000; Lower East Coast, 4.8 million. (BEBR: 1999)

Included in the region are the tourist meccas (Disney World, etc.) south of Orlando; the Everglades Agricultural Area (EAA) south of Lake Okeechobee; small interior towns such as Pahokee, La Belle, Immokalee and Belle Glade; and urban centers such as Fort Myers on the west coast and the highly urbanized cities on the east coast stretching from Fort Pierce in the northeast, through the Miami megalopolis, all the way through Key West. The South Florida Water Management District (SFWMD) also uses this geographical/hydrological delineation for its domain of responsibilities.

South Florida's development has been dependent on the need for drainage. Beginning in the late 1800s, a number of private, state, and federal efforts drained parts of the Everglades and allowed for limited development in the region, primarily centered along the high coastal ridge paralleling the southeast coast.

Alterations to the South Florida Ecosystem

Historically, the natural system of South Florida was not conducive to intensive human habitation. In its natural state, it is very wet. Average rainfall of 53 inches[1] occurs with 67% of that occurring between May and September. The combination of concentrated periods of rainfall and flat terrain produces a continually swampy, flooded condition throughout much of the region during the wet season, a subtropical characteristic that has made the region less than desirable for human habitation for most of its history.[2] South Florida's development has been dependent on the need for drainage. Beginning in the late 1800s, a number of private, state, and federal efforts drained parts of the Everglades and allowed for limited development in the region, primarily centered along the high coastal ridge paralleling the southeast coast. At that time, there were approximately 30,000 persons in the South Florida region. The coastal ridge lies roughly 10-20 feet above sea level and provided a relatively safe haven from seasonal flooding events experienced in the remainder of the region.

The most intensive period of drainage in the Everglades and Lake Okeechobee took place between 1905 and 1927, when six major canals and channelized rivers (the Caloosahatchee River, Miami Canal, North New River Canal, Hillsboro Canal, West Palm Beach Canal and the St. Lucie Canal) were connected to Lake Okeechobee in order to drain the area immediately southwest, south and southeast of the Lake for agricultural purposes.[3] To provide for more development and agriculture, and in response to severe flooding from a series of hurricanes, Congress authorized the Central and Southern Florida Project (C&SF Project) in 1948, one of the largest drainage and flood control systems in the world. The Central and Southern Florida Flood Control District was created by the Florida Legislature in 1949 to serve as the local sponsor for the C&SF Project. As described by the SFWMD,[4] the Project was authorized for flood control and other purposes and designed as a complete system of canals, storage areas, and water control structures spanning Lake Okeechobee, to both the Gulf and Atlantic coasts, and the north-south region between Orlando south to the Everglades. It was also intended to improve recreation and navigation opportunities. To construct this drainage system, the U.S. Army Corps of

1 South Florida Water Management District, August 2000A. *District Water Management Plan*. West Palm Beach, FL.

2 Fernald, Edward A. and Elizabeth D. Purdum, editors, 1998. *Water Resources Atlas of Florida*. Institute of Science and Public Affairs, Florida State University, Tallahassee, FL.

3 Fernald, Edward A. and Donald J. Patton, editors, 1984. *Water Resources Atlas of Florida*. Institute of Science and Public Affairs, Florida State University, Tallahassee, FL.

4 South Florida Water Management District, 2000A.

The most intensive period of drainage in the Everglades and Lake Okeechobee took place between 1905 and 1927, when six major canals and channelized rivers were connected to Lake Okeechobee...To provide for more development and agriculture, and in response to severe flooding from a series of hurricanes, Congress authorized the Central and Southern Florida Project (C&SF Project) in 1948, one of the largest drainage and flood control systems in the world.

Engineers (Corps) made major changes to the landscape beginning in the 1950s. As further described by the SFWMD,[5]

> The decade of the 1960s was a time of major construction for the C&SF Project. By the early 1960s the Water Conservation Areas were completed, and about 700,000 acres of land in the Everglades Agricultural Area had been drained and leveed. The dike around Lake Okeechobee was enlarged and extended. Pump stations were constructed. Dredges and draglines enlarged the Caloosahatchee River, excavated the Kissimmee River, and cut channels in the Kissimmee Chain of Lakes. Spillways, dams, and navigation locks were built on the canals. The Corps published the first in a series of maps, colored coded in red and green, entitled Central and Southern Florida Flood Control Project. Red lines showed works that were completed or under construction. Green lines showed works that were planned but not completed. Periodically, the Corps updated this map and reprinted it, and over the years more and more green lines became red lines.[6] However, not all the planned canals and structures annotated by green lines were ever built, due to environmental concerns, costs, and further evaluation of these planned facilities.

By the 1960s, the impoundments surrounding Lake Okeechobee (rising more than 20 feet above the mean level of the lake)[7] were completed to store water for urban and agricultural uses, as well as to prevent recurring flood disasters similar to the ones in the 1920s.[8] Between the 1950s and '60s the population of South Florida surged, bringing with it new demands for industrial and residential water in addition to the existing agricultural demands.[9] Completed in 1971, the once meandering Kissimmee River was dredged and straightened to allow for maximum water flow to Lake Okeechobee.

In 1972 the Florida Legislature passed the Florida Water Resources Act, which greatly changed the water management structure of the State. The act broadened the authority of the Central and Southern Florida Flood Control District to include responsibilities for water supply, water quality, and natural systems management. The act also divided the State into five water management districts, which would manage water from hydrologic geographical boundaries rather than political boundaries. Water management districts' responsibilities would now include the control and regulation of ground and surface waters and other uses. The Central and Southern Florida Flood Control District was renamed the South Florida Water Management District (SFWMD) in 1976 by the Florida Legislature, to bring that entity into general consistency with the other four water management districts both in title and function. Today, the entity remains

5 *Ibid.*

6 Huser, Tom, 1989. Into the Fifth Decade: The First Forty Years of the South Florida Water Management District, 1949-1989. South Florida Water Management District, West Palm Beach, FL.

7 Fernald, E.A. and E.D. Purdum, 1998.

8 South Florida Water Management District, January 1, 1999A. Everglades Interim Report. West Palm Beach, FL.

9 Fernald, E.A. and E.D. Purdum, 1998.

In 1972 the Florida Legislature passed the Florida Water Resources Act, which greatly changed the water management structure of the State. The act broadened the authority of the Central and Southern Florida Flood Control District to include responsibilities for water supply, water quality, and natural systems management.

and through Chapter 373 Florida Statutes, "one attains the right to use water through application to the appropriate water management district..."[10]

Today, the C&SF Project consists of a more than 1000-mile regional network of canals, levees, storage areas, and water control structures designed to provide reliable water supply and flood protection for existing and future development in South Florida. It was originally designed to service approximately 2 million residents.[11] The Project's "system of canals and pump stations, combined with state-of-the-art technology, drains regional floodwaters during times of abundant rainfall, tropical storms or hurricanes. The network connects to hundreds of smaller local and community drainage districts to effectively mange floodwaters. It moves water throughout the region for use by cities, farms and natural ecosystems; recharges drinking water supply wellfields; and is essential to the regions' successful development."[12]

Water historically meandered through the Kissimmee River and its flood plains, collected in Lake Okeechobee and periodically spilled over its banks into the "River of Grass" flowing through the southern portion of the Everglades into Florida Bay and other estuaries. Today, that water flow is artificially regulated and controlled, altering the natural quality, quantity, timing, and distribution that once defined and supported the historical Everglades ecosystem. The delicate hydrological system of the Everglades has been forever altered. Unfortunately, as Marjory Stoneman Douglas said, "(t)here are no other Everglades in the World."[13]

The Effects of the Altered System

The C&SF Project today drains approximately 1.7 billion gallons of water a day (bgd) to tide, testament to the success and efficiency of the drainage system.[14] Combined with increased population, a 50% loss of the natural system to agricultural and urban land uses, and increased pollution, the impacts on the natural system have been extensive.

Disrupted Hydrology/Water Quality Degradation

The hydrology of South Florida has been deeply affected by changes brought about by human activities over the past decades. Changes have been made to the water quantity, quality, timing and distribution. Not only has the entire integrated system of water flow been rearranged, but soil composition, habitat, the identity and numbers of land and water species, and the relationships between fresh and salt water have all changed. Functional losses to the system include: (1) reduced spatial extent of aquatic and total system productivity; (2) reduced aquatic productivity of the southern Everglades due to shortened hydroperiods and interrupted flows; (3) reduced spatial extent of wet prairie/ slough and related aquatic productivity throughout the remaining wet prairie/ slough-sawgrass-tree island mosaic; (4) loss of habitat diversity; and (5) reduced possible early dry season feeding habitat of wading birds.[15]

[10] South Florida Water Management District, 2000A.

[11] U.S. Army Corps of Engineers and South Florida Water Management District, October 1998. Overview: Central and Southern Florida Project Comprehensive Review Study. Jacksonville, FL.

[12] South Florida Water Management District, August 2000B. District Water Management Plan, Facility and Infrastructure Location Index Map. West Palm Beach, FL.

[13] Douglas, Marjory Stoneman, 1947. The Everglades: River of Grass. Rinehart and Company, New York, N.Y.

[14] U.S. Army Corps of Engineers and South Florida Water Management District, July 1999B. Rescuing an Endangered Ecosystem: The Plan to Restore America's Everglades. Jacksonville, FL.

[15] Davis, Steven M., Lance H. Gunderson, Winifred A. Park, John R. Pochardsom, and Jennifer E. Matttson, 1994. Landscape Dimension, Composition, and Function in a Changing Everglades Ecosystem. In Everglades, The Ecosystem and Its Restoration, Edited by Steven M. Davis and John C. Ogden. St. Lucie Press, Delray Beach, FL. Pages 419-444.

Half of the original Everglades has been drained, while the C&SF Project sends 1.7 bgd to tide or seepage. Sending this enormous volume of water to tide, often times in large pulses over an extended period, seriously threatens the health of the region's estuaries and bays. Generally, these water bodies now receive more water in the wet seasons and less water in the dry seasons than they historically received. Today, salinity fluctuations resulting from these regulated water cycles and degraded water quality are fundamental threats to the vitality and health of these ecosystems.

Half of the original Everglades has been drained, while the C&SF Project sends 1.7 bgd to tide or seepage. Sending this enormous volume of water to tide, often times in large pulses over an extended period, seriously threatens the health of the region's estuaries and bays.

With an average yearly rainfall of about 53 inches, historical freshwater sheetflow resulted in a head pressure that created large freshwater plumes well offshore in Florida and Biscayne Bays. With much of that water now stored in Lake Okeechobee and redirected into the Caloosahatchee and St. Lucie estuaries, saltwater intrusion threatens many of the region's wellfields and water supplies. Further exacerbating the problem is the loss of lands necessary to recharge the aquifers and provide for a more historical sheetflow and water gradient.[16] Most of these lands have been developed or paved.

Water quality is also a problem in South Florida. As described in 1994,[17] nutrients have been identified as a concern for Lake Okeechobee, the Everglades, the Indian River Estuary and the Caloosahatchee River. In particular, phosphorus and nitrogen from agricultural and urban runoff have contaminated Lake Okeechobee, the Everglades, and adjacent areas.[18] Other water quality issues include the widespread contamination of plants and animals throughout the Everglades ecosystem with mercury from unknown source(s), contamination of public drinking water supplies along the lower east coast with synthetic organic chemicals, contamination of the Miami River, and seagrass loss due to poor water quality. Toxicological contaminants of concern in the system include metals, organic compounds and pesticides.[19]

[16] Governor's Commission for a Sustainable South Florida, June 20, 1995A. Everglades Water Budget. Coral Gables, FL.

[17] South Florida Ecosystem Restoration Working Group of the South Florida Ecosystem Restoration Task Force, 1994. 1994 Annual Report. Miami, FL.

[18] South Florida Ecosystem Restoration Working Group of the South Florida Ecosystem Restoration Task Force, March 1999. Maintaining the Momentum. Miami, FL.

[19] Governor's Commission for a Sustainable South Florida, October 1995B. Initial Report, Coral Gables, FL.

[20] South Florida Ecosystem Restoration Working Group, 1999.

Water quality is also a problem in South Florida.

Loss of Habitat and Native Species

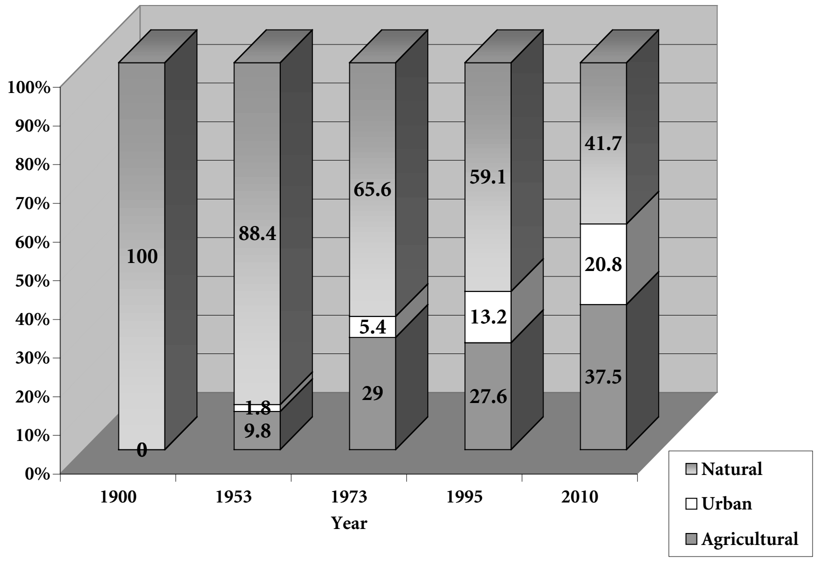
The growth and development in South Florida has also resulted in losses of habitat and native species. The spread of exotics species further exacerbates this trend. Specific impacts:[20]

- Wading-bird populations have declined by 90-95%.
- 68 plant and animal species are federally listed as threatened or endangered.
- The incidence of coral diseases in the Florida Keys National Marine Sanctuary has increased four-fold since 1996.
- Over 1.5 million acres of land are infested with invasive exotic plants.
- Since 1989 the biomass of turtlegrass in western Florida Bay has decreased by 25%.

Land Use Changes

South Florida's land cover has changed from 100% natural in 1900, to 59.1% natural, 27.6% agriculture and 13.2% urban in 1995. As recently as 1953, urban uses covered less than 2% of the region (see Figure 3). The C&SF Project allowed for such rapid conversion of land to urban uses.

Figure 3 South Florida Land Use (1900-2010)



Source: 1900, 1953, 1973: (Costanza, 1974) as compiled by SFWMD 1999. 1995: SFWMD 1999. 2010: (SWFRPC, 1999) as compiled by GCE staff.

The success of the C&SF Project, the desirability of South Florida's climate and geographical location, and economic opportunities are factors that have fueled the region's population explosion. After 50 years of intensive development, the region suffers in many areas from suburban sprawl. The southeast coast has voraciously developed much of the land west of the coastal ridge. As development moves further inland, many of the resources necessary to support and maintain older urban areas are diverted to support the new growth. Left behind, in many cases, are urban areas in a state of disrepair. Oftentimes, these areas are littered with "brownfields," sites that are contaminated or perceived to be so. Old infrastructure, a lack of financial incentives, and liability concerns prevent many of these areas from attracting developers and being revitalized. Many people feel the southwest coast is on the verge of making some of the same growth management "mistakes" as its southeast counterpart.

As recently as 1953, urban uses covered less than 2% of the region...As development moves further inland, many of the resources necessary to support and maintain older urban areas are diverted to support the new growth. Left behind, in many cases, are urban areas in a state of disrepair.

THE POPULATION OF SOUTH FLORIDA

The South Florida ecosystem includes all or part of 16 counties and is divided into four water supply planning regions (Figures 1 and 2). Currently, almost 7 million people, or about 49% of Florida's total population, reside in South Florida.[21] The region's population is expected to reach approximately 12 million by the year 2050.[22] This population is not static; it is constantly changing due to the dynamic nature of the region. The majority of the growth will be concentrated in the urban centers.[23] Currently, almost 85% of South Florida's population resides in these urban areas. Florida is expected to replace New York as the third most populous state by 2020.[24]

While the Lower East Coast (Palm Beach, Broward, Miami-Dade, and Monroe Counties) comprises only 9.5% of the State's land area, it is home to 31% of Florida's population.[25] Almost half of South Florida's future growth is projected for the Lower East Coast, as it is expected to grow by 72% from just over 4 million in 1990 to nearly 7 million by 2050.[26] Burchell *et al.*[27] note that, "[t]he five counties of southeast Florida will grow faster than 28 states in the United States in population and faster than 34 states in employment." By contrast, the group of primarily agricultural counties bordering Lake Okeechobee (Glades, Hendry, Highlands, Martin, Okeechobee, and St. Lucie) contain approximately the same amount of land area but comprise only 3% of the region's population.[28]

The Lower West Coast region (Lee, most of Collier and Hendry, and parts of Charlotte and Glades Counties) is one of the fastest growing regions in the United States. In 1990, the estimated population of the region was 632,000. It is expected to increase by 63% to 1 and 1.4 million by 2010 and 2050, respectively. The population of the Upper East Coast region (Martin and St. Lucie Counties) is expected to more than double by 2050 to about 529,000. However, this will still only comprise about 5% of the South Florida region's population.[29]

Figure 4 shows the historic and future population growth in South Florida from 1900 to 2050 by these four sub-regions. While all four sub-regions in the area experience growth, it is most pronounced in the Lower East Coast.

[21] Florida Consensus Estimating Conference, January 2000. Population and Demographic Forecast.

[22] U.S. Army Corps of Engineers and South Florida Water Management District, April 1999A. Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environmental Impact Statement. Jacksonville, FL.

[23] Lenze, David G., April 27, 1994. The Long-Term Economic Outlook for South Florida: Slower but Still Vigorous Growth. Presentation to the Governor's Commission for a Sustainable South Florida, at the West Palm Beach Ramada Hotel and Conference Center. Bureau of Economic and Business Research, University of Florida, Gainesville, FL.[24] U.S. Census Bureau, May 1997. Current Population Reports, Population Projections: States, 1995-2025. Washington D.C.

[25] U.S. Army Corps of Engineers and South Florida Water Management District, 1999A.

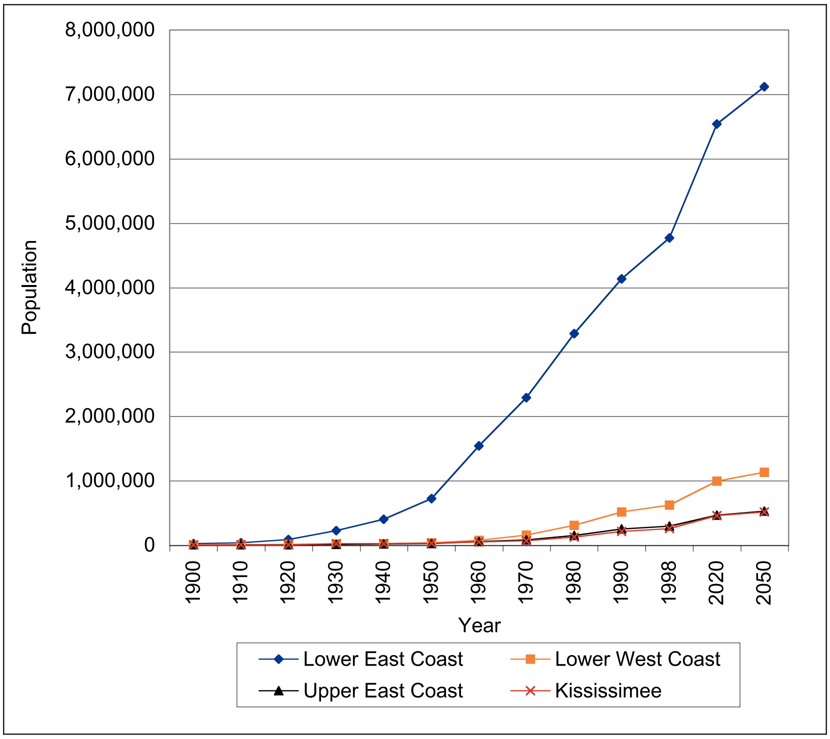
[26] G.E.C., 1996. *Final Report: Municipal and Industrial (M&I) Water Use Forecast Lake Okeechobee Regulation Schedule Study (LORSS)*. Prepared for U.S. Army Corps of Engineers, Jacksonville District.

[27] Burchell, Robert W., Nancy Neuman, Alex Zakrewski and Stephanie E. DiPetrillo, February, 1999. *Eastward Ho! Development Futures: Paths to More Efficient Growth in Southeast Florida*. Center For Urban Policy Research, Rutgers University, New Brunswick, NJ.

[28] U.S. Army Corps of Engineers and South Florida Water Management District, 1999A.

[29] *Ibid.*

Figure 4 South Florida Population (1900-2050)



Source: 1900-1998: US Population Division, U.S. Bureau of Census, Washington, D.C., 1999, 2020, 2050: Restudy, USACE, 1999.

In addition to the people who make South Florida their year-round home (residents), South Florida receives a large number of visitors each year, especially during the winter months (tourists). For instance, in 1994 Southeast Florida received 13.4 million out-of-state visitors[30] with total South Florida tourist estimates of 37 million annually.[31] Seasonal residents also frequent South Florida, making it "home" to many retirees and/or visitors for portions of the year, predominantly in the winter months. The degree to which this factor affects population varies, depending on two factors: location and time of year. For example, the Lower West Coast seasonal population may increase up to 30% during the year, while Miami-Dade County's population typically experiences a 10% variation.[32] During 1996, the State averaged 472,200 temporary residents per day throughout the year. However, this impact was felt predominantly during the dry winter months. Because the migratory behavior is predominantly weather related, there were nearly a million (971,200) temporary residents in the state on an average January day, while in the hotter summer month of August, only about 113,700 were recorded.[33] Lastly, South Florida is the destination of many international immigrants, many of whom arrive seeking part time work (migrant workers) or come to stay permanently but do not undergo the required immigration processing (undocumented population).

[30] Florida Consensus Estimating Conference, Spring 1995. *Economic Revenue and Budget Caseload Forecast,* Book I, Vol. X.

[31] South Florida Ecosystem Restoration Working Group of the South Florida Ecosystem Restoration Task Force, July 31, 2000. *Coordinating Success: Strategy for Restoration of the South Florida Ecosystem.* Miami, FL.

[32] South Florida Water Management District, April 1995. *District Water Management Plan*. Volume I. West Palm Beach, FL.

[33] Bureau of Economic and Business Research, 1997. *Draft: The Elusive Florida Snowbird.* University Press of Florida, College of Business Administration, University of Florida. Gainesville, FL.

Demography of South Florida

In order to understand the human dynamics of South Florida, it is important to understand the distinction between population and demography. Population is the whole number of people or inhabitants in a country or region. Demography is the statistical study of human populations, especially with reference to size and density, distribution, and vital statistics.[34] A distinction must also be made between immigration and in-migration. Immigration, or international migration, refers to the influx of people from foreign countries to South Florida. In-migration refers to the movement of people from other parts of the country or the state.

Migration, both immigration and in-migration, has played the predominant role in South Florida's population growth, accounting for 85% of the new residents in the three southeast counties between 1950 and 1990.[35] International migration played a significant role in those increases.

Another population attribute is how it changes over time. This is usually measured by "components of population change." These include Natural Change (births minus deaths per unit time), and Net Migration. Positive Net Migration occurs when in-migration exceeds out-migration over a specified time frame. Negative Net Migration occurs when more people leave a region than enter it for purpose of residence.[36] Figure 5 shows the components of change for the South Florida counties between 1990 and 1999.

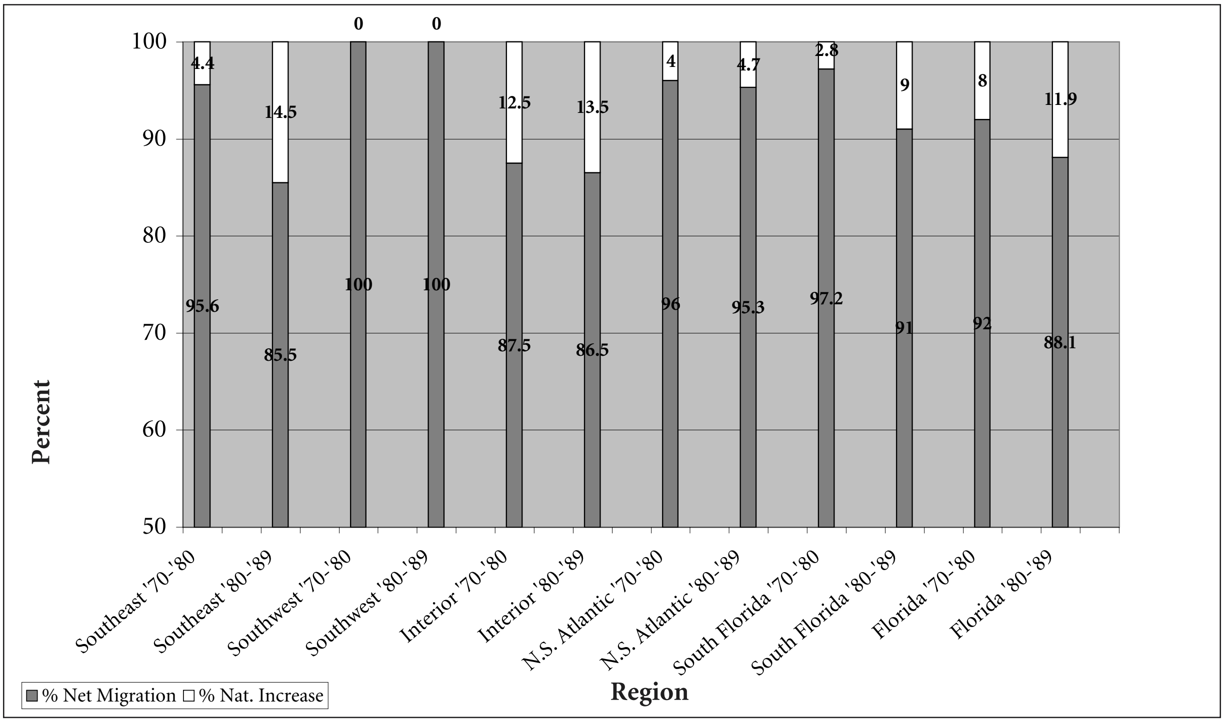
[34] Merriam-Webster Inc., 1987. *Webster's Ninth New Collegiate Dictionary*, MA.

[35] South Florida Regional Planning Council, February 1995. *Strategic Regional Policy Plan for South Florida.* Hollywood, FL.

[36] Shultz, Ronald, April 1991. Population Growth and Migration: Southeast Florida in Regional Context. In *South Florida: The Winds of Change*. Edited by Thomas D. Boswell, Prepared for the Annual Conference of the Association of American Geographers, Miami, FL: 43-61.

Migration, both immigration and in-migration, has played the predominant role in South Florida's population growth, accounting for 85% of the new residents in the three southeast counties between 1950 and 1990.

Figure 5 Components of Change in South Florida 1970-80 and 1980-89



Source: Ronald Shultz, 1991.

Table 1 Components of Change by Counties, 1990-1999

County	1990 Population	1999 Population	Births 90-99	Deaths 90-99	Net Int'l Migration	Net Domestic migration	Population + or -	Births minus Deaths	% Growth from Natural	% Growth from Int'l Migration	% Growth from Domestic
Broward	1,255,531	1,535,468	180,561	145,429	90,184	151,878	279,937	35,132	12.55%	32.22%	54.25%
Collier	152,099	207,029	23,017	16,606	7,603	41,593	54,930	6,411	11.67%	13.84%	75.72%
Glades	7,591	8,693	788	840	103	1,069	1,102	-52	-4.72%	9.35%	97.01%
Hendry	25,773	29,463	5,600	2,191	1,567	-1,258	3,690	3,409	92.38%	42.47%	-34.09%
Highlands	68,432	74,795	7,764	10,721	1,363	8,254	6,363	-2,957	-46.47%	21.42%	129.72%
Lee	335,113	400,542	40,776	40,166	5,466	60,178	65,429	610	0.93%	8.35%	91.97%
Martin	100,900	118,117	10,923	13,004	1,341	18,372	17,217	-2,081	-12.09%	7.79%	106.71%
Miami-Dade	1,937,194	2,175,634	301,761	172,737	337,174	-236,078	238,440	129,024	54.11%	141.41%	-99.01%
Monroe	78,024	79,941	8,430	6,570	3,322	-3,874	1,917	1,860	97.03%	173.29%	-202.09%
Okeechobee	29,627	32,386	4,773	3,105	797	395	2,759	1,668	60.46%	28.89%	14.32%
Osceola	107,728	150,596	18,505	10,004	4,988	29,552	42,868	8,501	19.83%	11.64%	68.94%
Palm Beach	863,503	1,049,420	111,406	106,994	48,131	128,203	185,917	4,412	2.37%	25.89%	68.96%
St. Lucie	150,171	181,850	20,805	17,342	3,167	25,700	31,679	3,463	10.93%	10.00%	81.13%
Region	5,111,686	6,043,934	735,109	545,709	505,206	223,984	932,248	189,400	20.32%	54.19%	24.03%
Florida	12,938,071	15,111,244	1,781,648	1,370,234	640,109	1,108,514	2,173,173	411,414	18.93%	29.46%	51.01%

Source: Population Estimates Program, Population Division, U.S. Census Bureau, Washington, DC, 2000

An examination of Table 1 shows that overall, the population of the South Florida region grew by 932,248 to a total of 6,043,934, (an 18% increase) between 1990-1999 (Note that Tables 1-4 do not include the Counties of Charlotte, Orange and Polk, (reducing the overall regional totals) since most of their population resides outside the SFWMD region). More than half of this growth resulted from international migration. Overall, Miami-Dade accounted for 66.7% of the region's total international migration. Miami-Dade County also had a negative net domestic migration of 236,078, meaning that many more people were moving out than in from within the state or country. At the same time, Miami-Dade's population increased by 238,440, caused mostly by a net international migration of 337,174, and nearly twice the number of births than deaths.

Between 1990-1999, Broward County had a population increase of 279,937, of which 90,184 (32%) was due to international migration and 151,878 (54%) net domestic migration. It is assumed that a large portion of this domestic migration was due to people leaving Miami-Dade and moving to Broward. In contrast to southeast Florida, the southwest region (Collier and Lee Counties) experienced most of its overall growth from domestic migration.[37] Note that less than 1% of growth was due to natural increase in Lee County, similar to Martin, Highlands, and Glades Counties.

Although he defined South Florida as a larger geographic region, Ronald Shultz[38] examined historic components of change for South Florida. Figure 5 provides further reaffirmation of the significant role of migration to the South Florida region (averaging 94.1% of growth between 1970 and 1989), showing the trends from 30 years ago. In almost all cases, and except for what is defined as the "interior region," the net migration percentages for the Southeast, Southwest, North and South Atlantic and South Florida

[37] U.S. Census Bureau, 2000. Population Estimates Program. Population Division, Washington, D.C.

[38] Schultz, R. 1991.

The migration percentages were so striking for Florida, not to mention South Florida, that Shultz[39] reports that, "[i]n fact, no other state in the nation has as high a proportion of its population growth due to net migration as Florida."

Table 2 Population Change by County and Ethnicity, 1990-2000

County	Total White Non-Hispanic 1990	Total White Non-Hispanic 2000	Total Black Non-Hispanic 1990	Total Black Non-Hispanic 2000	Total Am. Indian Non-Hispanic 1990	Total Am. Indian Non-2000	Total Asian & Pacific Islander Hispanic 1990	Total Asian & Pacific Islander Hispanic 2000	Total Hispanic 1990	Total Hispanic 2000
Broward	941,395	941,674	194,763	325,305	2,674	2,934	17,252	36,816	108,435	271,652
Collier	124,741	185,517	7,200	10,999	458	482	613	1,600	20,734	49,296
Glades	5,634	7,256	928	1,106	433	473	20	33	605	1,594
Hendry	15,204	15,890	4,381	5,245	555	210	117	152	5,757	14,336
Highlands	57,616	66,814	6,933	7,925	230	308	396	901	3,500	10,542
Lee	296,112	361,439	22,383	28,020	698	944	1,931	3,490	15,094	42,042
Martin	89,631	108,741	6,136	6,482	259	207	581	781	4,728	9,506
Miami/Dade	587,208	465,772	402,800	427,140	3,185	1,990	26,695	31,061	953,422	1,291,737
Monroe	63,715	61,462	4,254	3,567	263	272	633	676	9,580	12,553
Okeechobee	23,977	25,699	1,950	2,796	150	148	157	242	3,493	6,684
Osceola	**87,508**	**102,792**	**6,056**	**11,075**	**364**	**519**	**1,670**	**3,721**	**12,866**	**50,727**
Palm Beach	**683,741**	**798,484**	**108,833**	**152,433**	**1,244**	**1,617**	**9,092**	**17,364**	**66,614**	**140,675**
St. Lucie	**118,712**	**142,768**	**24,880**	**29,148**	**358**	**396**	**1,057**	**1,866**	**5,952**	**15,733**
South Florida	**3,095,194**	**3,284,308**	**791,497**	**1,011,241**	**10,871**	**10,500**	**60,214**	**98,703**	**1,210,780**	**1,917,077**

Source: Population Estimates Program, Population Division, U.S. Census Bureau, Washington DC., 1999 and U.S. Census Bureau, Census 2000 Redistricting Data (Public Law 94-171) Summary File, Matrices PL1, PL2, PL3, and PL4.

in general, exceed those exhibited by the State during the periods 1970-80 and 1980-89. The migration percentages were so striking for Florida, not to mention South Florida, that Shultz[39] reports that, "[i]n fact, no other state in the nation has as high a proportion of its population growth due to net migration as Florida. Even in the other fast-growing states like Arizona and Nevada, the proportion of growth due to net migration is well below 75%."

In looking at population change and the significant effect of migration, examination of the racial and ethnic makeup of the population is also informative. Table 2 shows that, although total population increased, the white, non-Hispanic[40] population decreased by about 10% of the total between 1990 and 2000.

At the same time, the total Hispanic population of the region increased from 24% to 30% of the total. Miami-Dade County has the highest Hispanic population, with Hispanic population percent in that county changing from 49% in 1990 to 57% in 2000. The increasing Hispanization of the region has been a subject described by Boswell and Curtis.[41] Who are the immigrants? Sampling Miami-Dade County's 1997 total of 45,707 immigrants shows that 25,000 came from Cuba. Other significant immigration origins for that year, in descending order included Haiti, Nicaragua, Columbia, Jamaica, Honduras and Peru.[42]

The overall trend of increased percentages of Hispanics in South Florida is depicted in Table 3. Ten of the 13 counties in the Table exhibited 100% or greater increases in Hispanic populations. Highlands and Osceola experienced greater than 200% increases in Hispanics, while also experiencing greater

39 *Ibid.*

40 "Hispanic" refers to "Hispanic" Origin" – persons who classify themselves in one of the Hispanic-origin categories listed on the census questionnaire – Mexican, Puerto Rican, Cuban or other Spanish/Hispanic origin. This latter category includes those whose origins are from Spain or the Spanish-speaking countries of Central or South America, or the Dominican Republic, or they are Hispanic-origin persons identifying themselves generally as Spanish, Spanish-American, Hispanic, Latino, etc. Origin can be viewed as the ancestry, nationality group, lineage or country in which the person or person's parents or ancestors were bom before their arrival in the U.S. Persons of Hispanic origin may be of any race. Households and families are classified by the Hispanic origin of the householder. Bureau of Economic and Business Research, 2000. The 2000 Florida Statistical Abstract. University Press of Florida, College of Business Administration, University of Florida, Gainesville, Florida.

Table 3 Percent Change by County and Ethnicity–1990-2000

County	White Non-Hispanic Percent Change 1990-2000	Black Non-Hispanic Percent Change 1990-2000	Am. Indian Percent Change 1990-2000	Asian & Pacific Islander Percent Change 1990-2000	Hispanic Parent Change 1990-2000
Broward	0.03%	67.03%	9.72%	113.40%	150.52%
Collier	48.72%	52.76%	5.24%	161.01%	137.75%
Glades	28.79%	19.18%	9.24%	65.00%	163.47%
Hendry	4.51%	19.72%	-62.16%	29.91%	149.02%
Highlands	15.96%	14.31%	33.91%	127.53%	201.20%
Lee	22.06%	25.18%	35.24%	80.74%	178.53%
Martin	21.32%	5.64%	-20.08%	34.42%	101.06%
Miami/Dade	-20.68%	6.04%	-37.52%	16.36%	35.48%
Monroe	-3.54%	-16.15%	3.42%	6.79%	31.03%
Okeechobee	7.18%	43.38%	-1.33%	54.14%	91.35%
Osceola	17.47%	82.88%	42.58%	122.81%	294.27%
Palm Beach	16.78%	40.06%	29.98%	90.98%	111.18%
St. Lucie	20.26%	17.15%	10.61%	76.54%	164.33%
South Florida	6.11%	27.76%	-3.41%	63.92%	58.33%

Table 4 Population 2000 by County and Race

County	Total Pop. 1990	Total Pop. 2000	White Non-Hipanic 2000	% White Non-Hispanic 2000	Black Non-Hispanic 2000	% Black Non-Hispanic 2000	Am. Indian Non-Hispanic 2000	% Am. Indian Non-Hispanic 2000	Asian/ Pacific Islander Non-Hispanic 2000	% Asian/ Pacific Islander Non-Hispanic 2000	Hispanic 2000	% Hispanic 2000
Broward	1,225,531	1,623,018	941,674	58.02%	325,305	20.04%	2,934	0.18%	36,816	2.27%	271,652	16.74%
Collier	152,099	251,377	185,517	73.80%	10,999	4.38%	482	0.19%	1,600	0.64%	49,296	19.61%
Glades	7,591	10,576	7,256	68.61%	1,106	10.46%	473	4.47%	33	0.31%	1,594	15.07%
Hendry	25,773	36,210	15,890	43.88%	5,245	14.48%	210	0.58%	152	0.42%	14,336	39.59%
Highlnds	68,432	87,366	66,814	76.48%	7,925	9.07%	308	0.35%	901	1.03%	10,542	12.07%
Lee	335,113	440,888	361,439	81.98%	28,02	0.36%	944	0.21%	3,490	0.79%	42,042	9.54%
Martin	100,900	126,731	108,741	85.80%	6,482	5.11%	207	0.16%	781	0.62%	9,506	7.50%
Mia/Dade	1,937,194	2,253,362	465,772	20.67%	427,140	18.96%	1,990	0.09%	31,061	1.38%	1,291,737	57.32%
Monroe	78,024	79,589	61,462	77.22%	3,567	4.48%	272	0.34%	676	0.85%	12,553	15.77%
Okee	29,627	35,910	25,699	71.57%	2,796	7.79%	148	0.41%	242	0.67%	6,684	18.61%
Osceola	107,728	172,493	102,792	59.59%	11,075	6.42%	519	0.30%	3,721	2.16%	50,727	29.41%
Palm Bch	863,503	1,131,184	798,484	70.59%	152,433	13.48%	1,617	0.14%	17,364	1.54%	140,675	12.44%
St. Lucie	150,171	192,695	142,768	74.09%	29,148	15.13%	396	0.21%	1,866	0.97%	15,733	8.16%
S. FL.	5,111,686	6,441,399	3,284,308	50.99%	1,011,241	15.70%	10,500	0.16%	98,703	1.53%	1,917,077	29.76%

Source: Population Estimates Program. Population Division, U.S. Census Bureau, Washington D.C. (1990 figures). U.S. Census Bureau, Census 2000 Redistricting Data (Public Law 94-171) Summary File, Matrices PL1, PL2, PL3, and PL4. (2000 figures)

than 100% increases in Asian and/or Pacific Islanders. Table 4 shows the year 2000 census counts, broken down by race/ethnicity. Comparing the numbers to the 1990 population shows growth in gross numbers across the board. Many of the traditionally rural counties are experiencing growth as continued development occurs either near the larger cities (Osceola example), or the trends in retirement community show growth being located in rural areas (Highlands County example). In all cases, the components of change and migration statistics show an increasingly diverse South Florida population, with significant increases in population occurring throughout the entire region.

[41] Boswell, Thomas D. and James R. Curtis, April 1991. The Hispanization of Metropolitan Miami in South Florida, *Winds of Change*, edited by Thomas D. Boswell (UM). Prepared for the Annual Conference of the Association of American Geographers, Miami, Florida. Pages 140-161.

Tables 2 and 3 showed the relative changes in race/ethnicity between 1990 and 2000 for the 13 counties wholly within the SFWMD. Not only is it instructive to look at changes, but it is particularly informative to look at the same information in combination with migration data. Boswell and Curtis[43] examined components of change in Miami-Dade County between 1980 and 1990 (Table 5). A close examination of that data shows a total of 100,000 net loss of non-Hispanic whites and Blacks (combined) due to domestic out migration. Non-Hispanic whites also show a minus of 1,350 in the county due to natural decrease, more deaths than births. The Black population during the decade of the 80s grew almost equally between natural increase and net immigration. The non-Hispanic white population lost population to natural decrease and domestic out-migration and emigration. This negative growth was more than offset by the large international immigration of Hispanics during that same decade. Of note are the shifts of ethnicity/race in and out of the county. These patterns are seen in the 2000 county statistics (Table 4) with the decreased percentage of that county now made up by Whites at 21% in 2000 versus 30% in 1990, and Blacks decreasing slightly (19% of county population in 2000 compared to 20% in 1990).

[42] Bureau of Economic and Business Research, 1999. *The 1999 Florida Statistical Abstract.* University Press of Florida, College of Business Administration, University of Florida, Gainesville, FL.

[43] Boswell, T.D. and J.R. Curtis, 1991.

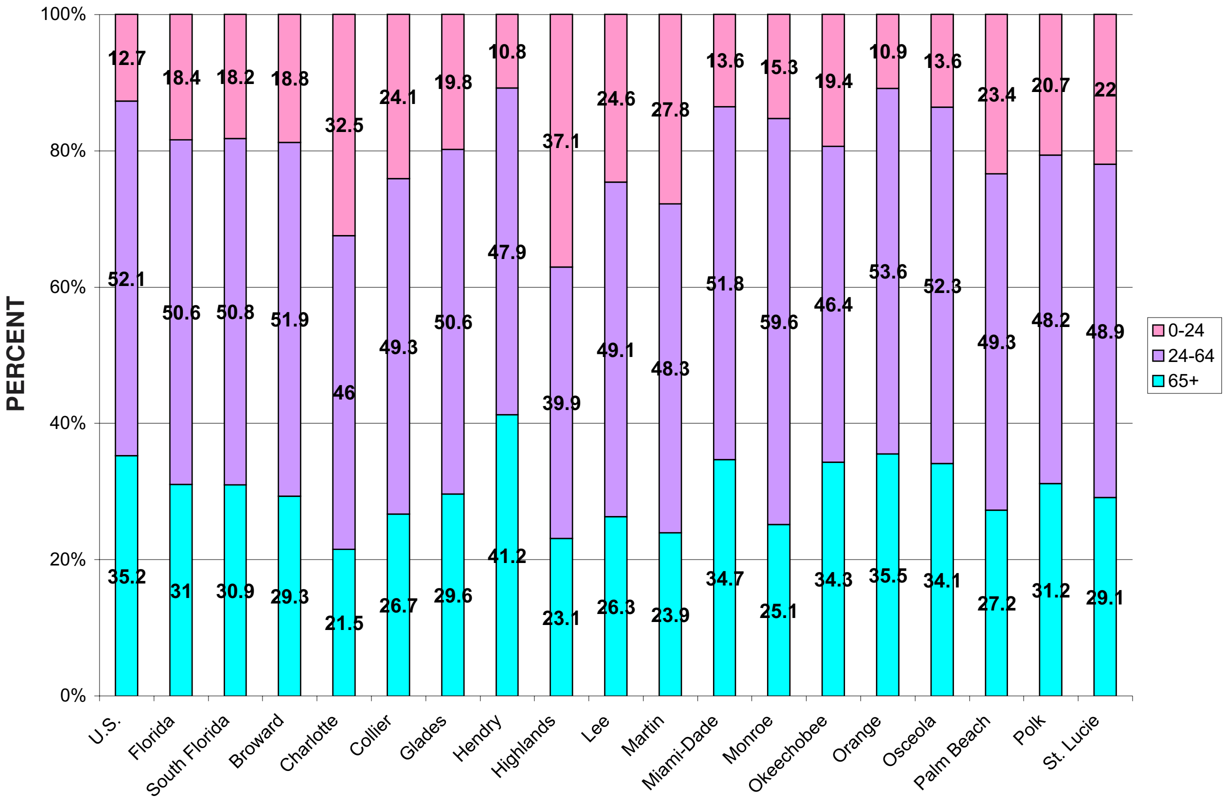
Table 5 Components of Population Change in Miami-Dade County: 1980-1990
Source: Boswell and Curtis, 1991

Components of Change	Hispanics	Blacks	Non-Hispanic Whites	Total Population
1980 Census Results	581,000	282,000	775,945	1,626,000
Births (+)	110,000	95,000	78,075	280,000
Deaths (-)	70,000	25,000	79,425	173,000
Natural Increase	40,000	70,000	- 1,350	107,000
In-Migration (+)	200,000	50,000	253,750	500,000
Out-Migration (-)	120,000	72,000	410,880	600,000
Net Domestic Migration	80,000	- 22,000	- 157,130	- 100,000
Immigration (+)	220,000	90,000	4,650	310,000
Emigration (-)	5,000	5,000	5,150	15,000
Net Foreign Migration	215,000	85,000	- 500	295,000
Net Total Migration	295,000	63,000	- 157,630	195,000
Total Change	335,000	133,000	- 158,980	302,000
Population Estimates for 1990	916,000	415,000	616,965	1,928,000

Since, for decades, Florida has also been renowned as a retirement haven, a review of the region's age characteristics is also essential. Many South Florida counties have a higher population aged 65+ than the 18.4% state average (Figure 6). The state average in turn is higher than the national average of 12.7%. The higher percentage of residents aged 65+ has a significant effect on the region's economy. These residents have special housing, health, transportation, and recreational needs that differ from that of younger age groups. Figure 6 shows that:

- Hendry, Orange, Osceola and Miami-Dade Counties have the highest percentage of population aged 24 years and below in South Florida.
- Monroe County has the highest percentage of population aged 25-64 years in South Florida.
- Charlotte, Highlands, Lee, and Martin Counties have the highest percentage of population aged 65+.

Figure 6 Age Distribution for U.S., Florida, South Florida, and Counties – 2000



Source: Florida Consensus Estimating Conference, Population and Demographic Forecast, 2000.

The Lower East Coast region has the highest number of residents aged 65+. This figure, projected to grow from 831,460 in 2000 to 952,196 in 2010, will continue to represent roughly 17% of that subregion's populace. Persons 65+ in the combined Upper East and Lower West Coast regions comprise roughly 24% of that total (both 2000 and 2010), with expected numeric increases from 238,978 to 301,402 between 2000 and 2010.[44] Overall, the age distribution of the South Florida residents shows an inversion of the age pyramid in the future. Weisskoff[45] notes that, "[t]he share of the young (19 years and less), which was 29% of the population

[44] Bureau of Economic and Business Research, 1999.

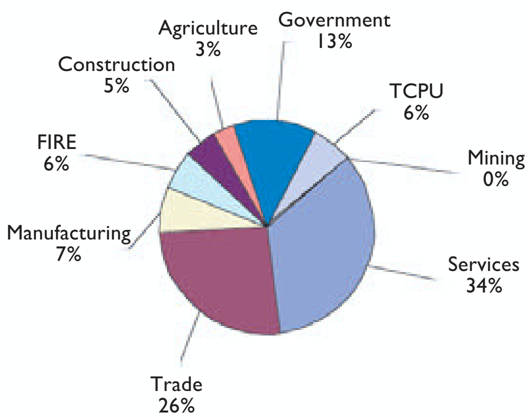
[45] Weisskoff, Richard, 2000. Missing Pieces in Ecosystem Restoration: The Case of the Florida Everglades. In *Economic Systems Research*. Vol. 12, No. 3. Pages 271-303.

1970, is expected to fall to 20% by 2045. The oldest cohort (65+) who accounted for 17.5% of the total in 1970 is expected to rise to 28%. Even these trends understate the importance of the older population due to the exclusion of the seasonal residents ('snow birds') from the permanent population."

THE SOUTH FLORIDA ECONOMY

In the past, the economy of South Florida has been dominated by construction, agriculture, tourism, and the service demands of a rapidly increasing resident base. The current trend, however, is for growth of more service-oriented industries, including banking, real estate, accounting, legal, and retail enterprises. Overall the service industry is the largest employer sector in the state, followed by trade (34%, 26% respectively – see Figure 7).[46] Total employment in South Florida is expected to grow from about 3 million in 1990 to about 5 million by 2050.[47]

Figure 7 Florida Employment by Sector



Source: Florida Department of Labor and Employment Security, Division of Jobs and Benefits, Bureau of Labor Market Performance Information, ES 202, 1997.

THE SERVICE INDUSTRY

In the period between 1982 and 1992, total employment in South Florida grew by 37.9%, a significantly higher percentage than the national rate of 22% for the same period. During this period, the region's service sector grew by 71.7%, while employment in manufacturing increased by only 1.9%.[48] Looking at the Southeast Counties only (Martin, Palm Beach, Broward and Miami-Dade), a recent reported noted, "[b]etween 1980 and 1995 the largest and most rapidly growing sectors of the region's economy were services and retail/wholesale businesses. Out of more than 2 million people employed, over 60% worked in those sectors... For the retail/wholesale sector, employment in general merchandise stores – such as the types of stores found in a shopping mall – are declining. For the service

[46] Florida Department of Labor and Employment Security, 1997. *ES 202*. Bureau of Labor Market and Performance Information, Division of Jobs and Benefits, Tallahassee, FL.

[47] U.S. Army Corps of Engineers and South Florida Water Management District, 1999A.

[48] Florida Department of Labor and Employment Security, 1994. *Market Information, Employment, Wages and Contributions Report, (ES-202) Annual Averages*. Bureau of Labor, Tallahassee, FL.

sector, employment is growing most rapidly in business and finance-related services."[49] Weisskoff[50] notes that "[i]t is the rise of service employment, from 30.6% of the labour force in 1970 to 80.5% in 1990 and to nearly 85% in 2045, that is determining the general character of the region."

Manufacturing is currently experiencing job losses due to international competition.[51] Employment in manufacturing and goods-producing industries have historically provided significantly higher wages than those in service-oriented enterprises.[52] Average annual salaries in South Florida for 1998 were about $24,000 for jobs in the service sector, compared to $33,000 for manufacturing, $36,000 for mining, and $26,000 for construction.[53]

TRADE

The South Florida region has emerged as a leading hub for trade within the global economy and, as a result, growth in international trade and port activity is accelerating significantly. While trade between South Florida and Latin America remains substantial, emerging trade with Europe and the Far East provides a critical juncture for global distribution of goods through South Florida ports.[54] Miami, in particular, has emerged as a leading city and "gateway" for trade within this hemisphere and within the greater global economy. The Florida Department of Commerce has estimated that each additional $1 billion of foreign trade creates approximately 16,000 additional jobs.[55]

South Florida is home to four major ports: West Palm Beach, Everglades (at Fort Lauderdale), Miami, and Key West. In 1994, the former three facilities collectively handled $18.5 billion in imports and exports. There are nearly 250,000 seaport-related jobs statewide. In addition to servicing the state's growing international trade industry, South Florida ports also provide for large waves of vacationing public.[56]

Tourism and trade also depend on the ability of Florida's airports to attract goods and passengers to the State. South Florida's airport facilities have experienced growth throughout the 1990s, largely due to merchandise trade between the South Florida region and Latin American/Caribbean markets.[57] The fifth largest cargo airport in the world serves the region – Miami International. Airports are also critically important to the region's tourist economy. Ninety-seven percent of Miami-Dade County's overnight visitors arrive in South Florida by air.[58]

TOURISM

Since the 1920s, tourism has been highly visible and has constituted a major component of the South Florida economy. Although the annual growth in visitors began to decline in the 1990s, South Florida continues to attract millions each year. In 1994, southeast Florida attracted 13.4 million out-of-state visitors, or 33% of Florida's total 41 million visitors.[59] In 1995, the

[49] Florida Atlantic University/Florida International University, 2000. *Draft-Imaging the Region: South Florida Via Indicators and Public Opinions*. Ft. Lauderdale, FL.

