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Rosenberg International Forum on Water Policy

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TABLE OF CONTENTS

Opening Remarks 1

Keynote Speakers 7

Factors for Success: Public- and Private-sector Roles in Securing a Safe and Reliable Water Supply in a Time of Global Change
Don Lowry 9

Mountains of the World — Water Towers for the 21st Century
Bruno Messerli 20

Upland Watershed Management in the Developing World
Sihem Benabdallah 40

Session One 51

Challenges in Upland Watershed Management: For What? For Whom?
Holger Hoff 52

Water Management in Alpine Regions
Pedro Arrojo Agudo 64

Hans Schreier, Session Discussant 79

Discussion 93

Session Two 99

Upland Watershed Management and Global Change — Canada's Rocky Mountains and Western Plains
Dave Sauchyn, Alain Pietroniro and Michael Demuth 100

Climate Change and Water Resources: Potential Impacts and Implications
Richard M. Adams and Dannele E. Peck 120

Adèle Hurley, Session Discussant 131

Discussion 132

Session Three: Case Study One 141

Systems-hydrology Tools for the Upper Catchments of the Jordan River and Lake Kinneret, Israel
Alon Rimmer 143

Policy and Adaptation in the Jordan Valley
Yousef Hasan Ayadi 171

Moneef Zou'bi, Session Discussant 195

Discussion 198

Session Three: Case Study Two 207

A Case Study of the Saskatchewan River System
D.W. Schindler and W.F. Donahue 208

The Honourable Guy Boutilier, Alberta Minister of Environment 229

The Honourable John Nilson, Saskatchewan Minister of Environment 233

Discussion 237

Session Three: Case Study Three 243

Impacts of Climate Change on the Management of Upland Waters: The Rhône River Case
Jean-Paul Bravard 244

Adaptive Management of Upland Rivers Facing Global Change: General Insights
and Specific Considerations for the Rhône Basin
Claudia Pahl-Wostl, Ger Berkamp and Katharine Cross 273

Alberto Garrido, Session Discussant 292

Discussion 294

Session Three: Case Study Four 301

An Overview of the International Joint Commission
Jack P. Blaney 302

The International Joint Commission: A Case Study in the Management
of International Waters
The Honorable Dennis Schornack and John Nevin 310

Discussion 321

Conference Summary 328

INTRODUCTION

In September 2006, environment ministers from Alberta and Saskatchewan, the former Deputy Prime Minister of Canada, and fifty of the world's experts in water-conservation and -management policy met at The Banff Centre for the Fifth Biennial Rosenberg International Forum on Water Policy. With a focus on upland watersheds and the effect of climate change on dwindling resources, the Forum explored the complex negotiations involved in managing water across borders and boundaries — provincial, state and national.

Forum participants included former Deputy Prime Minister the Rt. Hon. Herb Gray, Chair of the Canadian Section of the International Joint Commission (a treaty organization set up in 1909 to resolve transboundary water issues between Canada and the U.S.); Alberta Environment Minister Guy Boutilier; Saskatchewan Environment Minister John Nilson; Dr. Bruno Messerli, Vice-president of the Swiss Academy of Sciences and author of *Mountains as Water Towers*; Moneef Zou'bi, Director-general of the Islamic Academy of Sciences; and the University of Alberta's Dr. David Schindler, one of the world's foremost water experts.

These proceedings include the papers presented at the Forum, plus transcription of the discussions that arose from those papers.

The Rosenberg International Forum on Water Policy was established in 1996 with an endowment from Bank of America to the University of California Water Resources Center in honour of the Bank's retiring chairman and CEO, Richard M. Rosenberg. Rosenberg's lifelong interest and leadership in water policy is recognized through this ongoing global dialogue to enhance the environment and economic growth, reduce water-related conflicts and improve water policy. Previous sessions of the Forum have taken place in San Francisco, Barcelona, Canberra and Ankara.

Forum V of the Rosenberg International Forum was sponsored by the University of California, Bank of America, Max Bell Foundation, Alberta Environment, Alberta Ingenuity Centre for Water Research, The Calgary Foundation, Alberta Irrigation Projects Association, the Columbia Basin Trust and The Banff Centre.

With the generous support of Max Bell Foundation, this limited-edition volume of proceedings from the Forum is being distributed to key libraries across Canada.

OPENING REMARKS

Henry Vaux, Chair, Rosenberg Forum:

There are 52 participants from 24 countries at this fifth edition of the Rosenberg International Forum. The institutional host of this year's Forum is The Banff Centre, which has made its superb facilities available to us for the duration of the Forum. Leslie Taylor, with Mountain Culture, has provided the leadership here and has worked tirelessly on all the details surrounding this Forum for almost two years; we will acknowledge Leslie and her efforts a little later in the program. To welcome you here on behalf of The Banff Centre this morning, it is my pleasure to introduce Ms. Sarah Iley, who is Vice-president of Programming at The Banff Centre. Mountain Culture, which is the hosting group here, is one of her activities. So please join me in welcoming Ms. Sarah Iley.

Sarah Iley, Vice-president of Programming, The Banff Centre:

On behalf of the Board of Governors of The Banff Centre — and I want to acknowledge one of them who's in the room today, Don Lowry, who is one of your speakers — and also on behalf of our president, Mary Hofstetter, and the whole Banff Centre team, it's my very great pleasure to welcome you here for the Fifth Biennial Rosenberg International Forum on Water Policy.

I've had a chance to look at your itinerary, and I imagine that you've had a terrific couple of days so far, exploring the [Columbia] Icefield and some of our very beautiful lakes. I hope that the next two days of discussion are equally inspiring, because — as you'll see from some of the banners hanging around the campus — we're in the business, here at The Banff Centre, of inspiring creativity. For almost 75 years, the impact of our stunning mountain location, together with the creative atmosphere, the diverse group of participants from many backgrounds and disciplines, and the strong support from Centre staff, have combined to make a powerful experience for everyone who comes here. And I'm glad that you will have the opportunity to enjoy that environment, atmosphere, diversity and staff support.