[50] Weisskoff, R., 2000.

[51] Rust, Rebecca, Sepember 4, 1998. Quality Communities Committee: Labor Market Conditions. Presentation to the Governor's Commission for a Sustainable South Florida, at the Anne Kolb Nature Center, Hollywood, FL. Bureau of Labor Market and Performance Information, Division of Jobs and Benefits, Florida Department of Labor and Employment Security.

[52] Governor's Commission for a Sustainable South Florida, 1995B.

[53] Florida Department of Labor and Employment Security, February 2000. Office of Labor Market Statistics. Tallahassee, FL.

[54] Loiry, William, April 1995. Florida World Links – Trade and Investment Opportunities with the Four Dragons. *Florida Trend Magazine*. Trend Magazines, Inc. St. Petersburg, FL.

[55] University of Massachusetts, 1995. First Quarter Report. *Massachusetts Institute for Social and Economic Studies*, Amherst, Massachusetts.

[56] Florida Department of Commerce, June 1994. *Profile of the Florida Visitor*. Bureau of Economic Analysis Office of Tourism Research.

[57] University of Massachusetts, 1995.

[58] Governor's Commission for a Sustainable South Florida, 1995B.

[59] Florida Consensus Estimating Conference, 1995.

region drew in nearly $14 billion in tourism-related revenues. Miami-Dade County alone attracted 9.4 million visitors who spent $8.4 billion.[60] Everglades National Park is ranked in the top five tourist destinations in the nation, and the Florida Keys National Marine Sanctuary is the number one dive destination in the world.[61] Overall, the tourist growth rate and the number of tourism-related jobs in South Florida have contributed significantly to the economic well being of the region's citizens. As an industry, tourism employs more than 700,000 people and generates over $33 billion in taxable spending throughout the state. South Florida alone accounts for nearly 35% of these jobs.[62]

Aggressive competition, image and safety concerns, and immigration events in South Florida, however, threaten prosperity in tourism. Because tourism plays such a critical role in the region's economy, even modest decreases in visitors and expenditures are felt throughout the region. For every 1,000 international visitors lost, the State loses $1.1 million in tourism spending, 20 area jobs, and $295,000 in local payrolls.[63]

AGRICULTURE

Florida is the nation's ninth leading agricultural state, with annual farm cash receipts totaling $6 billion. Agriculture also contributes $18 billion in farm-related economic activities and employs 80,000 people per month.[64] South Florida produces $2.8 billion annually, or almost half the value of all farm cash receipts in the state.[65] South Florida counties lead the nation in sugar cane production (Palm Beach), oranges (Hendry), grapefruit (St. Lucie), and snap beans (Miami-Dade). Together, agriculture in these four counties generates approximately $2 billion annually.[66] More citrus is produced in this region than in any other state. The region also produces nearly 70% of the nation's winter and spring vegetables.[67]

Although agriculture contributes billions of dollars to the state's economy, the industry is facing economic as well as environmental challenges. Agricultural acreage in Florida and across the nation has decreased as local, regional, and state economies have grown and diversified. Between 1982 and 1992, the number of acres designated as agricultural in South Florida has decreased from 12.8 million acres to 10.7 million acres, a loss of 16%.[68] This reduction stems from increasing urban sprawl, soil subsidence, and the conversion of some agricultural lands to other uses (water preserve areas, etc.).[69]

Agriculture in South Florida has also been negatively impacted, especially the tomato industry, by trade agreements with Mexico and other market factors. The impact of the North American Free Trade Agreement on the competitiveness of domestic products is a critical issue for all of the region's industries. Manufacturers, producers, processors, and shippers warn of unfair advantages and a loss of their current competitive edge. They also express concern for the future normalization of relations with Cuba, especially

[60] South Florida Ecosystem Restoration Working Group of the South Florida Ecosystem Restoration Task Force, April 1998. Success In The Making: An Integrated Plan For South Florida Ecosystem Restoration and Sustainability. Miami, FL.

[61] U.S. Army Corps of Engineers, 1998.

[62] Governor's Commission for a Sustainable South Florida, 1995B.

[63] Cook, Susan, and William Evans, 1993. *A Portrait of Travel Industry Employment in the U.S. Economy*. Travel Industry Association of America Foundation.

[64] South Florida Ecosystem Restoration Working Group, 1998.

[65] Weisskoff, R., 2000.

[66] South Florida Ecosystem Restoration Working Group, 1998.

[67] Governor's Commission for a Sustainable South Florida, 1995B.

[68] U.S. Department of Commerce, Bureau of the Census, 1984. *1984 Census of Agriculture*; See also, U.S. Department of Commerce, Bureau of the Census, 1994. *1994 Census of Agriculture*.

[69] South Florida Ecosystem Restoration Working Group, 1998.

as that country's products enter the same market arena.[70] In spite of this trend, agriculture continues to demonstrate an ability to adjust by shifting to international markets, specialty products, and domestic niche marketing.[71]

UNEMPLOYMENT/POVERTY

Florida's unemployment rate, at 4.3%, mirrors the national average of 4.5%.[72] South Florida, however, has unemployment "hot spots." Hendry County has the highest unemployment rate in Florida, at 21.4%. This is mostly due to the seasonal nature of agriculture jobs, which account for half of all jobs in the county. Other counties with exceptionally high unemployment rates include St. Lucie, 15.1%; Glades, 12%; Okeechobee, 10.4%; and Highlands, 10.3%.[73]

While Miami-Dade County's unemployment rate is not as high as the other hot spots, at 6.4% it ranks above the State and national average.[74] The large number of people coming off welfare and joining the workforce, as well as the large numbers of immigrants, compounds the county's problems. The dilemma is that there are not enough low-skilled positions for all these people. South Florida has reached a saturation point in low-skilled employment. A deficiency in South Florida is that the region has 50% of the state's employment, while containing only 32% of the job growth.[75]

In Florida, approximately 2.2 million people live in poverty, with 52% in South Florida. Twenty-three percent live in Miami-Dade County, which has the highest poverty rate in South Florida at 25.4%.[76]

RAMIFICATIONS OF POPULATION AND GROWTH IN SOUTH FLORIDA

The population of South Florida and its economy can wholly account for the deterioration of the natural system and the region's water problems. Not enough water is available in the right places, for the right purposes, at the right time. How water is used, how much it is used, and when it is used and why are all factors that need to be considered in determining restoration alternatives for the Everglades. Understanding the economic constraints and citizenry needs is equally important, since those issues pose potential obstacles or conflicts over restoration objectives and dollars. The previous section described the population numbers, demographics, and economic needs as important characteristics of the region, since these trends, activities, and needs will affect and be affected by water management and Everglades restoration activities. Prior to discussing the Everglades restoration initiative, a final look at specific ramifications of the South Florida economy and population on the water resources is instructive. Trends in land use, water use and flood control will highlight the population and economic effects on the natural system and the concomitant water management and policy responses.

[70] Florida Department of Commerce, July 1993. *Florida and the North American Free Trade Agreement*. Bureau of Economic Analysis, Tallahassee, FL.

[71] Governor's Commission for a Sustainable South Florida, 1995B.

[72] Rust, R., 1998.

[73] Florida Department of Labor and Employment Security, 1998. Local Area Unemployment Statistics Program. Bureau of Labor Market and Performance Information, Division of Jobs and Benefits, Tallahassee, FL.

[74] *Ibid*.

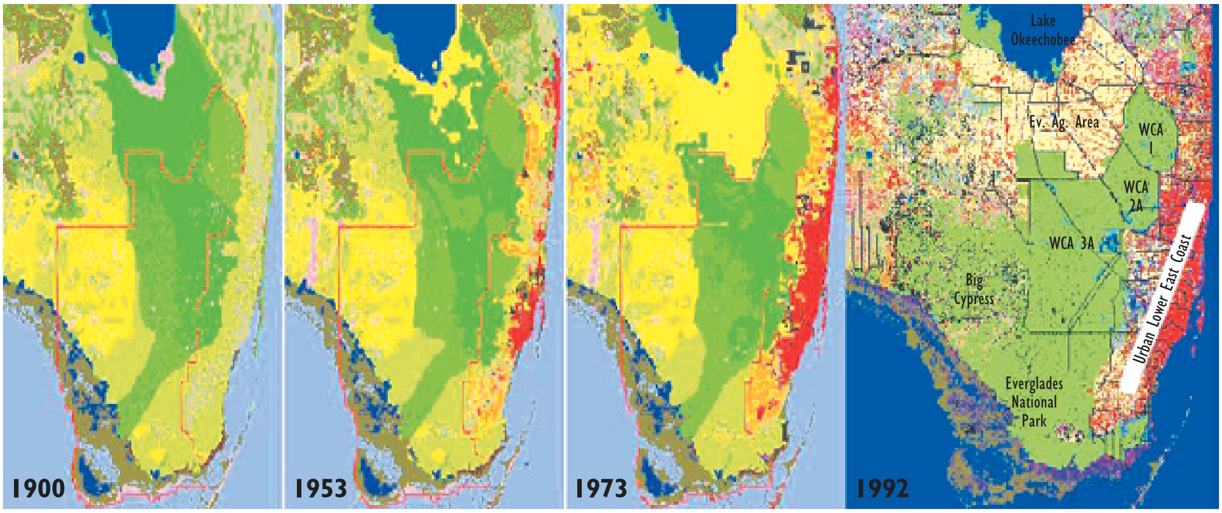
[75] Rust, R., 1998.

[76] U.S. Census Bureau, 1993. Small Area Income Poverty Estimates Program. Washington, D.C.

LAND USE

As described previously, population growth and economic endeavors have drastically changed the natural landscape of South Florida. Over one half of the original Everglades system has been lost. Figure 8 shows the extensive partitioning, constriction, and alteration of the landscape from 1900 to 1992 for the area south of Lake Okeechobee.

Figure 8 Land Use Changes by Category (Natural, Agricultural, Urban), 1900-1992.

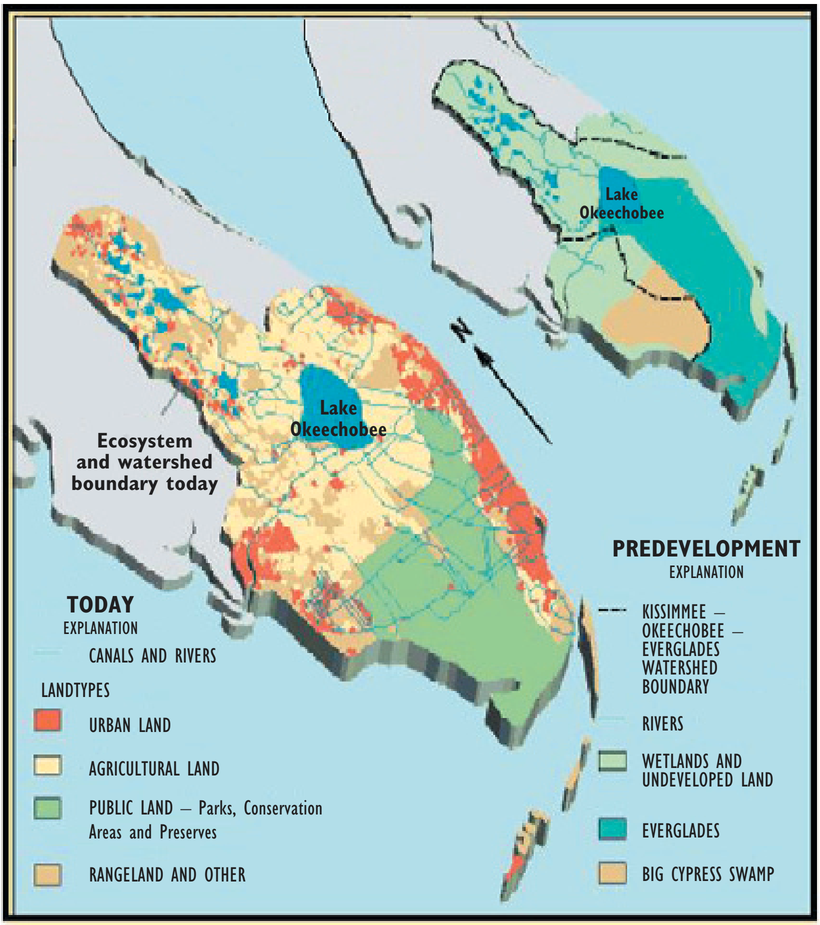


Source: SFWMD

Natural Agricultural Urban

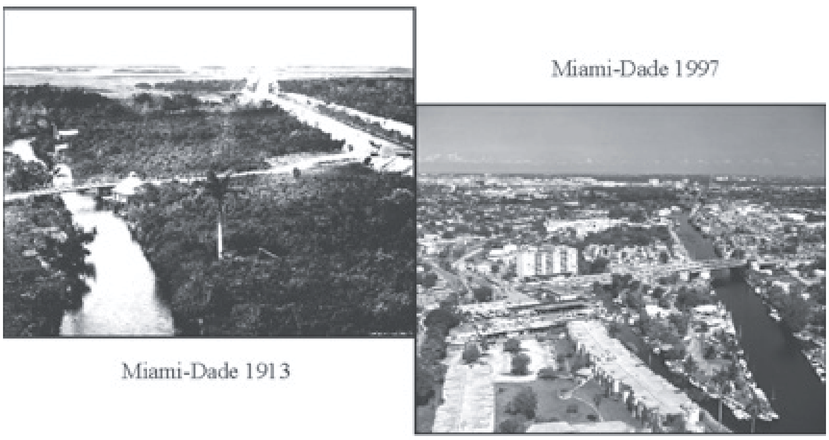
The introduction of agriculture and urbanization has forever changed the natural system and its ability to store, cleanse, and maintain its natural functions. Figure 9 shows the breadth of the entire greater Everglades system, its original state, and what exists today. Photos (Figure 10) depicting Miami in 1913 and 1997 unequivocally demonstrate that South Florida's rapid growth has had an unparalleled effect on the regional ecology.

Figure 9 Greater Everglades System Over Time



Source: SFWMD

Figure 10 Land Use Change in Miami-Dade County



The region's growth places increasing demands on land for urban uses, especially residential development. Burchell *et al.*[77] estimated that "existing development patterns" in the five Southeast Florida counties would consume 311,155 additional acres between 1995 and 2020, with 92% of that being used to accommodate residential development. Most of this land has and will come from lands presently in agriculture. Efficiency in land use has shown varying trends over the past decades. In a comparison of households per acre in Miami-Dade, Palm Beach and Broward counties,[78] density per acre increased between 1953 and 1973. However, between 1973 and 1995, "urban development was taking place at a lower density during this period than in the previous period."[79] Weisskoff notes the same trends for the entire South Florida region, noting that, "[t]he population boom is reflected in the remarkably high number of multi-family housing starts built during the 1970s and the subsequent rise in the number of single-family units in later decades."[80] With much of the urban area already fully built-out, and those areas within the urban corridor available but plagued by a multitude of disincentives for development, the only natural course is for development to push inland into the Everglades. Broward County, for example, has less than 200,000 acres left for development purposes.[81] The inland expansion not only reduces the spatial extent of the remnant Everglades, but also exacerbates the continuing regional problems of water supply and flood protection, and creates local problems associated with infrastructure and zoning.

One component of Everglades ecosystem restoration is the redirection of a proportion of the new growth back into overlooked communities and areas. On the southeast coast, the Eastward Ho! movement aims to spur redevelopment of an urban corridor spanning much of Miami-Dade, Broward, Palm Beach, Martin, and St. Lucie Counties through a public/private partnership.[82] While limited to the southeast coast, the philosophy of Eastward Ho!, the rejuvenation and revitalization of existing urban areas, is transferable to all urban areas in South Florida. The 1998 report "Building on Success, A Report from Eastward Ho!" of the South Florida Regional Planning Council[83] describes numerous community successes, which could be characterized as "smart growth," and describes positive steps communities can employ in this effort.

The Florida Department of Community Affairs, in moving forward with the Eastward Ho! and the sustainability movement, was authorized in 1996 by Section 163.3244 of the Florida Statutes to designate up to five local governments as "Sustainable Communities." The Sustainable Communities Program aims to promote enhanced planning efforts by rewarding communities that pursue balanced and harmonious economic growth, promote infill development and redevelopment, define urban development boundaries, and promote social progress and environmental protection. Legislation provided for regulatory and fiscal incentives for communities

77 Burchell, R.W., N. Neuman, A. Zakrewski, and S.E. DiPetrillo, 1999.

78 Florida Atlantic University/Florida International University, 2000.

79 *Ibid.*

80 Weisskoff, R., 2000.

81 Florida Atlantic University/Florida International University, 2000.

82 South Florida Regional Planning Council, July 1996. *Eastward Ho!, Revitalizing Southeast Florida's Urban Core*. In conjunction with the Treasure Coast Regional Planning Council. Hollywood, FL.

83 South Florida Regional Planning Council, December 1998. *Eastward Ho!, Building on Success, A Report from Eastward Ho!*. In conjunction with the Treasure Coast Regional Planning Council. Hollywood, FL.

that achieve the above-stated goals. In 1999, Governor Jeb Bush initiated an urban revitalization effort called Front Porch Florida. This effort seeks to advance an urban policy that will release the power of local communities in Florida's urban cores to rebuild their neighborhoods through a redevelopment process that is neighborhood-driven, asset-based, and focused on community relationships.[85]

Today, there is a heightened awareness of the adverse impacts resulting from conversion of agricultural lands to developed lands, or the loss of open space for environmental preservation or recreation. Studies are beginning to supply information about the true costs associated with South Florida's past and current growth patterns. For example, one recent report states that a growth management strategy that emphasizes compact growth rather than current sprawl patterns in the Eastward Ho! corridor would result in a $6.16 billion saving to local and state governments over a 25 year period.[86] During the 2001 Florida Legislative session, Governor Jeb Bush pushed for a bill which would link school concurrency with growth management and one that would instill "true" cost accounting procedures into local land use decision-making. Neither bill passed, but these and other growth management initiatives will be slated for future legislative sessions.

WATER USE

The population growth and its management of water (either for consumption or drainage) were the defining forces in altering the Everglades ecosystem. First through drainage, then through its use and movement, water is an ever increasingly significant component of the South Florida social, political and economic landscape. In 1995, nearly half of the state's freshwater withdrawal was attributed to the region of the South Florida Water Management District.[87] That region presently contains approximately half of the state's population.[88] As described previously, the South Florida region's population was as little as 30,000 in 1900 and was approximately 500,000 in 1950. Since then the region's population has grown to almost 7 million. The region's population is projected to reach almost 12 million by 2050. Most of the population is concentrated either along the Atlantic or Gulf Coasts, or in the interior City of Orlando and its suburbs. Agriculture, one of the major economic features of South Florida, is concentrated in the interior of the region, with dairy and beef cattle located north of Lake Okeechobee, sugar cane in the Everglades Agricultural Area (EAA) located immediately south of Lake Okeechobee and citrus grown in the non-coastal Southwest and Northeast portions of the region. Water demands for these agricultural and urban uses have steadily increased.

The water supply for South Florida originates from either surface water or ground water or a blend of the two. Surface water is highly managed, through the C&SF Project and through the more localized secondary and tertiary canal systems through the region. These canals and structures are

[84] Office of the Governor, October 7, 1999. Front Porch Florida, Press Release. State of Florida, Tallahassee, FL.

[85] Burchell, R.W., N. Neuman, A. Zakrewski, and S.E. DiPetrillo, 1999.

[86] Fernald, E.A. and E.D. Purdum, 1998.

[87] Florida Consensus Estimating Conference, 2000.

Today, there is a heightened awareness of the adverse impacts resulting from conversion of agricultural lands to developed lands, or the loss of open space that could be used for environmental preservation or recreation. Studies are beginning to supply information about the true costs associated with South Florida's past and current growth patterns. For example, one recent report states that a growth management strategy that emphasizes compact growth rather than current sprawl patterns in the Eastward Ho! corridor would result in a $6.16 billion saving to local and state governments over a 25 year period.

operated for flood control or water supply purposes. As described in the District's Water Management Plan 2000:[88]

> The heart of this modern surface water management system consists of Lake Okeechobee and the interconnected major features of the C&SF Project. These include the Kissimmee Chain of Lakes; the Kissimmee River; Lake Okeechobee and its outlets; the Water Conservation Areas; Everglades National Park and Florida Bay; and the coastal canal networks of Miami-Dade, Broward, Palm Beach, Martin and St. Lucie counties. Lake Okeechobee functions as a primary storage reservoir for excess (flood) waters from lands adjacent to and north of the lake. In addition, the lake provides water supply to downstream basins. Most of the water enters the lake from rainfall, local runoff, and discharge from the Kissimmee River, Fisheating Creek and Taylor Creek.

Ground water is the source of most water uses in South Florida. In 1995, almost 96% of the public water utility and 100% of South Florida's domestic self-supply came from ground water. Ground water also provided 32% of the water used for agricultural purposes. Overall, ground water supplied 53% of the total freshwater demands in the SFWMD.[89]

The SFWMD[90] report also states that three major aquifer systems are identified in South Florida. The Floridan, deep and extensive, is the primary water supply source for the northern reaches of the SFWMD, and is used for supplemental irrigation water as far south as Martin County. The Intermediate Aquifer (within the Hawthorn Group) is used mainly in southwest Florida. The most productive aquifers in that area are located in the Surficial and Hawthorn Aquifer Systems in northeastern Collier and southwestern Hendry Counties. The Surficial Aquifer System supplies much of the Southeast, particularly Miami-Dade, Broward, and the southern portions of Palm Beach County. Overall, water resources are deemed insufficient to meet all local demands in the SFWMD, and much of the region has been designated a "Water Resource Caution Area" where requirements for use of reclaimed water are often exerted. These areas are defined as "specific geographical areas, which have become critical or are anticipated to become critical within the next 20 years (Florida DEP Rule 62-40-520(2))." Certain other areas have been designated "Reduced Threshold Areas" where normal daily withdrawal thresholds for individual permits are reduced from 100,000 gallons per day (gpd) to 10,000 gpd.[91] Some variation does exist as the South Miami-Dade Water Use Basin individual permit's thresholds are 500,000 gpd.

Water is used for a variety of purposes or "user classes" (see Figure 11). These classes include public water supply, domestic self supply and small public utilities, commercial/industrial self-supply, recreational self-supply

[88] South Florida Water Management District, 2000A.

[89] *Ibid.*

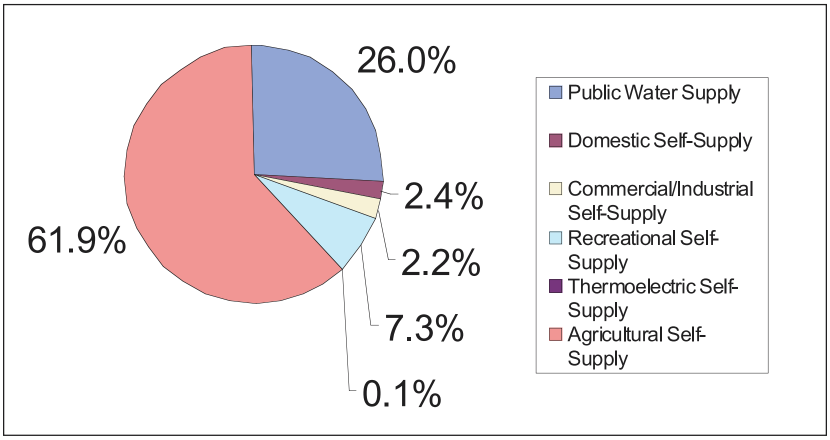
[90] *Ibid.*

[91] Fernald, E.A. and E.D. Purdum, 1998.

Overall, water resources are deemed insufficient to meet all local demands in the SFWMD, and much of the region has been designated a "Water Resource Caution Area" where requirements for use of reclaimed water are often exerted.

(much of this is for golf courses), thermoelectric self-supply and agricultural self-supply. The first five are usually grouped together and characterized as "urban" use. The needs of the environment or environmental demands are usually not included in the traditional "use" categories. This use is not easily calculated as it supports the natural systems by maintaining acceptable water levels and flows in the rivers, streams, lakes and wetlands; protects groundwater supplies; and provides adequate water for estuaries and coastal waters. This water is set aside to protect the resource from significant harm via the establishment of minimum flows and levels for watercourses in the region. The SFWMD's charge is to allocate the water to provide an "equitable distribution of the resource between environmental water needs and other reasonable and beneficial purposes."[92]

Figure 11 Water Demands for Six Categories of Use for the District in 1995
Source: SFWMD, 2000A

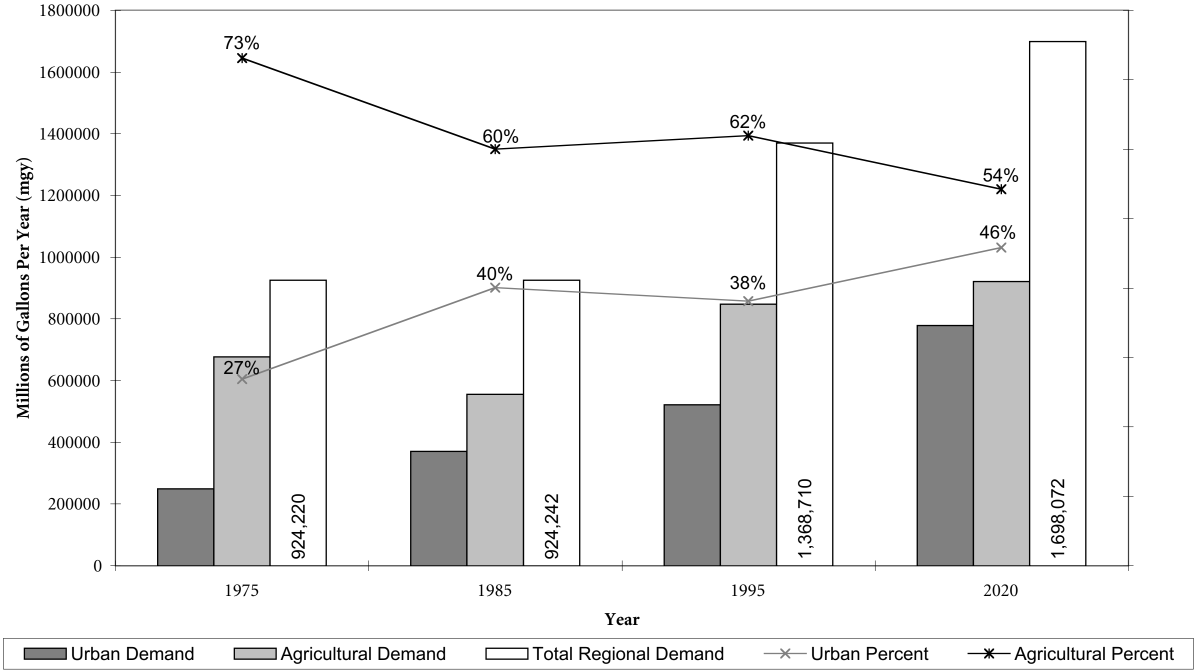


[92] South Florida Water Management District, 2000A.

In general, water demand is relatively constant throughout the year. During the winter tourist, and winter resident season, urban needs are highest. Agriculture demand tends to be lowest at this time. In the late spring agricultural irrigation demands are highest. This period coincides with the decline in the tourist and winter resident demands. Most of the water is replenished between May and October, when approximately 75% of the rainfall occurs.

Figure 12 shows historical and projected water use for the South Florida region. Currently (1995) the region uses approximately 1.3 trillion gallons/ year or approximately 3.5 billion gallons a day (bgd). Total water demand is forecast to increase by 24% between 1995 and 2020, alongside the projected 43% population increase for this period. This will result in an addition of approximately 1 bgd by the year 2020.

Figure 12 Human Water Demands for the South Florida Region (mgy)



Source: 1975, 1985: USGS Open-file Report 94-521 (Marcella, 1995).
1995, 2020: SFWMD, District Wide Water Assessment, 1998.

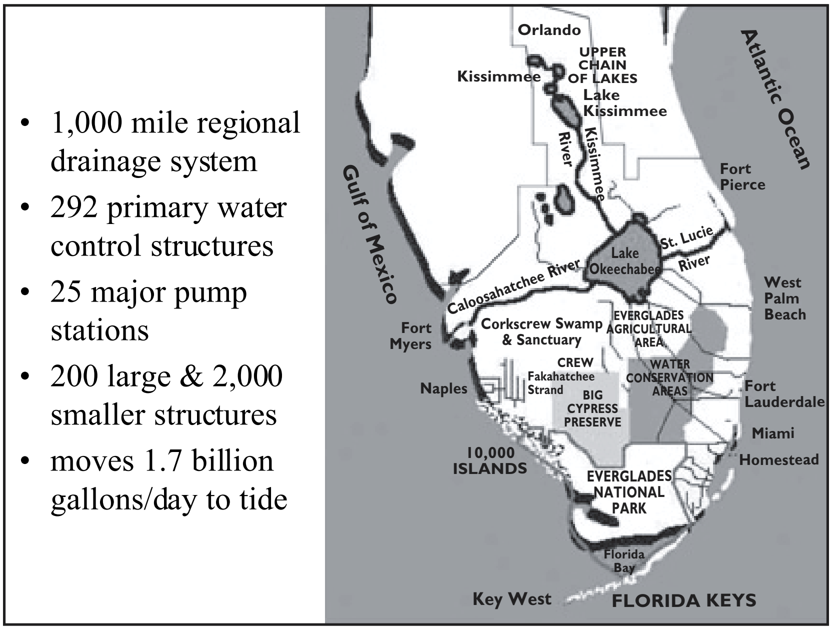
Urban demands, which have been rising steadily, are projected to increase 49%, while agricultural demands will increase 9% by 2020. By 2020, urban demands will be approaching the magnitude of agricultural demands, whose demands appear to be leveling off. The per capita use for the region is approximately 226 gallons per capita per day (gpcpd). This figure is projected to decrease to 215 or 178 gpcpd in 2050, depending on the breadth and aggressiveness of water conservation activities in the future.[93]

[93] U.S. Army Corps of Engineers and South Florida Water Management District, 1999A.

FLOOD CONTROL

As described earlier, South Florida today owes its existence to extensive drainage and flood control measures enacted and built over the past century (Figure 13). Through the C&SF Project system and the additional local drainage systems, over 1.7 bgd are discharged to the ocean and gulf. When the system was designed, only 500,000 persons lived in the region. It was designed to serve an estimated 2 million persons by the year 2000. The projected land uses for the system's design were primarily agriculture. With triple that population today, it is understandable that, as land use continues to convert from natural to agricultural and urban purposes, runoff has dramatically increased and the human vulnerability to flooding events has increased precipitously.

Figure 13 Flood Control in South Florida



Source: SFWMD

During extreme events such as hurricanes the system can act as a rapid conduit for water removal. For example, during Hurricane Irene,[94] the system discharged nearly 75 bgd from its canals through approximately 30 coastal structures or spillways from St. Lucie to Miami-Dade County, starting on the day following the storm. The system also pumped approximately 20 bgd through its 17 major pumping stations into the Everglades, Lake Okeechobee and out to sea. Juxtaposing daily water use (approximately 3.5 bgd) with average (1.7 bgd) or extreme flood control or drainage measures (80-100 bgd), one can see how flood control plays a major role in the water availability equation.

[94] South Florida Water Management District, October 31, 1999B. The SFWMD and You – Together We Are Part South Florida's Overall Drainage Solution, Press Release. West Palm Beach, FL.

THE COMPREHENSIVE EVERGLADES RESTORATION PLAN (CERP)

In 1992, the U.S. Army Corps of Engineers (Corps) was authorized to undertake a re-examination or "Restudy" of the Central and Southern Florida Project (C&SF Project). The Restudy was to "determine whether modifications of the existing project are advisable at the present time due to significantly changed physical, biological, demographic, or economic conditions, with particular reference to modifying the project or its operation for improving the quality of the environment, improving protection of the aquifer, and improving the integrity, capability, and conservation of urban water supplies affected by the project or its operation." (Water Resource Development Act (WRDA) of 1992). The "Reconnaissance Phase" of that project was completed in 1994. The WRDA 1996 then directed the Corps and its local sponsor (the SFWMD) to "develop as expeditiously as practicable, a proposed Comprehensive Plan for the purpose of restoring, preserving and protecting the South Florida ecosystem. The Comprehensive Plan shall provide for the protection of water quality in, and the reduction of the loss of freshwater from, the Everglades. The Comprehensive Plan shall include such features as are necessary to provide for the water-related needs of the region, including flood control, the enhancement of water supplies and other objectives served by the C&SF Project."

In April 1999, The Central and Southern Florida Project Comprehensive Review Study, Final, Integrated Feasibility Report and Programmatic Environmental Impact Statement[95] recommended a comprehensive plan to reverse the long trend of damages to the natural areas of central and southern Florida. In anticipation of the WRDA 2000 that would serve as the initial congressional authorization implementing the Comprehensive Plan, the State of Florida passed related legislation during its 1999 and 2000 legislative sessions. In 1999, the Florida Legislature documented the importance of restoring the Everglades ecosystem and sustaining the environment, economy, and social well being of South Florida (Sec. 373.1501 and 373.026 Florida Statutes). In these statutes, the Legislature also set up a review and approval process for CERP project components consistent with federal and state policies and purposes. In the spring of 2000, the State of Florida passed the Everglades Restoration Investment Act committing the State's 50% share of the overall costs for the Comprehensive Plan for the first 10 years of the plan's implementation. The Florida Legislature in 1999 and the U.S. Congress in 2000 approved the plan that would cost $7.8 billion, take more than three decades to construct and would be cost-shared 50/50 between the federal and state governments.

The Comprehensive Everglades Restoration Plan (CERP) is the most ambitious ecosystem restoration effort ever undertaken in the United States. This effort will capture most of the fresh water that now flows unused to the Atlantic Ocean and Gulf of Mexico to deliver it when and where it is needed most. Much of this "new" water will be dedicated to environmental restoration. At the same time, the remaining water captured by the restoration plan will benefit cities and farmers, enhance water supplies and support a strong, sustainable South Florida economy. The Plan encompasses numerous "projects" (over 60) including how South Florida's primary drainage system (the Central and Southern Florida (C&SF) Project) is operated, the creation of water quality treatment facilities, and other projects that will result in the creation of approximately 217,000 acres of new reservoirs and wetlands-based water treatment areas. The plan is ambitious, costly, and complicated. Yet without it, the trends of environmental deterioration and water shortage would continue.

The WRDA 2000 "approved" the Comprehensive Plan "as a framework for modifications and operational changes to the C&SF Project that are

[95] U.S. Army Corps of Engineers and South Florida Water Management District, 1999A.

The Comprehensive Everglades Restoration Plan (CERP) is the most ambitious ecosystem restoration effort ever undertaken in the United States. This effort will capture most of the fresh water that now flows unused to the Atlantic Ocean and Gulf of Mexico to deliver it when and where it is needed most. Much of this "new" water will be dedicated to environmental restoration. At the same time, the remaining water captured by the restoration plan will benefit cities and farmers, enhance water supplies and support a strong, sustainable South Florida economy.

needed to restore, preserve, and protect the South Florida ecosystem while providing for other water-related needs of the region, including water supply and flood protection." It stated that, "[t]he Plan shall be implemented to ensure the protection of water quality in, the reduction of the loss of fresh water from, and the improvement of the environment of the South Florida ecosystem and to achieve and maintain the benefits to the natural system and human environment described in the Plan, and required pursuant to this section, for as long as the project is authorized." The bill authorized four "pilot projects" and 11 "initial projects" all of which (except for the adaptive assessment and monitoring program) require the review and approval of a Project Implementation Report (PIR) prior to implementation. All future projects will require congressional authorization.

The CERP has two sets of goals and objectives:[96]

Goal – Enhance Ecological Values
- Increase the total spatial extent of natural areas
- Improve habitat and functional quality
- Improve native plant and animal species abundance and diversity

Goal – Enhance Economic Values and Social Well Being
- Increase availability of fresh water (agricultural, municipal and industrial)
- Reduce flood damages (agricultural/urban)
- Provide recreational and navigation opportunities
- Protect cultural and archaeological resources and values

Specifically the CERP will achieve the restoration of more natural flows of water, including sheet flow, improved water quality and more natural hydroperiods in the South Florida ecosystem. Improvements to native flora and fauna, including threatened and endangered species will occur as a result of the restoration of the hydrologic conditions. The CERP was also designed to enlarge the region's supply of fresh water and to improve how water is delivered to the natural system. Figure 14 depicts the type, location and range of the numerous projects planned to be implemented by CERP.

Included in the Plan were 6 pilot projects; 15 surface storage areas (~170,000 acres); 3 in-ground reservoirs (~11,000 acres); 330 aquifer storage and recovery wells; 19 stormwater treatment areas (~36,000 acres); 2 wastewater reuse plants; removal of over 240 miles of canals, levees and structures; and operational changes. Several of these projects have never been utilized in the location or scale as envisioned in the CERP (aquifer storage and recovery, seepage management for example). The CERP, through the "pilot project" components, will explore and test their feasibility and viability.

[96] *Ibid.*

Figure 14 Comprehensive Everglades Restoration Plan (CERP)

Source: U.S. Army Corps of Engineers

POLICY DISCUSSION

South Florida is at a confluence of a number of significant trends fueled by rapid and unending population growth. South Florida's land, water, economy and quality of life are all intertwined in a conundrum of growth challenges and opportunities, whose overall winners include the current residents, visitors, and the natural system, both present and future.

CHALLENGES

Significant trends in South Florida are largely attributed to its rapid and steady population growth. The high proportion of elderly and international and domestic migration; the emerging diversity of cultures, income ranges, and lifestyles; the advent and importance of tourists and winter residents to the regional economy; and the overall transient population of South Florida citizenry points to a broad, growing and dynamic South Florida population. With such a transient, divergent and dynamic population, the ecosystem restoration initiative must be perceived as part of the necessary "infrastructure" or basic quality of life in South Florida to remain viable. If not, the initiative will have to compete for its place amidst other looming issues such as crime, education, transportation, and economic development. As the population grows and ages, competing needs will continue to rise, such as health care, affordable housing, or special needs transit. With an economy increasingly dependent on the service and tourist sector, lower wages and greater market volatility may become more important factors in public funding capability and commitment for long-term Everglades restoration. The spread and diffusion of greater cultural, ethnic, and attitudinal diversity makes the plurality of South Florida richer, yet harder to reach.

While the South Florida population grows, so too will the economy and its requisite land uses. With trends of increased sprawl and greater per capita land use, increasing pressure for additional residential land use will continue. The direct link of population to increased land use and sprawl is noted by Kolankiewicz and Beck[97] who state that "real and sustainable controls on sprawl are not practicable without vigorous national and local efforts to attack half the source of sprawl by moving toward population stabilization." Growth management programs at the state and local level are under increasing scrutiny and potential revision. Their effectiveness is generally considered "unsuccessful," but without them most would agree that the South Florida landscape would be even worse off. Increased competition from overseas and increased regulatory requirements will also put additional pressure on agricultural lands to convert to more intensive "urban" uses. Greater "urbanization" will also result in increased pollution and decreases in the quality of the remnant natural system.

With such a transient, divergent and dynamic population, the ecosystem restoration initiative must be perceived as part of the necessary "infrastructure" or basic quality of life in South Florida to remain viable. If not, the initiative will have to compete for its place amidst other looming issues such as crime, education, transportation, and economic development.

For the CERP some specific challenges include proving "unproven" technology such as the regional scale aquifer storage and recovery or seepage management techniques which are being examined by pilot studies. These issues will need to be resolved and accepted by the public in order for them to be utilized. With these technological challenges, a construction time period of over 20 years, and tangible benefits coming in piecemeal, public outreach initiatives will be essential. Defining who the public is (newcomers, visitors, residents, linguistic sensitivity, etc.), educating the public about the need for ecosystem restoration, engaging them in the restoration process, and improving trust are a number of challenges outlined in the CERP Public Outreach and CERP Environmental and Economic Equity Program Management Plans.[98] These challenges are at the forefront as the Corps and the SFWMD embark on year one of implementing the CERP.

Public outreach has an equally important role in getting the public to understand its role in water resource management. As an example, in 2000-2001, the SFWMD experienced its worst drought of record, exceeding a 1 in 100 event for the area around Lake Okeechobee. As the agency went into water use restrictions in November 2000 – 10% voluntary and then 20% mandatory – as late as March 2001, the region overall had reduced its use only 11%. It was only with increased enforcement and building greater public awareness that water conservation responses have begun to come closer to the conservation goals. The insatiable thirst of the region, even in times of severe drought, clearly exemplifies the challenges for public outreach. Getting the public to understand its water use behaviors and implications is just one aspect of what will be needed in public outreach. Additional issues such as pollution, waste prevention, ecological

[97] Kolankiewicz, Leon and Roy Beck, 2001. *Weighing Sprawl Factors in Large U.S. Cities*.

[98] U.S. Army Corps of Engineers and South Florida Water Management District, August 2001A. *CERP Public Outreach Program Management Plan*. Jacksonville, FL; See also, U.S. Army Corps of Engineers and South Florida Water Management District, August 2001B. *Environmental and Economic Equity Program Management Plan*. Jacksonville, FL.

preservation, and community stewardship will need to become part of the South Florida persona. When, where, and how to do this needs to be determined to begin offsetting the often detached thinking and behaviors of the South Florida citizenry regarding the Everglades system.

Getting the public to understand its water use behaviors and implications is just one aspect of what will be needed in public outreach. Additional issues such as pollution, waste prevention, ecological preservation, and community stewardship will need to become part of the South Florida persona.

OPPORTUNITIES

Opportunities do abound in South Florida for the Everglades restoration effort. As the Corps and others state,[99] this is the time to "Get the Water Right." This means that by restoring the water quality, timing, quantity, and distribution, the plan will revitalize the natural system while improving water supply and maintaining its present flood control capability. The joint political commitment by the U.S. Congress and the State of Florida in 1999-2000 was an unprecedented effort and opportunity, one that will take enormous commitment, dedication, accountability, and delivery. The Corps and the SFWMD will have to prove they can deliver the project and that the professed benefits will be forthcoming, tangible, and measurable. The ability to plan and manage from an "ecosystem scale" is an advantage and opportunity that few jurisdictions in the nation possess.

How to reconcile intense population growth and development in a fragile ecosystem is the major task at hand. The CERP attempts, at an ecosystem scale, to provide the water component for the next 30-50 years. This will be done in the context of an economy and land use that will be continually growing and changing. Note that as the CERP is implemented 1.7 bgd will be freed up for other purposes, mainly environmental. At the same time, total water demand will be increasing approximately 1 bgd by the year 2020. Also remember, the system has the capacity to drain massive amounts of water, such as the roughly 95 bgd discharged immediately following Hurricane Irene. Future water demands must be met by a combination of greater water use efficiency, greater responses to environmental stimuli (rain, drought, price, etc.), and alternative water sources (ASR, reservoirs, desalinization, reverse osmosis, wastewater reuse, etc.).

How to reconcile intense population growth and development in a fragile ecosystem is the major task at hand.

As aptly stated by Weisskoff,[100] "South Florida's strong economy compounds its environmental problems, an expanding agricultural and commercial society serving a large tourist, retiree, and transient population. All this surrounds North America's only semi-tropical and largest remaining wetland, the Florida Everglades." The CERP attempts to reconcile these conflicting needs by using water as the "medium" or regional currency. With the CERP designed as a "win-win" for both the human and natural systems,[101] it is essential that the effort is not derailed. By allowing the region to continue its growth, however, the CERP in a sense becomes an "enabler" in current resource consumption patterns. Weisskoff[102] cautions,

> In the absence of restoration, the continuing growth of the regional economy faces severe constraints due to limited land and water.

[99] South Florida Ecosystem Restoration Working Group, 1998.

[100] Weisskoff, R., 2000.

[101] Kranzer, Bonnie, Winter 2000. Everglades Restoration and the Governor's Commission. In Women in Natural Resources, University of Idaho, Moscow, ID. Vol. 21, No. 2, Pages 24-28.

[102] Weisskoff, R., 2000.

> Current state and federal policies promote urban sprawl and agricultural expansion. Tax exemptions, wage subsidies, low impact fees and low utility rates are all packaged to attract new manufacturing, commercial and tourist facilities and to develop new housing. Generally low energy rates encourage the construction of larger air-conditioned homes, and low water rates promote green lawns all year round... In the absence of extremely aggressive policies of conservation, the present trend is to encourage greater resource use in the urban areas. In the countryside, the water-intensive and land-extensive technologies borrowed from temperate agriculture for the region's crops, dairies, and fishponds may prove highly inappropriate in the fragile, semi-tropical Everglades ecosystem. Either path – higher levels of activity with current resource intensities implicit in our static projections, or higher levels of population with higher intensities – will accelerate the ecological pressures. Absent in the growth modeling are the costs the region faces as a consequence of these pressures. The "restoration" efforts, designed by engineers from outside the region, needs to be complemented by efforts at "smart" consumption, designed and imposed by taxpayers inside the region, as the broad population comes to recognize the true social costs of living within a fragile ecosystem.

The restoration effort has to regain the hydrological and biological values that have been lost. Robertson and Frederick note that, "[t]here is no obvious biological reason why restoration should fail... it does not appear to be particularly difficult. The only real problem is political – the need to resolve competing uses of resources and competing visions of the future."[103] Zubrow *et al.* confirm this observation, explaining that, "[t]he problem of environmental restoration is not technical, it's cultural and economic... The solution must be seen to be more than a local problem or even a regional problem."[104] Like the diversity of communities that characterize South Florida, the vision and reality of Everglades restoration must be greater than the sum of its parts. Its vitality, diversity, and longevity must be ensured.

A constant vigil on the South Florida economy and population growth, magnitude, location and accompanying land uses will be imperative to ensure that the planning landscape for the CERP is not irrevocably altered. Integrating and updating population, land use, and economic factors into the CERP will be equally essential. The adaptive management process utilized in the plan's implementation should prove the arbitrator, and director of how, when, and for what purposes the ultimate CERP configuration and success is accomplished.

[103]Robertson, William and Peter C. Frederick, 1994. The Faunal Chapters: Contexts, Synthesis, and Departures. In Everglades, The Ecosystem and Its Restoration. Edited by Steven M. Davis and John C. Ogden. St. Lucie Press, Delray Beach FL. Pages 709-737.

[104]Zubrow, Ezra B. W., James R. Schumm, Symma Finn, Gail A. Panetske, and Justin Van Ness, 1995. The Biological Reserve: The Future's Last Stand. Futures 27 (4). Pages 437-446.

ACKNOWLEDGEMENTS
The author wishes to thank the staff of the Governor's Commission for the Everglades for their assistance in research, graphics and drafting of portions of this article. In particular, she wishes to thank Bill Hinsley (EarthTech, Inc.), Roberto Torres (The Nature Conservancy) and Webb Smith (Mangi Environmental) for their help. Mr. Hinsley and Mr. Torres compiled much of the data used in this paper and assisted in its graphic portrayal. They also assisted in crafting numerous renditions and talking papers on this subject for the author's use. The author would also like to thank members of the National Academy of Science Committee on the Restoration of the Greater Everglades Ecosystem, who encouraged her research and validated the need for exploring this topic. Finally she would like to thank the former Superintendent of Everglades National Park, Richard Ring, for his support and funding of a symposium on Incorporating the Social Sciences into Everglades Restoration. Such encouragement and support helped keep the energy flowing and served as an inspiration to continue this field of inquiry.

BONNIE KRANZER was the Executive Director of the Governor's Commission for a Sustainable South Florida, then the Governor's Commission for the Everglades, from April 1994 until it was disbanded in 2001. As Executive Director, she was the prime liaison with Commission members and represented that body on the South Florida Ecosystem Restoration Working Group and its various subcommittees, many of which she co-chaired. She is an employee of the South Florida Water Management District (SFWMD) and was on "loan" to the Commission as an in-kind service by that agency. Prior to her appointment as Executive Director, Dr. Kranzer served as the Program Evaluation Director and later the Policy Coordinator for the SFWMD. Prior to SFWMD, Dr. Kranzer was a Senior Policy Analyst in the Governor's Office of Planning and Budgeting. Dr. Kranzer received her Bachelors and Masters degrees from Florida State University, focusing on Archaeology, Geology, and Geography. Dr. Kranzer's doctorate is from Southern Illinois University – Carbondale in natural resources management. Dr. Kranzer is certified as a planner by the American Institute of Certified Planners (AICP) and has served as an adjunct professor for the Department of Urban and Regional Planning at Florida Atlantic University in Ft. Lauderdale.

Bonnie Kranzer, Ph.D., AICP, Senior Supervising Planner, South Florida Water Management District, c/o SFWMD Ft. Myers Service Center, 2301 McGregor Blvd., Ft. Myers, FL 33901, BKranze@sfwmd.gov

Freshwater Ecosystems and Human Populations: Great Lakes Case Study

David Rankin
Vice President and Director of Programs, Great Lakes Protection Fund

ABSTRACT
The Great Lakes of North America were brought to the brink of ecological disaster and are now being returned to a healthier condition. This paper reviews the relationship of human populations to the Lakes' ecosystem in broad terms and offers advice on go-forward strategies. The interaction of three major forces led to the Lakes' decline: altering flow regimes by conversion of the landscape, biological pollution, and chemical pollution. Great progress has been made in restoring chemical integrity to the waters of the basin ecosystem, and modest progress has been made in managing the consequences of biological pollution. In the future, work within the basin must expand to include flow restoration strategies. Beyond work within the basin, new foreign policy instruments must manage the global problems of air and biological pollution.

INTRODUCTION

This is a personal account. I have spent the last twenty years learning about the Laurentian Great Lakes, the world's largest freshwater ecosystem, identifying impairments and restoration opportunities, and aligning ideas, people, and resources to improve its ecological health. The opinions that follow are mine alone. They are not those of the Great Lakes Protection Fund, the Fund's directors, owners or staff, or any other organization.

This paper uses a case study approach. A brief history of the interaction of human populations and the basin ecosystem is presented. In the pages that follow, I begin to unpack the case by summarizing the state of the Great Lakes ecosystem, through the lenses of physical, biological and chemical integrity. I briefly describe the key threats to the integrity of the ecosystem. I attempt to link those threats to sources related to various human populations. Finally, I suggest ways in which our collective conduct might be changed to avoid continued injury and better take advantage of the ecological restoration opportunities we now have.

By necessity, this paper focuses on key interactions, key systems, key stresses and key opportunities. In the space available, a comprehensive treatment is impossible, and I have not attempted it. I have also chosen to be provocative, and have written this as means of beginning a new conversation on how we can effectively govern our behavior – both within and outside of government – in a recovering freshwater ecosystem.

The scale of the Great Lakes basin is difficult to comprehend, even for those who live and work in the basin. The five Great Lakes – Superior, Huron, Michigan, Erie and Ontario – themselves contain over 5,500 cubic miles of fresh water. This is 18% of the world's available supply. The drainage basin includes parts of eight U.S. states and two Canadian provinces.

THE CASE – THE GREAT LAKES ECOSYSTEM

In search of a water route to Asia, Europeans came to the Great Lakes in the 16th century. Instead of the fabled Northwest Passage, they found beaver and began a robust fur trade. Forts were established on key water bodies to protect trade routes. Soon, the forts became towns and as the fur bearing animals became harder to find, the towns became more important than the trade they were established to protect.

Over the next three hundred years, the Europeans and their North American descendents wrested control of the land from the native people they had found here. By the mid-1800s most of the native people were entreated from their land, and confined to reservations. Westward expansion was facilitated by the use of water transportation. The Erie Canal linked the Hudson to Lake Erie by 1825. In 1829, the Welland Canal had bypassed Niagara Falls. Numerous other canals, such as the Miami and Erie, linked the lakes to the Ohio and Mississippi River basins.

By the 1830s, commercial logging had begun in the Canadian portions of the basin. By the 1860s, the timber industry had started a logging boom in Michigan, Wisconsin, and Minnesota. The vast virgin forests of the upper basin fueled the growth of Chicago, Detroit, Milwaukee, Minneapolis, and St. Paul. White pines in these forests could reach 200 feet in height and each produce 6000 board feet of lumber. Trees could be cut down in winter and floated to river mouths on the snowmelt each spring. The cleared land allowed runoff to reach streams without obstruction. Virtually all harvestable timber had been cleared from the basin by the early 1900s.

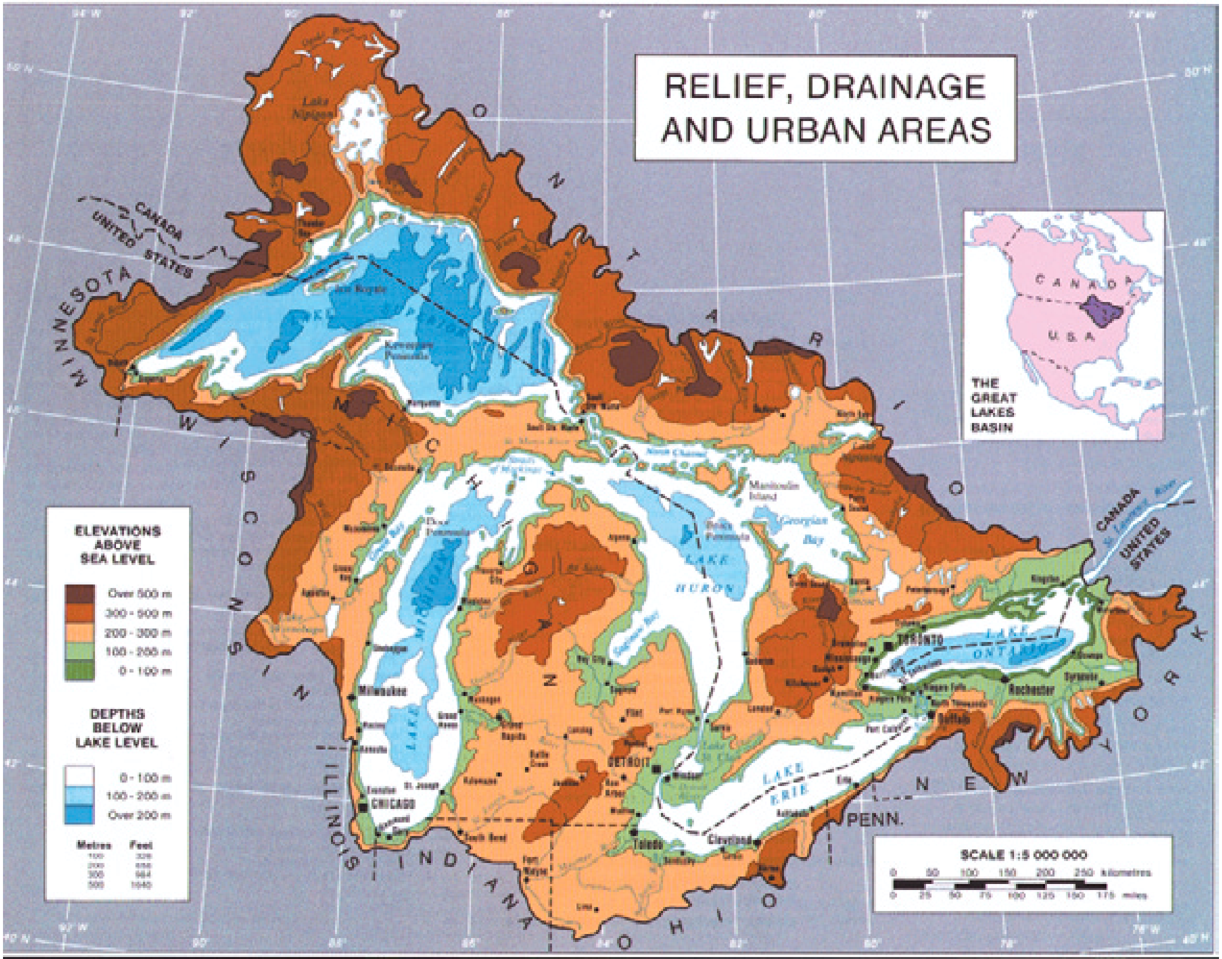
As the cities grew, manufacturing became an increasingly important economic force in the basin. The iron and steel manufacturing industry grew up on the shores of the Great Lakes. Iron ore from Minnesota, limestone from quarries throughout the basin, and coal from the nearby Appalachian plateau were easily moved by barge to large, integrated steel making facilities. This industry is still active on the south shore of Lake Michigan, at Sault St. Marie, Detroit, on the south shore of Lake Erie, in Hamilton, and Nanticoke. The sulfite paper making process was invented along the Welland Canal and the industry took hold throughout the basin, and is especially concentrated along Wisconsin's Fox River. Significant concentrations of the chemical manufacturing industry are located along the Niagara River, the St. Clair River, and near Michigan's Saginaw Bay.

In 1950, the region's population had reached some 28 million. Yet even in the early 1950s, it became clear the freshwater ecosystem was not inexhaustible. The basin fishery, once one of the world's largest, collapsed. Within fifteen years bulldozers were needed to remove dead fish from Chicago's beaches. The Cuyahoga River burned for three days. Lake Erie was unfit for human contact.

After almost half a century of focused work to restore the basin's fishery, it remains fragile – largely supported by hatchery-reared fish. After nearly thirty-years of pollution control – the world's toughest regulations and largest expenditure of public funds for pollution control – the most noticeable problems are gone. Rivers no longer burn. Most waters are safe for swimming most of the time. Yet problems remain. Fish still contain toxic chemicals – most states advise pregnant women to limit their consumption. The levels of some pollutants are again on the rise.

What have the lakes taught us about how human populations should govern themselves? What missteps have we taken in our relationship with this freshwater ecosystem and how might we avoid similar missteps in the future?

Yet even in the early 1950s, it became clear the freshwater ecosystem was not inexhaustible. The basin fishery, once one of the world's largest, collapsed. Within fifteen years bulldozers were needed to remove dead fish from Chicago's beaches. The Cuyahoga River burned for three days. Lake Erie was unfit for human contact. After almost half a century of focused work to restore the basin's fishery, it remains fragile – largely supported by hatchery-reared fish. After nearly thirty-years of pollution control – the world's toughest regulations and largest expenditure of public funds for pollution control – the most noticeable problems are gone…Yet problems remain.



Map of the Laurentian Great Lakes Region

BACKGROUND – AN INTRODUCTION TO THE GREAT LAKES

The Great Lakes ecosystem is the interacting components of air, water, land, and biota (including humans, of course) affecting the waters of the Great Lakes basin. This is a somewhat standard definition, appearing with minor changes in the Great Lakes Water Quality Agreement,[1] the proceedings of the State of the Lakes Ecosystem conferences, and many scholarly articles.

The scale of the Great Lakes basin is difficult to comprehend, even for those who live and work in the basin. The five Great Lakes – Superior, Huron, Michigan, Erie and Ontario – themselves contain over 5,500 cubic miles of fresh water. This is 18% of the world's available supply. The lakes cover an area of about 94,000 square miles. The watershed that drains into them covers just over 201,000 square miles. The system extends from roughly 41 to 51 degrees north latitude, and from 75 to 93 degrees west longitude.[2] The drainage basin includes parts of eight U.S. states and two Canadian provinces.

The Great Lakes are the only glacial feature visible from the moon. They were formed over several glacial episodes beginning some 500,000 years ago.[3] The lakes began as lowlands, probably river valleys associated with the predecessor of the St. Lawrence River. Great lobes of ice, up to two miles thick entered these valleys. Contrary to what one might imagine, glaciers are not permanently frozen to their beds. Where they are in contact with the ground, the ice melts, enters cracks, and periodically freezes. Material of all sizes, from fine "glacial flour" to large rocks and boulders become entrained in the ice. When a glacial advance stops, the entrained material is deposited. This glacial drift became the soil and upper strata in the Great Lakes basin. Loose drift can hold vast amounts of groundwater. Areas having substantial deposits of well-sorted sands and gravel are usually significant groundwater storage and transmission areas, and are known as aquifers.[4]

The present Great Lakes began to form with the retreat of the last glaciation – the Wisconsonian. The final substage of the Wisconsonian glaciation began retreating some 14,000 years ago and left the basin about 9,500 years ago. As the glaciers retreated, large lakes were formed at their edge. These "proglacial lakes" often deposited clays and other fine material, leaving patches of wet, poorly drained soils in the basin. These lakeplains are now home to unique biological communities in the basin.[5]

THE MOVEMENT OF WATER WITHIN THE BASIN

Water moves within the basin in accord with the hydrological cycle – the dominant physical process at work in the basin. Air carries water vapor over the basin, deposits it on the land, where it eventually enters the lakes. Once in the lakes, water moves in currents along the shores, is pushed by winds and storms, and eventually leaves through evaporation or transport to the Gulf of St. Lawrence.

The water that replenishes the Great Lakes comes from precipitation. Precipitation is, in turn, driven by the global climate. Rain and snow fall directly

[1] International Joint Commission. 1987. *Great Lakes water quality agreement.* Amended by protocol.

[2] Botts, L. and B. Krushelnicki. 1987. *The Great Lakes, an environmental atlas and resource book.* Environment Canada, US Environmental Protection Agency, Brock University and Northwestern University.

[3] Dorr, J.A. and D.F. Eschmann. 1971. *The geology of Michigan*, University of Michigan Press, Ann Arbor, Michigan.

[4] Daniel, G. and J. Sullivan. 1981. *The north woods of Michigan, Wisconsin, Minnesota and Southern Ontario – a Sierra Club naturalist's guide.* Sierra Club Books, San Francisco.

[5] Rankin, J.D. and S.R. Crispin. 1994. *The conservation of biological diversity in the Great Lakes ecosystem: issues and opportunities.* The Nature Conservancy, Chicago, Illinois.

on the lakes and on the lands drained by tributary rivers and streams. The majority of water that enters the system falls as rain or snow on the watershed, becomes ground water, and is discharged to the lakes through tributaries. Using new information,[6] it has been estimated that approximately 53% of the new water entering the Great Lakes takes this ground water pathway. The second largest category, about 24% of new water on a system-wide basis, is surface runoff that drains into tributaries and, ultimately, to the lakes themselves. Over-lake precipitation, subtracting evaporation losses, accounts for about 20% of the new water entering the lakes. The remaining 3% of known inputs to the lakes are the diversions into the system from the Hudson Bay drainage that enter in Lake Superior.[7]

On an individual lake basis, these contributions vary substantially due to local geology and the placement of the lake in the larger basin system. As one moves south and east in the system, the lakes increasingly depend on the waters flowing from the upper lakes. Lake Erie, on an average basis, receives nearly 90% of its new water supply from the outflow of the Detroit River.

The following is summary information on the movement of water through the Great Lakes basin. A lake-by-lake summary is provided to show how each lake is governed by several jurisdictions and remains connected to its own watershed while also being dependent on upstream sources of water.

LAKE SUPERIOR

Lake Superior, the largest, deepest, and highest in elevation of the lakes, borders Minnesota, Wisconsin, Michigan, and Ontario. Lake Superior contains 2,900 cubic miles of water and covers 31,700 square miles. Lake Superior has a drainage basin of 49,300 square miles. Three hundred and thirty-five tributary rivers and streams drain into the Lake (the Nipigon River flowing from Canada is the largest river and the St. Louis River flowing from Minnesota is the second largest), including large in-flows from the Long Lac and Ogoki diversions. Ninety-five percent of Lake Superior's drainage basin is forested, and the remaining 5% is split between agriculture, urban and industrial land uses. Less than 2% of the entire population of the Great Lakes, or about 740,000 residents, live around Lake Superior. As a result, the Lake has avoided many of the pollution problems associated with the other lakes.

The majority of water entering Lake Superior, some 49%, is ground water transported to the lake via the network of tributary rivers and streams. The surface run off carried by these same tributaries accounts for just 17% of the water that enters the lake each year. The net contribution of over-lake precipitation (after evaporative losses are considered), accounts for 28% of new water each year. The remaining 6%of the water that refreshes Lake Superior each year comes from the diversions into the system from the Hudson Bay drainage at Long Lac and Ogaki. Water exits Lake Superior through the St. Mary's River at a rate of approximately 78,000 cubic feet per second (cfs).

[6] Botts and Krushelnicki's Great Lakes Atlas is the primary source of water supply information. This information is largely derived from the 1985 IJC study on diversions and is known to be approximate. The new basis for disaggregating surface and ground water contributions is from *Indirect Ground-Water Discharge to the Great Lakes, USGS Open-File Report 98-529*. Calculation is extrapolation of USGS percentage contributions to Canadian portions of the basin. This is likely to overestimate the relative contribution of ground water to water supply budgets for Lakes Superior and Huron, but can be considered to be the best available estimate of the role of indirect ground water contribution to the basin water budget.

[7] Long Lac and Ogaki Diversions.

Less than 2% of the entire population of the Great Lakes, or about 740,000 residents, live around Lake Superior. As a result, the Lake has avoided many of the pollution problems associated with the other lakes.

LAKES HURON AND MICHIGAN

Lakes Huron and Michigan are usually described as a single hydraulic system because they share a common outlet to the lower lakes and possess the same long-term water level.

The United States-Canada border divides Lake Huron almost in half. The Canadian portion of the lake is wholly within Ontario. The United States portion is located entirely within Michigan. Lake Huron contains 850 cubic miles of water and covers 23,000 square miles. Lake Huron has a drainage basin of 51,700 square miles, two-thirds of which is in Canada. Sixty-six percent of the area around Lake Huron is forested, 22% is agricultural land, 10% is urban and industrial land, and 2% is devoted to other uses.

Lake Michigan is the only Great Lake located entirely within the United States, bordering Wisconsin, Illinois, Michigan, and Indiana. Lake Michigan contains 1,180 cubic miles of water and covers 22,300 square miles. Lake Michigan has a drainage basin of 45,600 square miles. The northern portion of the lake has very little population, development, and water consumption, although most of the tributaries in the northern part of the lake's drainage basin are dammed for power production. The southern portion is extensively urbanized with significant industrial, agricultural, and domestic water use, resulting in significant pollution, loss of wetlands, and other environmental problems. More than 10 million people reside on the lake's shoreline.

The Lake Huron-Michigan system is dominated by the flow from Lake Superior, which provides an estimated 42% of the year's water input. The contribution of ground water reaching the system through tributaries totals 35%-20% in Lake Huron and 15% in Lake Michigan. Surface run off transmitted through tributaries totals 12% of the annual average amount of water entering the system – 8% in Lake Huron and 4% in Lake Michigan. The net contribution of precipitation is 22% of the annual water budget – evenly divided between the two lakes. The system drains into the St. Clair River at about 187,000 cfs.

The Lake Huron-Michigan system is dominated by the flow from Lake Superior, which provides an estimated 42% of the year's water input.

LAKE ERIE

Lake Erie borders Michigan, Ohio, Pennsylvania, New York, and Ontario. The lake also receives surface and ground waters for the northeast portion of the state of Indiana. Lake Erie contains 116 cubic miles of water and covers 9,910 square miles. The shallowest of the Great Lakes, Lake Erie undergoes wide temperature swings, warming rapidly in the spring and summer and often freezing over in the winter. Lake Erie drains 30,000 square miles – 59% of that land is agricultural, 17% is forested, 15% is industrial and urban, and the remaining 9% is used for other purposes. Thirteen million people live within the Lake Erie basin, 86% of them in the United States. Despite its small size, the Lake Erie basin is the most populated of the Great Lakes and has the most agriculture. Lake Erie also has historically suffered significant damage from pollution.

Despite its small size, the Lake Erie basin is the most populated of the Great Lakes and has the most agriculture. Lake Erie also has historically suffered significant damage from pollution.

Eighty-eight percent of the water entering Lake Erie in a given year is, on average, from the upper lakes via the Detroit River system. The remaining 12% is evenly divided between surface run off and ground water transmitted via the lakes' tributaries. The precipitation falling on the lake is, on average, equivalent to the amount that evaporates from its surface. Lake Erie drains into Lake Ontario through the Niagara River and Welland Canal at a rate of 212,000 cfs.

LAKE ONTARIO

The smallest of the Great Lakes, Lake Ontario borders New York and Ontario. Lake Ontario contains 393 cubic miles of water and covers 7,340 square miles. Lake Ontario has a drainage basin of almost 25,000 square miles. Forty-nine percent of the basin is forested, 39% is used for agriculture, 7% is urbanized or industrialized land, and the remaining 5% is used for other purposes. Lake Ontario suffers from agricultural runoff and pollution. One of the greatest stresses on the Lake is the regulation of water levels through mechanisms comprising the St. Lawrence Seaway.

Like Lake Erie, the majority of water entering Lake Ontario is from the upper lakes – about 85% of the average annual amount. Some 9% of the new water entering Lake Ontario is from groundwater carried to the lake in tributaries. Five percent is surface run off carried in tributaries. The net contribution of precipitation accounts for nearly 2%. On an average basis, approximately 251,000 cfs (or 162 billion gallons per day) leaves Lake Ontario via the St. Lawrence River.

Other Hydrological Issues

Because of the size of the system, it responds somewhat slowly to environmental changes. Each lake has a large total volume relative to the amount of water entering and leaving. For example, using simplifying engineering assumptions, it has been calculated that a single drop of water deposited in Lake Superior on average takes 190 years to leave through the St. Mary's River.[8] This relatively prolonged hydrologic process means that the Great Lakes can require a significant amount of time to process changes in chemical water quality.[9] In addition, the large surface area of the lakes, covering 94,000 square miles, makes the lakes vulnerable to direct atmospheric pollutants that fall with rain or snow and as dust on the lake surface.

The system is also somewhat slow in responding to hydraulic changes. It has been estimated that up to 15 years is required for certain changes in the water inputs to the upper lakes to be fully felt in the lower lakes.[10] Nevertheless, changes in the long-term average flows and levels of the Great Lakes are somewhat predictable based on current knowledge and tools. Flows in the channels that connect the lakes and the levels of the lakes themselves are of critical importance to various users of the lakes, most notably the hydroelectric power industry and navigation interests.

[8] Lake Superior has a 191-year average retention time. Lake Michigan has a 99-year average retention time. Lake Huron has a 22-year retention time. Lake Erie has a 2.6-year retention time. Lake Ontario has a 6-year retention time. Botts and Krushelnicki, *Ibid*.

[9] As a result, pollutants that enter the Lakes are retained in the system and become more concentrated over time. Pollutants also remain in the system because of re-suspension, the mixing back into the water of sediment, and cycling through biological food chains.

[10] International Joint Commission Levels Reference Study Board. Submitted to the IJC 1993. *Levels reference study–Great Lakes-St. Lawrence river basin.* IBSN 1-895985-43-8.

Each lake has a large total volume relative to the amount of water entering and leaving. For example, using simplifying engineering assumptions, it has been calculated that a single drop of water deposited in Lake Superior on average takes 190 years to leave through the St. Mary's River.

THE RELATIONSHIP OF HUMAN POPULATIONS TO THE GREAT LAKES

The integrity of a freshwater ecosystem such as the Great Lakes is dependent upon the condition of its physical, chemical and biological components. Human populations can have both direct and indirect impacts on these components through resource consumption; residential, commercial, agricultural and silvicultural development; and the production and disposal of waste products.

Physical Integrity – What Have We Altered?

The physical integrity of the Great Lakes ecosystem is driven by the movement of water across and through the land, in streams and rivers, and in the lakes themselves. While it too is a critical process, the vertical movement of water in the open lakes, and the thermal stratification that limits mixing during the summer months, are beyond the scope of this paper. Suffice it to say that human population pressure has not widely altered the seasonal stratification of the open lakes, nor limited the mixing of the layers when stratification breaks down in the fall. Population pressure and resource consumption can, however, be linked to significant alterations in how water, energy, and materials have historically moved through the basin. Just recently we have begun to recognize the ecological consequences of the hydrological alterations brought about by water uses, diversions, and physical modifications to the land and waters of the Great Lakes.

Current Water Uses

No single, accurate, comprehensive database has been complied on the uses of Great Lakes basin waters. Progress is being made to create a data repository that satisfies the commitment to develop and maintain a "common base of data and information regarding the use and management of basin water resources..." contained in the Great Lakes Charter. In 1995, the annual report of the Great Lakes Regional Water Use Data Base Repository was made available, summarizing water use information that was available for the 1992 calendar year.[11] At that time, the states of Michigan and Pennsylvania supplied their best estimates for several use categories.

The largest single use of water in the basin is for the generation of hydroelectric power. The Great Lakes Commission reports that, in 1992, 908.7 billion gallons per day were used to generate hydroelectric power.[12] This represents over 94% of the total water reported to have been used in the basin. Neither the total use figure of 965.2 billion gallons per day nor the amount attributed to hydropower use includes the water used for hydroelectric generation in the state of Michigan. The USGS estimates that in 1990, 110 billion gallons per day were used in the state of Michigan to generate hydroelectric power.[13] The actual use by hydroelectric operation of basin waters likely exceeds one trillion gallons per day.

The largest single use of water in the basin is for the generation of hydroelectric power. The Great Lakes Commission reports that, in 1992, 908.7 billion gallons per day were used to generate hydroelectric power. This represents over 94% of the total water reported to have been used in the basin...The second largest use of Great Lakes water is to supply cooling water to the thermoelectric power industry...The remaining 2% of water used in the basin is divided among all other uses – industrial supply, public supply, domestic use where public supplies are not available, irrigation, livestock, and navigation.

[11] Great Lakes Commission. June 1995. *Annual Report of the Great Lakes Regional Water Use Data Base Repository.* Prepared for the Water Resources Management Committee of the Council of Great Lakes Governors.

[12] Great Lakes Commission. 1995. *Ibid.*

[13] USGS. 1993. Estimated Use of Water in the United States in 1990. *USGS Circular* 1081.

The dominant ecological impact of hydroelectric operations is altered system hydrology. These hydrologic changes include increased peak flows downstream of operations, diminished flows downstream and near power houses, increased rates of change between flow stages, and altered timing and frequency of flow events both upstream and downstream of these operations. In addition to changes in the movement of water, dams and their reservoirs alter how materials move from headwaters areas to the open lake. These materials include inorganic matter like clays, sands, cobbles and other sediment, organic matter like woody debris, and living organisms such as fish. In some cases, the interruption of sediment movement has caused the loss of beaches.[14] In the Great Lakes, the inability of fish to reach tributary spawning habitat has a significant impact on the health of open water fisheries.[15]

The second largest use of Great Lakes water is to supply cooling water to the thermoelectric power industry. The Great Lakes Commission estimates that 40 billion gallons per day are used to cool reactors and condensers used in the generation of electric power. This represents roughly 4% of the total use reported by the Commission for calendar year 1992.

Potential ecological effects from this use of water are largely attributable to the near field alteration of thermal regimes due to increased temperature and the possible release of trace contaminants used as cooling water additives. In terms of hydrological alteration, the cumulative effects of losses in wet cooling towers may merit attention. In compiling data for the 1992 use report, the ten jurisdictions each estimated the losses of cooling water to predict consumptive uses. The estimates ranged from "negligible" to 14% of water used.

The remaining 2% of water used in the basin is divided among all other uses – industrial supply, public supply, domestic use where public supplies are not available, irrigation, livestock, and navigation. The majority of the water is used for cooling industrial operations.

Even though the total volume of water use in these remaining categories is small, ecological impacts can be significant. For example, in the upper watershed, municipalities or industries often/can withdraw water from a stream, use it, and then return treated wastewater at a location significantly downstream. The intervening stretch of river or stream can be dewatered to some degree, affecting the viability of local and perhaps regional fisheries. Similarly, if withdrawals are made from ground water, and the water is returned directly to surface streams, the ecological integrity of the watershed can be degraded because of reduced base flows in the streams. Such streams can be dry in the summer, and subject to erosion in wet weather and sedimentation during lower flow periods.

The cumulative impact of extensive ecological degradation of the basin's headwater streams will be a more fragile open lake system that requires intervention to maintain a healthy fishery and adequate water quality.

[14] A good example is the Elwha Dam complex in Washington State. See the summary of environmental impact statement in *Smithsonian Magazine*, November 1998.

[15] Michigan Office of the Great Lakes. 1997. *State of the Great Lakes Annual Report.*

The dominant ecological impact of hydroelectric operations is altered system hydrology...The cumulative impact of extensive ecological degradation of the basin's headwater streams will be a more fragile open lake system that requires intervention to maintain a healthy fishery and adequate water quality.

Existing Diversions

Presently, more water is diverted into the Great Lakes basin than is diverted out. No systematic evaluation of the ecological impacts of these diversions exists. Some of the hydraulic changes are understood, however. The net impacts of diversions, regulation structures, and channel dredging result in an estimated increase in the level of Lake Superior by four inches, a lowering of the level of Lakes Huron and Michigan by just over a foot, an increase in the level of Lake Erie by just over an inch and a decrease in the level of Lake Ontario by about two and a half inches.[16]

Although separate diversions, both the Long Lac and Ogaki diversions add water from James Bay in Canada to Lake Superior at varying rates between 2,500 to 8,000 cfs. These diversions are used to generate hydroelectric power and to transport pulpwood logs southward. The diversions have significant local environmental effects on fish habitat.

The Lake Michigan Diversion at Chicago diverts on average 3,200 cfs of Lake Michigan water to the Illinois River, which drains into the Mississippi River. The diversion consists of three components: (1) water supply withdrawn for domestic and industrial uses and then discharged into the Illinois River as treated sewage; (2) runoff that once drained to Lake Michigan but is now diverted to the Illinois River; and, (3) water diverted directly into the Illinois River and canal system for navigation purposes, connecting the Mississippi River to Lake Michigan.

The Welland Canal diverts water from Lake Erie to Lake Ontario for deep draft navigation and hydroelectric power generation, bypassing the Niagara River and Falls. The diversion also supplies water for industrial and municipal use, including sewage dilution. During the navigation season 9,050 cfs is diverted through Welland Canal. 7,950 cfs is diverted at other times. The diversion has lowered the level of Lake Erie by (less than) approximately six inches and dropped the levels in Lake Michigan and Lake Superior by about two inches and one inch respectively. The Welland Canal has resulted in the virtual disappearance of indigenous lake trout stocks by creating an entry point into the upper lakes for the sea lamprey.

The New York State Barge Canal system connects the Hudson River to Lake Ontario by diverting water from the Niagara River into Lake Ontario via a route that connects with the Erie Canal, which connects to the Hudson River. The diversion takes between 700 and 1,100 cfs primarily for navigation purposes.

[16] IJC Levels Reference Study, 1993, *Ibid.*

Presently, more water is diverted into the Great Lakes basin than is diverted out. No systematic evaluation of the ecological impacts of these diversions exists.

Ecological Consequences of Physical Alteration

The Great Lakes, their connecting channels, and the lands they drain are part of a single, connected, ecological system. The major source of new water entering this system not only comes from the land, but moves through the land. Alterations in timing and amount of water supplied to the lakes not only impact downstream interests that desire to use the system's water for economic purposes, but impact water dependent natural resources near to those alterations, and distant from them in space and time.

New scientific information tells us that all hydrological alterations of aquatic systems have ecological consequences. While these consequences depend on the exact nature of the specific alteration, they have more to do with how the water is used, where in the system it is used, and when water is used, than how many gallons of water are used. A relatively small volume of water permanently removed from a sensitive habitat may have grave ecological consequences. Similarly, the rapid addition of water to a stream reach during spawning season can eliminate a source of young fish for an important fishery.

Recent scientific investigations have identified that the biotic composition, structure, and function of aquatic wetland and riparian systems depend largely on the hydrologic regime.[17] The hydrologic regime includes not only the absolute quantity of water at a given time, but also the frequency with which certain flows occur over a given time interval, the rate at which flow conditions change, the duration of various flow conditions, and the range of flows on a given system.[18] The biologically important time intervals for these variables can be as short as an hour and as long as several years. All of these conditions describe the ability of a given aquatic system to move materials and to support species and natural communities that have evolved in response. Moreover, these conditions control critical biological events including the ability of exotic species to establish themselves; dispersal of native species; cues for spawning, hatching and migration of native species; and changes to food webs and encroachment of vegetation.

In addition to the waters of the Great Lakes basin themselves, the exhaustible natural resources that are threatened by future water development projects are those that depend on the basin's waters in one way or another. They include the natural communities of the open lakes – phytoplankton, zooplankton, planktivorous fish, piscivorous fish and avian predators; natural communities on the coasts – wetlands, dunes, beaches, and shorelines; the plants, animals and natural communities of the rivers and streams tributary to the Great Lakes – species of fish, insects, plants, herps and mammals; riparian wetlands; embayment lakes; riparian plant communities; and upland pond and wetland communities fed by ground water. These natural resources are sustained not only by the waters of the Great Lakes basin but also by the movement of energy, materials, and biota in those waters.

Similarly, dams and other structures can also change the hydrology, and ultimately the ecology, of the basin. Depending on how they are operated, dams can dramatically alter the hydrologic regime. The magnitude, duration, frequency, timing, and rate of change of flow events can all be changed. For example, a hydroelectric dam designed to provide on demand peak power can almost instantly increase the flow in a river system from no flow to several times the historic annual maximum flow. Conceivably, this could happen on a daily basis. Further, such a facility can effectively "bury" historic spawning habitat beneath its reservoir. Demonstrated impacts of such operations include the loss of a self-sustaining fishery, loss of beaches due to sediment starvation, and fragmentation of aquatic habitat.

[17] See for example: Gorman, G.T. and J.R. Karr. 1978. Habitat structure and stream fish communities. *Ecology* 59:507. Junk, W.J., P.B. Bayley, and R.E.Sparks. 1989. The flood pulse concept in river-floodplain ecosystems. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106. Poff, N.L. and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences* 46. Mitsch W.J. and J.G. Gosselink. 1993. Wetlands. Van Nostrand Reinhold. National Research Council. 1992. *Restoration of aquatic ecosystems: science, technology and public policy.* National Academy Press. Sparks R.E. 1992. *Risks of altering the hydrologic regime of large rivers.* In, Cairns J., Neiderlejner B.R., Ovrvos D.R., eds. *Predicting ecosystem risk*. Vol. XX. Princeton Scientific Co. Noss R.F. and A.Y. Cooperrider. 1994. *Saving nature's legacy: protecting and restoring biodiversity.* Island Press. Richter B.D., J.V. Baumgartner, J. Powell and D.P. Braun. 1995. A method for assessing hydrologic alteration within ecosystem. *Conservation Biology* 10:1163. Poff N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. *BioScience* 10:11.

[18] Poff *et al. Ibid.*

When the hydrologic regime of open lake waters is altered through diversions, changes in outflows or other alterations in water supply, levels can change and the ability of the lake to support coastal wetlands can be diminished. For example, the International Joint Commission's Levels Study Board concluded that regulation of Lake Ontario's outflow has stabilized lake levels and caused "significant adverse damage" to coastal wetlands in the lake, and other adverse impacts on flood plain forest downstream. These impacts are strongly associated with changes in the frequency, timing, and duration of the periodic inundation that coastal wetlands require to maintain ecological integrity, rather than changes in long-term average levels or flows.

Chemical Integrity – What Have We Added?

Generally, two classes of chemicals are considered when evaluating the integrity of a freshwater resource: nutrients and toxics. Nutrients can be generally described as those compounds needed to support plant life. Toxics, on the other hand, are poisons that impair the ability of a system to support life. The Great Lakes have suffered problems from both types of chemicals.

In the late 1960s, Lake Erie was widely acclaimed to be "dead." Actually Lake Erie was far too alive, choking on nutrients. In fresh water systems, the ability of phytoplankton, small plants at the base of the food chain, to grow, is limited by the availability of phosphorous compounds. Add phosphorous and you get more phytoplankton. Because Lake Erie is relatively small, and highly urbanized, it was susceptible to nutrient enrichment. At the time, most sewage and industrial waste was poorly treated. Laundry detergents, which were ultimately released to basin waters through septic and sewer systems, also contained high levels of phosphorous. The high concentrations of nutrients caused large growth of algae. As the algae died, it decomposed in the water column and in the sediments removing oxygen from the lake. The loss of oxygen killed fish, and left foul smelling water, even after it was treated for drinking.[19]

The high concentrations of nutrients caused large growth of algae. As the algae died, it decomposed in the water column and in the sediments removing oxygen from the lake. The loss of oxygen killed fish, and left foul smelling water, even after it was treated for drinking...In the late 1960s, Lake Erie was widely acclaimed to be "dead." Actually Lake Erie was far too alive, choking on nutrients.

Such enrichment, called cultural eutrophication, was once common in the Great Lakes. While Lake Erie was the worst case, both Lakes Michigan and Ontario suffered from increased nutrient loading and were showing signs of eutrophication. Throughout the basin, river mouths and bays, including Green Bay, Saginaw Bay, the St. Louis River Estuary, the Muskegon River, the Bay of Quinte, and Hamilton harbor among others, were eutrophic because of the release of sewage and industrial waste.

Today, these problems are largely under control. Laws have been passed limiting the amount of phosphorous in detergents. Industries and cities have typically installed waste treatment systems. Where enrichment problems now exist they are largely localized and contained thanks to the efforts of the basin's citizens, governments, and industry.

In contrast to managing nutrients, where efforts could focus on a single element like phosphorous, managing the impacts of toxics must focus on a large list of chemicals. Toxic substances are those known to have an adverse

[19] Beeton, A.M. 1971. The Phenomenon of Lake Eutrophication. *Water Resources Engineering Educational Series – Freshwater Lakes and Their Management*, University of California.

impact on the living components of the ecosystem, that is, any substance which can cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological or reproductive maladies or physical deformities in one organism or its offspring, or which can become poisonous after concentration in the foodchain or in combination with other sources.[20] Such compounds include heavy metals (copper, nickel, lead, chromium, cadmium, and mercury for example) and complex, usually man-made organic compounds (polychlorinated biphenyls or PCBs, pesticides, herbicides, polynuclear aromatic hydrocarbons, and tetrachloro-dibenzo dioxins (TCDDs)). Toxic compounds come from a variety of human activities and reach the lakes through a variety of pathways, including effluent discharges to streams, rivers and lakes, deposition from the atmosphere, or via groundwater contaminated by leaking landfills. Once these compounds reach the lakes, they are often sequestered in sediments and released over time into the water column.

Toxic compounds come from a variety of human activities and reach the lakes through a variety of pathways, including effluent discharges to streams, rivers and lakes, deposition from the atmosphere, or via groundwater contaminated by leaking landfills. Once these compounds reach the lakes, they are often sequestered in sediments and released over time into the water column.

The widespread presence of toxic substances found in the Great Lakes in the 1960s and 1970s was primarily the result of the increased commercial production and widespread use of organic chemicals and metals that started during World War II and accelerated afterward. Environmental records assembled from radio-chemically dated sediment cores from Lake Ontario revealed the presence of several organic chemicals starting as early as 1915, but sharply increasing in the late 1940s and reaching peak levels in the early 1960s.[21] The IJC has verified that some 362 chemicals were present in the Great Lakes. One third of these may have toxic effects.[22]

Several types of toxic effect are associated with chemical contaminants in the Great Lakes. The easiest to understand is lethality. Some compounds, at a sufficient concentration, are lethal to aquatic life. Several heavy metals, for example, kill fish by destroying the ability of the gills to extract oxygen from water. Effluents from certain industrial processes, such as electroplating, once contained a sufficiently high level of dissolved heavy metals to be lethal to aquatic organisms. All such discharges are now illegal on the U.S. side of the basin.

A variety of sub-lethal effects are also associated with toxic compounds. At very low levels, some heavy metals can interfere with kidney function, the ability of fish to locate prey, and can make organisms more susceptible to disease. Some organic compounds have similar effects.

Carcinogenesis – the induction of cancer or tumors – is another consequence of toxic exposure. Numerous fish collected from areas contaminated with organic pollutants have lesions and tumors.

Perhaps the most insidious consequences of chemical contamination are those that pass from generation to generation *in utero*, or through the food chain from prey to predator. Teratogenic compounds are those that interfere with the development of young. They can cause birth defects such as crossed bills in birds, development of extra limbs in amphibians, or developmental impairments in humans. Chemicals can also bioconcentrate or biomagnify through the food chain. In the Great Lakes, minute concentrations of PCBs in

[20] GLWQA, 1987

[21] Beeton, A.M., C.E. Sellinger and D.F. Reid. 1999. *An Introduction to the Laurentian Great Lakes Ecosystem*. In Taylor, W.W. and C.P. Ferreri eds. Great Lakes Fisheries Policy and Management – A Binational Perspective. Michigan State University Press, East Lansing Michigan.

[22] Beeton *et al.*, 1999 *Ibid*.

Some compounds, at a sufficient concentration, are lethal to aquatic life. Several heavy metals, for example, kill fish by destroying the ability of the gills to extract oxygen from water.

Perhaps the most insidious consequences of chemical contamination are those that pass from generation to generation in utero*, or through the food chain from prey to predator. Teratogenic compounds are those that interfere with the development of young.*

the water column will concentrate some hundred fold in phytoplankton, thousands fold in zooplankters and planktivorous fish, hundreds of thousands fold in piscivorous fish, and up to six million fold herring gulls.[23]

Because some chemicals both biomagnify and possess carcinogenic, mutagenic and/or teratogenic properties, threats to the top of the food chain often drive clean up efforts. Humans who consume Great Lakes fish can be at elevated risk levels. So can fish-eating birds, such as bald eagles, gulls and terns. Fish-eating mammals, including mink, fishers, and otters can also be at risk.

Great progress has been made in reducing the input of toxic chemicals to the Great Lakes, and the levels of toxic chemicals in Great Lakes biota. In fact, the populations of fish-eating birds have expanded greatly since the early 1980s. Since their use and or manufacture has been banned, levels of PCBs, dioxins, pesticides, and herbicides have dramatically declined. Other substances have been addressed in controls adopted in statutes in place in the U.S. and Canada, most notably the U.S. Clean Water Act and control orders issued by the Province of Ontario.

Significant contamination remains. Because chemicals can be sequestered in sediments, a reservoir of contamination resides at the bottom of most Great Lakes harbors. Of 43 areas of concern identified by the U.S. and Canada, all had contaminated sediments and only one has been cleaned up sufficiently to be removed from the list.

Of particular concern are chemicals such as mercury, whose levels have increased in the environment, and those such as DDT/DDE, whose concentrations have stopped declining.

Atmospheric transport of chemicals into the Great Lakes basin is an increasingly significant input. Transport by air masses and deposition by precipitation is believed to be a significant source of lead, arsenic, cadmium, polynuclear aromatic hydrocarbons, Lindane, Chlordane, DDT/DDE, Dieldrin, toxaphene, and PCBs entering the Great lakes watershed.[24] Some of the compounds, such as DDT/DDE and Lindane, whose use is banned in both the U.S. and Canada, are believed to be carried in air masses from sources as far away as China, India, the former Soviet Union, and Central America.[25]

Biological Integrity – What is the Condition of the Living Part of the Ecosystem?
The basin ecosystem can be thought of as having seven biological compartments – the open lakes, the coastal shores, coastal wetlands, the lakeplains, tributary streams and rivers, the upland terrestrial communities and upland wetland communities. All are linked to one another, although the strength and importance of the relationships vary. For our purposes – evaluating the biological consequences of human population pressure on freshwater ecosystems – the biological condition of the open lake and tributaries is where we will focus. Closely associated are biological effects in both the coastal and inland wetland systems, as are changes in the abiotic features of the coastal shore and upland terrestrial communities.

[23] Colburn, T.F., A. Davidson, S.N. Green, R.A.Hodge, C.I. Jackson, and R.A. Liroff. 1990. Great Lakes, Great Legacy? The Conservation Foundation and the Institute for Research on Public Policy, Washington D.C. and Ottawa, Ontario.

[24] Keeler, G., J. Pacyna, T. Biddleman and J. Nriagu. 1993. Identification of Sources Contributing to the Contamination of Great Waters by Toxic Compounds. Submitted to USEPA.

[25] Beeton *et al. Ibid.*

Since their use and or manufacture has been banned, levels of PCBs, dioxins, pesticides, and herbicides have dramatically declined. Other substances have been addressed in controls adopted in statutes in place in the U.S. and Canada, most notably the U.S. Clean Water Act and control orders issued by the Province of Ontario.

Some of the compounds, such as DDT/DDE and Lindane, whose use is banned in both the U.S. and Canada, are believed to be carried in air masses from sources as far away as China, India, the former Soviet Union, and Central America.

The biological condition of the ecosystem has been significantly degraded. Some 145 non-native species have established themselves as permanent residents, often with disastrous consequences for the native species that they compete with or prey upon.[26] Some of the more notorious invading species include the sea lamprey, carp, the Eurasian ruffe, alewife, and the zebra mussel.[27]

The Open Lakes

The open lake biological community organizes itself around who eats whom. The base of the food chain begins with the phytoplankton, the small plant life discussed earlier. The phytoplankton convert sunlight and carbon dioxide into organic matter that serves as food. This food is consumed, for the purposes of our discussion, by zooplankton, tiny animals that graze on algae. The zooplankton, in turn, are eaten by small fish – planktivores. Larger fish, the piscovores, eat the small fish. The larger fish are eaten by birds, by mammals (including humans) or by "decomposers," the garbage collectors of the natural world. Viewed simply, decomposers are the bacteria that turn dead fish and plankton back into nutrients, consuming oxygen in the process.

While the above relationships still exist in the open lakes, the organisms responsible for doing the eating have changed dramatically in the last 100 years. Candidly, very little is known about the species composition of the phytoplankton community in the Great Lakes. While species previously not known to be in the lakes are routinely encountered, it is not known whether these are new introductions or simply new identifications. A bit more is known about the zooplankton. Some key zooplankton appear to be disappearing. Dioporia, a shrimp-like animal that is a preferred prey item by many Great Lakes fish has drastically declined in recent surveys in Lake Michigan. Non-native zooplankton are increasing in the system.

The fish community has been altered by the accidental and intentional introduction of non-native species. Let's use the members of the historic and present Lake Michigan food chain as an example. Historically, the planktivores included the lake herring and several species of deep-water ciscoes. Today, accidentally introduced species – alewife and rainbow smelt – fill their functional niche.[28] The alewife is now believed to constitute most of the biomass in lake Michigan. The alewife was introduced to the lake when an impoundment being used to grow them as bait fish failed in a storm and washed its contents into the lake. The alewife succeeded because it has the ability to out feed the native species. Alewifes and smelt are prey for intentionally introduced pacific salmon, which now replace the native lake trout as the top fish predator. The salmon are hatchery raised, and used to keep the alewife in check.

The same story, sometimes with different species names, is true for each lake in the basin.

[26] Great Lakes panel on Aquatic Nuisance Species, Personal Communication, 2000.

[27] Abell, R.A., D.M. Olson, E. Dinerstien, P.T. Hurley, J.T. Diggs, W. Eichbaum, S. Walters, W. Wettengel, T. Allnutt, C. Loucks, and P. Hedao. 2000. *Freshwater Ecoregions of North America–A Conservation Assessment.* Island Press, Covelo, California.

[28] Eshenroder and Burnam-Curtis. 1999. In W.W. Taylor and C.P. Ferreri eds., *Great Lakes Fisheries Policy and Management – A Binational Perspective.* Michigan State University Press, East Lansing Michigan.

The alewife is now believed to constitute most of the biomass in lake Michigan. The alewife was introduced to the lake when an impoundment being used to grow them as bait fish failed in a storm and washed its contents into the lake.

Tributaries and Connecting Channels

While it was not the case prior to European development of the waterways, most Great Lakes tributaries are largely separated from the open waters of the lakes biologically by dams and other structures. Historically, many fishes used tributaries as spawning and nursery habitat. Some 73% of common Great Lakes fish use river habitats for spawning.[29] Today, the tributaries are often managed as fishery resources largely separate from the lakes they once served.

Several Great Lakes tributaries once supported a diverse unionid mussel fauna. The St. Clair-Detroit River system was once home to 39 species, one of the most diverse mussel populations on the planet. Because of channel modification, pollution, and the invasion of the zebra mussel, those populations were largely gone by 1992.[30] Several relict populations remain, however. Fish Creek, in northeast Indiana, holds the only known population of the White Cat's Paw Pearly Mussel.

Other Biological Features

In spite of massive land conversion, pollution, and exotic species invasion, the Great Lakes basin contains a wealth of unique biological features. The Nature Conservancy, using state agency data, identified occurrences of some 131 globally rare species and natural community types in the basin.[31] Sixty-one of these have the global distribution limited to or predominantly within the basin. The vast majority of these globally significant features are supported by the basin's hydrologic regime.

ANALYZING THE CASE: DEGRADING AND RESTORING THE GREAT LAKES ECOSYSTEM

When viewed in hindsight, through the lens of 21st century environmental science, it is evident that we conducted three simultaneous, large-scale, uncontrolled experiments with the ecosystem. First, we altered its plumbing by reshaping the land and rivers. Second, we altered its chemistry by introducing nutrients and poisons. Last, we fundamentally altered its biological composition by introducing – sometimes knowingly, but usually not – non-native species. These alterations were synergistic – reinforcing one another – and led to a collapse of the system's ability to self organize and regulate itself.

These changes, and how we managed to do them, can be illustrated through a different (and equally highly simplified) telling of the case summarized at the beginning of this paper.

The clearing of the Great Lake's forests at the end of the 19th century made possible the fishery and water quality collapses of the mid-20th. By altering how water moved across the land, and physical conditions of the tributaries that drained the basin, the harvest of trees not only fueled the westward expansion of the basin's two countries, but prepared habitat for the most destructive invasive species the basin has yet encountered – the sea lamprey.

[29] Hayes. 1999. In W.W. Taylor and C.P. Ferreri eds., *Great Lakes Fisheries Policy and Management–A Binational Perspective.* Michigan State University Press, East Lansing Michigan.

[30] Edsall, T. 1998. Regional trends of biological resources-the Great Lakes, in status and trends of the nation's biological resources. vol. 1, U.S. Department of the Interior.

[31] Rankin and Crispin, IBID.

. . . it is evident that we conducted three simultaneous, large-scale, uncontrolled experiments with the ecosystem. First, we altered its plumbing by reshaping the land and rivers. Second, we altered its chemistry by introducing nutrients and poisons. Last, we fundamentally altered its biological composition by introducing – sometimes knowingly, but usually not – non-native species.

It is unclear if the sea lamprey was native to Lake Ontario or not. But the canals that connected the upper lakes to Lake Ontario, and Lake Ontario to the Hudson, made it possible for the lamprey to enter all of the Great Lakes. Lampreys are eel-like fishes that spend most of their long life cycle in the sediments of the streams in which they spawn. They spend their eighteen month parasitic phase patrolling open lake waters attaching themselves like giant leeches to the sides of large fishes and sucking them dry.

The tributaries that had transported logs and were subject to scouring during rain events were transformed into nearly ideal lamprey habitat. As they moved into their new homes after the logging was completed, they went largely unnoticed because of their small numbers and relatively long life cycle. But with abundant food, and no natural competition, they bred unchecked. Within two or three lamprey generations, the population of piscivorous fish started to decline dramatically.

With the fish-eating fish on the decline, there was no natural control for the planktivores – the fish that eat zooplankton. Their populations exploded. The faster one species could eat, the more that species could out-compete rivals. The introduced alewife, with its ability to use three feeding methods, not only grew its population, but also out-competed the native herring and ciscoes. And the population of zooplankton collapsed.

The introduced alewife, with its ability to use three feeding methods, not only grew its population, but also out-competed the native herring and ciscoes... the population of zooplankton collapsed.

With no zooplankton to eat them, there was no natural control for the populations of phytoplankton in the lakes. At the same time, we humans – who until now had little reason to treat our sanitary or industrial waste – were fertilizing the rivers and lakes with nutrients. With all the nutrients they could consume and few natural predators, phytoplankton populations exploded – causing the now infamous death of Lake Erie, robbing Lake Michigan of oxygen, thereby killing millions of alewifes near Chicago, and strangling Green Bay.

All of our actions were based in almost perfect ignorance of the ecological systems around us. As a people, we were acting without understanding that the Great Lakes were an ecological system, and we did so at our own peril.

None of this was done with malice and forethought. The men who spent winters in lumber camps did not set out to cause the collapse of the Great Lakes fishery. The commercial fishermen who stacked lake sturgeon like cordwood did not intend to drive the species close to extinction. The steel industry greatly expanded its operations in the basin to win the Second World War, not poison the lakes. Cities built sewers to protect their populations, not to over-enrich Lake Erie.

Yet the results were clear, even if the causes were multiple. No one cause – deforestation, industry, domestic sewage, or biological pollution – could account for the magnitude and scope of the environmental damage visited on the Great Lakes. Each sector could effectively argue that its actions could not possibly account for the problems. In fact, each sector could correctly argue that its share of the damage was but a minor fraction of the total problem.

All of our actions were based in almost perfect ignorance of the ecological systems around us. As a people, we were acting without understanding that the Great Lakes were an ecological system, and we did so at our own peril. As with any system, it will respond to inputs. However, as an ecological system that includes hundred of thousands of miles of lake surface area, it is slow to respond. Responses that are not immediate in time, or that are not near in space, go unappreciated and under valued by humans. Responses of ecological systems are frequently distant in time and space from the driving stimulus.

Different human populations interacted to the detriment of the ecosystem. First, the logging boom of the late 1800s was driven by the expansion of two countries. It wasn't that logging was the problem, per se. Rather, it was the method by which it was done, and the rate at which it occurred that was the problem. Fundamentally, the fact that it altered the basin's physical integrity, especially the hydrologic regime, is what matters most. But this change would have been far less important, if another group of individuals had not been busy unintentionally introducing non-native species by digging canals and increasing ship traffic. These two factors destabilized the system to such an extent that when a third population fertilized the Great Lakes nearly one hundred years later by adding untreated waste, the system virtually collapsed ecologically.

It wasn't that logging was the problem, per se. Rather, it was the method by which it was done, and the rate at which it occurred that was the problem. Fundamentally, the fact that it altered the basin's physical integrity, especially the hydrologic regime, is what matters most.

Initial Progress in Addressing Human-Induced Alterations

To address the state of the Great Lakes, an unprecedented response was mustered. In the 1960s, led by government agencies who largely lacked a clear statutory mandate, a coordinated resource and waste management strategy was launched. It was a "top-down, bottom-up" strategy driven by a scientific understanding of how the lakes operated as a system. The "top" and "bottom" in the strategy have not-so-much to do with people – they do not describe federal officials and local citizens – they describe the top and bottom of the food chain in the open lakes.

The "top-down" strategy was a two-part effort to restore top predators to the lakes. The lake trout population had been virtually wiped out by the sea lamprey. To restore its functional role in the system, it was decided to introduce pacific salmon. These fish could be raised in hatcheries and, once released into the lakes, could restore grazing pressure on the alewife. The second part of the strategy was to control sea lamprey populations. Spawning streams were chemically treated to kill lampreys. New physical barriers, called lamprey weirs, were installed in streams that had spawning habitat.

The "top-down" strategy had immediate pay-off. Government could and did act directly. Hatcheries began to produce salmon fry and release them to the lakes. This was a war of production, and the government had the means.