Just a little bit about The Banff Centre: We're a post-secondary learning institution that was set up by the Province of Alberta. Originally founded in 1933, we began with a single summer course in drama. Today, we are a year-round hive of activity, serving as a catalyst for creative thought, as well as the creation of new work, in 12 arts disciplines, in management leadership and in the area of mountain culture. Our programs and our conferences are designed to provide for individual and group renewal and transformation, encouraging participants to question assumptions, explore ideas, embrace change and exemplify excellence. Over the last decade, we have expanded and broadened our programming in the area of the mountain environment, and it's for that reason that we are particularly pleased to be the local hosts for the 2006 Rosenberg Forum.

As many of you know, we held an important international summit here during 2003, the International Year of Freshwater. The event was called Mountains as Water Towers, an evocative phrase created by Professor Bruno Messerli, and we're honoured that he's here with us again today. Since that pivotal event, the Banff Centre's commitment to sharing the stories and publicizing the issues of upland watersheds has continued to flourish. Your meeting here is part of that Banff Centre commitment. Certainly, you have some very critical issues to discuss. I mentioned to Henry earlier that I was pleased to get a preview of some of them when I tuned in to CBC Radio Calgary on Tuesday and was delighted to hear Bob Sandford and Henry Vaux outlining some of the challenges you will be discussing. I'm really glad that so many people in Alberta and across Canada were able to hear that interview.

Recognizing the importance of the task at hand, I first want to thank you, on behalf of The Banff Centre, for choosing this to be the location for this crucial meeting, and on behalf of the peoples of the world, I can say that we all look forward to learning the outcomes of your deliberations, because they will affect us all. Thank you very much.

Henry Vaux, Chair, Rosenberg Forum:

I neglected to introduce to you two of the most important people here at the Rosenberg Forum, lest there be any doubt about who makes this Forum happen: Let me introduce to you Ms. Kim Beaird, who's standing in the back of the room and who is the administrative officer of the Forum. And let me also introduce Al Beaird, over here to my left. Al basically takes care of the audiovisual needs and all of the other technical stuff that generally will go wrong on occasions such as this; and in Al's hands, it never does go wrong. Thank you, Al.

Now it is both a pleasure and a privilege for me to present to you the man whom this conference honours. He is the former chairman of Bank of America, he is widely credited with having rallied the California business community to address the problems of the great California drought from 1986 to 1992, and he is currently engaged in a large number of important philanthropic activities that benefit people from all walks of life. Will you join me in welcoming Mr. Richard Rosenberg.

Richard Rosenberg:

Thank you, Henry. It is a great pleasure to add my welcome to all the participants at the Fifth Rosenberg International Forum on Water Policy. As I said at the first Forum, in San Francisco in 1997, the establishment of this Forum in my name by Bank of America ranks as one of the highlights of my very long business and banking career. Bank of America, of course, is not in an industry that is normally considered water-intensive; however, we have hundreds, if not thousands, of customers that are, and we are vitally concerned with this subject on their behalf. But our interest is even more fundamental: Bank of America understands that sound and intelligent water policy is critical — not only to the economy of the United States, but to every nation in our increasingly global economy.

By any standard, the Rosenberg International Forum on Water Policy has been highly successful. In San Francisco in 1997, participants explored the sources of water conflict and identified ways in which conflict can be managed. At the Barcelona Forum, conflict between agriculture and environmental uses of water was explored. In Australia, participants discussed new innovations in water management from the developed and the developing world. And two years ago, in Turkey, the Forum discussed the critical and potentially explosive issue of the management of transboundary river basins.

I believe that we should take great pride in what has been achieved in the past nine years, including the regional conference that has occurred, and the ones that are planned as spinoffs from the Biennial Forum. The uniform high quality of the papers being presented — and the level of the discussions emanating from those papers and presentations — is, I believe, tangible evidence of accomplishments. But there is much work ahead if the Forum is to have the global impact of which it is capable. As Henry said, the original, underlying concept of establishing the Forum was to provide a means of generating ideas that would aid in the reduction of conflict in the management of the world's water resources. As I mentioned, we have taken some major steps to meet that objective — in the papers, the presentations and the discussions that have emanated from the Forum. Increasingly, however, I personally believe that these conflicts will necessitate involving the private sector, if for no other reason than financing. Better and more water resources are going to require a great deal more public-private partnership. But participation in the water sector by non-governmental entities has not always been welcomed. The private sector has had some unhappy experiences with water distribution and management. We need look no further than this past year's experience in Latin America to find evidence of this situation. Fortunately, this Forum will benefit from an outstanding water perspective from the viewpoint of the private sector when Mr. Don Lowry, President and CEO of EPCOR, delivers his address very shortly.

However, I believe that this Forum will not truly achieve its potential to do good in the world until we have more private-sector participation. I suggested this in Turkey in 2004, but I personally take responsibility for not helping the Calgary organizers in attracting more senior water-industry executives from the for-profit sector. If the Executive Committee — and the Advisory Committee, which Henry introduced — decides that it does want more representation from appropriate private-sector individuals, we must all work to make that happen, even if we have to have slightly larger attendance, which in some way, of course, does negate the wonderful interaction of the members of the Forum.

Nevertheless, in reviewing the program for this meeting, I am enormously impressed by the content, and I look forward to this year's Forum producing ideas and concepts that will have an extremely positive influence on water management. Please accept my personal thanks for your participation, and accept my best wishes for an interesting, enlightening and productive several days in addressing what I believe will ultimately be the most critical subject of the 21st century. Thank you.