The "bottom-up" strategy was a bit more difficult to implement. The essence of the bottom-up approach was to tackle the base of the food chain by reducing the input of nutrient chemicals. Finding sources to control was no problem. Virtually no municipalities provided biological sewage treatment. Similarly, most industries provided virtually no treatment of their wastes. But there was little agreement on exactly which nutrients were the problem, which sources should install controls, what performance levels were required, and who was to pay for the treatment equipment. Further, there was no legal requirement to do anything.

Virtually no municipalities provided biological sewage treatment. Similarly, most industries provided virtually no treatment of their wastes. But there was little agreement on exactly which nutrients were the problem, which sources should install controls, what performance levels were required, and who was to pay for the treatment equipment. Further, there was no legal requirement to do anything.

Nevertheless, progress was made. By the early 1970s, it became clear that phosphorous was the chemical of concern, performance targets were identified, the federal governments on both sides of the basin committed to action, and the U.S. passed the Clean Water Act, creating legal obligations and funding programs to share the cost.

As the nutrients were cleaned up, and the system began to return to its normal trophic condition, attention was turned to the toxic pollutants whose effects had been masked by eutrophication. Most of the effects were subtle, non-lethal impacts, but disturbing nonetheless. Gulls and other water birds were born with crossed bills. Fish had tumors, lesions, and eroded fins.

The control of toxics was complicated by some of the same factors that made controlling nutrients difficult: which compounds to control was unclear, acceptable levels (if any) were not known, and how these compounds interacted in the environment was not known. What did exist in the U.S. portion of the basin was a set of statutes that could drive the elimination of these materials from water, air, and land sources. By nearly any measure, the amount of toxic chemicals released into the basin and their effects in the environment have been greatly reduced.

Future Needs and Opportunities to Restore Ecosystem Health

The overarching challenge facing the Great Lakes ecosystem is to create governance systems that support its recovery. The behaviors to be governed are different than those we have had success with in the basin. Government programs and private initiatives have slowed, and in some cases eliminated, near-field pollution. Government programs have successfully kept the fishery on life support. But these are reactions to threats, not actions to restore the ecosystem. Reactive government programs ossify. They are suited to "rifle shot" responses to clear and temporary problems. Restoration governance needs to support action in three areas, outlined below.

The overarching challenge facing the Great Lakes ecosystem is to create governance systems that support its recovery. The behaviors to be governed are different than those we have had success with in the basin.

Restoring Natural Flows

First, the best restoration opportunity within the basin is to restore natural flow regimes to tributaries and coastal areas of the lakes. As discussed earlier, the tributaries need to re-connect to the open lakes, and also to the lands they drain. So-called non-point source pollution is not pollution in the classic sense – materials added to water. It is more usefully described as a result of changed flow regimes. Water moves across the land, into and through streams more quickly after rain events in altered landscapes. The high energy of moving water moves sediments more quickly and farther than it would if the landscape had not been altered. But the sediments being moved are not typically new materials – they are existing bed load being displaced in time and space. Bed load – in stream sediments – is not a pollutant. A pollution control framework will not succeed in restoring ecological health to these systems.

What is needed is a set of policies that value natural flows and support their restoration. To get there, we first need to encourage what I call "environmental hydrology," the science of the movement of water and its role in ecological processes. To my mind, this is no different than how "environmental chemistry" emerged in the late 1970s – when scientists began to focus on how chemicals behave in ecological systems and think differently about chemistry as a result. When hydrologists routinely think of water budgets in biologically relevant time frames – hours, days, weeks and months – in addition to typical annual water budgets, environmental hydrology will have arrived.

Environmental hydrology will need to guide how we use land and water. The removal of dams that no longer have a useful purpose is one tangible step. The re-operation of hydroelectric facilities is another. Freeing waterways to use their floodplains is another flow restoration strategy. Agricultural areas can be tapped to increase the ability of their lands to recharge aquifers and slow the runoff of rain and snowmelt to surface waters. New residential and commercial construction needs to be encouraged, and perhaps required, to improve existing flow regimes.

Perhaps most importantly, the world will hold us to our own standards of water use. The Great Lakes hold nearly one fifth of the world's supply of fresh water. As this becomes a scarce commodity throughout the world, increased pressure will be brought upon the basin to meet human needs, or market demand. International trade rules allow the governments of Canada and the U.S. to stop the sale of water only if it is done to conserve exhaustible natural resources and if the same rules apply to both domestic and international consumption. As it stands, water in the Great Lakes is presently free for the asking. If we are not able to export environmentally sensitive ways of using water and protecting supplies, we may be forced to export the water itself.

Perhaps most importantly, the world will hold us to our own standards of water use. The Great Lakes hold nearly one fifth of the world's supply of fresh water. As this becomes a scarce commodity throughout the world, increased pressure will be brought upon the basin to meet human needs, or market demand.

. . . Invasive species change the biological, and in some instances, the physical and chemical fabric of the ecosystem. Once established, they are virtually permanent features of the ecosystem.

Halting Biological Pollution

A second need for the Great Lakes is to halt the biological pollution of the ecosystem. This is a need that differs in two fundamental respects from the flow restoration opportunity described above. First, it is a need to stop an ongoing insult. Second, it must be addressed at a global scale. The organisms appearing in the Great Lakes, as well as other aquatic and marine ecosystems, are coming from places half way around the world.

Biological pollution is different in character from chemical pollution. The most persistent chemical pollutants in the basin are those materials that degrade slowly in the environment. They can become trapped in sediments and re-released over decades to the lakes. Invasive species, on the other hand, never degrade; they in fact expand their numbers and impact over time. They change the biological, and in some instances, the physical and chemical fabric of the ecosystem. Once established, they are virtually permanent features of the ecosystem.

The primary vector for non-native species to enter the Great Lakes is the ballast operations of commercial shipping. Ships carry ballast water to ride low in the water, increasing the ships fuel economy and operating safety. Organisms may be sucked into ballast tanks in foreign harbors and released in the basin as the ballast water is pumped out when cargo is taken on. Alternatively, some organisms may be trapped in the sediment in bottom of ballast tanks and released at some later date when those sediments are mixed with ballast taken on in the basin.

Another threat is also presented by ballast operations. In addition to fish, algae and invertebrates, ballast water can contain pathogenic micro-organisms that present a disease threat to humans and other animals. These pathogens are often the result of poor sanitation in the world's ports. Once added to a ballast tank, these organisms can greatly increase their numbers. Unlike most port cities in the U.S. and Canada, Great Lakes port cities typically use the lakes as drinking water sources. To protect the health of those who drink Great Lakes water, we have a vested interest in improving sanitation in port cities around the world.

The second most important vector for non-native species entering the Great Lakes is the series of breeches in the continental divide that separate the lakes for the Mississippi, Hudson Bay and Hudson River systems. These canal systems have been used by species as entry routes to the Great Lakes. Future public works project should look to restore the ecological separation of these systems, even if we maintain the ability to move goods in these canals. Clear operating standards should be developed to guide the present routine opening of the system to biological pollution.

Organisms may be sucked into ballast tanks in foreign harbors and released in the basin as the ballast water is pumped out when cargo is taken on.

Unlike most port cities in the U.S. and Canada, Great Lakes port cities typically use the lakes as drinking water sources.

Promoting Clean Development

The Great Lakes are linked to the rest of the planet not only by shipping routes but also by the atmosphere. The atmosphere is quickly becoming the most important pathway for chemical contaminants to enter the Great Lakes basin. Two sources deserve particular attention.

The atmosphere is quickly becoming the most important pathway for chemical contaminants to enter the Great Lakes basin.

First, the combustion products from coal-fired power plants present a threat to this system. Recently, utility companies in Minnesota and Wisconsin have made commitments to reduce the emissions of mercury. This is an important step. Requirements may yet need to be tightened using the authorities of the U.S. Clean Water Act and Clean Air Act. Similar controls may be required in Canada.

But these sources do not likely pose the greatest long or medium-term threat to the health of the Great Lakes. That threat comes from the desire of Asian peoples to enjoy a standard of living comparable to that enjoyed in North America in the late 1940s. The electrification of China, India, and rural parts of the former Soviet Union is just underway. If they chose the same technology that we did – massive coal burning power plants – the impact will be felt in the Great Lakes because of atmospheric patterns that deposit residues from that part of Asia in the Great Lakes region. Mercury, polynuclear aromatic hydrocarbons, and other toxic materials will concentrate in the lakes. The expansion of a commercial chemical industry will follow. Persistent, bioaccumulative toxics will also preferentially accumulate in the lakes and their resident biota. We need to promote a cleaner pathway of development than the one we chose. Distributed power, clean combustion, and efficient energy use are all exports that we can and should make.

The second source of concern is the expanding use of persistent, bioaccumulative pesticides in the developing world. DDT/DDE has been traced from the Great Lakes to use in the jungles of Central America. It is used to rid settlements of mosquitoes that spread malaria. A solution to a public health problem in one country is endangering subsistence anglers in another.

Again, these are problems of global scope. As we solve problems of local making in the Great Lakes basin, the lakes are increasingly affected by activities further away in space and time. The most important policy for the Great Lakes is likely to be foreign policy informed by ecosystem science, not domestic environmental policy. These are likely to take the form of aid, assistance and market-making policies, not regulatory policy.

As we solve problems of local making in the Great Lakes basin, the lakes are increasingly affected by activities further away in space and time. The most important policy for the Great Lakes is likely to be foreign policy informed by ecosystem science, not domestic environmental policy. These are likely to take the form of aid, assistance and market-making policies, not regulatory policy.

CONCLUSION

This case demonstrates three key inter-related principles. First, that large-scale action that manipulates freshwater ecosystems should not be undertaken without consideration of the ecological impacts of those actions. Every choice has consequences. Some are beneficial, serving to help restore degraded systems. Some are detrimental to the ecological health of the system, but may need to proceed for other reasons. Most choices have elements of both, causing some ecological disruption over some time horizon, but having some positive ecological consequences as well. To govern ourselves effectively, we must be aware of the full range of consequences our choices generate.

Second, ecological consequences are often distant in both space and time from the action(s) that cause them. This case shows how loggers at the end of one century can impact swimmers in the middle of the next. Yet, this lesson cuts two ways. First, it teaches us to be careful about actions that have negative impacts that may not appear immediately, but occur downstream affecting our neighbors or in the future affecting our children. It also reminds us that distant populations matter. The Great Lakes will suffer cumulative adverse impact from the actions of distant peoples. Second, and this is the under-appreciated good news, cumulative positive consequences will also lag the actions that produce them. Seemingly isolated good works, such as restoring wetlands or returning natural flow regimes to tributaries, will generate increasingly positive returns once there is a "critical mass" of such activity. Consciously choosing restorative alternatives – those that create ecological wealth, over sufficiently long time and space scales – will produce synergies that truly make the whole greater than the sum of the parts. This is the nature of systems. Both the distant positive and negative effects need to be considered in governance decisions.

Third, it is necessary to think expansively about the relationship of human populations to freshwater ecosystems. It is tempting, for example, to think of only those humans who live near a lake or river system as the human population that matters. However, ecological systems do not necessarily work that way. While a complete analysis is unlikely to not consider such local populations, those who live far away geographically, or have yet to be born, may be the stakeholders that matter most, and will drive governance action. It depends on what those human populations are doing. Freshwater ecosystems have many different human populations that affect them, and that are effected by them. Usually, simple measures like amount of water consumed, land developed, or pollution produced, are not, by themselves, useful measures of ecological harm. Neither are acres of open space, area of buffer strips, or number of rare species, useful measures of ecological health. The key is to understand the relationship that a series, or set, of human populations has with the ecological system, and which key ecological processes are being compromised or restored to health in that relationship. Such processes can be thought of as master variables and include natural flow regimes, the full complement of native species and functional niches, and a natural chemical regime. We must minimize disruptions to intact, healthy processes, and restore those that have been adversely impacted.

The key is to understand the relationship that a series, or set, of human populations has with the ecological system, and which key ecological processes are being compromised or restored to health in that relationship.

ACKNOWLEDGEMENTS
I wish to thank Jolie Krasinski and Sara Cappeller for their encouragement, assistance and support.

DAVID RANKIN directs the program activities at the Great Lakes Protection Fund, the nation's first ecosystem endowment. He is responsible for designing and operating the Fund's giving programs. This work includes developing the Fund's special initiatives, soliciting and reviewing project proposals, managing the Fund's portfolio of active grants and evaluating the program's effectiveness. Prior to joining the Fund, Mr. Rankin helped The Nature Conservancy establish a new Great Lakes Program. He has also held several senior management positions in federal and state environmental agencies. His degree in environmental sciences was earned at Miami University. Mr. Rankin has also completed graduate work in business administration, business strategy, and management.

David Rankin, Vice President and Director of Programs, Great Lakes Protection Fund, 1560 Sherman Avenue, Suite 880 Evanston, IL 60201, drankin@glpf.org

The Ecological Consequences of Changing Land Use for Running Waters, with a Case Study of Urbanizing Watersheds in Maryland

Margaret A. Palmer, Glenn E. Moglen, Nancy E. Bockstael, Shane Brooks, James E. Pizzuto, Cameron Wiegand, Keith VanNess

ABSTRACT

The concept of "Smart Growth" has emerged as a response to the trend of increasing low-density sprawl and to the limited policy instruments available for controlling it. In the U.S., the spatial pattern of this land conversion has tended to be one of "exurban sprawl," in which the rate of increase in newly developed land greatly exceeds the rate of population growth, and the location of this development in the rural-urban fringe has led to increases in vehicle miles traveled *per capita*, with its attendant deleterious impact on air quality. Because streams, rivers, and groundwater integrate the landscape, providing a conduit for the transfer of energy and material from terrestrial habitats into freshwater systems, they are particularly vulnerable to environmental impacts from land use change. To determine what these impacts may be and how we might mitigate them requires an ability to predict the rate and pattern of development and its environmental impacts. It also requires that the scientific, public and private sectors work together to identify land use polices that will protect fresh waters.

We formed an interdisciplinary team of academic and government scientists and policy makers to study and eventually develop predictive models for how land use change will affect stream ecosystems in urbanizing watersheds. We asked: What is the existing relationship within a historical context between land use and stream ecosystem structure and function for urbanizing watersheds? How will land use change over the next 20 years and what are the ecological consequences of these changes within running-water ecosystems?

In this paper, we begin by presenting a conceptual model of the general relationship between land use change and the flow of water to and within streams *(hydrology)*, the shape and dynamics of stream channels *(geomorphology)*, and the ecological condition of streams *(ecosystem structure and function)*.

We then identify four urbanizing watersheds just north of Washington, D.C. to use as a case study and describe the type of empirical work that is required to fully develop forecasting models. Third, we present very preliminary forecasts to illustrate how one of our study watersheds may change over the next 20 years. We suggest that if the patterns of population growth and movement (which influence land use change) continue as they are today, the watershed will be completely built out by 2020 and the ecological impacts will likely be significant. Encouraging development in areas of the watershed that are already partially developed ("priority funding areas" program), could result in exactly the same outcome. If, however, conservation easements can be secured for large undeveloped areas, the ecological impacts could be quite different. We close with a focus on efforts within a single county (Montgomery County) that demonstrate how the merger of state of the art science, proactive policies, and creative public outreach can make a difference in watershed protection.

INTRODUCTION

Human-induced changes to natural landscapes have been identified as one the greatest threats to freshwater resources.[1] Land use influences sediment, hydrologic, and nutrient regimes, which in turn influence aquatic biota and ecological processes in fresh waters.[2] The ecological consequences of land use change can persist for many decades,[3] and it is not yet clear if the ecological damage can be reversed. Demographic trends and human activities are such that the rate of urbanization of the landscape is increasing rapidly and there are no signs that this pattern of increasing human alteration of the landscape will slow.

Land use change in developed countries largely takes the form of conversion of land from agriculture and forests to residential use. In the U.S., the spatial pattern of this conversion has tended to be one of "exurban sprawl" in which

[1] Dale, V.H., S. Brown, R.A. Haeuber, N.T. Hobbs. N. Huntly, R.J. Naiman, W.E. Riebsame, M.G. Turner and T.J. Valone. 2000. Ecological principles and guidelines for managing the use of land. *Ecological Applications* 10, 639-670; See also, Sala, O. E. et al. 2000. Global biodiversity scenarios for the year 2100. Science 287, 1170-1774.

land is fragmented at a rate of two to three times the rate of population growth, and the number of vehicle miles traveled increases at four to five times the population growth rate. Because development generally occurs in areas well outside of urban centers, low-density sprawl is often serviced by septic fields rather than sewage treatment plants, increasing per capita nutrient loadings and fecal coliform discharges into the aquatic environment.[4] In addition, this spatial pattern can be expected to have consequences for carbon sequestration as vegetative cover is lost, and consequences for carbon emissions as automobile usage increases.[5]

POLICY TO MANAGE LAND USE: A MOTIVATION FOR RESEARCH

In the face of continued growth pressures, increasing road congestion, school crowding, and the rising costs of providing public services to fragmented land uses, many local governments throughout the U.S. instituted growth control measures in the 1980s and 1990s. Examples of these measures include re-zoning rural land to larger minimum lot sizes and withholding public utilities (*e.g.*, public water and sewer) from that land, both of which raise the costs of development. These policy instruments are not direct controls. In fact, few direct controls on residential development are allowed, given the prohibition against "taking without just compensation," otherwise known as the "takings" clause in the U.S. Constitution. Localities can and do place moratoria on building in areas without sufficient road or school capacity, but by law these moratoria are temporary until new infrastructure can be built.

In the last few years, the concept of "Smart Growth" has emerged as a response to the national trends of increasing low-density sprawl and to the limited policy instruments available for controlling it. Although not precisely defined, Smart Growth encompasses those potential policy instruments that could be used by local and state governments to redirect future growth away from contiguous areas of open space and toward areas that already possess considerable residential infrastructure[6] (see www.smartgrowth.org). Maryland's newly implemented Smart Growth program contains two major features.[7] The first is the targeting of growth areas, outside of which state funds to support infrastructure will not be forthcoming, but within which in-fill development is encouraged. The second is the outright purchase or the purchase of development rights of contiguous, undeveloped land by localities or states, potentially with subsidies from the federal government, to be held as undeveloped lands in perpetuity.

Before the advent of Smart Growth policy, growth controls were only occasionally motivated by environmental concerns. A few environmentally sensitive areas, such as the Critical Areas surrounding the Chesapeake Bay, were set-aside in the 1980s for protection. For the most part, growth controls have been motivated by the desire of localities to control congestion and the costs of providing public services. Smart Growth ostensibly addresses both

2 Naiman, R.J., J.J. Magnuson, D.M. McKnight and J.A. Stanford. *The freshwater imperative.* Island Press, Washington, D.C., 1995; See also, Palmer, M. A. *et al.* 1997. Biodiversity and ecosystem function in freshwater sediments. Ambio 26, 571-577; See also, Palmer, M. A. *et al*. 2000. Linkages between sediment biota and life above sediments: potential drivers of biodiversity and ecological processes. *BioScience* 50, 1062-1068; See also, Gleick, P. H. *The world's waters: The biennial report on fresh water resources.* Island Press, Washington, D.C, 1998.

3 Harding, J.S., E.G. Benfield, P.V. Bolstad, G.S. Helfman and E.B.D. Jones. 1998. Stream Biodiversity: the ghost of land-use past. *Proc. Nat. Acad. Sciences*. 95, 14843-14847; See also, Scully, N.M., P.R. Leavitt and S.R. Carpenter. 2000. Century-long effects of forest harvest on the physical structure and autotrophic community of a small temperate lake. *Canadian Journal of Fisheries and Aquatic Science* 57, 50-59.

4 Appleyard, S. 1995. Impact of urban development on recharge and groundwater quality in a coastal aquifer near Perth, Western Australia. *Hydrogeology Journal* 3, 65-75.

5 Brown, S., J. Sayant, M. Cannell and P.E. Kauppi. 1996. Mitigation of carbon emission to the atmosphere by forest management. *Common Wealth Forestry Review* 75, 80-91; See also, Silver, W.L., R. Ostertag and A.E. Lugo. 2000. The potential for carbon sequestration through reforestration of abandoned agriculture and pasture lands. *Restoration Ecology* 8, 394-407.

6 Duany, E.P-Z. and J. Speck. *Suburban Nation: the Rise of Urban Sprawl.* North Point Press,, N.Y., N.Y., 2000.

environmental as well as public finance problems, yet little in the way of analysis of the ecological consequences of Smart Growth development has been pursued. It is worth considering at this point what criteria might be used if the new regime of growth controls were to be motivated solely on ecological criteria.

Streams, rivers, and groundwater integrate the landscape, providing a conduit for the transfer of energy and materials from terrestrial habitats into freshwater systems and ultimately the oceans. Given the projected trends toward increasing sprawl, scientists are faced with tough questions. How is land use linked to the health of rivers and streams? Will our waterways be clean enough to meet even the minimum standards of the Clean Water Act (*i.e.*, fishable, swimmable)? Will so-called "Smart Growth" protect or improve the ecological health of watersheds? What ecosystem services do our waterways provide that are essential for us to protect, and what steps can be taken to ensure this protection?

The urgency of these questions requires an ability to predict the rate and pattern of development as well as its environmental impacts. It requires that the scientific, public, and private sectors work together to identify land use polices that will protect ecosystem services. The science underlying projections of how the amount, location, and form of future development of land may impact streams and rivers needs to be center-stage in influencing public policy in this arena. Scientists are increasingly being asked to provide policy makers and managers with projections of future environmental impacts assuming different rates of population growth, shifts in preferences and technology, and changes in the regulatory environment. Such predictions require an understanding of the complex relationships among the behavior of economic agents, and the regulatory constraints and incentives governing this behavior, resulting land use changes, and the ultimate effect on ecological processes.[8]

To develop this understanding, teams composed of scientists, managers, and policy makers must be assembled to integrate knowledge: (1) economists to forecast the amount and spatial pattern of land use change based on policy scenarios and projections of changes in demographics and real incomes; (2) hydrologists to link changes in land use to altered flow regimes; (3) geomorphologists to link land use change and hydrological change to changes in the morphology and dynamics of streams; (4) ecologists to link changes in land use, hydrology, and geomorphology to ecological processes; and (5) land use planners to take into account this new information in revising regional land use plans (Figure 1). Solving the "land use -ecological impacts problem" requires intensive collaborations among professionals from extremely diverse fields, who quickly find they are not only plagued with different disciplinary languages, but their efforts are challenged with critical knowledge gaps, disciplinary mismatches in modeling approaches and geographic and temporal scales, and considerable propagation of uncertainties.[9] Promises of new and expanded data bases, as well as more advanced mathematical and computing tools, offer hope that forecasting the effects of land use change on the future of fresh waters may be on the horizon.

[7] Maryland Department of Planning. *Smart Growth in Maryland*. http://www.mdp.state.md.us/smartgrowth/index.html, 2001.

[8] Nilsson, C., Pizzuto, J.E., Moglen, G.E., Palmer, M.A, Stanley, E.H., Bockstael, N.E., and Thompson, L.C., (in preparation). "Ecological Forecasting and Running-Water Systems: Challenges for Economists, Spatial Analysts, Hydrologists, Geomorphologists, and Ecologists." submitted to Ecosystems.

[9] Benda, L. *et al.* Avoiding train wrecks in interdisciplinary problem solving. BioScience (in revision).

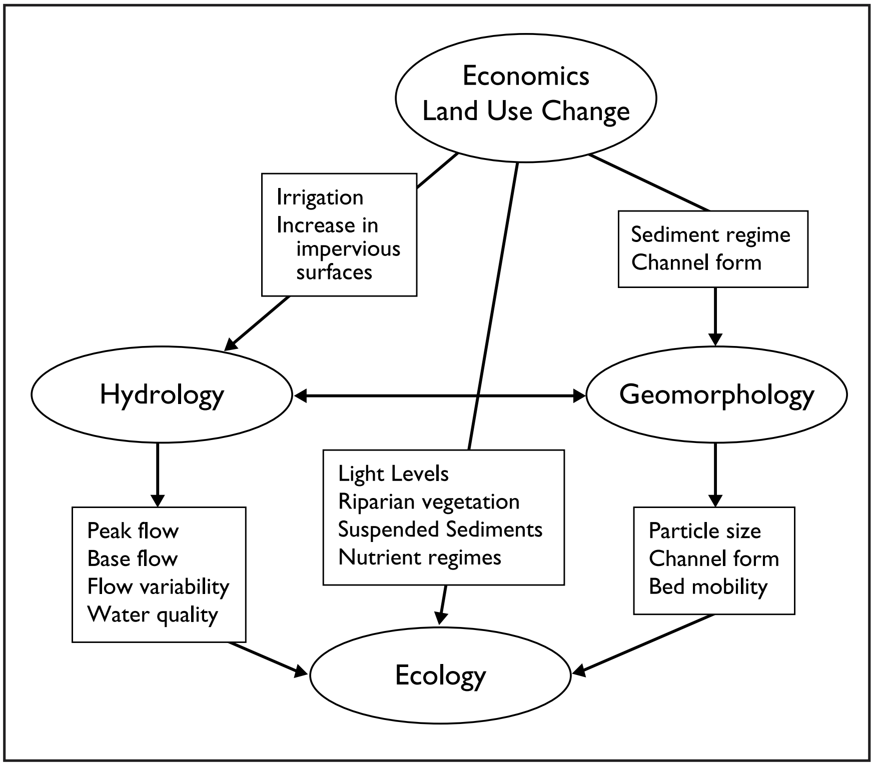


Figure 1 Conceptual model for the effects of land use change on stream and riverine ecosystems. The major mechanisms by which land use directly or indirectly (via hydrology or geomorphology) influences the ecological conditions are shown inside the boxes.

STUDYING THE LINK BETWEEN LAND USE AND FRESH WATERS

We have formed an interdisciplinary team to study and eventually develop predictive models for how land use change will affect stream ecosystems in urbanizing watersheds. Our goals are to ask: (1) What is the existing relationship within a historical context between land use and stream ecosystem structure and function for urbanizing watersheds? and, (2) How will land use change over the next 20 years and what are the projected ecological consequences of these changes within running-water ecosystems?

Our work is proceeding along three lines. First, we identified and conceptually modeled the general relationship between land use change and the flow of water to and within streams (hydrology), the shape and dynamics of stream channels (geomorphology), and the ecological condition of streams (ecosystem structure and function) (Figure 1). This part of our work was influenced by an international team of scientists who participated in three workshops held at the National Center for Ecological Analysis and Synthesis in Santa Barbara, California in 2000 and 2001. Participants brought expert knowledge to the table to synthesize current understanding of how land use influences running-water ecosystems.[10]

[10] NCEAS. Hydrological Regimes website. www.ucsb.nceas.edu, 2001.

Second, we identified four urbanizing watersheds just north of Washington, D.C. to use in an intensive empirical study. These watersheds were selected because they differ in their extent and pattern of development and drain into the highly valued Chesapeake Bay. Our empirical work involves two large efforts: 1) the collection of new and existing data on land use and the ecological conditions of these watersheds; and, 2) the assembly of new and existing data on human-induced changes in land use within these watersheds over the past decade.

Third, we are using the findings from the empirical study in conjunction with new or existing theory to develop models to predict the following: the amount and pattern of future growth (changes due to development) in these watersheds; changes in hydrology and geomorphology that will result from land use changes; and, the future ecological structure and function of streams within these watersheds. This phase is in the initiation stages – we are currently developing quantitative forecasting models. We will be using a forecasting approach in which predictions of spatial pattern, timing, and amount of land use change will be generated from economic models of development. Land use projections will then be used as input into hydrologic models that describe future flow regimes, and information on land conversion and hydrology will be used to forecast channel form, sediment supply, and particle sizes on the streambed. Finally, all of this information will be linked to models predicting various aspects of ecological change. In this paper, we use some highly simplified assumptions and models to produce "forecasting illustrations" of land use change for the year 2020 for one of our study watersheds. We refer to these as "illustrations" because they are meant only to demonstrate our process – the model development to generate actual forecasts will take several more years.

THE EFFECTS OF LAND USE CHANGE

Land use change occurs largely through human actions affected by economic incentives and constrained by regulation. These changes can have both direct and indirect effects on freshwater ecosystems-the former have immediate ecological impacts (*e.g.*, destruction of wildlife habitats), while the latter have impacts that are transmitted via altered flow or sediment transport patterns (*e.g.*, lower productivity due to increasing turbidity). Transmission of these hydrologically and geomorphically mediated impacts sometimes involves long lag times, but it can also occur quite quickly.

ECONOMIC BEHAVIOR AND LAND USE CHANGE

Although natural succession and climatic events are important forces in altering land cover over time, the predominant cause of land cover/land use change is human intervention. Actions that induce change take different forms in different parts of the world. In much of the U.S. (including our study area), and especially over the last few decades, the principal form of change has been the transformation of forests and farms into residential subdivisions, often with relatively large lot sizes.

To be of most use to environmental scientists, forecasts of future land use change must include the amount of change, its timing, and its spatial pattern. Until recently, economists have pursued two quite distinct types of analysis of residential development. Regional or macro-economic theoretical and empirical studies have attempted to explain changes in aggregate amounts of development and average housing prices either at a regional or national level. This type of analysis focuses on the temporal dynamics of the problem but abstracts the spatial dimension. In the short term, movements in the U.S. economy (interest rates, construction costs), together with the regional economy's competitiveness in national and world markets, affect rates of residential development. In the long term, as individuals have the ability to adjust to changing circumstances, demographic changes and migration patterns play an increasingly important role.[11] In both the short and long term, factors (including public policies) that affect the supply of land for housing will also exert an important effect. These regional and/or macro models are extremely important for explaining the total amount of development but have not been well integrated with spatially explicit models of micro-level decision making.

Microeconomic analysis of regional housing markets attempts to explain the variation in housing prices (and indirectly the value of land in residential use) within a region or land market. The spatial pattern of development has typically been addressed in theoretical models-the principal one being the bid-rent model of Alonso,[12] Muth,[13] and Mills[14] in which increases or decreases in commuting costs to one or more central business districts determine outcomes. The equilibrium model can be solved for both prices and densities of development, where the solution is characterized by concentric rings of decreasing density of development around city centers. While robust in explaining much of the early development around cities, this model is not very effective in explaining the patterns of fragmented, low-density sprawl that we have seen over the past few decades. The empirical microeconomics literature on price variation has typically employed hedonic property value models in which market prices are regressed on property characteristics. The approach has a theoretical underpinning[15] but all that can be observed is the result of many forces interacting. Nonetheless, hedonic models have been used to determine statistically the characteristics of properties that matter to people.

Given the importance of land use change, there are growing attempts to redress the shortcomings of the above models. One such approach, taken in this study, attempts to embed micro-economic models of decision making into more comprehensive and realistic spatial models and to integrate the spatial model with regional economic models of aggregate changes.[16] The owner of each undeveloped parcel of land is viewed as taking into account the various signals the market, as constrained by regulations, provides in deciding on the future of his/her parcel. In general, the owner of an undeveloped parcel faces three alternatives in each time period – to begin the process of development, to sell the development rights and preserve the parcel in perpetuity, or to post-

[11] Mills, E. and B. Hamilton. *Urban Economics*. Addison-Wesley, New York, 1994; See also, DiPasquale, D. and W. Wheaton. *Urban economics and real estate markets*. Prentice Hall, Englewood Cliffs, N.J., 1996.

[12] Alonso, W. *Location and land use*. Harvard University Press, Cambridge, Massachussetts, 1964.

[13] Muth, R. *Cities and housing*. University of Chicago Press, Chicago, 1969.

[14] Mills, E. *Studies in the structure of the urban economy*. Johns Hopkins University Press, Baltimore, MD, 1982.

[15] Rosen, S. 1974. Hedonic processes and implicit markets: product differentiation in pure competition. *J. Political Economy* 82, 34-55.

[16] Bockstael, N.E. 1996. Economics and Ecological Modeling: The Importance of a Spatial Perspective. *American Journal of Agricultural Economics* 80, 1168-1180; See also, Irwin, E. and N. Bockstael in *Advances in Spatial Econometrics* (ed. Anselin, L. and R. Florax, eds) (In press, 2002); See also, Irwin, E. and N. Bockstael. Interacting Agents, Spatial Externalities and the Evolution of Land Use Change. *Journal of Economic Geography* (In press, 2001).

pone either terminal decision and continue using the parcel in its current open space use. Once either the first or second decision is made, the parcel's future is no longer in question.

Factors that affect the decision – or put another way, the optimal timing of development or preservation – are factors that make a parcel more or less valuable in residential use vs. as open space use. There will also be personal factors that affect such a decision, but these cannot be modeled and must be treated as stochastic. Factors such as the characteristics of a parcel that make it valuable in residential use, factors that affect its value in farming or forestry, and factors that affect the costs of development of a parcel will enter into the decision. Incorporated into the model are factors that can be altered by direct and indirect policies – such as the lot sizes allowable by zoning, the provision of public utilities, the distances along publicly supplied roads, the terms of agricultural preservation programs that support public purchase of development easements, the location of publicly supplied open space, etc.

The importance of the various factors in affecting the value of land in different uses and the role of public policy in altering those factors are, by and large, research questions. The approach used in this paper as an illustration of the research process by which land use change is predicted employs historical data to estimate the parameters of the relationships influencing the change. The way in which factors that describe a land parcel and its location in the landscape affect its value in residential use is captured through estimation of hedonic models of residential property values. Competing risk hazard models are employed to estimate the parameters of models that attempt to capture the optimal timing of development or preservation, based on the predicted value in residential use, as well as factors that affect the value in other uses and the costs of conversion. These models help explain the order in which land parcels are converted over time. The rate of conversion is driven by regional aggregate demand for and supply of land for housing. With estimated parameters in hand, the models can be used to forecast the future, under scenarios in which different policies are adopted and/or different rates of population and income growth are forecast.

HYDROLOGICALLY-MEDIATED EFFECTS OF LAND USE CHANGE

The intimate links between the land and surface water in streams and rivers occur largely out of sight: movement of water and nutrients from groundwater through the deep streambed where groundwater and surface waters mix (hyporheic zone) into channels and in the reverse direction have huge impacts on the biological processes occurring within these waterways.[17] Additionally, more visible "above ground" links between the land and running waters have huge impacts on biological processes.[18] For example, overbank flows that inundate floodplains and riparian zones adjacent to running waters may determine the form and rate of a diverse array of ecologically important processes. Floodplain inundation may be required to initiate biogeochemical

[17] Boulton, A., S. Findlay, P. Marmonier, E.H. Stanley and H.M. Valett. 1998. The functional significance of the hyporheic zone in streams and rivers. *Annual Review of Ecology and Systematics* 29, 59-81.

[18] Lake, P.S. *et al.* 2000. Global change and the Biodiversity of Freshwater ecosystems. *Bioscience* 50, 1099-1107.

transformations that ensure long-term survival of diverse riparian vegetation through flow-mediated dispersal of seeds and opening of soil patches for seed germination.[19]

Because of the complex hydrological linkages between groundwater, surface water, and riparian zones, the impacts of changes in land use are also quite complex. Any change that influences the movement of water between land, soils, groundwater, hyporheic zones, surface waters, and floodplains has the potential to have dramatic ecological consequences. For example, in arid regions the reduction in transpiration caused by tree clearing causes saline water tables to rise and pollute surface waters.[20] Urban development tends to have the opposite effect, lowering water tables because the watershed is paved with impervious surfaces such as roads, buildings and carparks that reduce infiltration. Infiltration rates will be higher in areas of low density cluster development than in highly urbanized centers unless there is considerable investment in artificially constructed retention ponds and groundwater recharge sites.[21] Runoff from warm paved areas may cause thermal pollution in addition to delivering a plethora of organic and inorganic pollutants to the stream network.[22] Thus, we stress that an alteration in land use that influences *any* part of the visible or invisible water network (*e.g.*, the water table and thus, groundwater flows, overland run-off, overbank flows, etc.) may have important ecological consequences. Focusing on how land use influences mean flows, peak flows, or baseflows in streams is far too simplistic. Even if peak flows and baseflows are within acceptable ranges from an ecological standpoint, if groundwater residence times are too short and/or the exchange of water between the hyporheic zone and the groundwater environment is greatly reduced, nutrients may reach unacceptable levels in river channels and estuaries and biodiversity may be significantly reduced.

Surface flows are far easier to monitor than groundwater exchanges and thus most research linking ecology and hydrology has focused on water in the channel. Certainly, the importance of the flow regime in shaping aquatic communities is well-recognized in stream ecology; both flood flows and low flows have dramatic effects on the structure of biotic communities and rates of ecological processes.[23] Several striking examples of the importance of the natural flow regime include major changes in ecosystems caused by the introduction of flow regulation schemes.[24]

To date, our work has focused on the impacts of land use change on peak flows, in part because of the high quality hydrologic models that are available for predicting peak flows. Accurate measurement and prediction of low flows is limited, particularly with respect to how low flow behavior is influenced by land use change or changes in water appropriation policies. The inability to quantify changes in low flow behavior is problematic because the timing, duration, and spatial extent of low and no flow conditions can dramatically alter ecosystem dynamics, particularly when drought conditions are novel to a system and biota lack adaptations for resisting or recovering from desiccation.

[19] Stromberg, J.C., D.T. Patten, and B.D. Richter. 1991. Flood flows and the dynamics of Sonoran riparian forests. Rivers 2, 221-235; See also, Messina, M.G. and W.H. Conner. (eds.) *Southern Forested Wetlands Ecology and Management*. Lewis Publishers, 1998.

[20] Salama, R., T. Hatton and W. Dawes. 1999. Predicting Land Use Impacts on Regional Scale Groundwater Recharge and Discharge. *Journal of Environmental Quality* 28, 446-460.

[21] Tourbier, J.T. 1994. Open space through stormwater management: helping to structure growth on the urban fringe. Journal of Soil and Water Conservation 49, 14-21; See also, Ellis, J.B. 2000. Infiltration systems: a sustainable source-control option for urban stormwater quality management? *Journal of the Institute of Water and Environmental Management* 14, 27-34.

[22] Van Buren, M., W. Watt, J. Marsalek and B. Anderson. 2000. Thermal enhancement of stormwater runoff by paved surfaces. *Water Research* 34, 1359-1371.

[23] Poff, N.L. and K. Nelson-Baker. 1997. Habitat heterogeneity and algal-grazer interactions in streams: explorations with a spatially explicit model. *Journal of the North American Benthological Society* 16, 263-276; See also, Stanley, E.H., Fisher, S.G. and Grimm, N.B. 1997. Ecosystem expansion and contraction in streams. *BioScience* 47, 427-435; See also, Puckridge, J.T., F. Sheldon, K.F. Walker and A.J. Boulton. 1998. Flow variability and the ecology of large rivers. *Marine and Freshwater Research* 49, 55-72; See also, Richter, B.D. and H.E. Richter. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. *Conservation Biology* 14, 1467-1478.

Since low flows may be as important in regulating biodiversity and ecological processes in streams as are floods, new approaches for predicting flows at all stages are required.[25]

GEOMORPHICALLY-MEDIATED EFFECTS OF CHANGING LAND USE

Land use interacts with altered flow regimes to influence geomorphic factors that are critically important ecologically. Under scenarios of changing land use, the geomorphologic factors of most interest from an ecological perspective for streams like those in the Chesapeake Bay region include changes in the magnitude and frequency of bedload transport, increased suspended load, changes in bed particle size (not only mean particle size but also variability in particle sizes, as well as changes in the sizes of the largest particles on the streambed), and larger-scale features such as channel cross-sectional and planform geometry. If the availability of geomorphic microhabitats is reduced by land use changes, this can have dramatic consequences for the abundance and diversity of instream biota.[26] To fully comprehend the ecological consequences of altered land use requires linking information from hydrological models (*e.g.*, magnitude and frequency of peak flows) to geomorphic information (*e.g.*, size and mobility of the largest particles on the bed) and then to knowledge of faunal attributes (*e.g.*, ability of fauna to utilize flow refugia during floods).[27]

It is difficult to predict changes in stream morphology and dynamics in any watershed. We must take output from hydrological models and forecast particle size distributions using bedload transport equations that predict the movement of individual size fractions.[28] Boundary conditions that specify the volume flux and size distribution of the sediment supply are also needed, as well as initial conditions that specify the distribution of particle sizes throughout the watershed at the beginning of the time period to be simulated. These are daunting requirements, but they must be met if the geomorphic changes caused by land use are to be accurately assessed. Progress will require improvements in our understanding of sediment transport theory, as well as detailed fieldwork to calibrate models. Recent studies demonstrate, for example, that the fraction of the streambed in motion at different flows can be estimated, but only if detailed, site-specific observations are available for calibration.[29]

The interaction between flow and bed composition can exert significant control over biological processes that occur in streams.[30] The three most ecologically important geomorphic factors include substrate size and mobility, suspended sediment concentrations, and channel form. Because each of these three variables is so ecologically important, problems with effective quantification and modeling (particularly as a function of land use changes) are currently a central focus of our group work. Because urbanization is one of the more significant land use changes in our study area, the effects of urbanization also play a central role in our study. Urbanization can lead to increased channel

[24] Rosenberg, D.M. and V.H. Resh. *Freshwater biomonitoring and benthic macroinvertebrates.* Chapman and Hall, Routeledge, 1993; See also, Jansson, R., C. Nilsson, M. Dynesius and E. Anderson. 2000. Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. *Ecological Applications* 10, 203-224; See also, Nilsson, C. and K. Berggren. 2000. Alterations of riparian ecosystems resulting from river regulation. *BioScience* 50, 783-792.

[25] Nilsson, C., Pizzuto, J.E., Moglen, G.E., Palmer, M.A, Stanley, E.H., Bockstael, N.E., and Thompson, L.C., (in preparation). "Ecological Forecasting and Running-Water Systems: Challenges for Economists, Spatial Analysts, Hydrologists, Geomorphologists, and Ecologists." submitted to Ecosystems.

[26] Allan, J.D. *Stream ecology: structure and function of running waters.* Chapman & Hall, London, 1995; See also, Gordon, N.D., T.A. McMahon and B.L. Finlayson. *Stream Hydrology: an Introduction for Ecologists.* Wiley, Chichester, England., 1992.

[27] Biggs, B.J.F., M.J. Duncan, S.N. Francoeur and W.D. Meyer. 1997. Physical characterization of micro-form bed cluster refugia in 12 headwater streams, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 31, 413-422; See also, Matthaei, C.D. and C.R. Townsend. 2000. Long term effects of local disturbance history on mobile stream invertebrates. *Oecologia* 125, 119-126.

area,[31] and possibly incision,[32] changes that influence the water surface elevation during high discharges, which in turn influences bed mobility and other significant ecological variables.

ECOLOGICAL EFFECTS OF CHANGING LAND USE

Healthy freshwater ecosystems are those in which the ecological structure and function is sufficiently unperturbed so that biotic assemblages thrive and ecological processes continue unimpeded. The ecological structure of running-water systems includes the number and diversity of riparian plants, aquatic invertebrates, and fish, as well as various measures of water quality (*e.g.*, dissolved oxygen, nutrient concentrations). Further, ecologists consider the types and abundance of wood and riparian inputs as important structural attributes of running-water systems because they provide habitat and food for biota.[33]

Ecological function refers to ecological processes that are vital to the provision of ecosystem services (*e.g.*, the breakdown of organic material, the recycling of nutrients, primary production). Measurements of ecological function provide a different view of the state of ecosystems than do structural measures. Functional measures are dynamic and provide data by which different ecosystems may be compared even if the species abundance or composition varies. On the other hand, functional measurements are less routinely used and are rarely available from existing monitoring databases. Thus ecologists must often infer function based on structural measures.

To date, work on relating land use change to the ecological state of streams has been limited almost entirely to correlating structural measures of ecological condition to existing or historical land use patterns.[34] These correlations often use published data sources that were collected for water quality monitoring and assessment at large spatial scales.[35] Sampling sites are typically on major streams and/or tributaries that are inevitably responding to cumulative impacts of mixed land uses and an amalgam of environmental conditions (*e.g.*, climatic or geologic) making it difficult to attribute ecological state solely to changing land use.[36] Studies that examine a large number of sites (hundreds) can readily identify significant trends across the range of land use types, but they suffer from an inability to predict the ecological condition at any single location.[37] Thus, our understanding of how land use leads to ecological change in streams is qualitative and is derived in ignorance of the specific processes by which changing land use alters the ecological condition at a site. This is particularly true for our understanding of how the ecological states of streams are mechanistically linked to land use change via *specific hydrologic and geomorphic effects.*

We suggest that several factors are of preeminent (1st order) importance (Figure 2). First, modification of the watershed in ways that alters riparian vegetation may influence biota as well as the entire carbon-nutrient cycle. In the Chesapeake Bay region, the dominant species of plants contributing litter inputs to streams has changed dramatically over the last 300 years. However, as agricultural fields were first abandoned and then reclaimed, many of the

[28] Wilcock, P.R. 1998. Two-fraction model of initial sediment motion in gravel-bed rivers. *Science* 280, 410-412.

[29] Wilcock, P.R. 1997. *A method for predicting sediment transport in gravel-bed rivers. Misc. Report to the U.S. Forest Service*; See also, Wilcock, P.R. and B.W. McArdle. 1997. Partial transport of a sand/gravel sediment. *Water Res. Res.* 33, 235-245.

[30] Hart, D.D. and C.M. Finelli. 1999. Physical-biological coupling in streams: the pervasive effects of flow on benthic organisms. *Annual Review of Ecology and Systematics* 30, 363-395; See also, Cardinale, B.J., C.M. Swan, M.A. Palmer, S. Brooks and N.L. Poff. The influence of habitat heterogeneity on the rates of ecological processes in a stream ecosystem. *Ecology* (2002, In press).

[31] Hammer, T.R. 1972. Stream channel enlargement due to urbanization. *Water Res. Res.* 8, 1530-1540; See also, Pizzuto, J.E., W.C. Hession and M. McBride. 2000. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania. *Geology* 28, 79-82.

[32] Booth, D.B. 1990. Stream-channel incision following drainage-basin urbanization. *Water Resources Bulletin* 26, 407-417.

[33] Gregory, S.V., F.J. Swanson, W.A. McKee and K.W. Cummins. 1991. An ecosystems perspective of riparian zones: focus on links between land and water. *BioScience* 41, 540-551; See also, Naiman, R.J. and H. Decamps. 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics* 28, 621-658.

[34] Cole, J.J., G.M. Lovett and S. Findlay. *Comparative analyses of ecosystems: patterns, mechanisms, and theories*. Springer-Verlag, New York, N.Y., 1991.

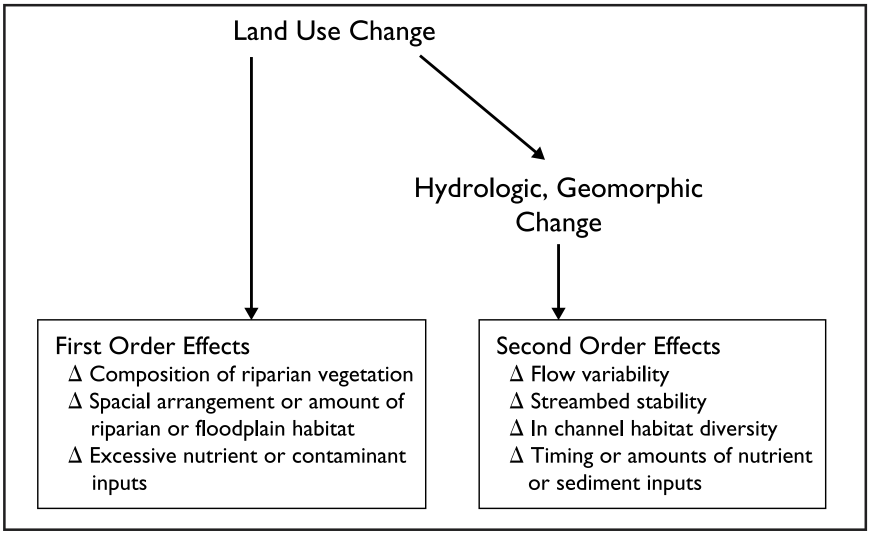


Figure 2 The primary factors that link land use and the ecological conditions of fresh water streams and rivers according to their assumed importance. First order factors are those that current research suggests will have the most profound or immediate impacts; second order factors are also important but may act more slowly or lead to less damage.

dominant plants were able to continue in their functional role in the watershed. Conversion of land to suburban/urban uses permanently alters the landscape in ways that eliminate these dominant plants in their functional roles, and this may influence the quality and quantity of food for invertebrates[38] that may in turn influence decomposition rates.[39]

Second, on the landscape scale, changes in the amount and arrangement of riparian and floodplain habitat have particularly dramatic influences on running-water ecosystems.[40] Stream and riparian zones not only serve as habitat but act as corridors for movement of biota. If these corridors are disrupted, this may lead to a series of ecological changes. For example, the patterns of dispersal and migration of species will be altered, causing invasion or isolation of species. In many parts of the world, a large portion of invaders will be alien species, causing interspecific competition and even loss of native species. Another effect is isolation of existing populations that will increase the risk of genetic depletion. Third, land use changes that magnify the influx of nutrients or contaminants (*e.g.*, from agriculture or commercial development) may have lethal or non-lethal effects on the biota and may alter rates of primary and secondary production.

Second-order factors that can influence ecological states when land use change occurs include a host of hydrologically and geomorphically-mediated effects (Figure 2). Changes in flow variability (*e.g.*, the timing and frequency of floods and droughts), streambed mobility (*i.e.*, how stable the bottom is for resident biota), sediment inputs and habitat diversity may have less immediate effects than habitat loss or contamination but they are well known to influence biodiversity.[41] Changes in light levels (*e.g.*, due to changes in water clarity or riparian vegetation) or nutrient inputs (*e.g.*, due to altered soils and run-off)

[35] Johnson, L.B., C. Richards, G.E. Host and J.W. Arthur. 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. *Freshwater Biology* 37, 193-208; See also, Townsend, C.T., C.J. Arbuckle, T.A. Crowl and M.R. Scarsbrook. 1997. The relationship between land use and physiochemistry, food resources and macroinvertebrate communities in tributaries of the Taieri River, New Zealand: a hierarchically scaled approach. *Freshwater Biology* 37, 177-191; See also, Wang, X. and Z. Yin. 1997. Using GIS to assess the relationship between land use and water quality at a watershed level. *Environmental International* 23, 103-114; See also, Thornton, K.W., G.E. Saul and D.E. Hyatt. Environmental Monitoring and Assessment Program Office of Research and Development, Environmental Protection Agency, Research Triangle Park, NC, 1994.

[36] Strayer, D.L. et al. Effects of land-cover change on stream ecosystems: roles of empirical models and scaling issues. *Ecosystems*. (submitted).

[37] Wang, X. and Z. Yin, 1997; See also, Strayer, D.L. et al., (submitted); See also, Peters, R.H. 1986. The role of prediction in limnology. *Limnology and Oceanography* 31, 1143-1159.

[38] Cummins, K.W., M.A. Wilzbach, D.M. Gates, J.B. Perry and W.B Taliaferro. 1989. Shredders and riparian vegetation. *BioScience* 39, 24-30.

[39] Webster, J.R. and E.F. Benfield. 1986. Vascular plant breakdown in freshwater ecosystem. *Annual Review of Ecology and Systematics* 17, 567-594; See also, Webster, J.R., J.B. Wallace and E.F. Benfield in *Ecosystems of the World 22: River and Stream Ecosystems* (eds. Cushing, C.E., K.W. Cummins and G.W. Minshall). Elsevier, Amsterdam, 1995.

may influence primary and secondary production which in turn changes nutrient cycling.[42] Both the first order and second order factors may have profound impacts on stream ecosystems, but we know little about how and when these impacts are realized. As a consequence, these factors are currently the subject of a great deal of study as evidenced for example by the many projects being performed under the auspices of the U.S. federally-funded Water and Watersheds Program.[43]

CASE STUDY: URBANIZING WATERSHEDS IN MARYLAND

The Chesapeake Bay region is a 64,000 square mile drainage area that encompasses portions of the states of Maryland, Virginia, New York, West Virginia, Pennsylvania, Delaware as well as the District of Columbia, and includes as tributaries a number of large rivers (the Potomac, Patuxent, Susquehanna, Shenandoah). Land use change in the mid-Atlantic region of the eastern U.S. coastal states is currently dominated by conversion of forests and farms to developed, chiefly residential, uses. We are focussing on watersheds within the Chesapeake Bay region situated just north of Washington, D.C. in Maryland. Here, the trends in the spatial pattern of urbanization are characterized by additions of dwelling units both at the extensive (exurban sprawl) and the intensive (fill-in development) margins, with development rates rising dramatically over the past several decades. In the mid 1980s, approximately 60,000 acres were converted to developed uses per year as compared to about 130,000 acres/year during the mid 1990s. Rather than seeing compact additions to the edge of suburbia, new trends are toward low-density, fragmented sprawl in otherwise rural areas.

Our study watersheds that drain into the Potomac and Patuxent Rivers include the Northwest Branch, Paint Branch, and Hawlings Rivers, and Cattail Creek (Figure 3). The land use pattern in these watersheds is largely the result of their location relative to Washington, D.C. and the rapid increase in employment opportunities in that city since World War II. For several decades, residential growth occurred in waves of new construction that added development to the edge of the city, forming traditional suburbia – an ever-widening ring of residential land use around D.C. For the last few decades, however, there has been pressure for non-contiguous development in all but the extreme northwest sections of the Montgomery County where very large minimum lot-size zoning and a transferable development rights program has discouraged subdivision development.

Our study watersheds lie primarily within the Piedmont physiographic province, range in size from 13 to 28 square miles, and were selected because they are experiencing major changes in land use but with differing patterns. Three of these watersheds are in a single county (Montgomery County) but one of them (Cattail) lies in an adjacent county (Howard County) that has different growth and planning policies Differences in policy environments make the watersheds particularly interesting to study. All four watersheds have similar

[40] Naiman, R.J. and H. Decamps, 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics* 28: 621-658.

[41] Palmer, M.A. *et al.*, 1997; See also, Poff, N.L. and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences* 46, 1805-1818.

[42] Sabater, F. *et al.* 2000. Effects of riparian vegetation removal on nutrient retention in a Mediterranean stream. *Journal of the North American Benthological Society* 19, 609-620.

[43] Water and Watersheds Program, U.S.E.P.A. http://es.epa.gov/ncerqa/rfa/water.html

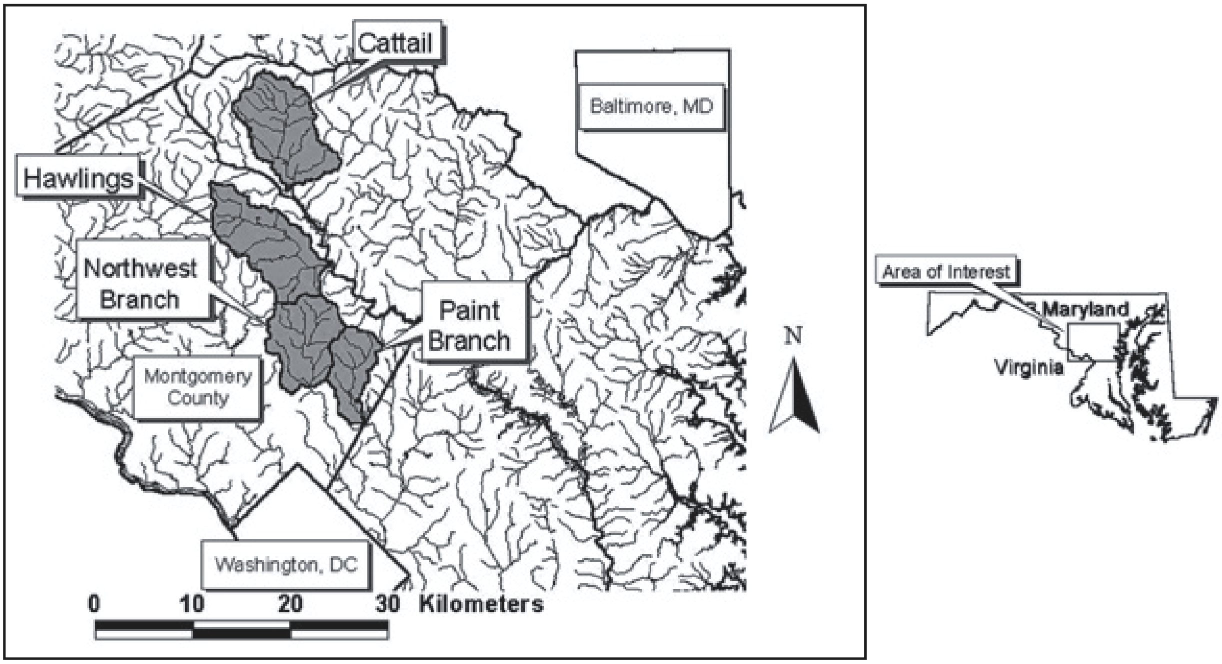


Figure 3 Geographic location and land use in the four Maryland study watersheds located just north of Washington, D.C. Northwest Branch, Paint Branch, and Hawlings are located within Montgomery County, while Cattail Creek is within a different jurisdiction: Howard County.

Table 1 Land use in four study watersheds in Suburban Maryland based on most recent data from the State of Maryland Office of Planning (1997).

Watershed	Residential	Agricultural	Forest	Other
Northwest Branch	48%	9%	28%	14%
Paint Branch	61%	9%	23%	7%
Hawlings	20%	41%	32%	6%
Cattail	14%	59%	25%	1%

amounts of land left in forest; however, Northwest Branch and Paint Branch have much more residential development whereas Hawlings and Cattail have more agricultural land (Figure 4, Table 1).

CURRENT WATERSHED CONDITIONS

In the summer of 2000, we began making field measurements to characterize the structure and functioning of each of the four study watersheds (Table 2). Our structural measurements include habitat assessments (diversity and amount of in stream habitat types, width and nature of the riparian vegetation, channel form), the abundance and diversity of aquatic invertebrates and fish, as well as, various measures of water quality (*e.g.*, dissolved oxygen, nutrient concentrations, etc.). We are also quantifying key ecological and geomorphic processes, including primary production, nutrient uptake rates, retentiveness, and streambed mobility.

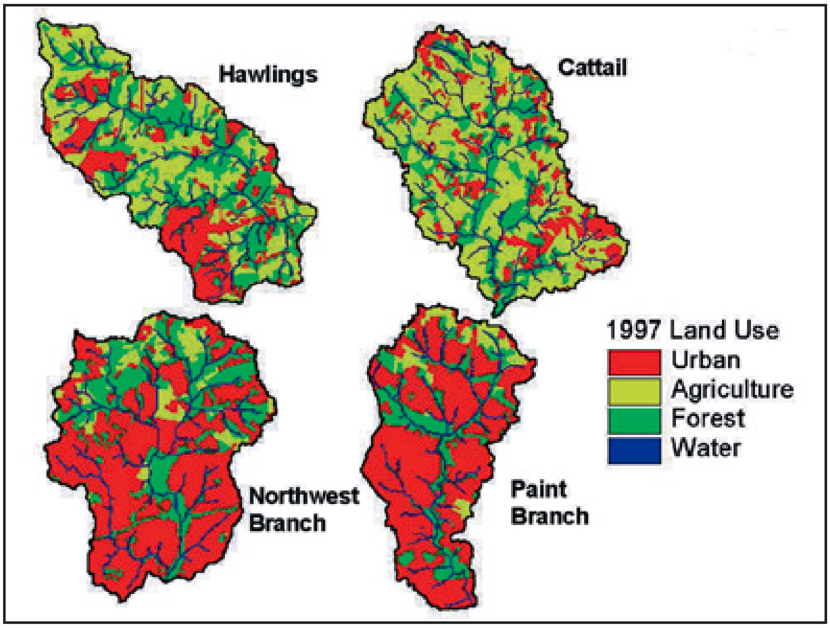


Figure 4 Land use distribution in the study watersheds as of 1997. Data are from the Maryland Department of Planning (http://www.op.state.md.us/data/mdview.htm).

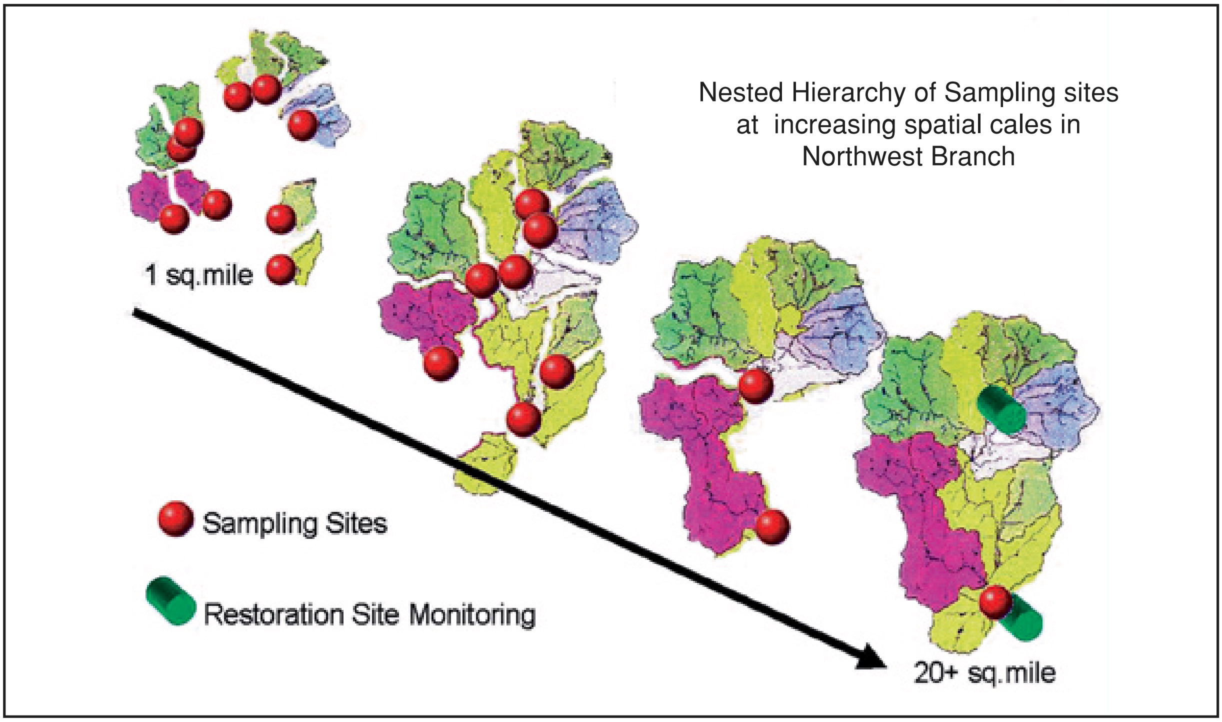


Figure 5 Illustration of nested hierarchy of sampling sites in Northwest Branch watershed. The smallest scale at which samples are collected are at sites that have small, primarily single-land use drainage areas of ca. 1 mi^2. The most downstream sampling sites are on the mainstem of the waterway and have drainage areas of 20 mi (or more in other watersheds) with mixed land use drainage areas. Sampling sites are located at the most major confluence points. Within this watershed a number of stream sites are targeted for restoration and these are also shown on the map since biological monitoring also focusing on these sites.

All measurements are being made on approximately twenty 75 meter-reaches per watershed. Many of these stations correspond to permanent Montgomery County stream monitoring stations. Selection of sites within each watershed was made to ensure that we sample in a hierarchical fashion from small (≈ 1 square mile) first-order subwatersheds to higher order tributaries at the main outlet of the watershed (Figure 5). With this design, we have ensured that sample sites at the "top" of our watersheds (*i.e.*, at the outlets from first-order subwatersheds) have drainage areas with fairly homogeneous land use (*i.e.*, primarily forested or primarily agricultural). We then sample at each major confluence where land use changes.

Table 2 Parameters being measured at study reaches within each of the four study watersheds in Maryland. The biotic parameters represent direct assessments of the fauna and ecological functioning of the streams; the physical parameters represent assessments of the habitat, flow, and geomorphic factors that influence the biota and ecological processes.

Structure	Function
Biotic	**Biotic**
Macroinvertebrate abundance, diversity, community structure	Whole reach primary production (Day-time 0_2 evolution)
Fish abundance, diversity, community structure	Whole reach community respiration (Night-time O_2 metabolic consumption)
Indices of Biotic Integrity (State and/or County Fish and Invertebrate IBIs)	NH_4, PO_4 Uptake rate
Physical	**Physical**
Cross-sectional morphology at riffles	Average Discharge
Channel bed slope	Average Transport Velocity
Riffle/pool ratio	Rate of water-atmosphere gas exchange
Particle size composition in riffles	Hydraulic Dispersion rate
Particle distribution (over 200-300m reaches)	Hydraulic Retention (Transient Storage)
Presence of man-made structures (e.g., pipe outfalls, bridges, culverts)	Riffle substrate particle stability
In-stream woody debris	
Aquatic and riparian vegetation, buffer width	
Canopy cover (shading)	
Undercut banks/overhanging vegetation	
Water quality (dissolved O_2, pH, temperature, conductivity)	

We will complete a full assessment of all sites within all four watersheds in winter 2001/2002. Using discharge data from gauges (USGS Streamflow gauges 01591500, 01591700, and 01650500) and existing models,[44] we will fully characterize the flow regime for each of our sites. We will then develop quantitative relationships between our ecological response variables and the hydrologic and geomorphic drivers that will allow us to understand how intensity, history, and spatial distribution of development influence ecological conditions at various scales. We will use these relationships to build models that will allow us to forecast and compare ecosystem condition using our different policy and growth scenarios.

In the remainder of this paper, we use the Northwest Branch watershed to illustrate the key issues we are addressing with respect to the influence of land use on stream ecosystems. Since we are in the first year (2001) of our field sampling, what we know now about the ecological conditions is based on past rapid bioassessment data for a subset of our sites that have been part of a monitoring program of the Montgomery County Department of the Environment. Their monitoring takes into account habitat conditions, invertebrate and fish diversity and results in a qualitative ranking of site conditions. In the Northwest Branch watershed, tributaries in the upper part of the watershed, particularly the headwaters, support the few remaining streams with excellent and good conditions (Figure 6). The fish community includes rosyside dace, northern hogsuckers, and five species of shiners. Although the same species can be found throughout the watershed, the community composition varies dramatically in response to habitat, flow, and pollutant stressors. In the middle section of Northwest Branch, the watershed contains a mix of low to higher density land uses along with large areas of forested parkland. Indeed, some of the widest stream buffers on the main stem in the entire county occur here but altered hydrology still prevails. The lower reaches of Northwest Branch contain more concentrated development, the hydrology has been altered significantly, and the stream conditions are generally poor to fair.

ALTERNATIVE WATERSHED FUTURES

Northwest Branch lies within Montgomery County, which is highly developed compared to many areas of the U.S., but still encompasses a large proportion of undeveloped land uses. As of 1997 about 32% of the county was in natural cover, 26% in agriculture, and 42% in developed uses. The Northwest Branch watershed has a somewhat higher proportion of developed area. Key pressures in the Northwest Branch watershed that have led to land use change include increases in real incomes in the region, increases in ex-urban populations (some of which is the result of flight from the city of Washington D.C.), and the provision of higher quality public services by the county. In the last 50 years, there has been a substantial shift in land use from primarily agricultural to residential (Figure 7). Of the 13,500 acres in the watershed, only about 1,300 acres of developable land of sufficient size to accommodate subdivisions of

[44] Soil Conservation Service. *Computer Program for Project Formulation*, Technical. Release 20, (Washington, D.C., 1984); See also, Donigan, A.S. and W.C. Huber. *Modeling of nonpoint source water quality in urban and non-urban areas.* EPA/600/3-91/039. U.S. EPA, Environmental Research Laboratory, Athens, GA, 1991; See also, Bicknell, B.R., J.C. Imhoff, J.L. Kittle, A.S. Donigan and R.C. Johanson. *Hydrologic Simulation Program–Fortran, User's manual for version 11. EPA/600/R-97/080*. U.S. EPA, Ecosystems Research Division, Environmental Research Laboratory, Athens GA, 1997; See also, United States Geological Survey. http://water.usgs.gov/software/hspf.html Reston, VA, 2001.

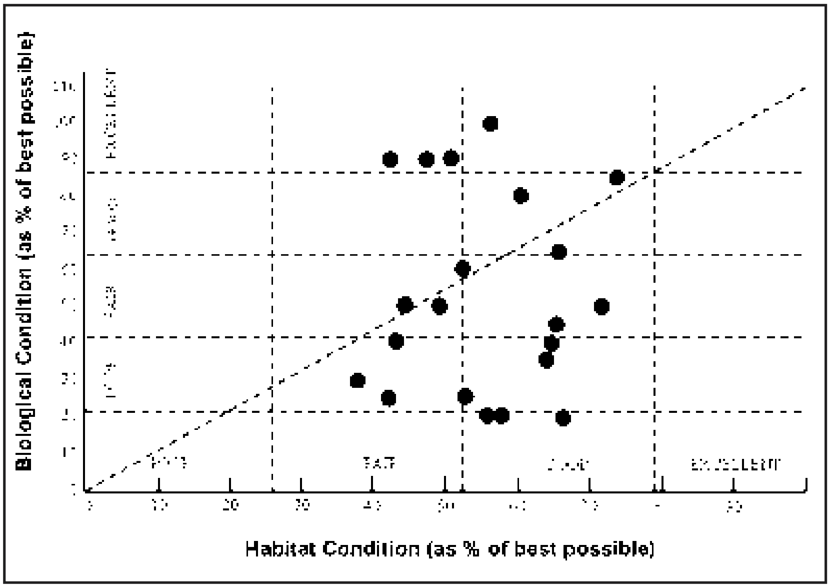


Figure 6 Relationship between habitat condition and biological condition in Northwest Branch watershed from the Montgomery County Department of the Environment's rapid bioassessment monitoring program.

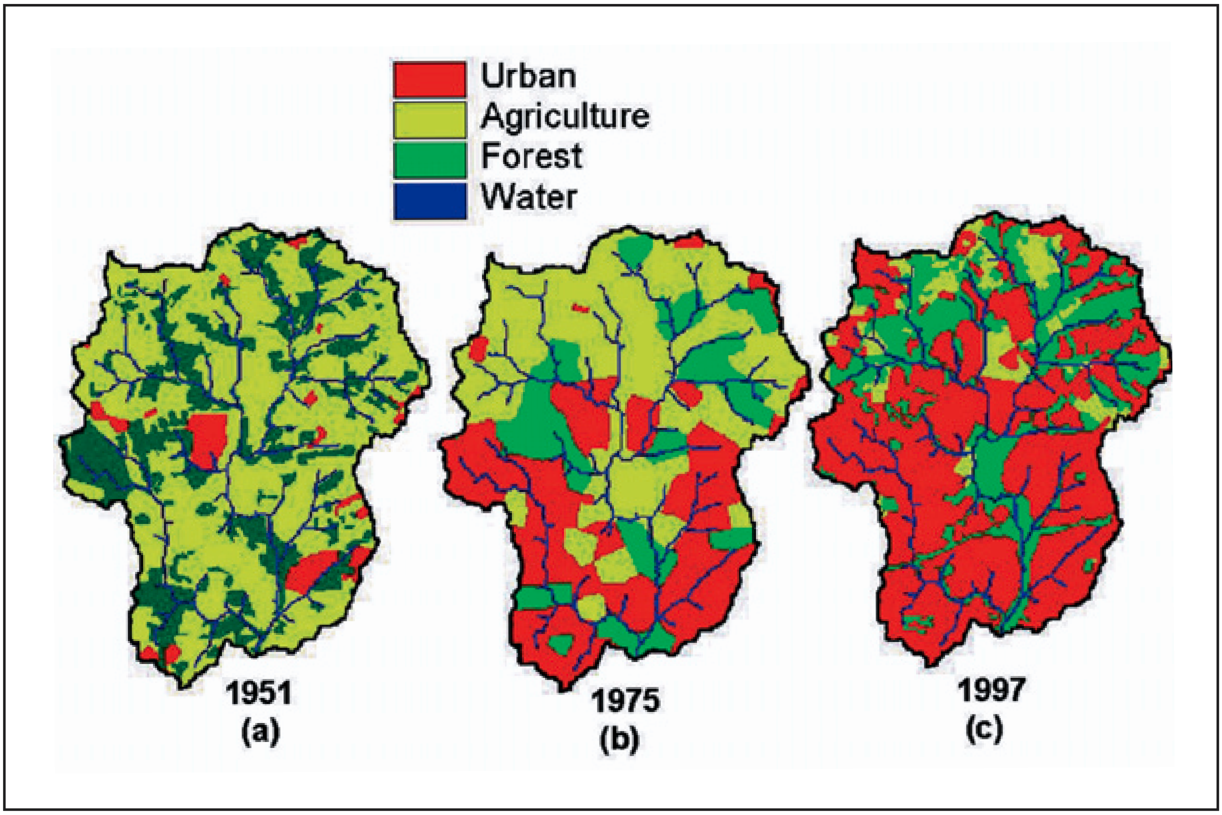


Figure 7 Evolution of land use in Northwest Branch watershed: 1951 (from aerial photography) (A), 1970's (from USGS GIRAS data) (B), 1997 (from Maryland Department of Planning) (C).

three or more housing units remain as of 2000. At current zoning densities, these 1300 acres could accommodate a bit less than 1000 new single-family dwelling units.

Land Use Change Forecasts Assuming Different Policies

To illustrate the forecasting process, we focus on the spatial dimension of the modeling approach and present preliminary results that capture the spirit of the forecasting exercise, but we do not yet take into account many of the particular features of Montgomery County and its policies that will ultimately be captured in our models. Here, we use Maryland Department of Planning projections for expected number of new households in the county over the next 20 years, which suggest the population will grow by about 860,000; this translates into about 70,000 new households by the year 2020. We present forecasting illustrations below by assuming that this growth is uniform over the next two decades and that the 70,000 new households induce an increase of about 20,000 new single family homes in the county. Not all new household formation results in new dwelling units, and not all new dwelling units are single-family houses.

How these new houses will be distributed spatially across the county and, as a result, how many will fall within the Northwest Branch watershed requires a spatial analysis. Different regulatory environments will generate different spatial patterns of development, depending on direct controls, such as changes in minimum lot size zoning, public acquisition of private lands, and incentives and disincentives for construction, such as provision of public utilities, roads, and schools, as well as changes in development fees. Some schemes will consume less land than others, while still providing the same number of new dwelling units. Some will accommodate a larger fraction of new homes on public water and sewer. Given the spatial heterogeneity in factors that affect profitability of development, a number of different spatial patterns could emerge.

Drawing on spatially explicit data on land use/land cover made available by the Maryland Department of Planning,[45] we determined that about 48% of the land use in the Northwest Branch is in residential use, 28% is in forest, and 9% is in agriculture. About 20% of the watershed is impervious. Using historic data on neighboring counties (Montgomery County historical data is not yet available), parameters were estimated for a model that explained how different characteristics affect the value of parcels in residential use. A second model was estimated, also using data on neighboring counties, that captured the likelihood that a parcel was developed, depending on its predicted residential value and factors that affected its value in other uses and conversion costs. We employed the parameters estimated for neighboring counties and projected the order in which parcels in Montgomery County that could be developed into subdivisions of three or more houses would likely be converted. A limitation of this forecasting illustration is that it does not model the alternative terminal decision of preserving land in permanent conservation easements. Nonethe-

[45] Maryland Department of Planning (2000). "Land Use / Land Cover in Maryland by Political Jurisdiction". Planning Data Services Division, GIS Section, Baltimore, MD.

less, the illustration points out qualitatively how we can approach explicit spatial modeling of land conversion and how differing policies can have effects on the spatial outcome.

In the estimated model, important factors found to affect the value of parcels in residential use included the commuting distance between the parcel and major employment centers, proximity of the parcel to the coastline, the size of the buildable lot, whether the lot was served by public utilities, the sociodemographics of the already established surrounding residential areas, and the general nature of the surrounding landscape (*i.e.*, type of land uses in close proximity). The factors that affect the cost of acquisition and conversion include the opportunity lost in agricultural use as captured by soil quality, the availability of public utilities, the size of the overall parcel and number of buildable lots, quality of soils for excavation, and type of vegetative cover. Estimation of the parameters of the hazard (or duration) model that explains the timing of past conversion produces the information needed to make preliminary forecasts of the timing of future changes.

Assuming that growth (development) occurs at the hypothetically projected rate and in this projected pattern without any major changes in policies, the "business as usual" illustration projects that the Northwest Branch will see major development occurring first in the headwater areas of the watershed (See Figure 8A.) There are many reasons for this, but prime among them is the profitability of developing large lot subdivisions in areas accessible to the city, but close to open space, either privately or publicly held. There are two simple scenarios that offer a considerable contrast to the business as usual forecast presented above. The State of Maryland is in the process of instituting a program under the rubric of "Smart Growth." As key features of this program, the state, in conjunction with counties, has designated two types of areas: "Priority Funding Areas" (PFAs) and "Rural Legacy Areas" (RLAs).

"Priority Funding Areas" (PFAs) are designated areas within which public infrastructure will be subsidized by the state and outside of which state subsidies will be denied. PFAs tend to be areas of in-fill-areas where capacity for new housing exists and where public utilities have already been provided – areas usually zoned for relatively small lot sizes. More than half of the Northwest Branch watershed falls within a PFA. Ironically, the order of development we predict in our first scenario under "business as usual" is just the reverse of what is being encouraged within the Priority Funding Areas program, as the PFA covers the lower part of the watershed. We have no way of knowing at this time how successful this feature of Smart Growth will be at redirecting development. If we assume that it is effective, then Montgomery County parcels will be developed in the order forecasted in our business as usual scenario except that any parcel within a PFA takes precedence over parcels outside PFAs. The result for the Northwest Branch is depicted in Figure 8B.

"Rural Legacy Areas" are large contiguous tracts of agricultural, forest, and natural areas designated as receiving top priority for outright public purchase

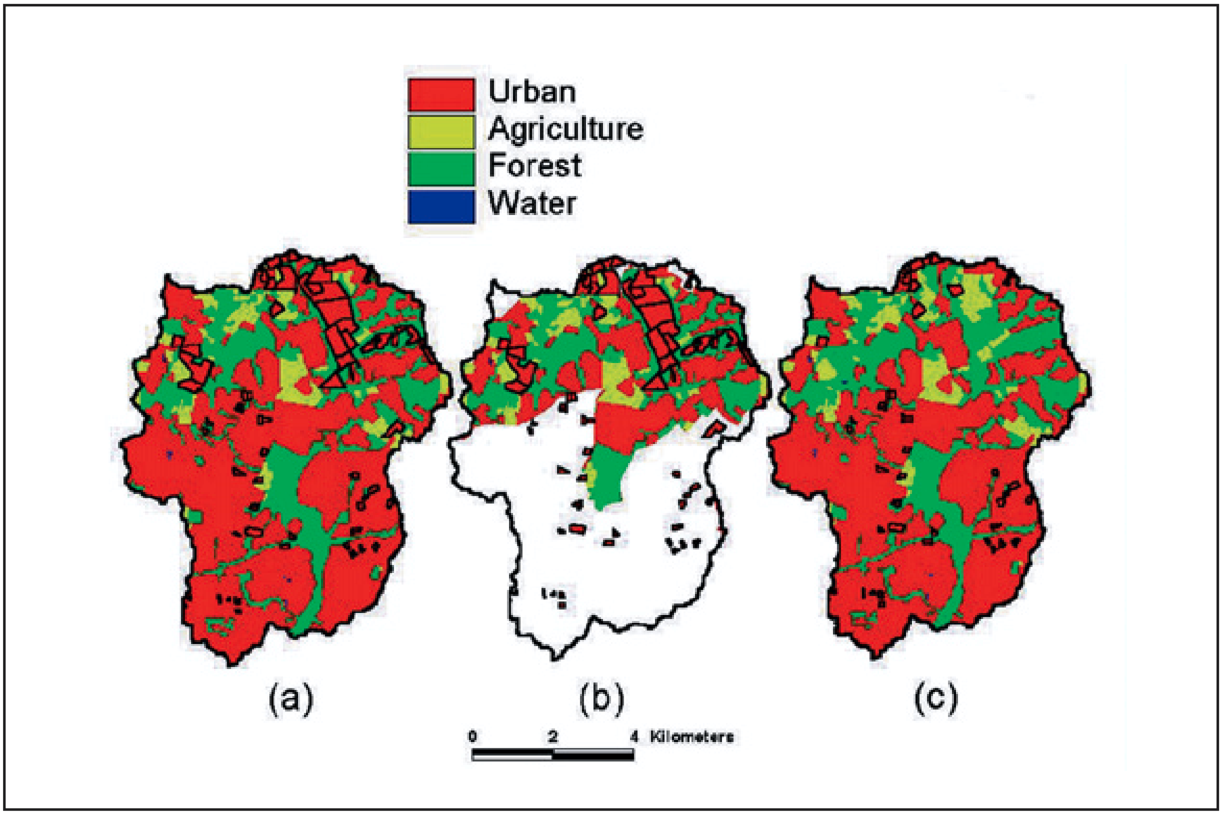


Figure 8A, B, C Alternative 2020 land use distributions in Northwest Branch: "business as usual" (A), "Priority Funding Areas" (B), and "Rural Legacy Areas" (C). Black outlines indicate developable parcels. White areas in (B) indicate location of PFA's. Notice smaller size and fewer number of developable parcels in (C).

or public purchase of development rights, as funds for such purposes become available. While some areas have already been identified as potential candidates, local governments and private land trusts will be encouraged to identify Rural Legacy Areas to be approved or denied by the Maryland Department of Natural Resources. Currently there are no Rural Legacy Areas identified within the Northwest Branch watershed. That does not mean that this feature of the program will not affect this watershed. For one thing, development could well be deflected from other areas that are preserved. For another, the creation of preserved open space affects residential values in the surrounding area and thus alters the relative appeal of remaining developable parcels. To provide further contrast to the "business as usual" and PFA examples above, we propose a hypothetical RLA example in which conservation easements are purchased on all developable parcels exceeding 0.1 km2 within the Northwest Branch, thus fixing the land use on these parcels to remain as it is under current (1997) conditions. This development scenario is shown in Figure 8C. Notice that the developable parcels shown in 8A and 8B are more numerous, and that in 8C the land use where the "missing" parcels would be tends to remain in agricultural or forested land uses.

The land use distributions under these alternative futures are also presented in Table 3. It is interesting to note that by the year 2020, both the "business as usual" and the "PFA" scenarios reach the same endpoint with all parcels being developed. We interpret this to indicate that, although the timing of development differs between these two scenarios, the ultimate hydrologic, geomorphic, and ecological consequences are likely to be the same, being perhaps somewhat delayed in the PFA scenario relative to the "business as usual" case. In contrast, the RLA scenario, because it removes some of the largest parcels from potential development, has a smaller residential fraction and level of imperviousness than do the other two cases and would be expected to have fewer associated deleterious environmental consequences.

Hydrological, Geomorphic and Ecological Implications

Since the quantitative relationships between our empirical measurements will not be made until our sampling is complete in late 2001/early 2002, at this point we can only speculate on the geomorphic and ecological implications of the alternative land use futures of Northwest Branch. In the upper reaches of this watershed, low-density land uses will still predominate in 2020, but the landscape will increasingly be in transition from some agricultural land with mixed forest to a more suburban landscape. The streams will also be in a state of transition, from carrying sediment loads and nutrients associated with past farming activities to a watershed condition that has higher imperviousness. As this area develops and the imperviousness increases, changes in watershed hydrology and ecology are inevitable. Increasing the impervious surface has well known negative consequences for stream ecosystems, caused by increased scour and channel erosion, thermal pollution generated by runoff from hot paved surfaces, and organic and heavy metal pollution largely from roads and car parks.[46] It is also common for the amount of riparian buffer to decline with such urbanization pressures; however, it is possible that there may be a shift towards more riparian forest along Northwest Branch because of the many buffer reclamation projects in this watershed.[47]

In general, we expect the land use change depicted in (Figure 7) to have produced increases in peak flows (the 2- through 100 year-flood events).[48] A change in flow behavior as this watershed has become urbanized over the last 50 years has already occurred, but changes over the next 20 years may further continue this trend (see Table 4). While peak discharges across all magnitude storm events are expected to increase under the urbanization illustrations depicted in Figures 7 and 8, changes in streamflow are likely to be more pronounced at smaller scales (*i.e.*, in the smaller first and second-order watersheds) and to be increasingly damped as the size of the watershed increases. In other words, measurements taken at the outlet of the watershed (*i.e.*, at the southern extreme of the overall watershed) represent an integration of all the incremental sub-watersheds within. Locally the changes are expected to be significant, so one should be careful not to view small predicted changes

[46] Van Buren, M., W. Watt, J. Marsalek and B. Anderson, 2000; See also, EPA. (Orlando, Florida, 1980); See also, Karr, J.R. and E.W. Chu. *Restoring life in running waters: better biological monitoring*. Island Press, Washington, D.C., 1999; See also, Tucker, K.A. and G.A. Burton. 1999. Assessment of nonpoint-source runoff in a stream using in situ and laboratory approaches. *Environmental Toxicology* 18, 2797-2803.

[47] Moglen, G.E. 2000. Urbanization, Stream Buffers, and Stewardship in Maryland. *Watershed Protection Techniques* 3, 676-680.

[48] Moglen, G.E. and R.E. Beighley. Spatially Explicit Hydrologic Modeling of Land Use Change. *Journal of the American Water Resources Association* (2002.).

Table 3 Comparison of land use evolution under three alternative futures in Northwest Branch watershed (see text for full explanation).

Condition or Scenario	Year	Percent Residential	Percent Agriculture	Percent Forest	Percent Impervious
Current	1997	47.2	9.2	28.4	20.1
Business as Usual	2005	53.4	7.1	24.4	21.6
	2010	53.5	7.1	24.4	21.6
	2015	53.6	7.1	24.3	21.7
	2020	53.6	7.1	24.3	21.7
Priority Funding Areas	2005	47.6	9.1	28.1	20.2
	2010	49.5	8.9	26.5	20.7
	2015	53.6	7.1	24.3	21.7
	2020	53.6	7.1	24.3	21.7
Rural Legacy Program	2020	48.0	8.8	28.0	20.3

at the overall watershed outlet as necessarily indicative of uniformly small changes throughout the smaller sub-watersheds nested within.

Table 4 illustrates the integrative nature of the watershed. Notice that the extremes, in terms of minimum and maximum discharge ratios, generally tend toward ratios of 1 with increasing stream order. For example, the minimum ratio in peak discharge, Q_p, at a given 1st order sub-watershed outlet is 0.08 between 1951 and 1997. In other words, for this particular sub-watershed, the 1951 discharge is 8% of the 1997 discharge. In contrast, the minimum ratio increases to 13 and 35% for the 2nd and 3rd order sub-watersheds, respectively. This same pattern can be observed elsewhere in the table.

Table 4 also illustrates the magnitude of change from past land use to the present in comparison to anticipated future changes. Observed at the outlet, the 2-year peak discharge in 1951 was only 73% of what it is currently. Depending on the future scenario being considered, the 2-year peak is only likely to increase 1 (in the RLA scenario) to 5% (in either the "business as usual" or PFA scenarios).

In the middle section of the watershed, there are more stormwater controls than in the lower reaches; however, the stormwater management technologies used are of older designs that are believed to be not as effective as methods used today. The lower reaches of Northwest Branch contain older and more concentrated development, where communities developed long before there were requirements for stream valley protection or stormwater management. The hydrology in these areas has been significantly altered and the stream condition is generally poor or fair. We anticipate that without significant changes in the expected development patterns in this region, increased variance in peak and low flows will occur.

Baseflows are also typically expected to decline with urbanization; however, leaky water distribution systems and homeowner watering patterns in highly residential areas make it difficult to predict how baseflow will respond. This is a research area that needs active investigation and requires a full understanding of not only the stream network and groundwater flows, but also the water supply network, stormwater drainage network, and landowner water use patterns.

For any development scenario, the areas within the watershed where human impacts would cause the most ecological damage will depend on the specific land use, but as a rule of thumb, it is probably safe to say that these areas would mostly be the headwater regions. Deforestation in headwater areas will affect the patterns of sediment transport and carbon cycling in the entire stream. Introduction of impervious surfaces in headwater regions will increase the variability of water discharge in the stream, and this will increase scouring of riparian areas[49] and probably pave the way for invasion of alien plants, etc. There are also cases where impacts in downstream parts of the watershed will affect upstream regions, especially when dams stop upstream migration of anadromous fish and associated patterns of nutrient cycling.

Geomorphologically, we anticipate a spatially and temporally complex pattern of changes that vary with changes in discharge and sediment supply. Channels should increase in size with increasing urbanization,[50] except where sediment eroded from upstream is accumulating in a particular reach.[51] The frequency and extent of bed mobilization should also tend to increase with increasing urbanization, although these variables are complex functions of

[49] Leopold, L.B. *Hydrology for Urban Land Planning: A Guidebook on the Hydrologic Effects of Land Use.* U.S. Geological Survey Circular 554 (1968).

[50] Hammer, T.R., Stream channel enlargement due to urbanization. Water Resources Res 8:1530-1540. 1972; See also, Pizzuto, J.E., W.C. Hession and M. McBride, Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania 2000. Geology 28:79-82

[51] Clark, J.J. and P.R. Wilcock. 2000. Effects of land-use change on channel morphology in northeastern Puerto Rico. *Geological Society of America Bulletin* 112, 1763-1777.

Table 4 Statistics for modeled 2-year peak discharge in Northwest Branch by stream order.

Condition or Scenario	Statistic	Order 1	Order 2	Order 3	Outlet
1997	Q_p mean (m^3/s)	2.35	5.35	12.24	29.4
	Q_p min (m^3/s)	0.40	2.00	8.46	-
	Q_p max (m^3/s)	7.95	9.97	16.62	-
1951:1997	Q_p ratio mean	0.84	0.77	0.79	0.73
	Q_p ratio min	0.08	0.13	0.35	-
	Q_p ratio max	1.00	1.00	1.00	-
2020:1997 (business as usual or PFA)	Q_p ratio mean	1.03	1.05	1.06	1.05
	Q_p ratio min	1.00	1.00	1.00	-
	Q_p ratio max	1.37	1.28	1.12	-
2020:1997 (RLA)	Q_p ratio mean	1.01	1.01	1.01	1.01
	Q_p ratio min	1.00	1.00	1.00	-
	Q_p ratio max	1.11	1.05	1.01	-

channel morphology, flow frequency, and sediment characteristics, and cannot be readily forecasted without detailed analysis. Channel morphology, sediment properties, and hence bed mobility, will also vary with differences in riparian vegetation.[52] Changes in riparian vegetation are only loosely correlated with changes in land use, so, although we can empirically document how riparian vegetation influences present channels, we may not be able to include this variable in our predictive models.

Ecological impacts expected under the future conditions scenario of higher peak flows, lower base flows, less stable beds, and potentially higher sediment loads (at least during the construction phase of development) include loss of species – particularly intolerant invertebrates (mayflies, stoneflies, caddisflies) and fish. We expect poorer water quality, primarily through additions of nitrogen from run-off from fertilized lawns, and an increase in the number of septic fields. With increased impervious area and increased population, we expect an increase in organic and heavy metal pollutants. Increased flow rates and nutrient addition may be ameliorated to some extent if buffer reclamation and stormwater retention projects are successful. With respect to the ecosystem functions, we predict a decrease in retentiveness (due to loss of habitat complexity) that would cause an increase in nutrient spiraling length, *i.e.*, nutrients moving rapidly downstream with little biological uptake locally. However, low nutrient uptake may be countered to some extent if development involves clearing of riparian vegetation that results in higher streambed light levels and thus elevated algal uptake of nutrients.[53] Such compensatory uptake is likely to be small if Montgomery County's current levels of riparian protection and reclamation are maintained.[54] Low nutrient uptake may also be countered if development leads to an increase in the concentration of suspended particulates. Nutrients may adsorb to these particulates and thus nutrient uptake may be seemingly high but for nonbiological reasons. Finally, with more impervious land area, reduced groundwater recharge will lower the contribution of heterotrophic metabolism in the hyporheic zone to the surface waters, thereby increasing the production/respiration (P/R) ratio.[55] Larger channel sizes provide more surface area to be colonized by algae, further amplifying P/R.

POLICY TO PROTECT WATERSHEDS

When watersheds are threatened by development, a frequent recommendation from environmentalists is to identify set-aside areas and protect them from further development. Ecologists would argue that these set-aside areas should be tracks of land that have been identified as environmentally sensitive or of particular ecological importance. The underlying conception is that this strategy will ensure a sustained ecological functioning of the streams and their riparian zones even under the pressure of an increasing human population density. The goals of this strategy are to avoid diffusive disturbance of the watershed and local disturbance of critical areas. These goals are consistent in principle with

[52] Sweeney, B.W. 1992. Stream forests and the physical, chemical, and trophic characteristics of Piedmont streams in Eastern North America. *Water Science Technology* 26, 2653-2673; See also, Reed, J.E. 133 (University of Delaware, Newark, DE, 1999).

[53] Sabater, F, A. Butturini, E. Marti, I. Muñoz, A. Romani, J. Wray, S. Sabater. 2000. Effects of riparian vegetation removal on nutrient retention in a Mediterranean stream. *Journal of the North American Benthological Society.* 19: 609-620.

[54] Moglen, G.E., 2000. "Urbanization, Stream Buffers, and Stewardship in Maryland." *Watershed Protection Techniques*, 3(2): 676-680.

[55] Findlay, S. 1995. Importance of surface-subsurface exchange in stream ecosystems: the hyporheic zone. *Limnology and Oceanography* 40, 159-164.

the goals of the Smart Growth policies being adopted by Maryland, but because the development decision is a complex one, it is not obvious that such policies will achieve this end.

Critical areas are generally divided into two types: (1) areas that meet certain evaluation criteria, and (2) areas that are valuable for ecosystem functioning or integrity. Four of the most frequently used and useful criteria for selecting areas to preserve are diversity, rarity (*e.g.*, endangered species), naturalness, and size. The identification and conservation of species-rich (diverse) areas have intuitive appeal particularly if they harbor rare or endangered species. Preservation of undeveloped land, particularly large tracks of "natural" lands, represents an obvious target for conservationists, particularly if these are situated in a matrix where development is fairly significant. We suggest that it is important to answer two questions: (1) Is there scientific evidence that setting aside areas for protection in watersheds, and clustering development in other areas, will improve the ecological condition of freshwaters? and (2) even if this is attractive from an environmental perspective, can we identify policies we know with confidence will lead to this type of Smart Growth?

THE NEED TO CONSIDER THE UNINTENDED CONSEQUENCES OF POLICIES

In our case study, we began with a story in which a certain number of new dwelling units are expected to be built each year. Can we restrict the number that are being added and divert those homes from critical or undeveloped areas to areas already developed? For legal reasons, most land use policies are quite indirect. Local governments in Maryland have historically adopted large lot zoning and withheld public utilities in order to discourage development in largely rural areas. However, this has resulted in unintended consequences. In an attempt to make development less profitable in these areas, the counties have produced a situation in which, if development happens, it involves the addition of septic fields and wells, making previously undeveloped areas more environmentally vulnerable. Further, the developed land is fragmented and low density, making it expensive to provide other public services. In Maryland and many other places, the prices people are willing to pay for land at the rural-urban fringe more than makes up for the added costs to developers of developing in this way.

Since local governments set most land use policy, some counties have discouraged diffuse development (*e.g.*, by setting extremely large minimum lot sizes). The problem is that housing markets often transcend individual jurisdictional boundaries, so the development is simply shifted to the next county that may be within the same sub-watershed.[56] Thus, policies may be needed at much larger (*e.g.*, statewide or regional) scales. Maryland's two "Smart Growth" initiatives, Priority Funding Areas and the Rural Legacy Program,[57] are both designed to be effective at statewide or regional scales.

Whether policies such as Smart Growth will have the intended effects – to identify critical areas, halt further development in these areas, and shift

[56] Bockstael, N. and K. Bell. 1997. "Land Use Patterns and Water Quality: The Effect of Differential Land Management Controls". In *International Water and Resource Economics Consortium, Conflict and Cooperation on Trans-Boundary Water Resources*, Richard Just and Sinaia Netanyahu, editors. Kluwer Publishing.

[57] Maryland Department of Planning (2000). "Land Use / Land Cover in Maryland by Political Jurisdiction". Planning Data Services Division, GIS Section, Baltimore, MD.

development patterns to infill – is an empirical question; however, it would be incorrect to assume that all further development will occur in the target zones. If the policy is effective in targeting growth, we still need to determine the environmental effects of higher intensity development in areas already partially developed. Is it necessarily better from an ecological perspective to have large contiguous areas that are almost completely impervious? If it isn't effective, where will the development occur and at what densities?

The Need for Outreach Efforts

While much more research is needed on the environmental effects of the *pattern* of development as well as when policy instruments may or may not be effective, efforts to involve the public should not be delayed. Educating the public about the environmental effects of an individual's actions in particular and urban sprawl in general should be considered key ingredients to successful watershed management and stream protection plans. As the waste recycling movement has clearly shown, aggressive and focused public outreach and education can do wonders to change public behavior to reduce impacts on the environment. Aggressive enforcement of pollution laws is also critical, but likely to fail or be less successful without an initial and sustained public education effort to make people aware of their personal stewardship responsibilities and related legal requirements and penalties for noncompliance.

Jurisdictions need to pursue public outreach activities much more aggressively. However, since the research we argued for will take years to complete, for now, they must rely on what science is available *and* their intuitive sense of what will do some good. There are certainly examples around where well-designed and funded public outreach programs have been very effective despite the fact that public outreach is generally one of the first things to be cut in budgets, particularly in difficult economic times.

In this paper, we have focused on addressing the ecological impacts of land use change by integrating diverse scientific and economic principles. But our focus has been primarily on the physical and ecological effects of different spatial configurations and densities of development. Models can also be developed to consider how the behavior of people in these places can significantly influence the actual versus predicted impact. For example, the Center for Watershed Protection has recently developed desk top models for estimating the effects of residential education in reducing nutrients from lawn overfertilization, inadequately maintained septic tanks, and pet wastes not picked up and properly disposed by pet owners.[58] This work often involves research in the form of public surveys and monitoring studies of targeted populations to judge the effectiveness that sustained public outreach may have when combined with legislation aimed at directing growth away from or to certain areas.

No matter what land use patterns emerge (*e.g.,* Smart Growth vs. sprawl), the habits, traditions, and behavior of people and businesses who populate the

[58] Caraco, D. *The Watershed Treatment Model,* Version 3.0. Center for Watershed Protection, Ellicott City, MD, 2001.

land will dramatically affect the final impacts on fresh waters. For example, nutrient loading scenarios are generally modeled based purely on empirical data of nutrient levels washing off different land use types. How do we adjust these models to account for people's varying behavior in fertilizing their lawns? In their efforts to achieve that artificially perfect and uniform green monoculture lawn, the Center for Watershed Protection estimates that 78% of individuals fertilize their lawns and that 65% of these overfertilize (more than twice/year). Conversely, some people never fertilize their lawns once they're originally established. The CWP estimates that 70% of the "overfertilizers" can be induced to voluntarily change their behavior. What if one jurisdiction pursued a major, continuing, multi-media, multi-cultural public outreach effort and actually succeeded in reducing use of lawn fertilizers by 50% or more? What if another jurisdiction judged nutrient loading problems to be so bad that it actually banned the fertilization of established lawns? This approach would be no more radical than the very successful ban on phosphate-based laundry detergents adopted to protect the Great Lakes and the Chesapeake Bay. Nor is it much different from the idea of banning of lawn watering in times of drought.

Using Policy, Science-Based Tools, and Public Outreach for Watershed Protection: The Case of Montgomery County

In 1998, Montgomery County, MD developed its *Countywide Stream Protection Strategy* (CSPS)[59] to enhance public understanding of why a quantitative, science-based understanding of local stream conditions and watershed management strategies was needed. Prior to this, watershed protection investments in stream buffers, stream restoration, and remedial stormwater management controls were uncoordinated among agencies and scattered geographically resulting in costly and relatively ineffective use of limited resources for environmental protection.

The Montgomery County Department of Environmental Protection (DEP) designed a program: (1) to develop science-based water quality information which would serve as the basic building block for reaching out to and educating the general public on watershed protection issues; (2) to explain how the county was addressing water quality problems with capital projects, education, and enforcement programs to reduce pollution sources; and (3) to help the public better understand and contribute to problem resolution by personally serving as stream protection stewards in their own watersheds.

To provide a framework for pursuing these objectives, DEP decided to collect biological and habitat data to evaluate stream conditions in its subwatersheds. To build consensus for this undertaking and later acceptance of results, DEP convened a Biological Monitoring Workgroup representing local and state monitoring agencies, environmental consultants, and environmental groups. This diverse group of scientists, engineers, citizens, and environmental community representatives quickly and remarkably reached consensus on sampling and analytical methods and data sharing protocols.

[59] Montgomery County Department of Environmental Protection. Countywide Stream Protection Strategy. http://www.co.mo.md.us/services/dep/Watershed/csps/csps.html. 1998.

DEP and partner agencies and volunteers collected biological information, and these data served as primary indicators to rank stream conditions in familiar, easy to comprehend "excellent, good, fair, or poor" terms (*e.g.*, see Figure 6). This type of information was useful to citizens in their own neighborhoods, but also allowed the county to use extensive GIS applications to identify and integrate land cover, zoning, and impervious area information by subwatershed and relate it directly to observed stream rankings. The county was then able to classify subwatersheds into management categories and designate priority subwatersheds based upon analysis of observed stream conditions and impacts from existing or planned development. Specific management tools were identified to address typical stream impacts found within with each management category.

What Montgomery County has done with CSPS represents an unusually proactive and focused effort by a local government, not only to develop stream and watershed protection goals, but also to involve and engage the public and elected officials in the process. The CSPS guides interagency cooperation in watershed monitoring and in the targeting of management programs. It stimulates citizen and business awareness and activism as essential components of subwatershed protection initiatives to protect neighborhood streams. It is used by the County Planning Agency to integrate consideration of stream resources directly into decision processes on land use alternatives and into legal land use master plan documents. County funding is now directed and scheduled to achieve specific stream protection goals in designated CSPS priority subwatersheds. The Montgomery County Executive and County Council have backed up their endorsement of the CSPS with budget actions authorizing a $26 million capital improvements program to support targeted stream restoration initiatives in 99 designated CSPS priority subwatersheds. Thus far, 22 projects have been completed and another 83 are in design or construction. Projects implemented thus far in the highly urbanized, 35% impervious Sligo Creek watershed have helped improve the stream's biological community from a "poor" to a "fair" rating. The creek now successfully supports 13 native fish species where once only 3 species were found. Amphibian populations were also restored to areas where new wetland habitats were created to help slow down and clean up storm drain discharges that had previously entered directly into the creek

Montgomery County has also used the scientific underpinning of the CSPS as a powerful educational and guidance tool to gain and sustain public awareness and interest in water quality management programs. The CSPS document has been widely disseminated for public review. The final CSPS report is easily accessed on the Internet (www.askDEP.com). This web site also contains many other creative and interactive data presentations and brochures on all aspects of watershed management roles that citizens can play in personal pollution prevention and stream stewardship. Recently, the National Association of County Officials (NACO) gave the county its 1999 Achievement Award for its efforts to develop and implement the CSPS, and neighboring jurisdictions are now developing stream protection strategies using the CSPS as its model.

We close with this final focus on the Montgomery County efforts because they illustrate that, while we need a great deal more scientific research to understand and forecast how land use change will influence the flow, morphology, and ecological integrity of rivers and streams, successful and proactive watershed protection is possible. The merger of state-of-the-art science, proactive policies, and creative outreach can make a difference.