Henry Vaux, Chair, Rosenberg Forum:

The International Joint Commission is an institution created some 98 years ago to resolve disputes over boundary waters between the United States and Canada. Its record of success in those 98 years is simply astonishing. More than 90 per cent of the boundary-water disputes between these two countries have been settled by the International Joint Commission unanimously. Our last case study tomorrow afternoon will focus on the IJC, as we call it, and the reasons that explain its extraordinary success. We are both fortunate and honoured to have all the members of the International Joint Commission present at this Fifth Rosenberg Forum — three from Canada and three from the United States — as well as the secretaries of each of the sections. Therefore, we thought it appropriate to have the Commissioners from each section welcome you all here to North America, and I wish to introduce first the Right Honourable Herbert Gray, Chair of the Canadian Section of the International Joint Commission.

Chairman Gray has a long and highly distinguished career in public service in Canada. For nearly forty years, he represented the Windsor West District of Ontario in the Canadian House of Commons. He was re-elected 13 times and held numerous ministerial and Opposition positions in the Canadian national government. In 1997, he was appointed Deputy Prime Minister of Canada. He was the first to occupy this position as a full-time Cabinet member, and it was a position he held for five years. Chairman Gray resigned his ministerial position and his position in the House of Commons to become Chairman of the Canadian Section of the International Joint Commission in 2002. It is hard to imagine, in the history of Canada, a public servant with a more distinguished or dedicated record than that of Chairman Gray. Will you join with me in welcoming the Right Honourable Herbert Gray to this Forum.

The Right Honourable Herbert Gray, Chair, Canadian Section, IJC:

Good morning, everyone; I am pleased to provide welcoming remarks at this opening session of the Rosenberg International Forum on Water Policy for 2006. Certainly, the fact that all six Commissioners and our two secretaries-general are here indicates our respect for this Forum and what it has achieved and what we are sure it will achieve. So I commend Bank of America and the University of California for creating the Forum in honour of the Bank's former chairman — whom we just heard — Richard Rosenberg. It's an honour to welcome him to Canada and for Canada to be the 2006 location of the Forum. As has already been pointed out, there can be no more important subject than water for scholarly work and the practical application of that work all over the world.

It's especially appropriate that Banff, here in the Canadian Rocky Mountains, is the site of this meeting, because the Forum's title, as has been pointed out, is "Managing Upland Watersheds in an Era of Global Climate Change". The papers to be presented confirm that mountains such as the Rockies are in effect natural water towers that feed upland watersheds and the rivers and streams that flow from them. As someone once said, when it comes to water, we all live downstream.

Now, just two weeks ago I had the privilege of being one of the speakers at the opening plenary session of the 2006 World Water Week, sponsored by the Swedish International Water Institute in Stockholm, and there — instead of this remarkable, elite, small group — there were some 2000 people from 144 countries who responded to its objective. And I'll explain why I talk about that forum: It is to serve on an annual basis as the arena for an exchange of views and experiences between members of the scientific, business, policy and civil-society communities in order to advance efforts related to water, the environment, livelihoods and poverty reduction. And this is what you of the Rosenberg Forum also do.

This Forum, in its own way, while smaller in total attendance, is in my view an equally important institution. I say this because it zeroes in on key aspects of global water issues, and one such aspect is your theme — issues in mountain watersheds, including the impacts of climate change on water agreements and treaties, and issues related to water scarcity in areas of perceived abundance. So I wasn't surprised to learn that representatives from more than 24 countries are with us today.

It has been said that co-operation over transboundary waters can be used to promote co-operation in other spheres, thereby potentially functioning as a conflict-prevention mechanism. Here in North America, the waters from mountain watersheds often are or become part of the boundary as transboundary waters between Canada and the United States. And there are those who say that the International Joint Commission plays a useful role — I admit, sometimes below the radar screen — in helping the United States and Canada keep their overall relations on a generally, or at least usually, harmonious basis, and not just on matters of transboundary water and air, in spite of the great disparity in size of population and economy.

I've said before, and I repeat here: Throughout the ages, people have learned to work out peaceful ways to share water, because there really is no alternative. And when it comes to water, there is a strong imperative for a peaceful consensus. I agree with those, such as Shira Yoffe and Professor Aaron Wolf at Oregon State University, who believe that water usually has not been a source of armed conflict but instead has been a source of agreement. And certainly, meetings of bodies such as this can help make sure that this continues to be the case in the future.

I'm sure we are here because we agree that water is absolutely fundamental to human existence and, in fact, to all life on Earth. And many would argue therefore that water involves a fundamental human right; without a sufficient supply of water, clean and pure for drinking and so many other uses, everything else matters but little. So I'm confident that this Forum can and will make a meaningful contribution in its own way to encouraging action to preserve this basic reality.

Again, as Canadian Chair of the International Joint Commission of Canada and the United States, I join in welcoming the Forum to Canada and I look forward to our discussions. Thank you very much.

Henry Vaux, Chair, Rosenberg Forum:

To bring welcoming remarks from the U.S. Section of the International Joint Commission, I am pleased to introduce to you Commissioner Allen Olson. Mr. Olson has had a distinguished career in both the public and private sectors. A lawyer by training, he has practised law in Minneapolis, Minnesota; and Bismarck, North Dakota. He also served for 15 years as Chief Executive Officer of Independent Community Bankers of Minnesota. And he was a full-time consultant to the Physicians' Health Plan of Minnesota. Mr. Olson has also served in a variety of high-level public positions. He served as Attorney-General of North Dakota for eight years, and in 1980 he was elected Governor of North Dakota. He has served in addition in a variety of roles related to the management of the Red River — the Red River of the North, we call it — which is an international river basin. He was appointed a Commissioner to the U.S. Section of the International Joint Commission in 2002. Like Chairman Herbert Gray, Governor Allen Olson honours us with his presence at this Rosenberg International Forum; please join with me in welcoming Governor Olson.

Allen Olson, Commissioner, U.S. Section, IJC:

Thank you, Henry; I would reverse that and say I am honoured to be a participant in this Forum.

As the last speaker in this inaugural session, I note that everything has been said but not everyone has said it. My remarks, therefore, will be brief. You've heard from Chairman Gray about some of what the IJC does, and you will hear more from our colleagues — U.S. Section Chair and Co-chair of the IJC, Dennis Schornack; and the former president of Simon Fraser University in Vancouver, Doctor Jack Blaney — on Saturday. So this morning, I will simply briefly remark on the larger picture, the role of the IJC in general U.S.-Canadian relations.