ACKNOWLEDGEMENTS

This work was supported by grants from the STAR Program of the Environmental Protection Agency. We wish to thank the many students and colleagues who are involved in various aspects of this research, but particularly Ed Beighley, Brooke Hassett, and Suzanne Olyarnik.

MARGARET A. PALMER is Professor of Biology at the University of Maryland (UM). She has also served as the Director of the Ecology Program at the National Science Foundation (NSF), Director of the Biological Sciences Program at UM, and visiting scientist at the Smithsonian Institution. She was recently named an Ecological Society of America Aldo Leopold Leadership Fellow. Her past awards also include being named a Distinguished Scholar-Teacher and a Lilly Fellow. She has contributed numerous papers in peer-reviewed journals on a broad range of marine and freshwater ecological topics, including the relationship between biodiversity and ecological processes in freshwater ecosystems and the influence of global environmental change on biodiversity linkages between land and freshwater ecosystems. She has edited and reviewed for many journals, among them *Limnology & Oceanography, Freshwater Biology, BioScience, Ecology,* and the *Journal of Marine Research.* She currently serves on the Scientific Advisory Board for NSF's National Center for Ecological Analysis and Synthesis. She has an undergraduate degree in Biology from Emory University in Georgia, and graduate degrees in Oceanography from the University of South Carolina.

Margaret A. Palmer, Department of Biology, University of Maryland, College Park, MD 20742 mp3@umail.umd.edu

Glenn E. Moglen, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742

Nancy E. Bockstael, Department of Agricultural and Resource Economics, University of Maryland, College Park, MD 20742

Shane Brooks, Department of Biology, University of Maryland, College Park, MD 20742

James E. Pizzuto, Department of Geology, University of Delaware, Newark, DE 19716

Cameron Wiegand, Department of Environmental Protection, Montgomery County, Rockville, MD 20850

Keith VanNess, Department of Environmental Protection, Montgomery County, Rockville, MD 20850

Water Management in the Binational Texas/Mexico Río Grande/Río Bravo Basin

Mary E. Kelly
Executive Director, Texas Center for Policy Studies

ABSTRACT

The 180,000 square mile binational Río Grande basin presents a full range of complex water management challenges:

- An arid region, with limited surface and groundwater supplies;
- Rapidly growing population centers and an economic shift from agriculture to trade, manufacturing and tourism;
- A river system that has been dammed, diverted and largely managed for agriculture;
- A lack of incentives or funds for improving irrigation efficiency;
- Simmering rural/urban conflicts, particularly over groundwater;
- Aquatic ecosystems that have suffered damage from reduced stream and spring flows and from river channelization projects;
- Areas where municipal, industrial or agricultural discharges have caused severe water quality problems;
- Difficulties in meeting basic water needs of low-income populations in an affordable manner;
- In some areas, water management decision-making that suffers from a lack of basic data about water availability, water use and projected demands;
- A complex (and somewhat outdated) set of local, state, and federal laws and institutions affecting water policy management; and,
- A U.S./Mexico water treaty that is increasingly less than adequate for dealing with the binational management challenges facing the basin.

These difficult, but pressing, challenges demand that policymakers begin looking at water management in the Río Grande basin in new ways. In addition to increasing public awareness of the limits on water supply in the basin, long-held notions about the relationships among growth management, economic development and water supply, as well as about how water should be used in urban and rural areas, will have to be re-examined.

The importance of irrigated agriculture – to food production, local economies and a rapidly disappearing way of life in the basin – cannot be ignored, but the level of attention and resources devoted to making irrigation systems efficient must be greatly increased.

Moreover, if we are to preserve a semblance of the natural river system in the basin, adjustments will have to be made to help re-establish and protect instream flows and springs. And, finally, in this basin, there is an urgent need to improve – and maybe even renegotiate – the U.S./Mexico framework for management of transboundary water resources.

INTRODUCTION

> *The Río Grande, long an adequate though never voluminous river except in flood tide, has been attended in modern times by concerned management in its government conservancy districts; but in many places the river has become only a trickle, and in other entirely dry, to be replenished only by flood from otherwise dry or meager local tributaries and by diminishing groundwater, this always in the face of increasing needs of its resources in both the United States and Mexico. –Paul Horgan*[1]

> *...we need to double water productivity – get twice as much benefit from each liter of water we remove from rivers, lakes and underground aquifers – if we are to have any hope of fulfilling the water requirements of 8 billion people and protecting the natural ecosystems on which economies and life itself depend. Meeting this challenge will involve making irrigation leaner and smarter.... –Sandra Postel*[2]

[1] Paul Horgan, *Great River: The Río Grande in North American History* (Wesleyan University Press: Hanover, NH 1984; preface to the 4th edition).

[2] Sandra Postel, *Pillar of Sand: Can the irrigation miracle last?* (W.W. Norton & Company; New York; 1999).

The Río Grande basin encompasses 180,000 square miles and covers portions of three U.S. states and five Mexican states (Figure 1). From the New Mexico/ Texas state line, the river runs just over 1,200 miles to the Gulf of Mexico. There are only a few major tributaries in this part of the basin: most important are the Río Conchos, which has its headwaters high in the Sierra Madre Occidental in Chihuahua, and the Pecos River, which begins in New Mexico and flows through a vast areas of West Texas before reaching the Río Grande. Most of the other significant tributaries lie in the Mexican portion of the basin, including the Ríos San Diego, San Rodrigo, Escondido, Salado, Alamo and San Juan.

Most of the Texas/Mexico Río Grande basin is characterized by low and sporadic rainfall, limited streamflow and low groundwater recharge rates. A notable exception is the high Sierra Madre Occidental in Chihuahua, a region of pine and oak forests.

From the New Mexico/Texas state line to just below El Paso, the river has been channelized, re-routed and otherwise managed more as an international boundary than a river system. Flow through this stretch is almost entirely dependent upon releases from two large upstream Bureau of Reclamation dams, Elephant Butte and Caballo. Completed in 1916 and 1939, respectively, these reservoirs are managed almost solely in response to the water demands of growers in the irrigation district of the Elephant Butte and El Paso Water Control and Improvement District (WCID). They are also used to supply Mexico with 60,000 acre-feet/year of Río Grande water, under a 1906 treaty.

From downstream of El Paso to just above the confluence with the Río Conchos, the flow of the river is severely reduced. This "Forgotten River" stretch is an isolated portion of the river, with only relatively smaller scale irrigation uses.

In normal rainfall years, the Río Grande is replenished by large flows from the Río Conchos, just above the sister cities of Presidio and Ojinaga.[3] The Conchos basin itself is heavily managed, with several large reservoirs having been constructed, primarily to supply irrigation districts. Most of the municipalities in the Conchos basin supply demand with local groundwater reserves.

Downstream of the confluence, the river flows through a series of large protected natural areas, including the Big Bend Ranch Texas State Park, the Cañon de Santa Elena and Maderas del Carmen protected areas in Mexico and Big Bend National Park. Downstream of Big Bend National Park to Amistad Reservoir, the river has been designated a Wild and Scenic River under U.S. federal law. River rafting is a popular and economically significant activity in this stretch.

Amistad Reservoir and the downstream Falcon Reservoir, both administered jointly by the U.S. and Mexico, are the primary water storage and supply structures on the Texas/Mexico stretch of the Río Grande. Completed in 1968 and 1953, respectively, they supply water for irrigation and cities on both sides of the lower stretch of the river. Together, these reservoirs provide a firm annual yield of about 1 million acre-feet/year.[4]

[3] Recent prolonged droughts in Chihuahua and increasing use of the Conchos have severely reduced its flows to the Río Grande in recent years. See section below on Water Availability; see also Mary E. Kelly, *The Río Conchos: A Preliminary Overview* (Texas Center for Policy Studies: Austin, TX, 2001, available online at www.texascenter.org/borderwater).

[4] Firm annual yield refers to the dependable supply, considering drought-of-record years.

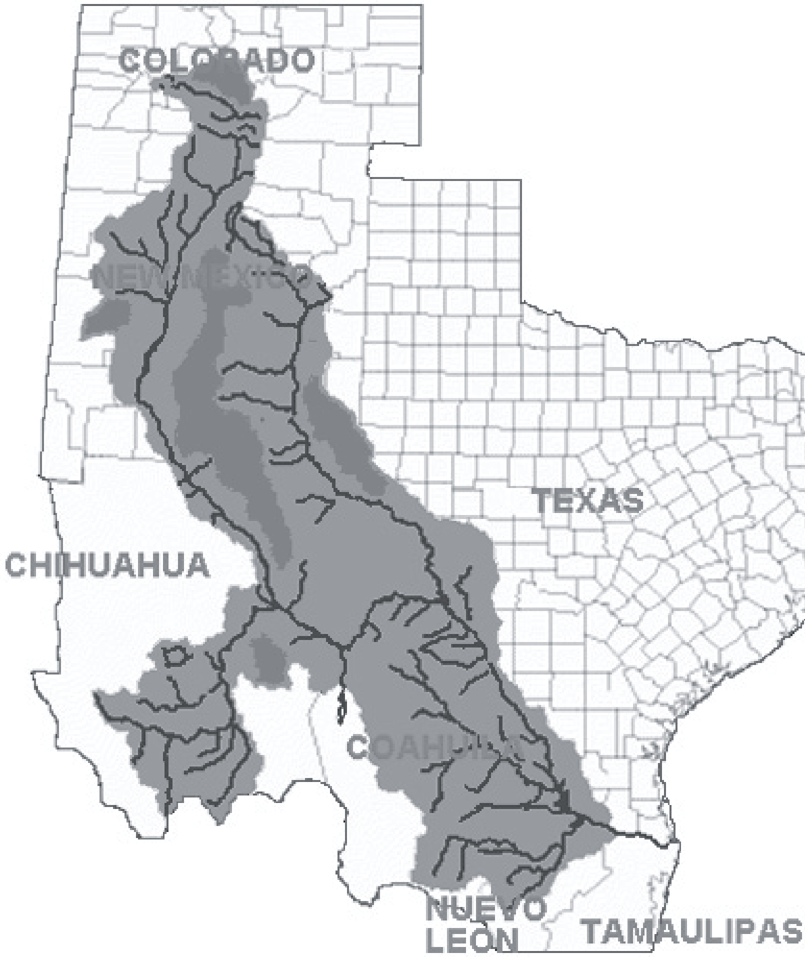


Figure 1 Río Grande Basin Map Source: Río Grande/Río Bravo Basin Coalition

Downstream of the Amistad/Falcon system, water is diverted directly from the river through a series of irrigation diversions and municipal pumping. The only major inflows in this reach are from the Río Alamo and the Río San Juan, both of which have been extensively developed for agricultural and municipal use in the Mexican portion of the basin.[5]

The watershed narrows considerably as the river flows toward the Gulf.[6] By the time it reaches the sea, the Río Grande has been reduced to a trickle, compared to pre-1962 average flows of almost 2.4 million acre-feet/year. In February 2001, the river failed to even reach the Gulf, as a sand bar formed across Boca Chica Bay. Officials claimed the sand bar was the result of unusual wave action, not solely reduced river flow, but the symbolism was not lost on the public or policymakers.[7]

[5] See Jurgen Schmandt, et al. *Water and Sustainable Development in the Binational Lower Río Grande/Río Bravo Basin.* Final Report to EPA/NSF Water and Watersheds grant program (Grant No. R 824799-01-0), (Houston Advanced Research Center, Center for Global Studies: The Woodlands, Texas, March 31, 2000 (available on-line at www.harc.edu/mitchellcenter/mexico/lrgv.html) (hereinafter HARC report) for a full discussion of management issues on the San Juan basin, and the relationship to growing water demand in the large industrial cities of Monterrey, Nuevo Leon and Saltillo, Coahuila.

[6] Irrigation return flows do not go back to the Río Grande in this reach; instead they pass through a series of canals and end up in the Laguna Madre of Texas or the Laguna Madre of Tamaulipas, both valuable hypersaline estuaries.

[7] See, e.g., "Río Grande flow interrupted by sand bar" *San Antonio Express News*, February 11, 2001.

POPULATION GROWTH

Population in the Texas/Mexico portion of the Río Grande basin is concentrated in several large urban areas, many of which are growing at extraordinary rates.[8] Table 1 shows the 1990-2000 population figures for the Metropolitan Statistical Areas (MSAs) in the Texas portion of the basin, and Table 2 shows comparable figures for major cities in the Mexican portion of the basin. The number of people living in the Monterrey area, the largest Mexican city in the basin, increased seven-fold between 1950 and 1995. Most rural areas of the basin are not densely populated; some are losing people or growing at very slow rates, though others are predicted to grow substantially over the next 50 years.

Table 1 1990-2000 Population in Major Metropolitan Areas of the Texas Portion of the Basin

MSA	1990	2000	% change
McAllen-Edinburg-Mission	383,545	569,463	48.47
El Paso	591,610	679,622	14.88
Brownsville-Harlingen-San Benito	260,120	335,227	28.87
Laredo	133,239	193,117	44.94

Source: 2000 Census Data, U.S. Census Bureau

Table 2 1990-2000 Population in Major Municipal Areas of the Mexico Portion of the Basin

Municipal Area	1990	2000	% change
Cd. Juarez	798,500	1,217,818	52.5
Cd. Chihuahua	609,059	670,208	10 (5-year)
Cd. Acuña	41,947	110,388	163
Piedras Negras	80,291	127,898	59
Nuevo Laredo	203,285	310,277	53
Monterrey	1,069,238	1,108,499	3.7
Reynosa	211,411	417,651	98
Matamoros	238,839	416,428	74

Sources: 1990 data: James Peach and James Williams, "Population and Economic Dynamics in the U.S.-Mexican Border: Past, Present and Future" in Paul Ganster, ed., *The U.S.-Mexico Border Environment: A Road Map to a Sustainable 2020* (Southwest Center For Environmental Research and Policy: San Diego State University Press, 2000), Chapter IV; 2000 data: Instituto Nacional de Estadísticas y Geografía, 2000 Census of Population and Housing, available on-line at www.inegi.gob.mx (Información por Entidad Federativa).

[8] For a more complete discussion of U.S./Mexico border area population trends, see the August 1999 issue of *Borderlines*, a monthly periodical published by the Interhemispheric Resource Center, available on-line at www.us-mex.org/borderlines. For extensive information on population and demographic trends in Monterrey and the lower portion of the Río Grande basin, see HARC report, supra, Chapter 3.

Demographic trends in the basin are characterized by a movement of people to urban areas, particularly Mexican cities right along the border, as well as high rates of natural increase in the population (due to a young population and, in some areas, high fertility rates). People have been attracted to the Mexican border cities by the presence of the maquiladora industry – these are plants, largely owned by U.S. and Asian companies, that conduct a variety of light manufacturing and product assembly operations. Mexico implemented the program in the early 60's in an attempt to meet its burgeoning need for employment, but it was not until the devaluations of the Mexican peso in the early 1980s that the program exploded.[9] There are now almost 3000 maquiladoras in Mexico, employing close to 1 million people, and maquiladora products represent the second largest source of export earnings in Mexico. Table 3 shows the number of maquiladoras and employees in major cities in the Mexican portion of the Río Grande basin.

[9] The 1994 devaluation of the peso (right after the North American Free Trade Agreement went into effect) caused another maquiladora growth spurt. Peso devaluations make wage rates in Mexico (which run about $1/hour in the maquiladoras) even more attractive to U.S. and other foreign companies.

Table 3 Maquiladoras in Major Municipal Areas in the Mexican Portion of the Basin

Area	YR	# Plants	# Employees	YR	# Plants	# Employees
Juárez	1980	121	42,412	2000	312	255,740
Cd. Chihuahua	1980	19	4,451	2000	85	52,722
Matamoros	1980	50	15,314	2000	38	14,475
Piedras Negras	1993	42	9,122	2000	38	14,475
Cd. Acuña	1992	50	18,615	2000	57	32,289
Nuevo Laredo	1993	54	16,418	2000	55	22,050
Reynosa	1993	78	34,258	2000	122	64 ,877

Data from December of each year; Source: Instituto Nacional de Estadísticas y Geografía, www.inegi.gob.mx.

Demographers predict that, even if fertility rates were to decrease and migration to the northern Mexican border were to slow, population growth in the border area will continue at high rates.

Population dynamics along the border suggest some demographically important patterns that permit forecasts regarding the future. First, Mexican municipios have shown strong natural increase – the excess of births over deaths – and levels of natural increase have traditionally been greater on the Mexican side of the border. But levels of natural increase on the U.S. side along the border, though generally lower than on the Mexican side, historically exceed the U.S. average.

To this strong natural increase is added the factor of an age distribution – especially on the Mexican side of the border – that favors future natural increase. Differences in age distribution across the border reveal that Mexican municipios have more "demographic momentum" than U.S. counties.[10]

[10] James Peach and James Williams, "Borderlands Demographic Trends", in *Borderlines*, August 1999 (Interhemispheric Resource Center: Silver City, New Mexico, available on-line at www.us-mex.org/borderlines).

Table 4 shows projected populations for some of the major urban areas in the Texas/Mexico portion of the Río Grande basin. One source predicts that the combined Las Cruces/El Paso/Juárez region could reach 6 million people by 2025 (compared to a current combined population of about 2 million).[11] The combined population of both sides Lower Río Grande Basin and Monterrey is expected to increase from about 5 million to 11 million by 2030.[12] Unquestionably, if such growth were to occur there or in other areas of the basin, it would put an untenable strain on water resources if current use patterns were to remain largely unchanged.

Table 4 2020 Population Projections from Major Municipal Areas in the Río Grande Basin

Area	"High" 2020 Scenario	"Low" 2020 Scenario	2000
El Paso	1.287,217	906,332	679,622
Laredo/Webb County	583,653	253,445	193,117
McAllen-Edinburg Mission/Hidalgo County	1,457,516	683,960	569,463
Brownsville-Harlingen-San Benito/ Cameron County	688,835	420,140	335,227
Cd. Juárez	3,166,092	1,676,142	1,217,818
Cd. Acuña	492,484	146,798	110,388
Piedras Negras	262,996	197,117	127,898
Nuevo Laredo	728,248	450,103	310,277
Reynosa	742,085	535,293	417,651
Matamoros	854,216	610,587	416,428

Sources: 1990 data: James Peach and James Williams, "Population and Economic Dynamics in the U.S.-Mexican Border: Past, Present and Future" in Paul Ganster, ed., *The U.S.-Mexico Border Environment: A Road Map to a Sustainable 2020* (Southwest Center For Environmental Research and Policy: San Diego State University Press, 2000), Chapter IV; HIGH Scenario = continuation of 1990-1995 migration pattern by age and sex; LOW = Migration rates set to zero after 1995 to illustrate growth from natural births/deaths in existing population.

A CHANGING ECONOMIC BASE

Local economies change over time, but in few places has such change been so dramatic and occurred so rapidly as in the Texas/Mexico portion of the Río Grande basin. Over the last few decades, the local economies in several areas of the basin have been radically transformed from heavy reliance on agriculture, including irrigated agriculture, to dependence on light manufacturing, transportation, trade, services and, increasingly, tourism.

[11] James Peach and James Williams, "Population and Economic Dynamics in the U.S.-Mexican Border: Past, Present and Future" in Paul Ganster, ed., *The U.S.-Mexico Border Environment: A Road Map to a Sustainable 2020* (Southwest Center for Environmental Research and Policy: San Diego State University Press, 2000), Chapter IV

[12] HARC report, supra, Chapter 3.

For example, local economies in the El Paso, Laredo, McAllen and Brownsville areas are now dominated by retail trade, services, light manufacturing and transportation, though agriculture continues to play an important role, especially in the Lower Río Grande Valley. Table 5 provides some basic economic data on the economies of the major Texas cities along the Río Grande. The transformation in cities in the Mexican portion of the basin has been even more striking. For example, Ciudad (Cd.) Juárez now has over 300 maquiladoras, employing over 250,000 people.[13] Table 6 shows the transformation in the Juárez economy between 1970 and 1990.

[13] U.S. Environmental Protection Agency and SEMARNAP, *U.S.-Mexico Border Environmental Indicators* (U.S. Environmental Protection Agency: Washington, D.C., 1997, available on-line at www.epa.gov/usmexicoborder/indica97).

Table 5 Economic Characteristics of Major Areas in the Texas Portion of the Basin

Non-Farm Employment Composition (%) as of Jan. 2001)	El Paso	Laredo/Webb	McAllen-Edinburgh Edinburgh-Mission/ Hidalgo County	Brownsville Harlingen-San Benito/ Cameron County
Mining (includes oil & gas)	0	2	1	0
Construction	5	4	6	4
Manufacturing	15	3	8	11
Transportation, communication, public utilities	6	19	4	5
Trade (wholesale & retail)	25	24	26	24
Financial, Insurance Real Estate	4	4	3	3
Services	24	21	26	30
Federal Government	3	3	3	3
State Government	3	2	3	3
Local Government	15	18	21	17
Market Value of Agricultural Products Sold (1997)	$76,673,000	$28,198,000	$197,235,000	$79,414,000

Sources: Texas Workforce Commission, Labor Market Information (www.twc.state.tx.us/lmi/lfs/lfshome.html; USDA 1997 Census of Agriculture, Highlights for Texas (www.nass.usda.gov/census97/highlights/tx/tx.htm).

Table 6 Transformation of Cd. Juárez Economy Between 1970 and 1990

% Employment by Sector	1970	1980	1990
Extraction	0.3	0.2	0.16
Assembly/Manufactiring	17.7	21.6	41.3
Construction	8.2	6.8	7.9
Electricity Production	0.4	0.2	0.48
Commerce	17.8	14.3	14.6
Communication and Transportation	4.2	5.2	3.7
Services	31.1	15	26.7
Agriculture	8.7	3.1	1.3

Source: Cesar M. Fuentes, "Usos del Suelo y Configuración de la Estructura Urbana en Cd. Juárez' in *Río Bravo Journal* Vol. 2 (1):3.

Other border river cities like Cd. Acuña, Piedras Negras, Reynosa and Matamoros are also heavily dependent on the maquiladora industries, even though only a few decades ago they were sleepy small towns serving, tied to local agricultural and ranching activities. A few of the Mexican border towns just below Falcon dam, such as Camargo, Guerrero and Diáz Ordaz, have not yet had a major influx of maquiladoras, and their population has remained stable or even decreased.

These economic transformations have not necessarily fostered prosperity on a broad scale, however.[14] Unemployment and poverty rates remain high and average per capita income remains low in many areas of the Texas border, though there has been some improvement in the last decade. (Tables 7 and 8 and Figure 2). Despite the growing industrial base, poverty is endemic in Mexican border cities, with 65 to 70% of the population in most of the Mexican border cities in the basin living below poverty levels (defined as three times minimum wage).[15] Even though new jobs are provided by the maquiladoras, the wage rates are low, especially relative to the cost of living.

[14] Office of the Texas Comptroller, *Bordering the Future* (Texas Comptroller: Austin, TX, 1998, available on-line at www.window.state.tx.us/border/border.html) (Chapter 2 – Growth Without Prosperity?) and Alejandro Canales, "Industrialization, Urbanization and Population Growth on the Border" in Borderlines, August 1999 (Interhemispheric Resource Center: Silver City, New Mexico, available on-line at www.us-mex.org/borderlines).

[15] E. Su·rez and O. Ch·vez, *Profile of the U.S./Mexico Border* (Infomexus: CD. Juarex; 2000), p. 70.

Table 7 Average 2000 Employment Mix in Selected Major Municipal Areas in the Mexican Portion of the Basin

% Employment by Sector	Cd. Juárez	Cd. Chihuahua	Nuevo Laredo	Monterrey	Matamoros
Agriculture, Livestock, Hunting, Fishing	0.3	1.4	0.5	0.2	0.7
Extractive & Electricity Production	0.5	0.8	0.8	0.6	0.7
Manufacturing/Assembly	43.1	28.9	21.8	29.4	39.1
Construction	3.5	8.1	8.3	8.2	7.1
Commerce/Trade	16.0	18.6	17.1	19.2	15.2
Services	27.6	31.0	32.0	32.9	27.0

NOTE: Totals do not add to 100% because of 12-month average of monthly data. Source: Instituto Nacional de Estadísticas y Geografía, Incadadores Económicos de Coyuntura, available on-line ar www.inegi.gob.mx (Infromación por Entidad Federativa).

Table 8 Per Capita Income in Major Metropolitan Areas in Texas Portion of the Border

Area	1998 Per Capita Income	% Below Poverty (1997)	1993 Per Capita Income	% Below Poverty (1993)
El Paso	16,359	27.8	12,790	36.6
Laredo/Webb	13,870	32.6	10,757	46.9
McAllen-Edinburgh-Mission/Hidalgo County	12,759	37.6	10,085	52.2
Brownsville-Harlingen-San Benito/Cameron Co.	13,766	35.3	11,042	49.8
Statewide	25,369	16.7	19,145	24

Sources: 1998 Per Capita Income: Texas Department of Economic Development, www.bidc.state.tx.us/overview/16metropci.htm; 1997 Poverty levels: U.S. Census Bureau, www.census.gov/hhes/saipe/stcty/997_48.htm; 1993 Per Capita Income: Texas Comptroller, Texas Area Facts (Austin, TX: 1996); 1993 Poverty Levels: E. Suárez and O. Chávez, Profile of the U.S./Mexico Border (Infomexus: CD. Juarez; 2000), p. 70.

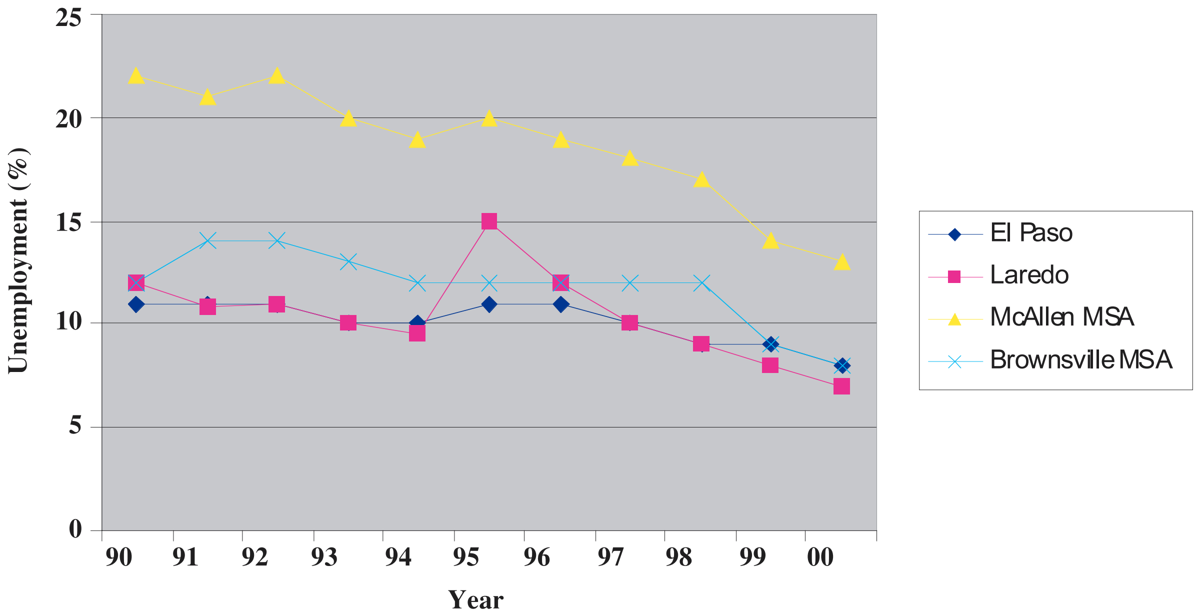


Figure 2 Unemployment Rate Trends in Major Municipal Areas in Texas Portion of the Basin Source: Data from Texas Workforce Commission, annual average rate. Data available at www.twc.state.tx.us/lmi/lfs/lfshome.html.

The rapid industrialization and growth of urban areas in the basin has imposed severe stress on schools, roads and, especially, on water and wastewater infrastructure. In an attempt to address these infrastructure needs, the U.S. and Mexico established the binational Border Environment Cooperation Commission (BECC) and the North American Development Bank (NADBank) in a side agreement to the North American Free Trade Agreement (NAFTA).[16] While some progress has been made in funding new water and wastewater systems, most cities and rural areas in the basin cannot afford to borrow at NADBank's loan rates, and thus projects remain dependent on grant funds, a large portion of which have been supplied through the U.S. Environmental Protection Agency.[17]

[16] For more information on these institutions, see www.cocef.org and www.nadbank.org.

[17] See www.texascentr.org/bordertrade/borderwatch for more information on current issues related to BECC/NADBank operations.

WATER AVAILABILITY AND WATER QUALITY[18]

The limited water resources of the arid Río Grande basin have been developed and – in many instances – over-exploited to provide a year-round supply of water for irrigated agriculture, industry and the growing municipalities. During the 20th century, a number of large reservoirs were built on the Río Grande and its major tributaries and extensive well fields were drilled in the basin's aquifers. The dams, while providing storage, have greatly reduced the downstream flow of the main stem and its tributaries. In some areas, groundwater pumping has reduced or even eliminated spring flow or allowed the infiltration of saline water into fresh water zones.

Upstream of El Paso, the Elephant Butte and Caballo reservoirs are used to store about 2 million acre-feet of Río Grande waters, and releases from these reservoirs almost completely determine the flow of the river through the El Paso/Juárez area. These releases are tied solely to the needs of irrigators in the Elephant Butte and El Paso area irrigation districts and to provide the required 60,000 acre-feet/year to Mexico.[19] In a vigorous effort to move away from dependence on the rapidly diminishing Hueco Bolson aquifer, the city of El Paso now gets about half of its annual water supply from the Río Grande. It has secured this supply by leasing or otherwise acquiring irrigation water rights in the El Paso County Water Control and Improvement District No. 1.

El Paso's switch to surface water has not been easy. Barriers have included difficulties in negotiating acquisition of irrigation rights and poor water quality in the river during times of low releases from the upstream reservoirs. And, even with the move to surface water, El Paso still depends primarily on the local groundwater for the remainder of its supply.

These aquifers are being mined at dangerously high rates, however, as Cd. Juárez and El Paso have grown over the last few decades. Many observers have predicted that, at current pumping rates, the Hueco Bolson may run dry for all practical purposes in 20 years. Juárez is completely dependent on the Hueco Bolson, and is now being forced to investigate other local (and not so local) groundwater sources.[20] El Paso is meanwhile looking to west-to rural counties-for future groundwater. It has purchased some "water ranches" from which it hopes to export groundwater to the city. This move has predictably caused serious conflict with the rural counties, especially because Texas does not regulate groundwater pumping through state law. Essentially, Texas still relies on the "law of the big pump," more formally known as the "rule of capture." Under this doctrine, a landowner can pump as much groundwater as it wants, even if a neighboring landowner is damaged.

Reductions in the flow of the Conchos River at its confluence with the Río Grande have caused serious binational issues in the last few years. Due in part to drought, in part to increased use of water in the Conchos basin, and in part to a reservoir management strategy designed to preserve Conchos water for irrigation uses in Chihuahua, the flow of the Conchos has dropped well below the minimum 350,000 acre-feet/year (over a five-year period) required by the 1944 U.S./Mexico water treaty.[21]

[18] This section provides a very brief overview of water quality and water quantity issues in the Texas/Mexico portion of the Río Grande basin. For more detail on water supply, see references listed throughout this section, especially the Texas Regional Water Plans, the HARC report and the Texas Center for Policy Studies' Conchos Overview report. For more detail on water quality, see Texas Natural Resource Conservation Commission, *1994 Water Quality Assessment of the Río Grande Basin* (TNRCC: Austin, TX; 1996); International Boundary and Water Commission, *Binational Study Regarding the Presence of Toxic Substances in the Río Grande/Río Bravo Watershed and Its Tributaries* (IBWC: El Paso, TX; 1994 (Phase I) and 1997 (Phase II)).

[19] See, e.g. *Far West Texas Regional Water Plan* (Rio Grande Council of Government: El Paso, January 2001), pp. 1-42 to 43; 5-12 to 13.

[20] See, e.g., Diana Washington Valdez, "Juárez hunts new sources of water as crisis looms", in *El Paso Times*, February 14, 2001.

[21] For more discussion, see section below on Transboundary Implications and Mary E. Kelly, *The Río Conchos: A Preliminary Overview* (Texas Center for Policy Studies: Austin, TX, 2001, available on-line at www.texascenter.org/borderwater).

Most of the municipalities and industries in the Conchos basin currently depend on groundwater to supply demand. While complete hydrogeological studies of most of these aquifers are lacking, Mexico's National Water Commission (Comisión Nacional de Aguas or CNA) has identified several that are over-exploited (*i.e.*, annual pumping exceeds annual recharge) and is developing plans to help cities implement conservation measures and/or find new groundwater or surface water supplies.

Reduced flow from the Conchos has greatly reduced water storage in Amistad and Falcon, with the reservoirs reaching the lowest levels since they were put into operation in the 1960s, severely constraining water supply for municipalities and irrigators on both sides of the Lower and Middle Río Grande. On the U.S. side, the river is already over-appropriated (*i.e.*, paper water rights exceed, some say almost double, the amount of water routinely available in the system), and the low reservoir levels have made the situation much more volatile.

Drought is a relatively frequent occurrence in the Río Grande basin, though for the last several years dry conditions have been severe and persistent, especially in the Conchos sub-basin and on both sides of the Lower Río Grande Valley. Initially, below normal rainfall levels affected primarily dryland farmers and subsistence agriculture in northeastern Mexico. The drought has been particularly hard on indigenous communities in the Sierra Tarahumara in Chihuahua, affecting their bean and maize harvests severely and causing widespread hunger.[22]

Persistence of low rainfall patterns, however, and Mexico's decision to store water in the reservoirs in the parched Conchos basin, have resulted in greatly reduced inflows to and storage in the Amistad/Falcon system, constraining water supply for both municipalities and irrigators the middle and lower Río Grande. The reservoirs reached some of the lowest levels since their completion in the 1950s. By 1995, the situation forced the International Boundary and Water Commission to negotiate an emergency minute order under the 1944 Treaty in order to allow Mexico to borrow water for Tamaulipas municipalities.[23] The agreement was never implemented as late 1996 and early 1997 rains alleviated the immediate pressures on the municipalities.

Nevertheless, in Nuevo Leon and Tamaulipas, irrigation was curtailed and many dryland farmers didn't even plant crops. For example, in 1995-1996, estimates put crop losses at 600,000 acres of sorghum, corn, bean and wheat crops; Tamaulipas corn production dropped 44% in the 1994-1995 season and 1995-1996 was also extremely difficult. In 1996, the Mexican government was forced to import almost $2 billion worth of grain to alleviate growing hunger, with much of the grain going to northern Mexico.[24] Sugar cane, citrus and vegetable growers in the Texas portion of the lower Río Grande also suffered some substantial losses due to constraints in irrigation supplies in the 1994 to 1996 period, and municipalities were

[22] See, e.g., "Drought on the Border", in *Austin American Statesman*, May 7, 1996; "Five-year drought shoves Northern Mexico toward disaster", in *San Antonio Express News*, May 19, 1996.

[23] International Boundary and Water Commission, Minute 293, Emergency Cooperative Measures to Supply Municipal Needs of Mexican Communities Located Along the Río Grande Downstream of Amistad Dam, October 4, 1995.

[24] See, e.g., David Hurlburt and John Garrison. *The Drought in Northern Mexico* (Draft Report for the U.S./Mexico Policy Studies Program; LBJ School of Public Affairs, University of Texas: Austin, Texas, 1996); "Drought Continues, Grain Shortage Worsens", in *El Financiero International*, June 3-9, 1996; "Milionarias perdidas por sequía", in *El Bravo de Tamaulipas*, April 23, 1996.

forced to implement conservation plans. Flows from the Conchos continued to be much lower than normal during the late 1990s (Figures 3 and 4) and Mexico began to accrue a "deficit" under the 1944 Treaty (see Legal and Institutional and Transboundary Implications Sections below for more discussion). Briefly, for the October 1992 to October 1997 cycle used for Treaty accounting purposes, Mexico accumulated a deficit of just over 1 million acre feet; low flows continued after 1997, adding another 0.4 million to the deficit.

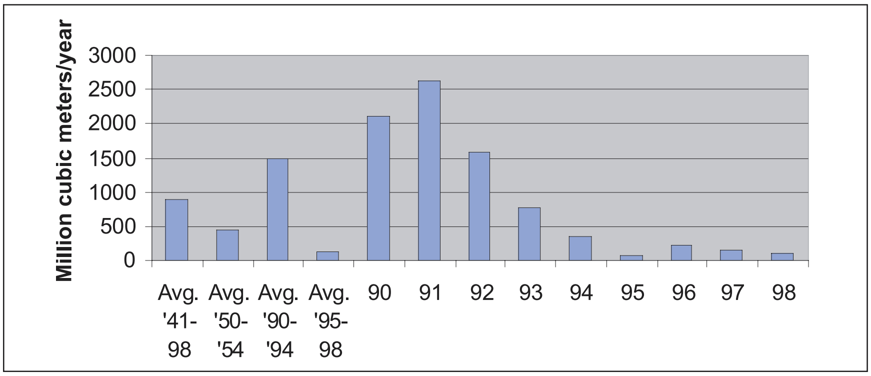


Figure 3 Flow of Río Conchos into Río Bravo. Source: Flow data from the International Boundary and Water Commission, El Paso, Texas.

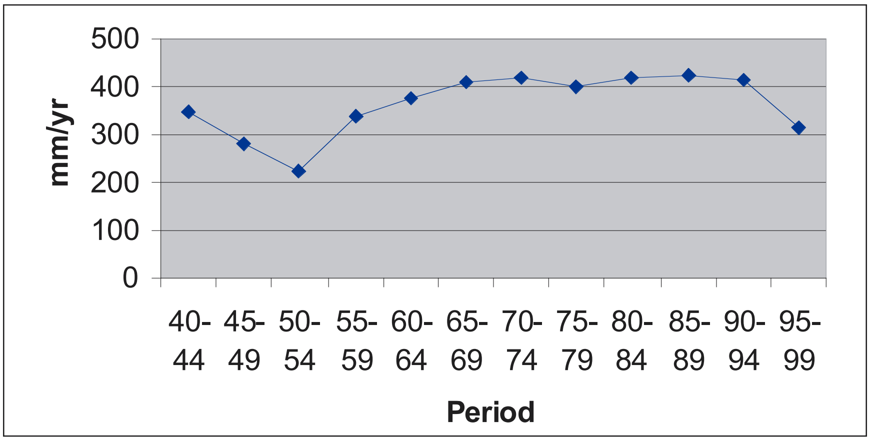


Figure 4 Average Annual Rainfall in the Conchos Basin. Source: Rainfall data from the International Boundary and Water Commission, El Paso, Texas.

Continued low levels of rainfall in the Valley and over Falcon/Amistad system aggravated irrigation shortages in the Lower Río Grande Valley of Texas. Last year, Valley farmers began tallying up their losses, which some claim have reached $400 million/year, and started demanding immediate "repayment" of the deficit that Mexico had accrued.[25] In March 2001, the IBWC signed a new minute order that attempts to set out a plan for meeting immediate needs (through the summer 2001 growing season), while looking toward better drought management and basin management plans to prevent a similar situation from occurring. (See Appendix at the end of this article and Legal and Institutional and Transboundary Implications sections below).

[25] See, e.g., "Parched Battle: Río Grande Valley drought sparks friction on both sides of border" in Dallas Morning News, March 26, 2000.

Water pollution complicates water supply management, and this is evident in many parts of the Río Grande basin. Pollution from dairies and irrigation return flows makes the river water above El Paso unusable for municipal purposes during low flow periods. Brackish water from irrigation return flow drains in the El Paso/Juárez area has also degraded water quality in the shallow Río Grande alluvium aquifer. Below El Paso/Juárez, the flow in the river primarily consists of treated wastewater from El Paso, untreated wastewater from Juárez and irrigation return flows. With a BECC/NADBank-supported project, Juárez is just now getting sewage plants-though they will provide only primary treatment at this point.

Municipal and industrial discharges (no cities in the basin have functioning secondary sewage treatment), irrigation return flows and agricultural chemicals have degraded water quality in the Conchos basin.[26] A 1994 binational water quality study and a follow-up study in 1997 found high levels of arsenic (possibly from arsenic based herbicides used on cotton) in the Lower Río Conchos, as well as other toxic pollutants.[27]

The Pecos River is notoriously high in total dissolved solids and is typically unsuitable for municipal or domestic needs, though it is used for irrigation in some of the rural counties through which it passes.

Water quality in Amistad and Falcon reservoirs remains relatively good, largely because of the size of the reservoirs. Downstream of Amistad, sewage and industrial wastewater from Nuevo Laredo and discharges from the Laredo area have caused water quality declines. In the stretch from Falcon to the mouth of the Río Grande, sewage from Mexican border municipalities, which can include industrial discharges, has also lowered water quality. High salinity is also a concern in this stretch.[28] In this lower portion of the river, reduced river flows have also allowed saltwater infiltration from the Gulf. This change has reduced the diversity of aquatic species and several freshwater fish have disappeared, replaced by more salt-tolerant species.[29]

Some of the Mexican municipios are now on the road to having at least primary sewage treatment, however again, with technical and financial support from the BECC/NADBank institutions. Municipal wastewater projects approved by BECC and financed by NADBank are slated for Cd. Acuña, Cd. Juárez, Piedras Negras and Reynosa.

Little information is readily available on water quality in the other major Mexican tributaries.

CURRENT AND FUTURE DEMAND FOR WATER[30]

Irrigation is by far the largest use of water throughout the Texas/Mexico portion of the Río Grande basin. In the El Paso/Far West Texas region, it accounts for about two-thirds of water use; in the Lower Río Grande Valley of Texas it is closer to 85%; in the Conchos basin, irrigation accounts for over 90% of water use.

[26] Mary E. Kelly, *The Río Conchos: A Preliminary Overview* (Texas Center for Policy Studies: Austin, TX, 2001, available on-line at www.texascenter.org/borderwater), page 11-12.

[27] International Boundary and Water Commission, *Binational Study Regarding the Presence of Toxic Substances in the Río Grande/Río Bravo Watershed and Its Tributaries* (IBWC: El Paso, TX; 1994 (Phase I) and 1997 (Phase II)).

[28] Region M Regional Water Supply Plan, August 2000, pp. 1-36 to 1-38.

[29] HARC Report, supra, Chapter 7.

[30] Detailed data on current and projected water uses are available in the following: (1) For El Paso and the upper Texas/Mexico portion of the Río Grande: Far West Texas Regional Water Plan;(2) For the middle and lower Río Grande: Regional Water Plans for Region J and M and HARC report, supra; and (3) For the Conchos basin: TCPS' Conchos Overview report, supra, and Comisión Nacional de Aguas, *Programa Hidráulico de Gran Visión, Estado de Chihuahua (1996-2000)* (1997). For information on the regional water planning process in Texas and contacts for obtaining the plans, see www.twdb.state.tx.us.

In the U.S. portion of the basin, municipal water demand is the next largest category of water use, ranging from 10-45% of use, depending on location. (Municipal use in the El Paso county area, for example, represents over 40% of total use, while in the Lower Río Grande Valley, it accounts for only about 14%).

Municipal use in the Mexican portion of the Río Grande is reported to be about 14% of total use, though in some areas (such as the Conchos basin) it is less than 10% of total use and in some areas (such as the Cd. Juarez area) it exceeds 35%. Other significant consumptive water uses in the basin include industrial operations,[31] livestock watering, electricity generation, and oil and gas production. Hydropower production occurs in a few areas, most notably at the Las Boquillas dam in the Conchos basin.

A major factor in current water use is inefficiency-in both municipal and irrigation systems. Table 9 shows reported water use efficiency information for various irrigation districts and municipalities in the basin. Clearly, reducing these losses will be critical to meeting future water demands, and some efforts are already underway. For example, a recent study of irrigation in the Lower Río Grande Valley of Texas revealed that the Brownsville Irrigation District was able to reduce water use by 33% by just implementing surge irrigation and metering.[32]

[31] For example, in El Paso, which has more manufacturing than other Texas border counties, industrial water consumption accounts for about 3% of total use in the County.

[32] "Extension recommendations playing key role in reducing water demand", Texas A&M University Agricultural Extension Service, Press Release, March 8, 2001; contact g-fipps@tamu.edu.

Table 9 Reported Water Use Efficiencies in Selected Irrigation Districts and Municipalities

Entity	Reported Efficiency	Source
El Paso Water Control and Improvement District #1	41 to 66% "historical" efficiency (may be improved by some recent canal lining, but no data to confirm)	Texas Natural Resource Conservation Commission, *1994 Water Quality Assessment of the Río Grande Basin* (TNRCC: Austin, TX; 1996) and Far West Texas Regional Water Plan
Conchos Basin Irrigation Districts	About 40%	Comisión Nacional de Aguas, *Programa Hidráulico de Gran Visión Estado de Chihuahua (1996-2000)* (1997)
Irrigation Districts in the Lower Rio Grande	About 64% overall	"Extension recommendations playing key role in reducing water demand," Texas A&M University Agricultural Extension Service, Press Release, March 8, 2001, contact g-fipps@tamu.edu
Major Municipal Areas in Mexican portion of the basin	40-80%	Comisión Nacional de Aguas, various reports
Water delivery efficiency for cities in the Lower Río Grande that receive water from the irrigation districts	75%	Region M Regional Water Plan

In urban areas, inefficiency results from leaks in water distribution systems and, in Mexican municipios, a lack of metering of water use. In the Conchos basin, for example, Cd. Chihuahua is estimated to have a 30% loss of water from its municipal system, though losses may, in fact, be higher because only about 3/4 of the distribution system is metered.

Even with these inefficiencies, however, per capita municipal water consumption in Mexican municipalities is generally only about one-half Texas per capita consumption rates. This difference is largely the result of comparatively much higher water use in the U.S. for lawns, landscaping, and swimming pools.

With respect to both irrigation and municipal use of water, price incentives for conservation have generally been lacking, in both the U.S. and Mexico. Irrigation water itself is generally very low cost (though farmers in both countries are beginning to have to bear an increasing share of the cots of constructing, operating and maintaining irrigation works). Similarly, the cost of water for municipal use has been low. Water for domestic use has been essentially free in most Mexican municipalities, as these cities are just beginning to meter and charge for water. With the exception of El Paso, cities in the Texas portion of the basin have been slow to adopt conservation price structures (*i.e.*, charging more per unit of water as use increases).

One real constraint on increasing the price of water for domestic use, however, is the low-income levels of a high percentage of border residents. Many people along the Texas border are already paying a large share of their monthly income for water (and this is especially true for residents who do not yet have centralized potable water service).[33] In Mexican cities, there is public resistance to paying for water service, linked largely to doubts about the reliability of the service and concerns about transparency in municipal management of revenues.

Most areas of the basin are predicted to experience an increase in municipal and industrial uses and a decline in irrigation water use over the next few decades. Tables 10 and 11 summarize some readily available recent water use projections.

Because irrigation accounts for such a tremendous share of water use throughout the region, strategies for meeting future demand must be focused on conservation in the irrigation districts. In addition, in some areas of the basin there is a more fundamental need to reexamine how reservoir releases are managed.

In the Lower Río Grande Valley of Texas, for example, the regional water planning group has projected future municipal and industrial needs can be met through aggressive conservation in the irrigation and municipal sectors and targeted water re-use. This won't come cheap, however. The planning group found that about $200 million would be required over the next 30 years to make the necessary improvements in irrigation efficiency. Even with these improvements, however, the planning group's analysis predicts that in a "drought-of-record," some irrigation demand will go unmet.

[33] For an overview of the problems with lack of water and sewer service in Texas "colonias" visit http://chud.tamu.edu/chud/colonias/colonias.html.

Table 10 Water Use Projections for Selected Areas in the Texas Portion of the Basin

Region	2000 Sector	AF/year	%	2050 Sector	AF/year	%
Far West Texas (El Paso and nearby rural counties along the Río Grande)*	Irrigation	342,848	67	Irrigation	298,848	51
	Municipal Other **TOTAL**	137,956 28,622 **509,426**	27 6	Municipal Other **TOTAL**	252,270 34,624 **585,742**	43 6
Region M- Lower Rio Grande Valley of Texas (Maverick to Cameron County)**	Irrigation	1,532,737	85	Irrigation	1,233,925	71
	Municipal Other **TOTAL**	252,451 10,032 **1,803,221**	14 1	Municipal Other **TOTAL**	486,618 17,380 **1,737,923**	28 1

AF is acre-feet; one-acre foot is equal to 325,851 gallons – approximately enough water to cover a football field one-foot deep.
* Source: Far West Texas Regional Water Plan
**Source: Lower Río Grande Regional Water Plan

Table 11 Water Use Projections for Selected Areas in the Mexican Portion of the Basin

Area	2000 estimated	2020
Cd. Juárez municipal use	150,000 AF/yr	300,000 AF/yr
Cd. Chihuahua municipal use	81,000 AF/yr	98,000 AF/yr with aggressive conservation
		140, 000 Af/yr without aggressive conservation
Tamaulipas Border Region (municipal and industrial use)	86,000 AF/year	379,887 AF/yr

As noted above, in the El Paso/Juárez areas, both cities are looking for additional sources of groundwater to meet future needs, as well as to conservation and transfers from irrigation to municipal use and even, at least in the case of El Paso, to desalination of brackish water. The Far West Texas regional water plan, however, did not examine the kind of aggressive irrigation conservation that is being relied up on in the Lower Río Grande Valley plan.

In the Conchos basin, the Mexican federal government developed estimates in 1997 of the resources it will need to make the necessary municipal and agricultural conservation investments, to better monitor flows and operate reservoirs and to better monitor water quality. The total investment needs projected for the state of Chihuahua between 1997 and 2000 was about $500 million, or about $170 million per year, with the majority being for agricultural water conservation. This level of investment would be equivalent to about 80% of the state's total budget in 1996.

Where will these funds come from? The government identified federal sources of funding such as various government infrastructure programs (some of which are largely funded by loans from the World Bank) and credit from Mexican national development banks, including BANOBRAS and BANRURAL. It also projects that some funds will come from Chihuahua state government programs and from the U.S./Mexico binational border development bank, NADBank. There is plenty of competition for these for these limited funds, both within Mexico and along the border, however. It remains to be seen what level of priority will be given to the investment needs in Chihuahua and in the Conchos basin in particular.

More fundamental questions about future water demand are not yet fully on the table in most debates and planning efforts; however, some questions are increasingly lurking around the edges. These questions include:

- Will border urban areas formulate growth management plans that more directly tailor economic development and growth policies to a sustainable level of water availability – rather than the current approach of seeking out new water supplies to meet growth "projections"?[34]
- What is the future role of irrigated agriculture in the basin, in terms of the types of crops that are grown, the precedence of irrigation rights in major reservoir systems and the need to maintain food production and viable rural communities?
- How might climate change affect overall water availability in the basin?[35]
- How can urban areas, particularly in the U.S., move their residents toward more understanding of the limits of local water resources, reducing expectations that every homeowner can have a big green lawn, a swimming pool and live in a subdivision with giant fountains at the entrance drive?
- How can environmental water needs be fully integrated into water management planning?

WATER FOR THE ENVIRONMENT

There is no escaping the fact that water for environmental needs (instream flow and spring flow) ranks low on the totem pole in an arid basin with irrigated agriculture and growing municipal water demand. This is evident from the way the Río Grande and its major tributaries have been managed over the course of the last several decades. Río Grande flows below Elephant Butte/Caballo, between El Paso and the entry of the Río Conchos, and in the lower reaches of the river upstream of the Gulf of Mexico have all been severely reduced over the years, with a consequent degradation in aquatic habitat and changes in or loss of riparian habitat. Overgrazing and extensive groundwater pumping have combined to reduce and even eliminate spring flow in many areas of the basin.[36]

[34] See Texas Center for Policy Studies, *Growth At Any Cost: Reconciling Economic Development Policy and Water Conservation in the Lower Río Grande* (TCPS: Austin, TX, July 2000, available on-line at www.texascenter.org/publications) for a discussion of these issues in the Texas/Mexico Middle and Lower Río Grande areas.