Our unique Commission, as you have heard already, will celebrate its 100th birthday in 2009. So for nearly one hundred years, the IJC has played a critical role in helping two great countries remain great friends. Herb Gray's predecessor, as Co-chair of the IJC and Chair of the Canadian Section — Maxwell Cohen, a distinguished law professor from McGill University in Montreal — once described the IJC as the oldest and most durable of the constellation of Canada-U.S. joint institutions. In an age of change, of which we are reminded virtually every day, I think durability is the greatest compliment that can be paid to an institution — or to anyone, for that matter. To remain relevant, to remain useful and, yes, to remain a consistent source of science-based, politically tempered advice for one hundred years, is truly a remarkable achievement.

While differences of opinion and policy sometimes divide the United States and Canada, the relationship between our two nations remains strong and is getting stronger. I am proud that the IJC is part of the tapestry that weaves our two countries together.

As Herb has said a couple of times, one of his colleagues at one point remarked about U.S.-Canadian relations, speaking as a Canadian, "The Americans are our best friends, whether we like it or not." As an American who has never lived for any period of time at least a few minutes and at most a few hours from the international boundary between the United States and Canada, and who often has regretted how little Americans appreciate and know about their northern neighbour, I would paraphrase the quote from Herb's colleague and say that for Americans, Canada is our best friend, whether we know it or not.

I think those are sufficient comments to set the stage for this extraordinary event. We will, in the next few days, have an opportunity to further the friendships and acquaintances we made over the last two days. And as an innocent who had visited Banff two or three times — I can't recall exactly — to participate in events like this, and who made a quick trip west to Lake Louise and the remarkable presence in those mountains, who thought I had seen the Canadian Rockies, let me say: Thank you, Mr. Rosenberg, Henry, and all of those who organized this, for taking this innocent a few kilometres beyond Lake Louise to see the real Canadian Rockies. I have made a commitment to myself and my 12-year-old grandson, who has an interest in science and for whom we subscribed to *National Geographic* a few years ago, that I will stand on the Athabasca Glacier, with him, and tell him that he must recognize that within his lifespan he may not be able to stand on that glacier, and that he and his generation have a responsibility to at least respond to that reality, and make it better if he can.

Thank you for the opportunity to participate with you in this Forum; I look forward to the next two days. Thank you.

KEYNOTE SPEAKERS

Henry Vaux, Chair, Rosenberg Forum:

Before we begin this keynote session, I want to take a minute to explain to you a new procedure at the Rosenberg Forum which each of you will be expected to participate in. One of our co-sponsors asked that we prepare a coherent summary document of the discussions and papers that were presented in these sessions, and we have decided to generate the data for that report in the following way. At this session and at each of the sessions throughout the remainder of today and tomorrow, you will be given a four-by-six card. At the end of the session and before you leave here, we would like you to write on that card the three most important points that you thought came out of the session and the discussion. You do not have to identify yourself; you only need to say: "These were the three most important lessons," or "These were the three most important principles." Simply tell us what you thought were the three most important things that emerged from this session. We will do that at every session; and then at the end of the conference, I will go home and write a summary based on the data you have provided us with. Thank you.

One other housekeeping item. When we come to the discussion sessions, which are at the heart of the Rosenberg Forum, we have some ground rules that are based on some hard-earned experience in San Francisco and Barcelona which had to do with the tendency to make speeches at forums like this. If you wish to be recognized during the discussion section, set your name tent on end, like this, and that will be the indication that you wish to say something. When you're called on, you will have two minutes in which to make your intervention. At the end of two minutes, Professor Mordechai Shechter will advise you that your two minutes are up and that you have 15 seconds to wrap up your intervention. At the end of that 15 seconds, he will advise you that you need to sit down. You may have a second intervention, but only after every one who wishes to have a first one has been heard. This seems to work better than you might think.

So with those in mind, let us turn now to the keynote session for this Forum. The keynote session features three speakers from different parts of the world who will offer you different perspectives on the Forum theme, which again is "Managing Upland Watersheds in an Era of Global Climate Change".

Our first keynote speaker this morning is Mr. Don Lowry, who is President and Chief Executive Officer, EPCOR Utilities Incorporated, a national water and power company headquartered in Edmonton, Alberta. EPCOR Power has a market capitalization of more than $1.5 billion and operates 11 major generating stations in North America. And, I might add, some of these generating stations are among the most technically advanced in the world. EPCOR water operations serve more than a million customers in 50 communities in western Canada and include not only the provision of water supply but the construction and operation of facilities for cleanup and rehabilitation of contaminated waters. Prior to joining EPCOR, Mr. Lowry worked for twenty years in the telecommunications industry, where he held key leadership positions and helped to shape the growth of telecommunications in Canada. As President and CEO of EPCOR, he has overseen the doubling of both earnings and assets in recent years. Those of you who had the opportunity to talk with Mr. Lowry on our field trip last night and this morning will be aware that he has a passion for water resources. As a key business leader in Canada with interests in ensuring effective management of water resources, he follows in the rich tradition pioneered by Richard

Rosenberg himself. The title of his keynote address this morning is "Factors for Success: Public- and Private-sector Roles in Securing a Safe and Reliable Water Supply in a Time of Global Change". Will you join me in welcoming Mr. Don Lowry.

Factors for Success: Public- and Private-sector Roles in Securing a Safe and Reliable Water Supply in a Time of Global Change

Don Lowry, President and Chief Executive Officer, EPCOR Utilities Inc.

Mr. Chairman, distinguished guests, ladies and gentlemen, thank you very much for inviting me here to speak to you today. I am honoured to be the first "business" person or leader, I believe, to speak to such a distinguished group, and I hope that after listening to what I have to say, there will be others that follow in my footsteps.

Specifically, I would like to thank Dr. Henry Vaux and Bob Sandford for inviting me to speak with you at this fifth edition of the Rosenberg International Forum on Water Policy. Their interest in having me address this very important forum, I believe, is rooted in a desire expressed by Mr. Rosenberg to link scientific and policy scholarship to business practice here and elsewhere in the world. I appreciate this opportunity to share some of our views as a business, and mine as a business leader, on the topic of water — which, it is true, I am passionate about.

I've been asked to speak about the challenges and obstacles Canadians are facing to maintain safe and sustainable water systems. Evaluating the respective critical roles of the private and public sectors, and how these roles must be reconsidered in order to ensure that we have healthy, safe water, is a critical part of this discussion. Overall protection of our upland watersheds is also part of the dialogue, as is the state of Canadian water infrastructure.

I believe, after the last few days spent on the bus, and the opportunities I've had to learn from my colleagues, that I have a much deeper appreciation not only of the knowledge of what is occurring but, I think, of the challenges. And I view it positively, given the excitement of what we can do by collaborating and working together. I was deeply moved and learned a lot, and certainly have a lot more respect that on a global basis we share much more in common than we have differences.

So let me begin by first introducing my company, EPCOR, to you.

Simply put, we are one company with two lines of business — water and power — operating in three regions in North America: Alberta; B.C. and the U.S. Pacific Northwest; and Ontario and the U.S. Northeast. We are one of Canada's 25 largest privately held corporations, and the sixth-largest utility by revenue, which totalled $2.7 billion last year,[1] and our assets are approximately $5 billion. Our headquarters are in a little community 400 km north of where we sit here, and we like to call it Edmonton.

Our people, who number approximately 2600, have developed some of North America's most sophisticated water and waste-water systems. Listening, again, to some of you on the bus, I'm not going to share with you technologies or some approaches that you haven't already done, but rather I want to share with you some of the things that we are also doing. Our systems and the accomplishments we've done include treating acid-water drainage from an abandoned copper mine in B.C., developing process water solutions for challenging applications in Alberta's oil sands, and delivering clean, safe drinking water to over a million Canadians, as was previously mentioned, in more than 50 different communities.

We have an interesting history as a company. Our company was created as a municipal utility over a hundred years ago. We began as one power company and one water company on the banks of the North Saskatchewan River — as I say, 400 km north — and you saw the headwaters of the North Saskatchewan River as well. Our water company started off with a horse-drawn water cart delivering water to residents along the banks of the North Saskatchewan. I have a photograph of that water cart in my office, and our water company used that to celebrate our 100th anniversary and distributed it to our customers and clients, but it keeps us humble and looking back to our origins and what water distribution really started for with us.

Since then, we have transformed the company from what was once a city department to an independently managed, city-owned corporation. This has led to a market-oriented, customer-focused company that is North American in scope.

We do trade on the Toronto TSX — under EPCOR as preferred shares; and through our power fund, which is the largest power fund in Canada, under EP.UN, and that company itself is $1.75 billion.

Our company is perhaps unique in that we design, build, operate and finance water and waste-water systems. Our expertise includes both advanced and highly automated water-treatment systems, using ultraviolet, and remote systems capable of monitoring all sizes and types of facilities.

Advances in both artificial intelligence and remote monitoring have helped us deliver best-in-class water-quality standards to smaller communities throughout western Canada. Our ability to monitor and maintain water and waste-water systems under the trained eye of water professionals in Edmonton is particularly beneficial when you are supporting struggling and smaller companies and municipalities with tight regulatory requirements and limited budgets. As I was talking with Paul, and he shared with me as well, we use high-speed Internet to pull data to bring that back to one central area in order to accomplish that task in a far more efficient way than how it had been done before.

EPCOR's water-sustainability and -delivery function is important when considered in the wider Canadian context of increasingly serious water-system challenges.

To an audience familiar with global water crises, it may be surprising to hear that Canadians talk about serious water-quality and -availability issues. In a world where a billion people do not have adequate access to reliable water supply — and in which five million people yearly die from largely preventable water-borne diseases, the situation that exists in Canada must be hardly urgent compared to that.[2]

In comparison to many others, Canadians should have little to worry about when it comes to water management and supply. Indeed, Canada is endowed with one of the greatest per capita freshwater supplies in the world. Canada's rivers annually discharge 7% of the world's renewable water supply.[3] And while water has been a significant source of transboundary conflicts in the world, we live peaceably alongside our neighbours, as we heard from the IJC Commissioners earlier, with 40% of Canada's boundary with the United States composed of water.[4]

But, as other speakers at this forum will indicate, our water systems are being seriously challenged by growing populations, declining infrastructure and inadequate watershed protection. This will oblige Canadians to make significant changes to our existing water systems, policies and strategies if we are going to continue to deliver safe, reliable water and if we don't want water-availability and -quality issues to limit our future development. So in my opinion, that means that in

Canada we have to address five significant goals. And in my remarks with you today, I want to embellish on those five significant goals:

- First, we have to dispel the myth of limitless abundance of water in southern Canada.
- Secondly, we have to pay the full cost of water supply and delivery so that we can afford to build new infrastructure, maintain existing ones and appreciate water for the value it represents.
- Three, enforce the laws on the books today so that operators have the incentive to invest in infrastructure and innovation and to operate the systems as they are designed to be operated.
- Fourth, provide communities with the right tools to meet challenges that they face. We believe this demands improving existing service-delivery models, building partnerships between public and private sectors. Let's work together; in well-structured partnerships, no one can do it all, be it public or private. And this will involve lower costs, higher quality.
- And lastly, let's move to a better integration of watershed-management strategies with larger land-use policy.
- Our success in achieving these goals will demand that we transcend some of the negative stereotypes that exist in this country as a result of unfortunate situations abroad with respect to the private operation of public water-treatment and -distribution systems.

The Canadian Water-supply Condition

Because we take water for granted — which I am sure many of you wish you could do — Canadians do not act with the same sense of urgency upon issues relating to water until there is a crisis. A crisis, however, is what I believe is looming for Canadians if we don't reconsider the value of water.