[35] See, generally, *Preparing for Change: the Potential Consequences of Climate Variability and Change; Southwest Assessment* (1998), available on-line at www.ispe.arizona.edu/research/swassess/index.html.

[36] Regarding these impacts in the upper portion of the Texas/Mexico Río Grande basin, see Mary E. Kelly & Salvador Contreras, *Water Use and Water Management Policy in the Chihuahuan Desert Ecoregion* (Prepared for the World Wildlife Fund, 1998; available from the Texas Center for Policy Studies); Eric Dinerstein, et al (eds.), *Ecoregion-Based Conservation in the Chihuahuan Desert: A Biological Assessment* (World Wildlife Fund, et al: Washington, D.C., October 2000). See also HARC study, supra, Chapter 7 (re: Lower Río Grande Basin).

As discussed in more detail in the next section, the legal framework for water management in both Texas and Mexico generally treats environmental water needs as a low priority and offers few real opportunities to ensure that minimum instream flow needs are met, especially where rights to use river water have already been appropriated, or, in much of the basin, over-appropriated.

For example, recent water planning efforts in Texas were, in theory, supposed to establish regional plans that would ensure sufficient water will be available for the protection of natural resources.[37] The RWPGs were required to consider environmental water needs, including instream flows, during the development of the regional plans. The planning guidelines required the evaluation of alternative water management strategies for their effects on environmental water needs and directed the RWPGs to consider and pursue environmentally sensitive water management strategies where feasible.

In general, both the Region E and Region J planning groups fell short in accounting for, and allocating water to, environmental flows. Prior to the finalization of the plans, comments were taken on the draft plans. The U.S. Fish and Wildlife Service (USFWS) comments on the draft Far West Texas plan stressed that it was "very concerned about instream flows in the Río Grande and springs that support Independence Creek in Terrell County...."[38] Comments of the Texas Parks and Wildlife Department (TPWD) on the draft Far West plan include concern that environmental needs are not categorized as a water demand. The department also raised concern that the plan lacked strategies to protect the existing quantity of water flowing in the Río Grande river and that the plan did not provide for protection or even consideration of the natural resources, such as the Río Grande River, that are supporting a growing ecotourism and recreational tourism industry. Planning group officials say they will take these comments seriously and try to address them in the next phase of regional planning.[39]

The TPWD comments to the Plateau Region's draft plan (Region J) state that the plan is deficient in its evaluation of environmental flow needs and that the degree of impairment of these flows, due to existing and proposed water development, had not been properly assessed. The review of both region E and J's plans by the National Wildlife Federation (NWF) raised this same concern.[40,41]

Thus, near-term efforts to restore instream and spring flow are likely largely be based on voluntary cooperation among non-governmental organizations, governmental agencies, water users and landowners. One such cooperative effort is just getting underway for the stretch of the river from Fort Quitman (about 80 miles downstream of El Paso) to Amistad Reservoir. As noted, this is a relatively isolated stretch of the river, much of it bordered by desert ranchland and state and federal protected natural areas.

In June 2000, former Interior Secretary Bruce Babbitt and his Mexican counterpart, SEMARNAP chief Julia Carabias, signed a "Joint Declaration to Enhance Cooperation to Protect the Ecological Integrity of the Río Grande/Río Bravo." The Declaration expresses the two governments concerns over

[37] The Regional Planning Guidelines are included in 31 Texas Administration Code (TAC) part 10 ß357.

[38] Letter to Tom Beard, Chairman, Far West Texas Regional Water Planning Group, dated September 29, 2000, David Frederick, U.S. Dept. of Interior, U.S. Fish and Wildlife Service.

[39] Barbara Kauffman, Río Grande Council of Governments, pers. communication, 2/28/01.

[40] Letter to Tom Beard, Chairman, Far West Texas Regional Water Planning Group, dated September 29, 2000, Myron Hess, National Wildlife Federation, Gulf States Natural Resource Center.

[41] Letter to Jonathon Letz, Chairman, Region J Water Planning Group, dated November 1, 2000, Myron Hess, National Wildlife Federation, Gulf States Natural Resource Center.

"declining water quantity and quality, habitat degradation, drought conditions and development pressures" in the Fort Quitman to Amistad reach. It set up a binational task force to examine "options and opportunities" to secure minimum instream flows in the reach and conserve the native riparian habitat. The Task Force, under the direction of the International Boundary and Water Commission (IBWC) has held a number of meetings to begin implementing the Joint Declaration.

The two primary options for securing significant instream flow in this reach are both beset by difficulties, however. One option is to increase the volume and year-round nature of flows from Elephant Butte and Caballo. While this could also have important benefits for El Paso (if the water was ultimately returned to the river), there are major legal, institutional and political hurdles to overcome to change the way these two reservoirs are managed. The second option, applicable from the confluence with the Río Conchos down to Amistad involves ensuring that flows from the Conchos remain at levels about minimum treaty flow requirements. That option, which involves a number of sticky binational water management issues, is discussed in more detail below.

LEGAL AND INSTITUTIONAL FRAMEWORK FOR WATER MANAGEMENT

Water management in the Texas/Mexico portion of the Río Grande basin involves a complex set of laws and institutions, as well as highly charged policy debates. Relevant laws include the 1906 and 1944 Water treaties between the U.S. and Mexico; the Río Grande Compact; the Pecos River Compact; Texas surface and groundwater statutes; and, Mexican federal water law. Important institutions include the U.S. and Mexican sections of the International Boundary and Water Commission; the Texas/New Mexico and Pecos River Compact Commissions; Mexico's National Water Commission; various state agencies and local governments on both sides of the border; and, irrigation districts.

TREATIES AND COMPACTS

- 1906 Río Grande Convention (U.S.-México)
- 1944 U.S./México Treaty for the Utilization of the Waters of the Río Grande (and the waters of the Colorado River)
- 1938 Río Grande Compact (Colorado, New Mexico, Texas)

Two treaties govern binational management of the Río Grande. The 1906 Río Grande Convention requires that the U.S. deliver 60,000 acre-feet/year of water to Mexico, just above Juárez. This water comes from the Elephant Butte/ Caballo system, and has generally been used for irrigation in the valley south of Cd. Juárez. Given the extensive drawdown of local aquifers, it is likely that Juárez will soon seek to move this water to municipal use.

The pertinent features of the 1944 Treaty regarding binational allocation of the surface waters of the Río Grande from Fort Quitman to the Gulf of Mexico are shown in Table 12.

Table 12 Major Features of U.S./Mexico 1944 Water Treaty

MEXICO	UNITED STATES
All waters reaching the main channel of the Río Bravo from the Río San Juan and the Río Alamo, including the return flow from the lands irrigated from these two rivers.	All waters reaching the main channel of the Río Bravo from the Pecos and Devils Rivers, Goodenough Springs and the Alamito, Terlingua, San Felipe and Pinto Creeks.
One-half the flow in the main channel of the Río Bravo below the lowest major international storage dam (Falcon), so far as it is not specifically allocated under the Treaty to either of the two countries.	One half of the flow in the main channel of the Río Bravo below the lowest international storage dam (Falcon) so far as it is not specifically allocated under the Treaty to either of the countries.
Two thirds of the flow reaching the main channel of the Río Bravo from the Ríos Conchos, San Diego, San Rodrigo, Escondido and Salado and the Las Vacas Arroyo, subject to the U.S. right to an average of at least 350,000 AF/yr in cycles of five consecutive years.	One-third of the flow reaching the main channel of the Río Grande from the Ríos Conchos, San Diego San Rodrigo, Escondido, and Salado and the Las Vacas Arroyo, provided that this third shall not be less, as an average amount in cycles of five consecutive years, than 350,00 AF/yr. The U.S. does not acquire rights in the Mexican tributaries in excess of the 350,00 AF/yr except the right to use one-third of the flow reaching the Río Bravo from these tributaries, although the one-third may be in excess of 350,00 AF/yr.
One-half all other flows of the main channel of the Río Bravo not otherwise allotted, including contributions from all unmeasured tributaries between Fort Quitman and the lowest major international storage dam (Falcon)	One half of all the flows of the main channel of the Río Bravo not otherwise allotted by the Treaty, including contributions from all unmeasured tributaries between Fort Quitman and the lowest major international storage dam (Falcon).

The 1944 Treaty has, up until the last few years, worked reasonably well and disputes between the U.S. and Mexico over division of the waters of the Río Grande have been minimal. With the recent prolonged drought and increased use of the river, however, the inherent weaknesses of the Treaty are becoming more apparent. For instance, the treaty fails to define what constitutes an "extraordinary drought." This has caused dispute about whether the prolonged period of reduced rainfall in Chihuahua over the last few years is the type of drought recognized by the treaty.

In addition, the Treaty essentially uses a process whereby Mexico must "repay" water in subsequent years when it fails to provide the minimum 350,000 acre-feet/year (over a five year cycle). It is unclear whether such "repayment" is sensible or feasible in situations such as the present where Mexico, for whatever reason, has accumulated a large deficit. Even if Mexico had the water to make up the deficit, moving such a vast amount of water into the Amistad/Falcon system between now and the end of the current repayment period (October 2002) makes little sense, as much of the water would likely be lost to evaporation and transpiration from the reservoirs.

Finally, the treaty does not address binational allocation of transboundary groundwater reserves, currently a problem in El Paso/Juárez, but potentially troublesome in other areas of the Texas/Mexico border as well.

In the last few years, these weaknesses in the Treaty have forced the U.S. and Mexico (generally through the IBWC) to scramble to negotiate *ad hoc* agreements for resolving immediate crises, as political pressure mounts in both countries.[42] To date, these negotiations have focused almost exclusively on short-term solutions, rather than on developing medium to long-term basin and drought management plans.

There are some signs that this is changing with the current crisis. Through IBWC Minute #307 (see Appendix to this article), signed on March 16, 2001, Mexico has now agreed to provide enough water for Texas farmers to irrigate during the summer 2001 growing season, and the countries have agreed to cooperate developing some type of drought response and "sustainable management" plan for the basin. This more comprehensive approach, however, has come from individual policy makers responding to political pressure, and is not something fostered or encouraged by the Treaty itself.

Texas/New Mexico interstate disputes over management over Río Grande basin waters have sometimes rivaled the current binational conflict.

The 1938 Río Grande Compact sets out obligations of New Mexico to deliver water to the Elephant Butte reservoir, from where it is transferred to downstream users, including those located in Texas. The Compact allows for certain accrued credits and debits between the states, which in the past has resulted in heated controversy and costly litigation. Currently, New Mexico and Texas have, for the most part, resolved most of their differences and are working more cooperatively through the Texas/New Mexico Compact Commission, though the U.S. Bureau of Reclamation's quiet title suit may bring new confusion and disputes.

The 1948 Pecos River Compact between Texas and New Mexico governs the allocation of the Pecos River basin above its confluence with the Río Grande. The Compact provides that New Mexico must deliver to Texas, subject to streamflow and other conditions, the same amount of flow that Texas received from the Pecos in 1947. It provides for a cooperative program for salvage of water from consumption by phreatophytes (water-consuming vegetation) and alleviation of high salinity in certain areas of the basin. Texas and New Mexico have also litigated the provisions of this Compact. In 1990, the states settled their dispute, with New Mexico agreeing to pay Texas $13.8 million in damages.

Interstate conflicts have also arisen in the Mexican portion of the basin, though there are no interstate compacts to govern distribution of waters between Chihuahua and downstream Mexican states or between basin states such as Nuevo Leon and Tamaulipas. Irrigated agriculture and municipalities in Tamaulipas have had their allocations from the Río Grande severely reduced over the last few years as a consequence of reduced inflows from the Conchos River.

In addition, growers in the Río Bravo Irrigation District in northern Tamaulipas have been battling the adjoining state of Nuevo Leon and the city of Monterrey over the effects of the El Cuchillo dam. Completed in 1994, this dam cut off much of the flow of the Río San Juan in order to store the water for municipal and industrial use in Monterrey. Downstream irrigators in Tamaulipas were supposed to receive return flows from Monterrey's new sewage treatment plants to replace the San Juan waters. The border city of

[42] This was the case with IBWC Minute #293, providing for the U.S. to loan water to Mexico to meet municipal needs in the Mexican portion of the Lower Río Grande Basin and with the more recent Minute #307.

Reynosa, Tamaulipas was forced to switch its supply from the San Juan to the Río Grande main stem. The return flows never materialized and many of the Tamaulipas farmers suffered substantial losses. Political controversy, social unrest and litigation ensued, eventually resulting in the resignation of Nuevo Leon's governor and forcing the federal government to promise compensation to the Tamaulipas farmers.[43]

Texas essentially relies on the prior appropriation doctrine for surface water management, though it also recognizes riparian rights claimed before 1969. With the exception of the El Paso to Fort Quitman stretch, the state has adjudicated water rights in the Texas portion of the Río Grande basin. The El Paso to Fort Quitman stretch adjudication was initiated in 1997 by the Texas Natural Resource Conservation Commission (TNRCC), but has been stayed pending resolution of a "quiet title" suit brought by the U.S. Bureau of Reclamation over water rights in the Elephant Butte/Caballo system.[44]

As noted above, most of the water rights in this segment are irrigation rights held by the El Paso Water Control and Improvement District No. 1. The city of El Paso has been leasing or otherwise acquiring these water rights and converting them to municipal use in order to reduce its dependence on the Hueco Bolson aquifer.

Texas rights to use Río Grande water from Fort Quitman to the Gulf of Mexico are administered by the Río Grande Watermaster.[45] In cooperation with the IBWC, which manages the Amistad/Falcon reservoir system, users below the reservoir make a "call" for releases from the reservoir. As noted above, the Río Grande in Texas is "over-appropriated:" that is, paper water rights exceed the firm annual yield of the river/reservoir system. State law requires a minimum reserve of water in the system to satisfy municipal water rights and, thus, in times of low storage levels irrigation users may not receive their full allotment.

The presence of the Watermaster and the manner in which water rights are administered in this stretch of the river[46] have fostered a growing water rights market in the Lower Río Grande Valley, with municipalities leasing or purchasing irrigation rights to meet growing demand. This is likely to continue, as suburbanization continues to take over Valley farmland. Some municipalities, however, pump directly from the river and/or depend on the irrigation district distribution system for transport of the water to the municipal system.

Groundwater in Texas is not regulated at the state level. Instead, Texas continues to rely on the "rule of capture" or "absolute ownership." Under this rule, the surface estate owner has ownership rights to all the groundwater she can pump for use at any location in any manner, without bearing responsibility to neighboring landowners or other users of the aquifer. Despite that fact that this court-made doctrine is based on outdated assumptions – *i.e.*, that the movement of groundwater is unknowable – the

43 For more information on the El Cuchillo controversy see HARC report, supra, final sections of Chapter 4 on agriculture in Tamaulipas.

44 For further discussion of this important litigation, which has now been transferred from federal court to New Mexico state court, see Paso del Norte Water Task Force, Water Planning Report, *supra*.

45 Distribution of water rights among Texas users was hashed out in a series of Texas court cases in the late 1950s and early 1960s. The record drought of the 1950s forced users and the state to court to get a firm definition of water rights. It is this court adjudication that essentially resulted in over-appropriation of the river downstream from Fort Quitman.

46 Essentially, because all water used must be "called" from the upstream Amistad/Falcon system, there are no "third party" adverse impacts to consider in the transfer of rights from one use/place of diversion to another.

courts have declined to move to a rule of "reasonable use" and the political barriers to legislative change have so far been insurmountable.

Thus, groundwater management in Texas has been confined to those areas of the state where local interests have formed "groundwater management districts." Among other things, these districts can require meters, prevent waste, regulate well spacing and, under current law, limit exports of groundwater outside the district.[47] Rural counties in the west Texas portion of the Río Grande basin are increasingly looking to formation of groundwater districts to protect their local groundwater supplies from export to El Paso and other urban areas.

Water resource management in Mexico is largely the province of the federal government. Article 27 of the Mexican constitution establishes the legal framework for water resources management in Mexico. It essentially provides the federal government with ownership of and jurisdiction over almost all surface water and groundwater. The federal government issues permits for water use, pursuant to the 1992 federal water law.[48] The "permits" include concessions to private interests and assignments to governmental entities, such as municipal water supply systems. These permits can be in force for anywhere from 5 to 50 years, with extensions available. No permit is required for domestic uses that do not involve construction of a water distribution system.

In theory, permit issuance is contingent on water being available. In many areas the hydrological and current water use data needed to determine water availability may not exist or may be insufficient or unreliable.

Mexico has not developed what is known in the U.S. as a "prior appropriation" system for allocating water in times of shortage. Under the prior appropriation doctrine, "senior" water rights (*i.e.*, the oldest water rights) can be fully satisfied before junior water right holders in the same basin get their water. Thus, under Mexico's system it appears that all users may have their allocations reduced during times of shortage. The 1992 water law gives the federal government broad discretion to impose water use restrictions and allocations in areas of shortages or periods of drought. Significantly, use restrictions can also be imposed to "protect or restore" an ecosystem, as well as to prevent over-exploitation of aquifers, preserve potable water sources and prevent contamination.

Mexico's water rights registry is still somewhat incomplete and inconsistent, but it has been greatly improved over the last several years with funding from a World Bank loan. Developing an accurate and complete water rights registry will be important to the success of future water management efforts (including the potential for a water rights market) in the Conchos basin, and in Mexico as a whole. In Chihuahua, for example, CNA reports that it has registered about 3,850 water rights (122 for surface water use and 3753 for groundwater use). According to CNA, this accounts for about 27% of the water use systems, but about 77% of the annual volume

[47] Legislation has been filed in the current session of the Texas legislature to limit the powers of groundwater districts to regulate exports.

[48] Water use authorizations issued prior to the 1992 law remain effective if they area registered in the Public Water Rights Registry established by the 1992 act.

of water used in the state. In the Conchos/Río Bravo basins, CNA reports that the registry has about 27% of the known water supply projects included, but the registry's reported volume of water "extracted" exceeds the extraction estimated from other sources of data by 25%.

The federal government imposes a fee for development and use of surface and subsurface water, with certain important exceptions. In 1996, the fee varied with the location of the use and the time of year, but generally ranged from about $1 per thousand cubic meters for use in aquaculture, recreation centers or generation of hydroelectricity to $50 to $100 per thousand cubic meter for potable water. The government does not charge a fee for extraction and use of water for personal domestic use, for domestic use in small towns and villages, or for agricultural use in irrigation districts or unidades de riego (with the exception of "agro-industrial use").

The federal government's dominant role in water resources management is lodged in CNA, which is now part of Mexico's environmental agency, SEMARNA (Secretaria de Medio Ambiente, Recursos Naturales). There is a division of CNA that deals with water in the northern border states, and a part of that division is devoted to oversight of water issues in Chihuahua. Recently, CNA has begun to work more cooperatively with state governments, including that of Chihuahua, involving the states more closely in planning and decision-making.

At the state level, there are "Juntas Centrales de Agua y Saneamiento" (Central Directorate of Water and Sewer) that are primarily responsible for the state's role in water issues. Larger municipalities have their own water and sewer departments and there are also "Juntas Rurales de Agua Potable," rural water supply directorates.

Irrigation districts are generally established by presidential decree. In recent years, the federal government has moved to delegate responsibility for operation of the districts to "user associations." The user associations hold title to the water rights and are to implement a system of fees to help pay for the operation and maintenance of the water delivery structure. The ultimate objective is to have the districts be financially and operationally self-sufficient.

The 1992 water law contains a procedure for establishing "Consejos de Cuenca," or basin management councils. The purpose of the basin council is to improve inter-governmental coordination in water resources management and to improve cooperation among the governmental entities, water users and other interests, including the public. A Consejo de Cuenca for the Río Bravo basin in Mexico, including the Río Conchos, was established in 1994, but there has been almost no progress in getting the Consejo off the ground.

TRANSBOUNDARY IMPLICATIONS

As discussed above, the persistent drought in Chihuahua has led to significantly less water from the Conchos reaching the main stem of the Río Bravo. In fact, flows have been reduced to the point where Mexico is now is a "deficit" situation with respect to the 1944 U.S./Mexico water treaty that governs allocation of the Río Bravo/Río Grande.

The 1944 Treaty provides that one-third of the flow reaching the main channel of the Río Bravo from the Ríos Conchos, San Diego, San Rodrigo, Escondido and Salado and the Las Vacas Arroyo is allocated to the United States, provided that this third shall not be less, as an average amount in cycles of five consecutive years, than 431,721 Mm^3/year (350,000 acre-feet per year). The vast majority of this water comes from the Conchos basin, as flow in the other tributaries is minimal during much of the year.

In the five-year cycle ending on October 2, 1997, Mexico owed the U.S. about 1,240 Mm^3 (1.024 million-acre feet). This is more than double the deficit incurred by Mexico during the drought of the 1950s, which is the only other time Mexico has failed to meet the minimum flow requirements during a five-year cycle. By February 2000, Mexico had accumulated an additional 0.48 Mm^3 (0.40 MAF) deficit in the current five-year cycle.

According to Article 4 of the treaty, total flow from these Mexican tributaries can average less than 350,000 acre-feet/year over a five-year cycle without Mexico being in "violation" of the treaty if there is a situation of "extraordinary drought." The treaty requires that Mexico make up the deficit in the subsequent five-year cycle.

Unfortunately, the treaty does not provide further definition of the term "extraordinary" drought. This lack of certainty is now at the heart of a raging controversy, as U.S. farmers in the Lower Río Grande are alleging that the drought in Chihuahua was not so severe as to justify Mexico's withholding of flows in the Conchos basin. Based on a report by the consulting firm R.J. Brandes and Associates, the farmers essentially claim that the Conchos basin received about 80 percent of its normal rainfall during the 1993 to 1997 period and that because flow in the Mexican tributaries did not cease "entirely" there was no "extraordinary drought."[49] They further claim that, under the treaty, Mexico should have released water stored in reservoirs in the Conchos basin to meet the 350,000 acre-feet/year requirement.

Mexico has responded that the lower levels of rainfall, particularly in the Conchos basin, do constitute an extraordinary drought, though it did not dispute the Brandes report calculation of an average 80% of normal rainfall during 1993-1997. Nevertheless, as shown in Figure 4, above, only during the late 1940s and early 1950s was average annual rainfall in the Conchos basin less than during the 1995-1999 period. Mexico further argues that it is entitled, under the treaty, to withhold enough water in reservoir storage to meet water demands in the Conchos basin, before water is released to the

[49] The Brandes report places annual average rainfall in the Conchos basin at 47% of normal in 1994 and 69% of normal in 1995, with three others years (1993, 1996 and 1997) experiencing normal or near normal rainfall levels.

Río Bravo to satisfy treaty requirements, as long as it pays back the water owned in the subsequent five-year cycle. It also states that the storage capacity of the reservoirs on the Conchos is less than assumed by the U.S. since there has been significant sedimentation in some of those reservoirs.

The dispute has reached the level of the respective state departments in Mexico and U.S. The International Boundary and Water Commission (IBWC), a binational agency set up under the treaty to administer the water allocation between U.S. and Mexico, has been meeting with government agencies and water users in both countries in an attempt to resolve the disputes. Since February 2000, through a combination of releases from the Conchos and transfer of Mexico-owned water in the Amistad/Falcon reservoir system to U.S. ownership, Mexico has reduced its deficit for the 1992-1997 cycle to about 841 Mm^3 (690 MAF). Under the treaty, this entire deficit must be repaid by the time the current five-year cycle ends on October 2, 2002.

IBWC Minute # 307, included in the Appendix to this article, is the most recent result of these negotiations. It may provide a "short-term" fix and set the two countries on a better path to dealing with Río Grande basin management issues and drought planning. Nevertheless, fundamental problems remain to be addressed. The current controversy over the interpretation and implementation of the 1944 Treaty indicates the need for the two countries to better define the term "extraordinary drought" and, possibly, to clarify other provisions of the treaty. Moreover, in the future it is not unlikely that there will be increasing controversy over the use of transboundary groundwater in the basin, and the 1944 Treaty is silent on those matters.

WATER POLITICS AND PROSPECTS FOR PROGRESSIVE CHANGE

Water management policy is one of this desert region's thorniest issues. Water politics in the Texas/Mexico Río Grande basin involves many different and sometimes powerful interests, and often these interests are in direct competition, with only a narrow middle ground.

In the Texas portion of the basin, a diverse set of actors participates in water policy decision-making, including municipal water supply entities, irrigation districts, ranch and farm associations, environmental and conservation organizations, community organizations representing low-income residents lacking access to clean water, industrial water users, academic researchers, the state water agencies, inter-state compact commissions, the federal Bureau of Reclamation and, to a lesser extent, the federal Environmental Protection Agency, the National Park Service and the U.S. Fish and Wildlife Service.

In the Mexican portion of the basin, the set of actors is similar but somewhat less diverse due to the centralization of water policy management decisions at the federal level and the limited resources of non-governmental organizations. Most of the decision-making authority resides in the Comisión Nacional de Aguas (Mexico City and regional offices), which is housed in the national environmental agency, SEMARNAT. Other actors include policy divisions of SEMARNAT, irrigation districts and agricultural users associations, state and municipal water supply systems, industrial users, residents associations, and some academics and conservation and human rights organizations.

At a binational level, management of the shared surface waters of the basin is largely in the realm of the International Boundary and Water Commission, though the BECC and the NADBank are starting to play more important roles regarding water and wastewater systems, and state and local governments are more involved every day in cross-border water discussions. Over the last several years, the IBWC has become more open to dialogue with state and local governments and user groups and, by necessity, more interested in drought management, basin management and environmental restoration issues. In times of dispute, such as the present, both the U.S. State Department and the Secretaría de Relaciones Exteriores in Mexico play a significant, and often determinative, role.

In neither country, however, is water management policy free of political party influence. In Texas, the historically strong opposition of many farmers and ranchers to changing the rule of capture means that groundwater is often used as a political issue. Property rights issues associated with water pricing, conservation requirements or water rights marketing can also be taken up as political issues on a local or statewide basis.

In Mexico, water allocation can also become a hot political topic – used by one of more of the parties to build public support or accuse opponents of corruption or mismanagement. Access to water can become an issue in local urban political fights, as officials sometimes seek to garner support for their party as a trade-off for building or improving water supply structure for a particular industrial park or neighborhood.

This wide variety of interests and the tendency for water issues to become highly politicized, combine with other factors, to pose substantial barriers to progressive changes in water management policy in both Texas and Mexico.

In Texas, one of the most intractable barriers to changes has been, and will likely continue to be, resistance to change, especially on the part of large irrigators. As municipal and industrial water needs grow, agricultural water users have developed legitimate concerns about whether they will be able to maintain adequate water to support their operations. In some cases, these concerns go to the core values of quality of life and the ability to sustain viable rural agricultural communities. In others, the concerns are more directly related to profit margins in crop production or to preserving legal title to water in order to be able to market it in the future to municipalities or others.

This resistance comes into play with regard to several aspects of water management policy in the Texas portion of the basin, including: (1) addressing subsidy and water pricing issues; (2) the need for a better framework for groundwater management and (3) the need to restore or preserve instream flows and reduce aquifer depletion.

Although it is one of the most direct tools for change, litigation may also be an obstacle in some instances. For example, the Bureau of Reclamation's "quiet title" suit over the Elephant Butte/Caballo project – whatever its merits – carries the risk of polarizing the positions of different interest groups. On the other hand, without litigation, there is sometimes no leverage to begin the complex negotiations required to move toward more progressive water management. This has been the case throughout Texas – and much of the rest of the Western United States – for many decades.

Another obstacle to change is the lack of political will on the part of decision-makers to confront the many complex and controversial issues surrounding water management policy in the Texas/Mexico Río Grande basin. Political will often requires a broader public awareness and knowledge of the issues than generally exists on most water management issues. In most areas of the basin – with the exception of severe drought periods – discussion of water management issues is often confined to professionals, government officials, and interest groups instead of taking place in newspapers, on television or in other spheres of general public participation.

This situation is beginning to change somewhat. Examples include the relatively high profile of water issues in the El Paso/Juárez area[50] and the widespread publicity given to the demands of farmers in the Lower Río Grande Valley that Mexico repay its "debt" under the 1944 Water Treaty. The latter situation has yet to move beyond accusations and finger pointing, however, though that may change in the near future.

Similar obstacles exist in the Mexican portion of the basin, as well as others not faced in Texas. With the traditional centralization of water management authority in the federal government, the states and local governments, water users, and other interests are fighting for a voice. On paper, the Río Bravo Consejo de Cuenca provided one potential venue for more non-federal involvement, but it has not materialized as an active or influential forum.

Another issue in Mexico, at least with respect to municipal water supply systems, is that when the local administration changes, there is often a wholesale change in technical personnel. This lack of continuity can seriously interfere with plans to improve efficiency of water distribution systems and with longer-range planning for water supply and conservation.

A third issue in Mexico is the need for development of better opportunities for public participation in water management decisions. In the U.S., there are several opportunities, including water rights hearings, rulemaking, planning processes (such as the Regional Water Planning groups) and open forums where interested parties are encouraged to openly discuss water issues. Such opportunities are fewer and farther between in Mexico, though they are increasing every day. SEMARNAT's new focus on Water and Forests should help considerably in this

[50] With the support of the respective federal governments, local leaders have now formed the binational Paso del Norte Water Task Force to discuss more sustainable long-term water management policy for the El Paso/Juárez/Doña Ana region.

regard. Some opportunities have also been provided by the BECC project certification process, which is open and participatory, and involves local communities directly in decisions about new water and wastewater supply projects.

One important element of meaningful public participation in the water policy arena (in both countries, for that matter) will be increased availability of good information on water use and water supply. In Mexico, in particular, water users, non-governmental organizations and researchers often have difficulty in obtaining basic information held by the Comisión Nacional de Aguas or municipal or state water supply entities.

The dominant issue in water politics in Mexico, however, is money. More resources are needed to improve government data collection and analysis; to strengthen the agencies responsible for water management; and to improve the water management capabilities and infrastructure of irrigation districts and municipal water supply systems. Currently, competition for scarce financial resources tends to put most water management decision-making in Mexico at constant risk of politicization.

Despite these formidable obstacles, there are some prospects for progressive change on the horizon. Though the recent drought in northern Mexico has caused devastation to many farmers and ranchers and ignited a war of words on the part of Lower Río Grande Valley farmers, it has also had the effect of elevating Río Grande basin water management issues on the binational, national and state policy agendas. This has coincided with a national, and even global, focus on freshwater supply issues that provides an important backdrop. The central challenge is to maintain this level of interest and engagement even if the immediate effects of the drought subside in the next few years.

Part of taking up this challenge is the need to demonstrate that there are opportunities for progress-opportunities that can help break policy gridlock or spur new alliances of interest. Several opportunities in the basin deserve special attention:

- **Opportunities for Agricultural Water Conservation:** Given that irrigation is by far the dominant use throughout the basin, and given the relatively low to moderate use efficiencies, this is the sector where conservation will have the most benefit. Achieving significant conservation in the irrigation sector, however, will require substantial financial investment. Where will the resources come from? First, they can come from municipalities that need additional water rights. These municipalities have an incentive to fund irrigation system improvements, though there is work to be done to make sure the legal framework clearly allows the municipality to secure the rights in the water that is conserved (and in some cases, a portion of the conserved water might be dedicated to instream flow needs). This approach will likely be easier in the U.S. than in Mexico, given the lack of resources available to most Mexican municipalities.

In other cases, it is going to take substantial government investment to improve old and inefficient distribution systems – and, for Mexico, that probably means money borrowed from the World Bank or other lending institutions, such as the BECC/NADBank.

Agricultural conservation can also be achieved through discouraging production of high water use crops in water short areas; through better metering of use; and – though politically difficult – through appropriate water price adjustments.

- **Opportunities for municipal water conservation:** Municipal conservation will be necessary in the Texas portion of the basin to reduce per capita consumption to sustainable levels. This will mean more widespread adoption of native plant landscaping ordinances and increased use of treated effluent for aquifer recharge or various outdoor watering uses. In Mexico, the biggest opportunity to reduce municipal use is improving the water distribution infrastructure to reduce the 30-50% losses occurring in some systems. The BECC/NADBank process may provide some of the resources needed for these projects, but major investments will be needed.
- **Development of viable water rights markets that have public acceptance and transparency:** Water rights markets are one of the most important parts of a future overall sustainable approach to water management in the basin. Developing viable water markets, however, will require appropriate water price incentives, clear legal titles (an important challenge in Mexico), a framework for an appropriate degree of transparency to water rights transactions to prevent speculative profit-taking on what is essentially a public resource, a framework to prevent adverse effects on rural communities and a way to account for and meet environmental water needs.
- **Increased emphasis on potential stream and spring restoration projects:** While current opportunities for instream flow and spring flow restoration may currently be somewhat limited in the basin due to over-appropriation of water, in some instances rural communities and conservation organizations may find common ground in restoration projects that benefit both the environment and local economies, by attracting or retaining tourism and outdoor recreation opportunities. The current binational efforts surrounding the "Forgotten River" stretch will be an important pilot project.
- **Developing and making available more and better data on water use and water supplying and increasing public awareness of the basin's water supply constraints:** In many areas of the basin, but particularly in the Mexican sub-basins, more information is needed on water use patterns, water availability and environmental water needs. The availability of water from many of the

basin's aquifers is not well understood. And, we lack good scientific knowledge of the instream flow required to maintain healthy aquatic ecosystems and riparian habitats.

But having more and better data is not alone an answer. There must be a concerted effort on the part of water management agencies and non-governmental organizations to build broader public awareness of water scarcity and water policy issues in the basin. The efforts of the Río Grande/Río Bravo Basin Coalition, with its annual Día del Río and water issues conference are a good step in the right direction, but much more is needed in this large and diverse region.[51] The public needs a better understanding of who is using water for what purpose, where conservation opportunities exist and what happens if we fail to take advantage of these opportunities. This education needs to be done in a manner that, to the extent possible, avoids further polarization among water users and interest groups, but it is essential to building the political will necessary to grapple with the difficult choices that must be made in the coming years.

- **Building a better binational framework:** The current Mexico deficit under the 1944 Treaty, and other information, is demonstrating some of the inherent weaknesses of the treaty. While political obstacles are likely to prevent a broad renegotiation of the treaty, there are now opportunities to make necessary adjustments, including defining "extraordinary drought" and developing drought management and basin management plans that prevent future disputes and provide for meeting consumptive and non-consumptive water needs on a more consistent basis. In addition, local and state cross-border discussions are beginning to increase binational understanding of the limits of water resources in the Río Grande basin, but there is still a long road ahead. Both countries will have to confront the need to rethink long-held notions about the relationships among growth management, economic development and water supply, as well as how water should be used in urban and rural areas.

[51] For more information on this broad and growing binational coalition, see www.rioweb.org.

MARY E. KELLY is the Executive Director of the Texas Center for Policy Studies (TCPS), a public interest policy research and technical assistance organization based in Austin, Texas. Areas of expertise at TCPS include U.S./Mexico border environmental issues including Río Grande freshwater ecosystem, the state of the environment in Texas, and the relationships between economic development decision-making and the environment. Ms. Kelly has written extensively on border environmental issues. She is currently working on an assessment of the Río Conchos basin in northern Mexico. In conjunction with the Comisión de Solidaridad y Defensa de Derechos Humanos, A.C., she recently completed a study for the North American Commission for Environmental Cooperation examining the effects of NAFTA on forestry in Chihuahua. Ms. Kelly obtained her law degree in 1985 from the University of Texas, with honors. She also holds a Bachelor of Science degree in Chemical Engineering from the University of Arizona (1979, with distinction) and spent four years as an engineer with Radian Corporation. She is "of counsel" to the Austin law firm of Henry, Lowerre, and Frederick and was an associate and partner at that firm from 1986 to 1990.

Mary E. Kelly, Texas Center for Policy Studies, 44 East Avenue, Suite 306, Austin, TX 78701 mek@texascenter.org

INTERNATIONAL BOUNDARY AND WATER COMMISSION
UNITED STATES AND MEXICO

Washington, D.C.
March 16, 2001

Minute No. 307

PARTIAL COVERAGE OF ALLOCATION OF THE RIO GRANDE TREATY TRIBUTARY WATER DEFICIT FROM FORT QUITMAN TO FALCON DAM

The Commission met at the Department of State in Washington at 10 a.m. on March 16, 2001, with high-level representatives and officials of the two Governments, to consider measures proposed by the Government of Mexico in the fourth year of the current five-year accounting cycle, in partial fulfillment of its obligation under subparagraph (c) of paragraph B of Article 4 of the United States – Mexico Treaty for Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, dated February 3, 1944.

The Commissioners made note of the discussions by United States President George W. Bush and Mexican President Vicente Fox Quezada held in San Cristobal, Guanajuato on February 16, 2001, at which the request was made of Mexico to provide to the United States a volume of 600,000 acre-feet (af), equivalent to 740 million cubic meters (Mm3) of water through July 31, 2001 in order to reduce the present deficit in the allocation of the portion of the Mexican Rio Grande tributaries. In furtherance of that conversation, the Commissioners reviewed the data provided by the Principal Engineers and observed that from the end of September 2000 through March 3, 2001, a volume of 232,674 af (287 Mm3) had been accounted in favor of the United States, such that there remains to be covered through July 31, 2001 a volume of 367,252 af (453 Mm3). They observed that this volume could be covered based on the following estimates:

a) Unmeasured Treaty Tributary Runoff – It is estimated that from March 4, 2001 to July 31, 2001, runoff to the Rio Grande, from rainfall to the unmeasured tributaries, will be between 159,710 af (197 Mm3) and 239,159 af (295 Mm3).

b) One-third of Treaty Tributaries Runoff - It is estimated that from March 4, 2001 to July 31, 2001, the runoff to the Rio Grande from the six Mexican tributaries and one third assignment of this volume to the United States in accordance with the Treaty, will range from 64,046 af (79 Mm3) to 84,314 af (104 Mm3).

c) Venustiano Carranza Dam Releases - An additional net volume of 38,103 af (47 Mm3) can be expected from Venustiano Carranza Dam, which is the one-third that corresponds to the United States, after losses, from the 138,631 af (171 Mm3) which are pending transfer from this dam.

INTERNATIONAL BOUNDARY AND WATER COMMISSION
UNITED STATES AND MEXICO

...2

Based on the above, the Commissioners observed that the Principal Engineers of the Commission identified two scenarios, a more positive one under which one could expect a volume of 594,250 af (733 Mm3) by July 31, 2001 and a more conservative estimate under which one could expect a volume of 494,533 af (610 Mm3), which includes the flows delivered since October 2000. On this basis, there results a range of 494,533 af to 594,250 af, which is the volume that could reasonably be expected by July 31. The above demonstrates that it is necessary to agree to a contingency plan in the event that the more favorable scenario does not occur and that by July 31, Mexico has not been able to deliver the requested volume of 600,000 af (740 Mm3). This contingency plan could consider in the first case, the extension of assignment of the unmeasured tributaries through September, which could be feasible to meet the United States request. In the second case, consideration could be given to covering the shortfall through September 30 with waters from the Luis L. Leon, La Fragua, Centenario and San Miguel Dams.

The Commissioners made note that for the estimates provided by the Principal Engineers on the above mentioned quantities an average of runoff recorded in 1993 – 1999 and an average runoff recorded in 1999 were considered.

The Commissioners discussed the need for the two Governments to continue discussions through the Commission to arrive at an agreement before the end of 2001 on additional measures that the Government of Mexico will take to cover the outstanding prior cycle deficit and on any other measures that they consider necessary concerning the last year of the current cycle.

At the same time, they observed that the two Governments, animated by a spirit of friendship that prevails in the relationship between the two countries and committed to prevent recurrence of the situation considered in these discussions will work jointly to identify measures of cooperation in the areas of drought management and sustainable management of this basin.

Based on the above, the Commissioners submit the following recommendations for the approval of the two Governments:

1. That the two Governments adopt the framework described in this Minute to ensure that Mexico provides to the United States 600,000 af (740 Mm3) in accordance with the two scenarios described above.

2. That the two Governments continue discussions, through the Commission, to arrive at an agreement before the end of 2001 to develop additional measures that the Government of Mexico will undertake to cover the outstanding prior cycle deficit and on any other measures that they consider necessary concerning the last year of the current cycle.

INTERNATIONAL BOUNDARY AND WATER COMMISSION
UNITED STATES AND MEXICO

...3

3. That the Government of the United States and the Government of Mexico, animated by the spirit of friendship that prevails in the relationship between the two countries and committed to prevent recurrence like the situation considered here will work jointly to identify measures of cooperation on drought management and sustainable management of this basin.

4. That this Minute shall enter into force when the Government of the United States and the Government of the United Mexican States have approved this Minute.

The meeting was adjourned.

Robert Ortega
Acting United States Commissioner

J. Arturo Herrera Solis
Mexican Commissioner

Manuel R. Ybarra
United States Section Secretary

Jose de Jesus Luevano Grano
Mexican Section Secretary

Freshwater and Human Population: A Global Perspective

Stan Bernstein
Senior Research Adviser
United Nations Population Fund (UNFPA)

ABSTRACT
Water challenges in the United States, the topic of most of the studies in this issue, are both similar to and different from those elsewhere in the world. On a global scale, variation in the dimensions of the water challenge is even more dramatic. Over 500 million people now live in countries where choices about water use are difficult if not critical. This number may increase to over three billion within the next twenty-five years. Population growth, production inefficiencies, changing diet preferences, and cross-border conflicts worsen this challenge. Climate change will only further endanger the least advantaged. Whether quantity is an issue or not, poor water quality is a consistent threat to health. Greater efforts are needed to ensure that available water is not only adequate but safe, and that the natural systems that deliver it are protected or restored. Urbanization trends will intensify demand in urban and peri-urban areas, where capacities are already challenged. Rural areas are already most under-served, yet their needs continue to grow. The burden of meeting household water needs falls most heavily on women in non-industrialised countries. Advances in empowerment will be thwarted if the time, effort, and health burden on women and (particularly girls) children are not reduced. Concerted action on many fronts is needed to reduce deprivation and improve the prospects for sustainable development. Solution of the world's water problems will require political will, technological advances, local participation and decision-making, and moderation of population growth consistent with people's desires.

INTRODUCTION

When addressing questions of the balance of population and resources, arguments frequently are cast in the positions of extreme optimists (sometimes called "cornucopians") and pessimists (sometimes called "neo-Malthusians"). These controversies are often expressed in terms of the degree to which a glass is seen as full or empty.

When regarding the issue of population and water resources, a number of different factors need to be considered. It must remembered that:

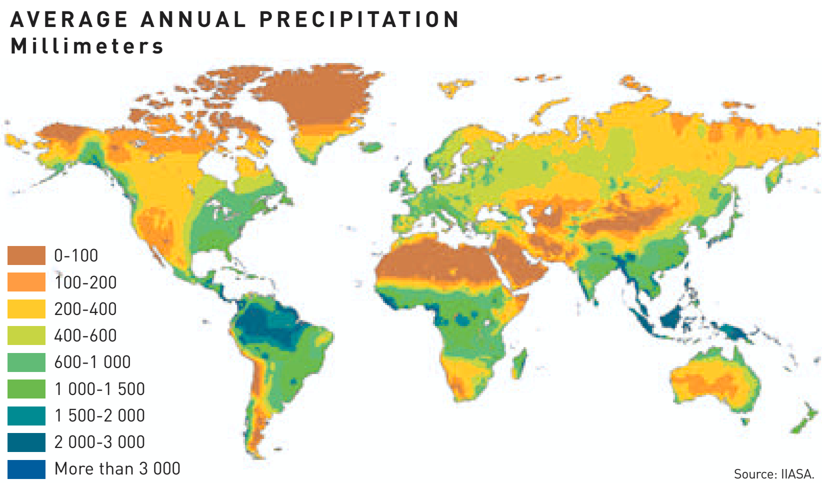
- The "glass" is leaky;
- The contents will be divided among different uses (more than two-thirds of it will go to farmers);
- Women will be the ones who most often carry water to their families in non-industrialised countries;
- People will throw a variety of biological and chemical wastes into it;
- Disease can be spread by it;
- Some people can't get access to it, while others are almost floating in it;
- People are taking actions that affect the natural filtration systems that clean it; and,
- Important non-human uses exist for it (for animals and fish and as part of essential ecosystem services including toxin removal, etc.).

Water is also a substance for which there is no true substitute. It can serve as a natural limit on the size or the quality of life of populations dependent on it.

Unlike the case with other resource issues, we cannot make more water to meet various needs. Most of the water in the world is not freshwater — essential for most human purposes. Researchers are able to make educated guesses about how much water there is. Only about 2.5% of all water on the planet is freshwater (not salty oceanic water) and only about 0.5% is accessible groundwater or surface water.

The balance between the number of people and the amount of available freshwater is precarious.[1] Rainfall quantities vary greatly around the world (See Figure 1). Portions of Northern Africa and Western Asia in particular receive very small amounts of rain.

Figure 1



Source: Harrison, Paul and Pearce, Fred. 2001. *AAAS Atlas of Population and Environment,* Victoria Dompka Markham, Editor. 215 pages. American Association for the Advancement of Science and the University of California Press.

The availability of water between and within nations is related to income. The most developed regions have, on average, substantially higher rainfall than those less and least developed.[2] More importantly, investments allow countries to develop reservoirs, dams, and other technologies to capture fresh water run-off and available ground water.

We now have 6.1 billion people in the world. Global population over the past 70 years has tripled. But the amount of freshwater available remains basically constant. Per capita *availability* of water has, therefore, declined significantly. Although population growth is slowing (now 1.2% per year, due to both a denominator effect – the larger the base, the smaller the proportional increase – and lower fertility), we are still adding around 77

[1] There are an estimated 9-14 thousand cubic kilometers of freshwater available each year in the form of runoff (e.g., in streams and rivers) and water returned to underground aquifers (Falkenmark, M. 1994. "Population, Environment and Development: A Water Perspective" in *Population, Environment and Development: Proceedings of the United Nations Expert Group Meeting on Population Environment and Development, New York, 20-24 January1992.* New York: United Nations, pp. 99-116; and Cohen, Joel E. 1996. *How Many People Can the Earth Support?* New York: W.W. Norton and Company). A quantity of freshwater falls as rainfall that is contributed to this total. However, the direct capture of rainfall depends on where it occurs and the technologies available for its use.

[2] Water resources in more developed regions are 10,852 cubic meters, compared to 6,196 and 7,065 in less developed regions and least developed regions, respectively. See: United Nations. 2001. *Population, Environment and Development 2001.* Wallchart. New York: Population Division, Department of Economic and Social Affairs, United Nations.

million people per year. Satisfying the water needs of this many additional people has been estimated to require an amount roughly equal to the flow of the Rhine each year. Declining fertility reflects desire for smaller family size and higher capacity to realise it through greater access to reproductive health information and services.

During the period when population has tripled, water use has increased six-fold. Some of that is due to increases in productivity and wealth that affect the technologies of economic production (where water is an important industrial input) and patterns of food and other consumption. The increase in water usage over the last 70 years has resulted to a large extent from an accelerated pace of use over the past four decades, at the same time that populations have been increasing most rapidly.

There have been changes in the content of the diets with improvements in income. As income becomes available, people prefer to shift to higher quality foods. This has lead to an increase in meat consumption. Demand for meat in developing countries is projected to double between 1995 and 2020.[3] The water resources needed for grain production are well understood: 1,000 cubic meters of water are needed to produce 1 cubic meter of cereal crops in moderate conditions (as much as three times more is needed in drier settings).[4] Production of animals for human consumption requires substantial inputs of grain and additional water for the animal. Each kilocalorie of meat requires roughly ten kilocalories of grain.[5] Water requirements increase dramatically the higher the importance of meat in diets.

Since water falls unevenly around the world, distribution and equity issues assume great importance. Within a country as rich and infrastructure-endowed as the U.S., there are extreme variations in rainfall quantities. Unlike poorer countries, the U.S. has an enormous and technically adept infrastructure to estimate needs and move water around.

Globally, of the annual available freshwater, 54% is being used. If consumption per person remains steady, by 2025 we could be using 70% of the total because of population growth alone. If per capita consumption everywhere reached the level of more developed countries, we could be using 90% of the available water each year.

Such extrapolations are based on simple assumptions about the efficiency of water use. These assumptions are actually problematic, however. During the period of six-fold increase in water use in developed countries, per capita consumption of water has levelled off or declined.[6] This relative per capita stabilisation, however, has largely been due to greater efficiencies in industrial and agricultural water use efficiency in more developed countries. Technologies for more efficient use of water are increasingly available in developing countries – for example, drip irrigation instead of flood irrigation – but cost and cultural restrictions must be addressed.

3 Pinstrup-Andersen, P., R. Pandya-Lorch and M. Rosegrant. 1999. *World Food Prospects: Critical Issues for the Early Twenty-First Century*. Washington, D.C.: International Food Policy Research Institute

4 For this and additional information on water requirements for agriculture see Cohen, *op. cit.*

5 Different animals have different grain requirements (cattle having among the highest). The range of water inputs for different animals and other details of dietary impacts of food consumption are reviewed in Cohen, *op. cit.*

6 Peter Gleick. 2000. "The Changing Water Paradigm: A Look at Twenty-first Century Water Resources Development." *Water International* 25(1): 127-138.

Sandra Postel has estimated that relatively low cost technologies could double agricultural productivity per unit of available water.[7] Certainly further transfers and new technologies are possible. Significant additional progress can be made to save and protect water resources in relatively under-developed settings. This will require training of staff and educational outreach to facilitate behaviour change.

WATER AVAILABILITY

Global population is projected to reach 7.2 billion by 2015. It is further projected that there will be 9.3 billion people by 2050.[8]

These estimates have gone up since the prior estimates of the United Nations Population Division in 1998 by 418 million people. The additional 418 million people projected for 2050 will all live in countries already suffering from water scarcity or stress. Countries are characterised as water-stressed or scarce depending on the amount of renewable water available.[9] Water stressed countries have fewer than 1,700 cubic meters per year of water available per person. In this circumstance, choices among alternate uses of water (for personal consumption, agriculture and industry) become difficult, often with episodic and scattered unavailability. Water scarce countries have fewer than 1,000 cubic meters per year. At this level, there is usually not enough water to provide adequate food,[10] economic development is hampered, and severe environmental difficulties develop.

In the year 2000, 508 million people lived in the 31 water stressed or scarce countries. By 2025, 3 billion people will be living in 48 such countries.[11] The increase will be fuelled by a two-fold increase in people living in conditions of scarcity and a six-fold increase in people living under water stress.

There are large differences of water availability within countries. The number of people in a country with average water availability below specific values is not an accurate measure of the number of people affected. Multiple measures give a better picture. Unequal distribution of access within both stressed and unstressed countries requires identification of the numbers, location and characteristics of populations facing water stress.

For some purposes, countries are not the appropriate units for analyzing water flows. Many of the world's major river basins encompass more than one country. River basins are a more ecologically sound unit for summary. Policies need to ensure adequate access to water of appropriate quality for both upstream and downstream users of river systems, wherever national borders may lie. In critically constrained areas, for example in Western Asia, regional security may depend on perceptions of water security. The science for monitoring regional rainfall (including its capture and use) does not respect geographical boundaries.

Currently 2.3 billion people (about 38% of the world population) live in water river basins that are at least stressed; 1.7 billion live in basins where

[7] Sandra Postel. 2001. "Growing More Food with Less Water." *Scientific American.* 284(2): 46-49.

[8] United Nations. 2001. *World Population Prospects: The 2000 Revision: Highlights*. New York: Population Division, Department of Economic and Social Affairs, New York: United Nations.