The challenge revolves around the fact that increasing demand for safe water in Canada is now overwhelming a rapidly aging and unreliable infrastructure. Adding additional stress is the fact that about 60% of the fresh water that I noted drains north, while 85% of our population is within 300 km of our neighbour to the south, the United States.[5]

This audience will recognize that this is not a unique challenge. It is one faced by many nations. We are not used to facing such problems here in Canada, and as a result, Canadians are having difficulty grasping what they mean. What these problems are telling us is that we are not different from anyone else. As some recent tragic incidents have revealed, we are beginning to face the same issues others are facing. We are not special.

Six years ago, seven people died and 2300 people fell seriously ill in Walkerton, Ontario, because they were drinking water contaminated with E. coli bacteria.

In 2001, a *Cryptosporidium* outbreak endangered the health of 7000 residents in North Battleford, Saskatchewan.

Last year, contaminated water forced the residents of a largely aboriginal community in Kasechewan, Ontario, to evacuate their homes because of water contamination.

Each year, hundreds of Canadian municipalities have to issue boil-water advisories. This fact usually goes unknown by most other Canadians. As of August 4 of this year, 83 boil-water advisories had been issued on Indian reserves across Canada.[6] Here in Alberta, Health Authorities issued 123 advisories between 2002 and 2004. Today, 59% of reserve drinking-water is deemed "at risk".[7]

Health problems related to water pollution in general cost Canadians an estimated $300 million per year.[8]

The City of Edmonton experienced a giardia outbreak in 1982 that was linked to 895 cases of that illness.[9] That crisis prompted a vigorous response — first by the City's water department, and then by EPCOR.

The response included increased time for chlorine to be in contact with the water; use of activated carbon particles to improve the water's taste, smell and colour; plus the use of electronic monitoring systems on the clarifiers and filters. Today, in Edmonton alone in 2005, we performed over 109,000 tests on the region's drinking water, monitoring 326 different physical, chemical and microbiological parameters.[10]

We have also installed what was then one of the largest UV treatment systems in the world. In 2002, Edmonton became the first Canadian city of its size to have its drinking water protected by UV. As an aside, when you travelled out here to come to this conference, you passed by a community called Canmore, which EPCOR also serves, and there we have also installed a UV system.

Edmonton is just one city, and Canada is a huge country. Inadequate infrastructure remains one of the most serious challenges facing our water systems. Across Canada, many municipalities are facing severe infrastructure deficits for both water and waste-water services. The government of Canada recently reported that the nation's waste-water-treatment facilities had exhausted 63% of the utilities' useful life by 2003.[11]

An Ontario report found that in that province alone, $30 to $40 billion of new investment was required in water and waste-water facilities.[12] Here in Alberta, the value of actions outlined in the province's Water for Life strategy in February 2004 was estimated at $916 million over the next 10 years.[13]

Towards System Sustainability, and the Public-/Private-sector Role

So the challenges facing our water systems are multidimensional and multi-faceted in their origins and certainly are not unique to Canada. It requires a diverse-stakeholder approach that reconsiders — and, I think, appropriately redefines — the role of the public and private sectors.

Our ability to consistently deliver a safe and reliable supply of water depends on two key factors: securing, first, a sustainable quantity and quality of raw water, and then building and managing sustainable systems for its treatment, distribution and effective demand management.

An effective system must involve a strong and vigorous public sector, one that sets a clear, rule-based regulatory regime, working in tandem with municipal and private-sector players to offer sustainable and, I believe, reliable water supply, open to alternative delivery models. Neither the public nor the private sector can deliver effective results alone. What we need are strong, well-structured partnerships.

So how do we deal with this urgent need for building and managing the infrastructure?

Full-cost-recovery Model

A starting point is coming to grips with the real cost of water. Water is not a free good; it is a precious resource that should be used responsibly and conserved. We need to pay the full cost of water and water delivery so that we can invest in the necessary system improvements and new infrastructure.

According to the Organization for Economic Co-operation and Development, Canadians pay some of the lowest water rates in the world.[14] What you pay does not relate to what it costs. In many communities, water rates remain low because they are subsidized by municipal governments through allocations to water utilities in municipal budgets. A recent report by an expert panel in Ontario reviewing Ontario's water system noted that municipalities in the province recovered only 65% of the total costs of providing their water.[15]

While low rates may create the illusion of affordability, these limit the opportunities for reinvestment, prevent overall system sustainability and reinforce the misconception by the public that there is abundant supply. Reflecting on the capital-intensive nature of water and waste-water services, the report noted: "[U]tilities are starved for the funds they need to maintain their systems properly."[16] Ultimately, rates that do not reflect the full cost of producing and delivering the service eventually lead to a gap between what the service and infrastructure are able to provide and what is needed, which can then only be sustained by further subsidies.

Provincial governments in Canada use water-licence systems to control how much water is withdrawn, for what purpose, and by whom. But there are far too many instances where the true cost of treating and distributing water is hidden by subsidies, or absorbed by the tax system.

Customers of water and waste-water services should fund the full cost of building and operating the systems through which they receive benefits, for two reasons:

First, it will create a pool of funding that is sufficient for the ongoing maintenance and support of the systems and contribute to their long-term sustainability — provided those additional costs are not diverted for other uses by the municipalities. Secondly, it sends an appropriate price signal, one that reminds us to conserve and make prudent use of this resource. If it's free, we assign no value to it.

Imagine, if you pulled up to the gas pumps today, that you could take all the gas that your vehicle could consume. I thank some of us— not this group, but others — might drive the same vehicles we were driven around in on the [Columbia] Icefield if there were no charge for gasoline. I'll draw another example much closer to home. Three weeks ago, the resort community of Tofino, in B.C., ran out of water. Tofino just happens to be in one of the areas of the highest precipitation in Canada. In Tofino, they pay about 63 cents per cubic litre for their water. The costs are about $1.65. They underfunded the development of a reservoir. How much do you think you pay in Tofino for a *bottle* of water? You can't buy a bottle for under $2.50. So there's another example close to home.

Only 61% of Canadian urban water consumption is metered. Estimates show that when your water is metered you use approximately half. Here in Canada, the average consumption is 474 litres for an average family;[17] if you're like me and have two girls, you'll use much more.

However, in the city just east of us here [Calgary], they have only half of their one-million population metered and they don't forecast till the year 2013 to get the other half metered. So if you're not metered, you let the water run.

More fundamentally, we do not appropriately price for large-scale water extraction, as we do for most other resources that we value. For example, for every square cubic metre of timber logged in Canada, governments appropriately charge the logger anywhere from $8 in Ontario to, I believe, somewhere around $20, $25 in B.C.[18] And in an oil-producing province such as Alberta, the government has a sophisticated regime of oil-royalty rates based on the amount of oil or gas extracted — again, pegged on a percentage basis to the world price, which I think is just under $70 today. As a percentage of that price, I may add: between 5 and 40%.[19] For minerals, the Alberta government charges 55 cents per tonne for coal used for the production of electricity, and 37 cents per tonne for the withdrawal of silica sand.[20] Now, hold that figure for a moment in your head: 37 cents a tonne, we charge for the extraction of silica sand.

Yet for raw water in Alberta, the government charges an annual one-time fee — for example, users are charged $150 annually for 125,000 cubic metres of water.[21] Irrigation water fees are paid only according to the land area irrigated, not the volume of water. You want to make a lake? Go ahead and make a lake, if you've got a permit. Typically, the cost of the fee only covers the administration of issuing the permit.

The question I would pose to you then, and to anyone concerned with the future of our resource management, is this: Does charging more for sand than we do for water make sense, if we're really focused on the future values, so that our children and our children and our grandchildren can have businesses and industries? I don't think so.

We believe that if governments mandate that pricing regimes transition towards a full-cost recovery, then our public and private water utilities will be able to more properly maintain existing facilities, build new ones and together succeed in conserving our water resource.

I think the political realities, though, pose a significant challenge; no one wants to pay more for basic services — from a starting point where many consider water a free good, on principle. Customers are accustomed to paying rates well below the real costs. So, practically speaking, I think the process of transiting from where we are today is going to take time, it's going to take public education, it's going to take engagement in thoughtful, candid, unvarnished, courageous discussions as to where we are today, and it will involve public, private, industry, users and consumers. And it will take time. But I believe it starts at forums such as this one.

Our own experience, though, as EPCOR, tells us that you *can* successfully run water and water systems on full-cost-recovery models — because we do.

Working together with our regulator, the City of Edmonton, we adopted a performance-based rate structure or regulation in 2001 that is fully cost-based, including as well the recovery of risk capital on an ROE basis of 11%. The performance-based rate structure establishes performance targets for EPCOR that we are required to meet for water quality, safety, service, and the environment. If we don't meet these, we're fined; we're punished severely. We have an incentive to perform, but I don't want to leave you with the message that we only perform when punished. However, there is balance to the system; by having that incentive, the efficiencies we gain are shared with the customers in a better-managed, better-quality system.

Rates are set annually, with cost increases *below* inflation. That's part of the formula. There is a built-in incentive for us to achieve these targets efficiently, as we cannot pass through all costs. In fact, all — and I'll share this with you, as well — the standards by which we run this system not only meet but most often exceed the Province of Alberta's provincial drinking-water standards, which are more stringent than the National Guidelines for Canadian Drinking Water Quality recommended by the federal government of Canada's Department of Health. Alberta, in many ways, leads on environment and energy standards, and I think that message has to get across.

Since the initiation of the performance-based rate structures, water consumption has *declined* 4% in Edmonton. Guess what? When you meter it, and you charge for it… The city has *grown* in the same period significantly as a part of the success of the Alberta economy.

So they *are* compatible: higher costs, higher quality, better service.

EPCOR has used this model to maintain appropriate rates aimed at cost recovery in order to ensure continued investment and efficiencies in the systems, while at the same time improving performance. For example, our water-main breaks are at their lowest level since the early '60s, and our water-loss rate, at 3%, is half the national average. And we have an incentive to keep it there and lower it. Why? Not only because of the performance-based regulation, but because we also reinvest in our system; each year, on a program basis, we are replacing our water mains. And for the last decade, we have been renewing our cast-iron pipe infrastructure, replacing it all. So on a program basis, we are turning over that system continually.

Enforcing Our Laws

Another aspect of our water-system management that needs significant reform is regulatory and enforcement regimes. We must begin enforcing the laws that are on the books.

As an aside, I also believe, as a businessperson, that with [the] *Sarbanes-Oxley* [*Act*] and the Canadian form of that, CSOX, that if the laws on the books had been enforced with speed, haste and urgency, we wouldn't be burdened today with what I think is the excessive swing of that type of regulation. And by me communicating this to you today, I again hope that we enforce the laws that we have on the books on water, so that we don't have another excessive swing.

Enforcement encourages good management, and it provides a strong incentive for investment in the system. Owners and operators of water and waste-water systems will invest in their operations if they are held liable for poor performance. If not, they let them run down.

Our governments have rarely held operators accountable for failing to meet essential regulatory requirements or for damage done to public health and the environment.

In fact, studies have shown that publicly run operators are among the most frequent offenders. Why? The reason is that many municipal governments are protected by liability limitations and have the capacity to pass on the costs of non-compliance to ratepayers. There is also a difficult conflict: Since provincial governments often provide capital grants to municipalities for publicly run water facilities, they also understand that strict enforcement could require expensive upgrades.[22] In many cases, governments that carry a regulatory responsibility also understand that by prosecuting offenders they would actually be prosecuting themselves.

The numbers, though, are significant. In Ontario, for example, 101 sewage facilities were out of compliance with provincial limitations in 2002. These 101 instances of non-compliance were penalized by a grand total of three charges and one fine — a $10,000 penalty for failing to ensure that the facility was run by a licensed operator.[23] And this situation occurs in many, many other jurisdictions.