[9] Falkenmark, M. *op. cit.*

[10] Soil quality, agricultural efficiency and land patterns use may lead to food purchases ("virtual water" imports) where these can be afforded. This also poses allocation decisions among alternate uses of scarce funds.

[11] Tom Gardner-Outlaw and Robert Engelman. 1997. *Sustaining Water, Easing Scarcity: A Second Update*. Washington D.C.: Population Action International.

scarcity conditions prevail. By 2025 these numbers will, respectively, be 3.5 and 2.4 billion.

BASIC WATER RIGHTS

Human rights concerns have been a foundation of population programs since 1968, when the basic right for individuals and couples to make informed choices concerning the number, timing and spacing of their children and to have access to the means needed to implement them were recognised.[12] There is now increasing talk – recently in the Secretary General's statement on World Water Day (March 22, 2001) – that water is a basic right.

Work has been done in support of this idea, outlining a basic daily water requirement (BWR) and urging recognition of it as an international rights standard.[13] The proposed standard for a basic water right is 50 liters per capita per day for the purposes of drinking water, sanitation services, bathing, and cooking and kitchen needs. This quantity of water refers to domestic consumption amounts, unlike the water system flow measures referenced above.

Data on domestic water use are not yet of high quality; different collection methods are used in different countries, and standards for quality assessment have not yet been uniformly set. Country reports are available, despite data difficulties, as to their estimates of domestic water use. There were 61 countries in 2000 that were using less water than the BWR with combined populations of 2.1 billion people. By 2025, from population growth alone, these countries will be the home to 2.7 billion people; by 2050, 4.2 billion people (over 45% of the global total) will be living in countries at this average, below BWR, consumption level.

This absolute minimal standard does not take into account the other necessary uses of water – for agriculture, for ecosystem protection, and for industrial uses. If a more generous standard of 100 liters per person per day is set as a consumption standard to reflect the omitted needs, in 2000 there were 3.75 billion people in 80 countries below this level. By 2015, the population of these countries will increase to 4.6 billion; by 2050, to 6.4 billion.

WATER QUALITY

Absolute quantities of water potentially available or actually consumed do not capture the full challenges of water needs. The quality of the available water is far from adequate. It is commonly reported that about 1.1 billion people do not have access to clean water (whatever its quantity).[14] Fully 2.4 to 3.0 billion people lack access to sanitation. In developing countries, 90-95% of sewage and 70% of industrial wastes are dumped untreated into surface waters where they pollute the usable water supply.[15]

[12] This was included in a resolution of the International Conference on Human Rights held in Teheran (United Nations. 1968. *Final Act of the international conference on human rights*. New York: United Nations.)

[13] See Peter Gleick. "Basic Water Requirements for Human Activities: Meeting Basic Needs." *Water Resources Journal*. Pp 83-92; and "Water as a Basic Human Right."

[14] WHO. 2001. *Global Water Supply and Sanitation Assessment 2000 Report.* Geneva: World Health Organization.

[15] See statistics collated in Hinrichsen, Don, and Bryant Robey. 2000. "Population and the Environment: The Global Challenge." *Population Reports.* Series M. No. 15. Baltimore, Maryland: Population Information Program, Johns Hopkins University School of Public Health.

WATER QUANTITY

Many countries are providing as much water as they are because of unsustainable patterns of use. If more water is withdrawn than is replenished by natural processes, the excess is essentially "mined" from reserves. These can be recent local aquifers or, in extreme cases,[16] ancient sources of underground "paleo-water." The water tables under some cities in China, Latin America, and South Asia are declining at over one meter per year.

People are diverting water for their purposes at rapid rates. The proliferation of large dams to capture surface run off is now levelling off, particularly in more developed countries, as the damage they cause and their susceptibility to filling with silt are better appreciated. Displacement of populations continues to result from large dam projects in countries such as China.

The damming of natural flows and diversion of water for irrigated agriculture is causing the "drying up" of rivers. The Yellow River in China ran dry from 600 kilometers upstream to the river's mouth every year in the 1990s. In 1997, it ran dry a record 226 days.[17] The Rio Grande River on the U.S.-Mexico border developed a sandbar at its mouth recently, highlighting the loss of its flow. The most dramatic example of the dangers of flow disruption has been the drying up of the Aral Sea. Diversion of rivers for irrigated cultivation of cotton led to loss of two-thirds of the volume of this formerly largest of inland seas, as well as salinization.[18]

When several nations border on the same body of water and divert feeder rivers for their separate needs, the pace of loss can be particularly dramatic. Lake Chad in Africa has lost 95% of its area in 40 years as a result of drier weather and increased demand for irrigation.[19] Settled farmers have replaced the nomadic cultures and fishermen that depended on its waters.

QUANTITY AND QUALITY RELATIONS

Water quality is not merely an issue of the freedom from pollutants of water sources at the point they are delivered to people's use. Natural systems purify circulating water when there is enough available. When water becomes progressively scarcer, it is also generally of poorer quality. This poses a challenge to water management in relatively water-available sites. In water scarce settings, the maintenance of acceptable water quality is particularly challenging.

The quality of water, and the quantity that is captured, depends heavily on decisions about land use and on methods of industrial and agricultural production. Water cannot be considered or treated separately from the natural systems through which it flows. Excess pesticides and other chemical runoff from the land and acid rain from atmospheric contamination demonstrate how where waters flow affects quality. Restoring natural flow patterns to river systems is a vital step toward improving its quality.

[16] An example is water mining in the Libyan Arab Jamahiriya.

[17] UNESCO. 2000. *Global Issues and Sustainability: Critical Thinking/Problem Solving Approach*. Draft publication of the UNESCO Global Education Network Initiative (GENIe), supported in part by the David and Lucile Packard Foundation. Geneva: United Nations Educational, Scientific and Cultural Organization.

[18] Paul Harrison, Fred Pearce (writers), Victoria Dompka Markham (ed.). 2001. *AAAS Atlas of Population and Environment*. Berkeley, Los Angeles, London: University of California Press.

[19] Coe, Michael T., and Jonathan A. Foley. 2001. "Human and Natural Impacts on the Water Resources of the Lake Chad Basin." *Journal of Geophysical Research* 2001 106(D4): 3349.

POPULATION DISTRIBUTION AND WATER

Urbanization is one of the major demographic trends of the current period. Some of the "cornucopian" optimists suggest that the entire population of the world could live in an area the size of the state of Texas in the United States at an acceptable population density. Such views ignore the current challenges of providing water to such a location. It would be a significant challenge to get resources to such population concentrations and to take wastes away.

In general, higher population densities are associated with greater economic dynamism and accelerated development. Urban areas provide the opportunity for efficiencies in service delivery but, faced with rapid and unplanned growth, they are often overwhelmed. There are sizeable peri-urban (settlements around the fringes of cites) and urban populations with unmet water needs and resulting bad health. Clean water is not available to, at a minimum, 6% of urban dwellers and 14% lack sanitation.[20] These figures reflect a first-time decline in coverage compared to previous estimates; population growth in cities is out-pacing service provision at a rate that demands reflection in official statistics.

By 2030, every major region in the world will be majority urban. By 2015, 1.3 billion people will be living in cities of more than 1 million people; 500 million will live in cities with more than 5 million people. In the less developed regions, overall urban residence will increase from 1.9 to 3.9 billion people between 2000 and 2030. This compares to the modest increase from 0.9 to 1.0 billion in more developed regions.[21] Such growth is unsustainable and will have severe consequences for quality of life and surrounding environments.

Growth is fastest in infrastructure-deficient small cities and in informal settlements around many large developing country cities. In Africa, 37% of urban dwellers live in informal settlements; in Asia 18%, and in Latin America and the Caribbean, 9%.

Because of their lack of large scale infrastructure and inadequate education or cultural sensitivities to alternatives (*e.g.*, water-free sanitation systems), clean water supplies and sanitation are most lacking in rural areas (29% and 62%, respectively).

If people can realise their reproductive desires, population growth will decline. Slower population growth will reduce the impacts on the local environments, provide the opportunity for expansion of efficiencies, and extend the time scales for priority setting.

[20] World Health Organization. 2001. *Global Water Supply and Sanitation Assessment 2000 Report.* Geneva: World Health Organization. However, the official estimates clearly under-estimate water and sanitation deficits.

[21] United Nations. 1999. *World Urbanization Prospects*. New York: Population Division, Department of Economic and Social Affairs, New York: United Nations.

THE BURDEN OF WATER REQUIREMENTS

Water collection demands fall most heavily on women in non-industrialised countries. They spend more than five times the amount of time men do seeing to their families' needs for water in many settings. The level of the burden depends on the available sources of water. The more distant the source, the higher the burden on women as collectors.

Distance affects both time commitment and the quantity and quality of household use. When the source is a public standpipe at greater than a kilometer from home, use is typically less than 10 liters per day. When it is closer, water consumption may readily reach 20 liters per day. This contrasts both with house connection sources at significantly higher levels, and with natural sources (wells and running freshwater) requiring significant dedication of time and effort for collection.

NEW CHALLENGES RELATED TO WATER NEEDS

There is a growing possibility of increased international conflict (both economic and military) related to the growing competition for water.[22] More than 200 river systems cross national boundaries. Thirteen major rivers and lakes are shared by 100 countries. Diversion of water and purity of water could create tensions at an increasing rate as supplies shrink.

There are great uncertainties as to the future impacts of climate change on water availability. Rainfall patterns are likely to change, including the intensity and timing of storms, the rate of evaporation, etc. This poses significant questions concerning the sustainability of human settlement patterns.

Purely technological fixes to water scarcity are likely to prove difficult. Desalination of seawater now accounts for less than 1% of the water people consume. It is likely that this will increase; but it is only feasible in countries wealthy enough to take on the costs – currently oil producing states of west Asia – with no need to transport the water over long distances. The transport of icebergs has proven infeasible to date. Movement of fresh water in large plastic bags pulled by ships has been of some value in the eastern Mediterranean. As with desalination, however, it is of little help to water scarce land-locked countries and to inland populations. Collection of large amounts of fresh rainfall that lands on the oceans may become feasible but the effects of reflected light and heat from the plastic sheets required cannot be known in advance (or necessarily be positive). Transport of such water to needy populations may very well be infeasible.

The challenge of meeting the water needs of the world's population is already severe. Ominous trends suggest that the difficulty will increase. Concerted action on many fronts is needed to reduce deprivation and improve the prospects for sustainable development. Careful consideration of the tradeoffs and a participatory approach is essential. Finding solutions to the world's water problems will require expanded dialogue, political will, technological advances, local participation and decision-making, and moderation of population growth consistent with people's desires.

[22] Nichiporuk, Brian. 2000. *Security Dynamics of Demographic Factors*. Population Matters. A RAND Program of Policy-Relevant Research Communication. Santa Monica, California: Arroyo Center, Army Research Division, RAND Corporation; and Central Intelligence Agency. 2001. *Global Trends 2015: A Dialogue about the Future with Nongovernment Experts.* Washington, D.C.: Central Intelligence Agency. Web site: www.cia.gov/cia/publications/globaltrends2015/index.html).

STAN BERNSTEIN is a Senior Research Adviser in his ninth year with the United Nations Population Fund (UNFPA). He has been the primary researcher and writer of the annual UNFPA publication, the *State of World Population* report, for the past seven years. Prior to his work for UNFPA he was a researcher and teacher at the School of Public Health, University of Michigan for nearly two decades. There he worked on the "Population, Environment and Development Program" supported by USAID. He has also conducted extensive fieldwork in African and Asian countries including Egypt, Senegal, Ghana, Ethiopia and Bangladesh, Zambia, and the United Republic of Tanzania. He was responsible for policy recommendations and strategy development in the area of population and environment in these settings. He has also participated in preparatory and plenary sessions of the UN International Conference on Population and Development (ICPD), including the ICPD Expert Group Meeting on Population, Development and the Environment, and in its five-year review that culminated in UN General Assembly Special Session in 2000. The State of World Population 2001 report "*Footprints and Milestones: Population and Environmental Change*" addresses the complex inter-relationship of population, environment and development strategies and the emerging international consensus on pathways to sustainability. For a copy of the report, please visit www.unfpa.org.

Stan Bernstein, Senior Research Advisor, United Nations Population Fund, The News Building, 220 East 42nd St., 23rd Floor, New York, NY 10017, bernstein@unfpa.org

Population and Environment Linkages: A U.S. Government Perspective

Margaret Pollack
Bureau of Population, Refugees, and Migration, U.S. Department of State

NOTE: The following is a transcript of Margaret Pollack's remarks at the Experts' Meeting on the Impact of Human Population on Freshwater Resources, hosted by the Yale School of Forestry & Environmental Studies, March 22-23, 2001.

I am delighted to be here with you today. I want to thank the co-sponsors of this workshop – the National Wildlife Federation, the Center for Environment and Population, and the Population Resource Council – three dynamic groups doing good work around the world, as well as our host, the Yale School of Forestry & Environmental Studies.

But what really makes me the most delighted about being with you today is that all of you are what I sometimes fear is becoming an endangered species. Each and every one of you – by agreeing to participate in this workshop – is clearly interested in American foreign policy. You understand that, more and more, events overseas will have an impact here at home, on our security, our jobs, and our environment.

The U.S. government's emphasis on family planning as an important public health intervention goes back more than 30 years. It arose at a time of rising concern about the environment, poverty alleviation, and the women's movement. Today, our international population policy is based on the premise that achieving a healthy and sustainable world population is vital to U.S. foreign policy interests. It is an important element of our broader comprehensive strategy for sustainable development, which integrates our goal of achieving a healthy and sustainable world population with those of protecting the environment, building democracy, and encouraging broad-based economic growth. Our commitment is not rhetorical and is longstanding.

Every day each one of us shares the Earth and its resources with 214,000 more people than the day before. We add the equivalent of a San Francisco every week and a Mexico every year – with 95% of that growth occurring in the developing world. In country after country, the natural resources base is shrinking while the pressures upon it – fueled by increasing consumption and population growth – are increasing.

Per capita supplies of fresh water are a third lower than in 1970. Already, 80 countries with 40% of the world's population suffer from water shortages at some time during the year and at least 300 million people live in regions with severe water shortages. By 2025, that number could be 3 billion.

Human activities have destroyed 11% of the globe's arable land – an area the size of China and India combined. The loss of land and soils stretches the world's ability to provide food in support of today's population. Every year, because of population growth and environmental degradation, the world's farmers must feed 78 million more people with 27 billion fewer tons of topsoil.

Each year, some 40 million acres of tropical forest disappear, an area about the size of Washington State, as trees are cleared for cropland, human settlements, and fuel wood. The destruction and fragmentation of forests and other wildlands are leading to the extinction of plant species which could lead to new food sources and cures for cancer and other diseases. Experts estimate that 27,000 plant or animal species are disappearing each year.

Official U.S. foreign assistance is focused on reducing the pressures of a growing population on the environment. Through our international environmental assistance, the U.S. government is supporting programs to improve the management of more than 2.5 million acres of tropical forests, coral reefs, and grasslands. We are expanding access to potable water, sewage treatment, and housing for more than a half million low-income families annually. And we are promoting the adoption of cleaner production and manufacturing processes in such countries as Ecuador, Egypt, and Indonesia, as well as promoting water conservation in several countries in Central America and the Middle East.

In addition, with U.S. international population assistance funds, we are supporting a number of special projects to connect population and environment issues. For example, in Honduras, the U.S. Agency for International Development (USAID) is funding an interactive tool called a "Farm Management Plan," which is used by rural families to better manage natural resources. This tool, in turn, has inspired a parallel interactive booklet entitled the "Family Management Plan." This booklet is used by rural couples to reflect on their desired family size, and the timing and spacing of their children in relation to their available resources. The men have become more receptive to learning about family planning in the context of agricultural management and the women now have the family planning information and services they desire.

In Madagascar, USAID's Environmental Health Project combines natural resources management with improved health care. Family planning services, sustainable agriculture, increased food security, and environmental conservation are directly linked by cross-training service providers in these areas.

Through the University of Michigan Population and Environment Fellows, USAID also helps facilitate natural resource and family planning linkages in Africa, Asia, and Latin America. A specific example of this work can be found in Mexico's Yucatan Peninsula, where the Fellows, working with local groups, found that providing reproductive health care as an entry point for environment-related activities involving women in community conservation efforts also led to a more open discussion of family planning needs.

The U.S. government effort towards the goal of achieving a healthy and sustainable world population – much of which we do through our environmental and international population assistance efforts – is promoting environmentally sustainable economic development in other countries. We have a profound interest in safe, voluntary family planning, a moral interest in saving human lives, and a practical interest in building strong families and environmentally sound communities.

Advocacy on population and environment issues is required by all of us, at all levels, to ensure the resources necessary to implement programs that protect women's health, save children's lives, and secure our plant's environment. As we look to future, we will want to continue to focus our international assistance activities on ways in which all nations can advance in three pillars of sustainable development: economic growth, social development, and environmental protection.

MARGARET POLLACK is Director of the Office of Population in the Bureau of Population, Refugees, and Migration in the U.S. Department of State. Previously, Ms Pollack worked for six years in the State Department's Bureau of International Organization Affairs (IO), where she was responsible for UN development and humanitarian issues. While in IO, Ms. Pollack was instrumental in negotiating the creation of the Joint UN Program on HIV/AIDS (UNAIDS). Ms. Pollack was a member of the U.S. delegations to both the UN International Conference on Population and Development (ICPD) held in Cairo in September 1994 and the Fourth World Conference on Women held in Beijing in September 1995. She was also the U.S. lead negotiator for the five-year review of the implementation of the ICPD Program of Action held at the UN in 1999. Ms. Pollack received a B.A. from Pomona College in 1978 and an M.A. in international affairs from The George Washington University in 1985.

Margaret Pollack, Director, Office of Population, Bureau of Population, Refugees, and Migration, L-505, SA-1, U.S. Department of State, Washington, DC 20522-0105. m.pollack@state.gov

Talking Population: The Challenges of Communicating on Global Population and the Environment

Kathy Bonk
Communications Consortium Media Center

Henry Griggs
Independent Communications Consultant

ABSTRACT
A comprehensive program of public opinion research is a key element in devising communications strategies on complex, controversial topics. Among the questions research can address are: *who* will be most likely to support your positions, *what* messages and messengers will be most influential with them, and *which* media outlets to approach with story ideas and placements. Two case studies are examined: research on global population growth and on protecting the planet's biodiversity. The lessons of these efforts are widely applicable, even to relatively straightforward issues of local concern. They include: know your audience, know the messages and messengers they will respond to, and tailor your public activities and media outreach accordingly.

INTRODUCTION

The President of the Society of Environmental Journalists was once asked to name the biggest environmental story that was getting too little coverage. Without a pause, he cited rapid population growth, noting that although it is matter of global concern, "It has no hook."

In just a few words, this statement summed up the challenges facing anyone who tries to communicate with the news media or influential segments of the public about population issues. Thoughtful people are aware that the global population is growing, and they intuitively recognize the impacts of that growth on natural resources and human relations. They might even have some sense of the social dynamics, including the status of women in developing countries, that affect desired family size and the spacing of children. But lacking a news "hook" – a single notable development or major new trend – even the most thoughtful journalists tend to overlook stories about global population. And when a story fails to make news, it also fails to get on the public policy agenda.

Issues like clean air and water directly affect people's lives every day – unlike the "bigness" of global population. Thus, linking water shortages or sprawl to the need for more investment in international family planning programs is one important way to raise the salience of the issue of global population. But establishing concrete links to big issues is just one way to bring them to the attention of the public.

...lacking a news "hook" – a single notable development or major new trend – even the most thoughtful journalists tend to overlook stories about global population. And when a story fails to make news, it also fails to get on the public policy agenda.

Starting in early 1992, the Communications Consortium Media Center (CCMC) led efforts to develop a major, multi-year communications strategy on global population with the support of the Pew Charitable Trusts and its Global Stewardship Initiative, which assembled an array of environmental, population policy, religious, and other organizations. Our main tools for framing the debate and targeting audiences and messengers were public opinion research in the form of scientific surveys, mathematical analysis of the surveys to identify population clusters with shared attitudes, and in-depth focus groups.

In the mid-1990's, we also conducted a similar research effort around the issue of protecting the broad diversity of life on the planet. Again, the challenges centered on finding the segments of the public most likely to respond sympathetically to a communications campaign on biodiversity, devising messages that would resonate with them, and determining the most effective avenues for reaching the target audiences. Both cases have important lessons for communicating on complex issues.

Properly conducted, successful research-based strategies like these will not only get press coverage, but will also energize supporters and equip them to add their own momentum to the strategy's progress. For instance, at the earliest possible stage of both the population and the biodiversity campaigns, we invited stakeholder organizations to participate in the design of the public opinion surveys, to contribute to the focus-group discussion guides and to witness focus groups for themselves. Because of this, our colleagues viewed the resulting data, analysis, and strategy recommendations with a strong sense of ownership. Some of the major lessons gleaned from these two campaigns are described below.

RESEARCH: AMERICANS RESPOND TO RAPID POPULATION GROWTH

When Americans are asked an open question about the critical problems facing the world, rapid population growth rarely makes the list. Clean air and water top of the list of environmental concerns in most public opinion polling. Yet, when specifically asked to rate population growth among other environmental problems, as many as three in ten (29%) say that it is the most serious.[1] Even so, there is no apparent urgency about it. There is a lack of consensus about this complex issue, which is both global and intimate.

Meeting the challenge of rapid population growth entails diving into a tangled nest of controversies about sex, abortion, and family planning, reproductive health, the empowerment of women, foreign assistance, immigration, and government's role in determining family size. Finally, there is the simple fact that the impact of population growth is most acute in nations many Americans cannot even find on a map.

As this background suggests, there is intense disagreement about the causes of rapid population growth and whether it will result in major problems in the future or work itself out over time. One extraordinary point has emerged from the research, however. As Global Stewardship Initiative Director Susan Sechler noted, "People may disagree about the seriousness or causes of rapid population growth, but they were fully supportive of the solutions." In this case, the solutions included improving child survival rates, making contraceptives available to all who want and need them, and expanding the educational and economic opportunities open to girls and women in developing nations.

[1] Human Values and Nature's Future: Americans Attitudes on Biological Diversity. An Analysis of Findings from a National Survey by Belden & Russonello and R/S/M. October 1996. Interviewing conducted February 29 through March 12, 1996; 2005 adults 18 and older nationwide.

From this finding, we identified a basic rule of communicating on global population issues: focus on the solutions and do not debate the problems.

TARGETING: WHOM DO WE REACH AND HOW DO WE REACH THEM?

A major portion of our efforts on population centered on setting the stage for the United Nations Conference on Population and Development (ICPD). Slated to take place in Cairo, Egypt in September 1994, ICPD became an important "hook" for American news media and a single focus for the policy discussion of population.

As the message development work proceeded, analysis of the polls showed that from a purely demographic perspective, three groups should be targeted for educational messages on global population: women with advanced education, who are sensitive to environmental concerns and constitute an important bloc of voters; people over the age of 60, who are more likely to respond to appeals about the condition of the planet for future generations; and younger people, ages 16 to 24, who are likely to be concerned about the environment.

From this finding, we identified a basic rule of communicating on global population issues: focus on the solutions and do not debate the problems.

Next we tackled the related questions: how do we reach these people, and what sources do they rely on for timely news and credible commentary? A desirable approach is to include questions about news sources in the survey research; however, since all news outlets have extensive information about their audiences, it is possible to use that information to put yourself in the shoes of the people you want to influence.

If your main objective is to reach key members of Congress, the *Washington Post*, *The New York Times*, and the members' hometown media are critical first targets. When a particular issue is the focus of ongoing controversy, then it becomes important to show members that there is support for a position on the editorial pages and in the op-ed columns of newspapers around the country. Since CNN and C-SPAN are piped into nearly every office on Capitol Hill, it is valuable to get interview slots on those networks, and to design events that will attract coverage by them. The weekend talk shows fuel much of the discussion among the policy elite in Washington, so getting useful information into the hands of the panelists on those programs is an indirect way of reaching administration and congressional targets.

On the other hand, if you are trying to reach scientific communities, a mention in the policy pages of publications like *Science, Scientific American,* or any of a number of more specialized publications can be much more effective than air time on C-SPAN. Then again, when one is trying to reach the business community, publications like *Forbes, Fortune,* the *Wall Street Journal* and *Business Week* take on added importance.

The general rule is to find out where the people you are trying to influence get their news and information, and to devise tactics to get into that flow of information. Communicating on population meant that considerable outreach efforts were directed to major women's magazines, which tend to be overlooked in policy-related campaigns. Print outlets that tend to attract an older audience were another focus. Additionally, women journalists were targets, since they are likely to "connect the dots" on population issues, international assistance, and women's rights.

Of course, we approached any outlet that had favorably commented or reported on population issues in the past, on the premise that they would require less educating. Finally, we mounted an explicit effort to counter the widespread use of the term "population control" because of its unfortunate suggestion of imposed values and coercion.

The results of this effort were gratifying. The ICPD prompted a flood of coverage and commentary on population issues, including nearly 5,000 newspaper clips, which ranged from news reports and commentary to op-ed pieces and editorials. The articles noted both the urgency of action and the new thinking on population policy that were at the heart of the Cairo agenda. In particular, a large number of articles and editorials made specific reference not only to meeting the global need for family planning services, but also to the newly enhanced role of women in making global policy.

Communicating on population meant that considerable outreach efforts were directed to major women's magazines, which tend to be overlooked in policy-related campaigns.

FRAMING THE DEBATE – VALUES AND PRIORITIES

The language, symbols, anecdotes, and other information used in a communications strategy are critical factors in determining whether it will succeed or fail. And just like targeting, the best way to develop and test different themes with different audiences is through public opinion research. It is extremely important, however, to talk to people in terms that matter to them and to do so in ways that cut through the glut of information they receive day after day. We learned during the campaign on biodiversity that such terms must include more than an array of facts and figures. The most successful media campaigns combine factual arguments with messages that appeal to the deeply-rooted values shared by most Americans.

In-depth research by the Washington, D.C.-based polling firm Belden, Russonello & Stewart, based on decades of available data, concludes that most Americans share basic or primary values including responsibility for one's family, caring for one's self, personal liberty, hard work, spirituality, honesty and integrity, and fairness and equality. A secondary set of values includes responsibility to care for others, personal fulfillment, respect for authority, and love of country or culture.

Although the importance of these broad concepts seems obvious, many communications strategies either ignore values altogether, or mistakenly try to be everything to everyone. Different segments of the public emphasize different values when coming to a position on topics of social importance. However, with a basic understanding of the importance of these enduring values, and an awareness of the major issues, you can develop straightforward, value-centered messages to advance even the most complex proposals.

For example, in 1998 and for several years leading up to it, opinion polls generally showed that the public considered promoting safety and stopping violence to be a top issue. (See Figure 1, which is based on a compilation of survey results over the past several years before and after September 11, 2001. It summarizes the answers to: "What are the top issues facing America today?")

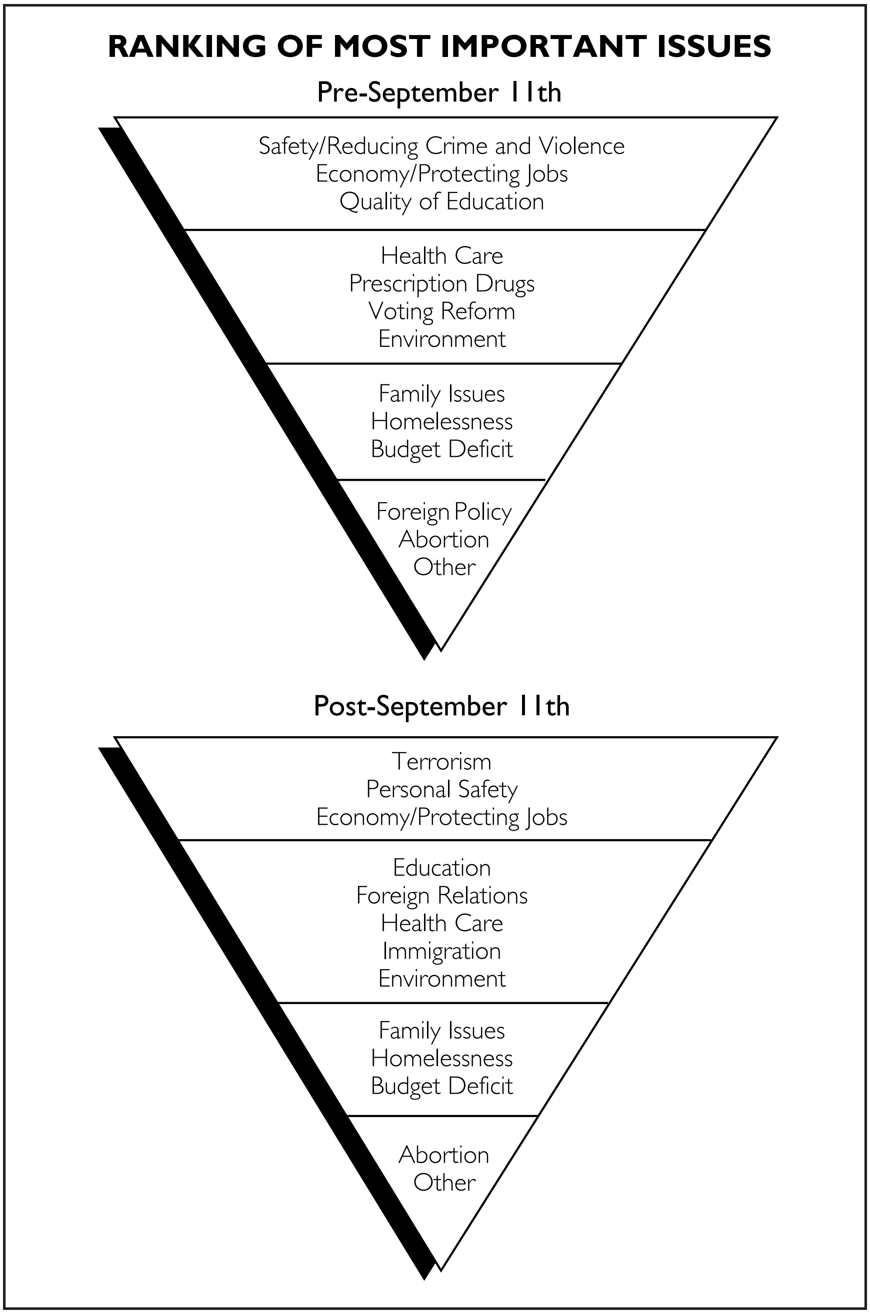


Figure 1 Ranking of most important issues, pre- and post-September 11th.

Given this information, we were asked how to effectively frame children's issues, especially "programs related to childcare or foster care." Although they care about them, most Americans do not rank these as top concerns. They are generally considered third-tier issues. However, if one frames these same children's services as "programs that promote safety and prevent violence," emphasizing the elements that have strongest resonance with the public, the majority of the public and media will listen and be more supportive. Conversely, if spokespersons use terms such as "risk assessments" and other social work jargon, the public and media will definitely "tune out."

DEVELOPING MESSAGES

Some communicators worry that "framing" messages in this way seems like a cynical approach to manipulating segments of the public. However, while it is true that some campaigns are based on the principle, "Tell the people what they want to hear," the advice here about framing should not be construed to countenance lying. In the long run, lies, contradictions, and inconsistencies will be rooted out by people's common sense and value systems.

To succeed, a communications strategy needs messages that are simple, clear, focused, and consistent.

To succeed, a communications strategy needs messages that are simple, clear, focused, and consistent. Once they are set, those messages should be integrated into all materials and emphasized in the training of spokespersons. Message points should be re-examined on a regular basis, and revised to reflect new trends and developments.

PROTECTING THE DIVERSITY OF LIFE ON EARTH

CCMC was involved in a major research effort by environmental groups to devise a communications strategy around preserving biodiversity – the great variety of life on the planet. The project involved dozens of organizations and three distinct phases that included focus groups and a comprehensive public opinion poll.

Unfortunately for proponents of biodiversity preservation, the research found that although a large majority of Americans supported the principle of protecting endangered species, most were unfamiliar with the term "biodiversity," and some who heard it for the first time had mixed reactions. One focus group participant said it sounded like "a government program, and I'm not ready for it." Others described it as the "circle of life," picking up a theme from a then-popular movie, "The Lion King."

The survey research placed special emphasis on learning about the underlying values that inform the public's view on the environment. The most widely held values were responsibility to family and a sense of personal stewardship of the Earth, and a responsibility to leave the planet in good condition for future generations. At the start of those discussions, participants expressed a near-consensus conviction that humans need to protect plant and animal species to preserve the balance of nature – and that if humans were responsible for contaminating parts of the planet, they had a responsibility for cleaning them up. In other words, they made a huge distinction between problems caused by people and environmental problems attributable to natural disasters.

Similarly, when asked early in the survey about their personal level of support for maintaining biodiversity, 87% said it was important to them. Demographically speaking, those who believed maintaining biodiversity was "very important" were found to have lower incomes, live in cities, and disproportionately to be African American or Latino. Politically, they tended to be Democrats or Independents.

The most resonant themes centered on protection of ecosystems, because most people had no trouble identifying the benefits that proceed from environmental stewardship, like clean water. However, the focus groups and the survey both found that this broad support for maintaining natural habitats and protecting species plummets when the public considers other issues such as jobs, property rights, human convenience, and whether all species are equally worthy of protection.

Demographically speaking, those who believed maintaining biodiversity was "very important" were found to have lower incomes, live in cities, and disproportionately to be African American or Latino. Politically, they tended to be Democrats or Independents.

A second major objective of the poll was to analyze how segments of the population could be divided according to attitudes on biodiversity. A mathematical analysis identified eight distinct segments of the American public that shared demographic traits and also similar attitudes about biodiversity. Two of them, totaling 23% of the public, were identified as likely targets of support for maintaining biological diversity; three other segments, or 34%, were deemed persuadable; added together, the supporters and persuadable constitute a targeted majority of 59%.

This research also went a step further than most by asking respondents to identify their favored leisure activities and the sources of information most important to them. This line of inquiry established some interesting possible targets – for instance, younger men who had gone cross-country skiing the previous year.

CONCLUSION

The type of comprehensive, sophisticated research that went into the biodiversity and global population strategies can help to set targets in several ways. It can tell you *who* will be most likely to support you, *what* messages and messengers will be most influential with them, and *which* media outlets to approach with story ideas and placements. While most not-for-profit groups are more likely to have concerns and goals that are closer to home than biodiversity protection and the rate of global population growth, the principles behind framing the message for target audiences on complicated global issues apply to local efforts. In short, know your audience, know the messages and messengers they will respond to, and tailor your public activities and media outreach accordingly.

KATHY BONK is President and Executive Director of the Communications Consortium Media Center (CCMC). For over two decades, Ms. Bonk has worked on a wide range of public policy issues, primarily focusing on children and families, health care, global population, and media reform. In 1988, she established CCMC, a nonprofit center that develops educational and communications strategies on social policy issues. Ms. Bonk is co-author of The Jossey-Bass Guide to Strategic Communications for Nonprofits. Ms. Bonk directed CCMC's work on the Pew Global Stewardship Initiative from 1993 through 1996. This multi-year public education effort, funded by The Pew Charitable Trusts, sought to move the United States toward a position of leadership on problems concerning rapid worldwide population growth. As part of this initiative, Ms. Bonk was instrumental in increasing worldwide media coverage of the range of issues successfully presented at the UN Conference on Population and Development (ICPD) in Cairo in 1994, and was an advisor to the U.S. delegation for the UN's Fourth World Conference on Women in Beijing in 1995. Ms. Bonk has a B.A. from the University of Pittsburgh.

Kathy Bonk, President & Executive Director, Communications Consortium Media Center, 1200 New York Avenue, NW, Suite 300 Washington D.C. 20005. kbonk@ccmc.org

HENRY GRIGGS is a co-founder of CCMC and a co-author of the Jossey-Bass Guide to Strategic Communications for Nonprofits. Early in his career, he worked in the Elections and Survey Unit of CBS News in New York City. He spent five years in the public affairs department of the American Federation of State and Municipal Employees (AFSCME), a large public employees union, for which he conducted on-the-ground media campaigns in 35 states. Mr. Griggs joined CCMC full-time in 1992. He became an independent consultant in 1994 while continuing to manage CCMC's long-standing project on energy and the environment. His current clients include national and regional nonprofits working on environmental and economic issues. He holds a bachelor's degree from Harvard College.

Henry Griggs, Senior Consultant, Communications Consortium Media Center, 1200 New York Avenue, NW, Suite 300 Washington D.C. 20005. hgriggs@ccmc.org

Meeting the Challenge of Mobilizing Grassroots Advocacy in Support of Clean and Abundant Water

Pamela E. Goddard
National Wildlife Federation

ABSTRACT
Motivating citizens to become politically active on behalf of environmental issues has long been a challenge for the conservation community. The problem is that while public opinion polling consistently demonstrates widespread support for clean water, the public has yet to make the vital connections between water quality, water quantity, and the impact of population pressures. To begin to address this challenge, this paper will examine how the public views environmental concerns in general, and water issues in particular. It will analyze what motivates an individual to take action and which spokespeople they most trust. Finally it will discuss the types of advocacy messages that resonate with the public and the challenges we face to rally around water quantity.

ENVIRONMENTAL VALUES

Much research has been devoted to studying the values that Americans apply to environmental concerns. According to Belden, Russonello & Stewart Research and Communications, "values:

- are limited in number and shared by most Americans;
- usually endure across a person's lifespan, and only change slowly from generation to generation; and,
- are organized by people into groups and arranged hierarchically, with some values taking precedence over others."[1]

In their publication, *Communicating Values, Talking about the Environment*, Belden *et al.* divide values into primary and secondary values, i.e. by level of importance. According to Belden and her colleagues, primary values include responsibility to family and self, personal liberty, commitment to work, spirituality, honesty, and fairness. Secondary values include responsibility to others, personal fulfillment, respect for authority, and love of country. When environmental concerns are fitted into this matrix, the values "represent a mixture of primary and secondary values...but often lean toward the secondary values group."[2]

Indeed, public opinion polling has historically supported the view that the environment is a secondary value or "tier two" concern to most Americans. Yet when we discuss water, the numbers begin to change. Each year, *Money Magazine* conducts a poll to determine what factors Americans consider when deciding where to live. In the April 2000 survey, **clean water ranked as the top priority**, above crime rate, available health care, and taxes.[3] In a Greenberg-Quinlan/Tarrance Group poll conducted after the 2000 elections, 69% of the respondents placed clean water and clean air among their top three concerns, surpassed only by education (76%) and health care (75%). This was higher than taxes (60%) and Social Security/Medicare (67%).[4]

The public's concern for clean water is further highlighted when Americans are specifically questioned regarding their feelings about a broad range of

[1] Belden, Nancy, John Russonello and Kate Stewart. *Communicating Values, Talking about the Environment.* Washington, DC: Belden, Russonello & Stewart Research and Communications, 1999.

[2] *Ibid.*

[3] *Money Magazine*, April 2000.

[4] Greenberg-Quinlan and the Tarrance Group survey. *League of Conservation Voters.* November 2000. Telephone survey of 1,200 registered voters. Margin of error +/-2.8% in 95 out of 100 cases.

environmental issues. A CNN/Gallup/USA Today poll conducted in January 2000 gave those surveyed a list of eight diverse environmental problems and asked how much they personally worried about each problem. Seventy-two percent said they worried a great deal about pollution of drinking water. This was followed by pollution of rivers, lakes, and reservoirs (66%), and contamination of water and soil by toxic waste (64%). Environmental concerns like damage to the ozone layer, global warming, and urban sprawl all polled below concern about water.[5] A Princeton Research Associates' poll asked those surveyed which issue was the most important environmental problem facing the world today. Water and air pollution were at the top of the list for 19% of those surveyed. Global warming, protection of endangered species, and acid rain all fell at the bottom of the list.[6] Finally, a Peter D. Hart Research Associates poll found that clean water and clean air are "very important" to 74% of Independent voters, forming a swing block of 14% of all voters.[7] Thus, when the public is asked specifically about environmental concerns, water is at the very top of their list.

FROM AWARENESS TO ACTIVISM

Although the public is thinking about water, thought does not directly translate into action. This merits a discussion of what motivates people to act. According to the Midwest Academy, a renowned training center for grassroots organizers, people take action when they are aware of a problem, when they understand the problem easily, and when they believe they can make a difference.[8] Most people first become aware of a problem because they believe it is affecting them personally.[9] However they do not normally take action unless they understand the problem intellectually, see its cause and effect, and believe that they have a role in a solution.

For example, the conservation community has made great strides in convincing citizens to recycle. People know that throwing things away wastes materials and energy, and contributes to our overflowing landfills. They also understand that when they recycle a can or jar, rather than throwing it away, it will be used to make new products. Participation in recycling is second nature to most Americans. By contrast, the environmental community has not been as successful in its battle to combat global warming. Most people do not understand the issue. They do not understand how their actions contribute to it, and they do not believe that they can help to stop it. In the polling data previously discussed, global warming consistently polled at the bottom of the public's concerns.

Once citizens decide to become involved, what are the venues in which they wish to take action? According to Diane MacEachern, author of *Enough is Enough: The Hellraiser's Guide to Community Activism*, most people begin with steps in their own backyard. They share information with their families, friends, and communities and often start with simple actions like writing a letter to an elected official regarding a neighborhood concern.[10] This type of behavior spurred the rise of the NIMBY (Not In My Backyard) movement a few decades ago. MacEachern contends that:

[5] CNN/Gallup/USA Today poll. January 13–16, 2000. Surveyed 1,027 adults including 887 registered voters and 512 likely voters. Margin of error +/- 3% for all adults, +/-4% for registered voters and +/-5% for likely voters.

[6] Newsweek/Princeton Research Associates survey. April 13-14, 2000. Surveyed 752 adults. Margin of error +/-4%.

[7] Peter D. Hart Research Associates survey. *League of Conservation Voters.* October 2000.

[8] Bobo, Kim, Jackie Kendall and Steve Max. *Organizing for Social Change: A Manual for Activists in the 1990s.* Midwest Academy. California: Seven Locks Press, 1996.

[9] Bolling, David M. *How to Save a River: A Handbook for Citizen Action.* Washington, D.C.: Island Press, 1994.

[10] MacEachern, Diane. *Enough is Enough: The Hellraiser's Guide to Community Activism.* New York: Avon Books, 1994.

> NIMBY also properly reflects a venerable American tradition: the right of individual citizens to protect their safety and way of life by uniting in a common cause. For many people, those concerns have led them to expand the concept of 'backyard' to include community and country.[11]

Many citizens who begin as community activists often either form their own issue campaign-directed organizations or join with other established groups to take action on their campaign.

Another venue for action is consumer choice. At a November 2000 presentation to the Clean Water Network in Washington, D.C., pollster Celinda Lake stated that most of the Americans that she polled after the elections would like to take action through their consumerism. Specifically, they would like to: pay an organization to "do the right thing" like The Nature Conservancy, which buys and preserves green space; or to buy "green" products with guidance from a knowledgeable national group on which products are environmentally sensitive. Interestingly, most Americans consider the ratings of their legislators to be helpful in choosing whom to elect. Many want to use their ballot as a consumer choice for an environmentally savvy lawmaker. Finally, Lake said that the public has a deep belief in the power of technology and its ability to address our environmental problems. Citizens are motivated to act in support of campaigns that rely on technology to solve pressing environmental concerns. They believe we can overcome our mistakes of the past and repair damage done to the environment.[12]

It is also apparent that the public is more inclined to be concerned and to take action when they hear about an issue from what they consider to be a trustworthy and credible source. For example, citizens generally believe an environmental issue is legitimate if they read about it in their newspaper or hear about it on television. Fortunately, national conservation organizations are also seen as credible sources of information. In a CNN/Gallup/USA Today poll conducted in January 2000, respondents were asked how much they trusted different groups to protect the quality of our nation's environment. Thirty-four percent of those polled said they trusted national environmental groups a "great deal." This was followed by trust of local environmental organizations (28%) and federal agencies (27%). Ranking at the bottom of the scale was trust in the U.S. Congress (10%), and large corporations (9%).[13]

MOBILIZING ACTION ON WATER

So the question posed is: How does water fare with the public, particularly in light of the challenges we face in mobilizing grassroots action? The polling data demonstrates that most Americans are worried about clean water. However, the majority of the polls show a concern with water quality, not water quantity. There are some regional exceptions, where discussion of water quantity is covered in the press and affects those citizens' daily lives. For example, water shortage discussions have long been the norm in parts of California, Texas, and

[11] *Ibid.*

[12] Lake, Celinda. Presentation at *Clean Water Network Conference.* November 14, 2000.

[13] CNN/Gallup/USA Today poll. January 13–16, 2000.

other western states. More recently, the topic has come up in the Great Lakes region, since diversion of water from the Great Lakes has become an international trade issue.

Among the many hurdles in mobilizing grassroots action are educating the general public about water quantity problems and illustrating the link between quantity and population pressures. This issue must be presented in a manner that shows citizens how they personally are affected by water quantity problems and how their actions can make a difference. This means that a close connection between water quantity and its impact on individuals and families should be clearly demonstrated. The call to action should also include a consumer choice aspect that allows Americans to act through their pocketbooks. The message should come from credible spokespeople and coverage of the issue must increase in newspapers, television, and other media to ensure that the citizens understand the problem and want to help solve it. If the conservation community works through these obstacles, it will be on the road to success in mobilizing a strong grassroots base to positively effect policy change.

REFERENCES

Belden, Nancy, John Russonello, and Kate Stewart. *Communicating Values, Talking about the Environment.* Washington, D.C.: Belden Russonello & Stewart Research and Communications, 1999.

Bobo, Kim, Jackie Kendall, and Steve Max. *Organizing for Social Change: A Manual for Activists in the 1990s.* Midwest Academy. California: Seven Locks Press, 1996.

Bolling, David M. *How to Save a River: A Handbook for Citizen Action.* Washington, D.C.: Island Press, 1994.

CNN/Gallup/USA Today poll. January 13-16, 2000.

Fried Carla, Jeanhee Kim, and Amanda Walmac. The Best Places to Live. *Money Magazine.* April 2000: 132-153.

Greenberg-Quinlan and the Tarrance Group survey. *League of Conservation Voters.* November 2000.

Lake, Celinda. Presentation at *Clean Water Network Conference.* November 14, 2000.

MacEachern, Diane. *Enough is Enough: The Hellraiser's Guide to Community Activism.* New York: Avon Books, 1994.

Newsweek/Princeton Research Associates survey. April 13-14, 2000.

Peter D. Hart Research Associates survey. *League of Conservation Voters.* October 2000.

PAMELA GODDARD has been the Senior Grassroots Outreach Manager of the National Wildlife Federation since February 1999. A long-time grassroots organizer, Ms. Goddard spent ten years working for the Sierra Club's Legislative Office in Washington, DC. At the Sierra Club, Ms. Goddard served as an Assistant Political Director and as a lobbyist and organizer on a number of conservation issues including clean water, wetlands, takings, and endangered species. In the mid-1990s, she was the Wetlands Co-Chair of the Clean Water Network, a coalition of hundreds of grassroots organizations working for the passage of clean water legislation. Also before joining NWF, Ms. Goddard spent two years as the Campaign Manager of the National Breast Cancer Coalition, a grassroots advocacy organization dedicated to the eradication of breast cancer. She received a bachelor's degree from Grinnell College in Grinnell, Iowa.

Pamela Goddard, National Wildlife Federation, 1400 16th Street, NW, Suite 501, Washington, DC 20036. goddard@nwf.org

Population
Resource
Center

Center for
Environment &
Population

NATIONAL
WILDLIFE
FEDERATION®
www.nwf.org™

Human Population and Freshwater Resources
Experts' Meeting
March 22-23, 2001
at the
Yale School of Forestry & Environmental Studies (Yale F&ES)
New Haven, Connecticut
Co-organized by
the Center for Environment and Population (CEP), National Wildlife Federation (NWF), and
Population Resource Center (PRC)

AGENDA

Thursday March 22, 2001

Morning session
The Slifka Center, Susman Hall,Yale University
80 Wall Street
New Haven, CT

9:00--9:10 **Welcome and introductions.** James Gustave Speth, Dean, Yale F&ES, and Professor in the Practice of Environmental Policy and Sustainable Development.

9:10--9:30 **Setting the scene.** Laying out the background and the context in which the meeting is being held, meeting objectives, discussion of expected outcomes. Co-sponsors Victoria Markham, CEP; Karin Krchnak, NWF; Nancy Thorne, PRC.

9:30--9:45 **Where are we now.** Introduction to the issues, including the connections between population and consumption factors and water quality, availability, and environmental impacts; new and emerging issues; policy, outreach, advocacy options for discussion. Stan Bernstein, Senior Research Adviser, United Nations Population Fund-UNFPA.

9:45-- **Case studies.** (Time includes presentations and questions):

9:45--10:15 **1. Western water**. Denise D. Fort, Professor of Law, University of New Mexico and Chair, Western Water Policy Review Advisory Commission.

10:15--10:45 **2. Southern Florida ecosystem**. Bonnie Kranzer, Executive Director, Governors' Commission for the Everglades.

10:45--11:00 Coffee Break

11:00--11:30 **3. Great Lakes**. J. David Rankin, Program Director, Great Lakes Protection Fund.

11:30--12:00 **4. Chesapeake Bay**. Margaret A. Palmer, Professor of Biology, University of Maryland, and President, Ecological Society of America, Aquatic Section.

12:00--12:30 **5. Rio Grande, U.S. and Mexico.** Mary E. Kelly, Executive Director, Texas Center for Policy Studies.

12:30--1:30 Lunch

Afternoon session

1:30-- **Panel Discussions.** Panelists will make brief presentations, then discuss links between the case studies, policy, media and advocacy (time includes presentation and discussion).

1:30--2:15 **Media and Public Outreach.** Kathy Bonk, Director, Communications Consortium Media Center (CCMC).
Crafting and conveying population-environmental messages to the media. Followed by discussion on how to reach the media with messages on water issues.

2:15--3:00 **Policy and Decision-Makers.** Margaret Pollack, Director, Office of Population, U.S. Department of State.
Reaching policymakers on the issues. Followed by discussion on integrating issues into local to national U.S. policies.

3:00--3:15 Coffee Break

3:15--4:00 **Activitists and Advocacy.** Pam Goddard, Grassroots Coordinator, National Wildlife Federation (NWF).
Reaching grassroots activists. Followed by discussion on how to apply the population-water issues to advocacy campaigns and grassroots activism, training, and materials.

4:00--4:30 **The Issues and Academia.** John Wargo, Yale F&ES, Professor of Environmental Risk Analysis and Policy, Director of the Environment and Health Initiative.
Discussion of population, health and water research, U.S. policies, and legislation.

Friday March 23, 2000

The Slifka Center, Yale University
Zucker Reading Room and Library

9:00--12:00 **Discussion Topics:** The following topics will be discussed specifically for **each** of the **three** **target audiences: 1) policymakers/U.S. Congress; 2) grassroots activists; 3) media:**

A. Main Issues

1. What are the **top issues** that define the relationship between population factors and freshwater resources? What is the best way to frame the issues for the various audiences?

B. Understanding and Addressing the Issues

1. What **approach** should be taken so the target audiences can better understand and address the issues? What should we try to convey that can realistically be accomplished over the short (3-5 years), mid (10-15 years), and long term (25-50 years)?

2. What **initiatives have proven successful,** which haven't, and which should be emulated? Where are the **gaps,** what research, policy, public outreach is needed?

3. What are the **best messages** that will resonate with the audiences? Who is currently most effective at getting the message(s) out? Who are the **best messengers or influentials** for the target audiences?

4. What are some **new approaches** to addressing the issues? How can we present the issues in a new light with regard to U.S. domestic and foreign policy, the media, the public?

5. Where should **financial resources and NGO efforts** be concentrated to effectively educate the public and policymakers?

C. Groups' Strategy

1. How can **this group** work to move local, regional and international population and water issues forward?

12:00 **Close**