Of the 78 Indian Reserve water operations in Alberta, only 14 were fully certified as recently as last February.[24] Numbers like this are not only indicative of enforcement shortfalls but also serve to show us that communities are struggling to attract and keep qualified staff.

This brings me to my last point of discussion: opportunities for public- and private-sector partnerships.

Partnerships

Private-sector partnerships and organizations can offer resources to communities which the public sector may not otherwise be able to effectively provide. All levels of government and private-sector partners need to work together to deliver effective watershed-management strategies, create value through facility sharing and seek the benefits of alternative service-delivery methods.

Partnerships between governments and the private sector allow the public sector to reduce costs and share risk, while maintaining a public interest in a key, vital service to local communities. This does not mean that governments should necessarily divest themselves of ownership of assets and retreat to a purely regulatory role. Rather, using their interest or ownership in certain water systems or assets, governments can ensure that predetermined levels of service are maintained, without playing a direct management and operational role.

Public-private-sector partnerships offer a number of potential benefits. First, in a well-structured partnership, the risks of cost overruns, service demand and schedule delays are borne by the private sector, not the taxpayer. Competitive tendering can encourage innovative private-sector solutions to facilities management, design and construction. These partnerships also offer government greater flexibility to tailor projects to best meet local needs.[25] I'll give you some examples: Up in Fort McMurray, they were endeavouring to procure a new waste-water facility; it had been put out to tender, and the costs were coming in excessively high. We as a member of the private sector submitted a tender that was almost half the price. The reason? We proposed to build that facility in a modular fashion in Edmonton, ship it in component parts and assemble it there. As opposed to the government — the municipality — which was proposing to pour the concrete, put the steel in and fabricate the structure on site. And if any of you have been to Fort McMurray, it is like a gold rush; the cost of labour and of concrete is simply excessive. So there is a good example of innovation.

Opponents to public-private partnerships often suggest that these projects experience higher costs since the private sector must borrow at higher interest rates, and gouges an unnecessary profit margin from these. And governments, of course, are a less risky investment because they can always return their cost overruns to the public.

Yet, the evidence is to the contrary. In the United Kingdom — and I'll just cite one report here, and then I'll give a few examples — the Treasury department undertook a survey to challenge that. Their survey revealed the following: overall cost savings of 20% with the public-private partnership compared to publicly procured operations. The report also found that only 24% of these projects were delivered late, compared to 70% when the public sector managed them. Cost overruns occurred only 22% of the time under partnerships, whereas they occurred 73% of the time when exclusively public.[26]

EPCOR has delivered similarly positive results for many communities, using public-private-partnership models — bringing in major construction projects on time, on budget and safely. I will give a few examples. On Vancouver Island, British Columbia, we worked with the District of Sooke to build the community's first sewer system and waste-water-treatment plant for 8700 residents. The project was completed for $5 million less than budgeted, six months ahead of schedule. Another, the town of Okotoks: They had budgeted, under their leadership and municipal direction, $26 million to complete their water and waste-water plant. We completed the project this spring for $11 million, on time, on budget and significantly below original estimates. I think, even more importantly, it represents a step towards resolving long-term issues of shortage of capital and shortage of people to get the job done.

Looking Ahead

Stepping back, I think we must acknowledge that Canada is indeed endowed with remarkable supplies of natural resources. We have not been faced with the same challenges that so many other countries have with respect to conflicts and issues with water. We have also made positive strides towards improving our water systems in the wake of recent water-quality incidents — some of which I've mentioned — including making greater use of innovative technologies.

Governments are also tightening regulatory requirements and making better efforts to control and monitor water quality. The Alberta government — I would like to acknowledge — has, I think, made better efforts to educate the public about water scarcity through its Water for Life program. This strategy, conceived by former Environment Minister Dr. Lorne Taylor, who is with us today, has significantly increased awareness of a new way of governing water, overseeing watersheds, and collaboration between private and public. Also, our Minister today, Guy Boutilier, has taken that a step forward and has certainly engaged the public and the private sectors and advanced that in a strong leadership model, and I look forward to working with him in the future.

But overall, our society is still behaving as if water were infinite in its availability. It is not. That is why we have to do so much in order to protect this precious resource.

I cannot stress enough the importance of governments, industry and citizens working together to agree on solutions to the challenges I touched on today. Our experience as a company in many communities shows that these challenges can be overcome, especially when we work together and we come to the table — and there is some slack in the system which allows us to do that — committed to resolve issues.

We believe that when well structured, partnerships have the ability to manage infrastructure and personnel challenges in pursuit of long-term goals towards building strong and reliable water systems. The process begins with proper upland watershed management and it is supported by broader public awareness of the importance of water to our way of life and our future. But in the end, it means the supply of clean water to people. Though global and climate-change challenges will add new dimensions to these efforts, we hope that our continuing work will serve as an example that will help others to be more successful in managing their water.

Going forward, our company, and the 450 water professionals within our business, will continue contributing solutions to what we believe is one of the most pressing issues facing the world today. We look forward to working with many of you to make the solutions a reality.

Thank you for your time this morning.

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Henry Vaux, Chair, Rosenberg Forum:

Thank you, Don. Our next keynote speaker this morning is Dr. Bruno Messerli, the distinguished Professor of Geography from the University of Bern, in Bern, Switzerland. Dr. Messerli is a researcher and scholar who is widely regarded as one of the most knowledgeable people in the world about the role of mountains and upland hydrologic processes in the hydrologic cycle. He has conducted research on major mountain regions around the world, including the Andes, the Himalayas and the Swiss Alps. In recent years, he has also provided leadership for a variety of research efforts into the implications of global change on mountain environments; and I might offer a personal note from the field trip, that it was fun to observe how Dr. Messerli draws energy simply from being in these mountain environments — a man who truly loves the mountains of the world. In addition to his scholarly pursuits, Dr. Messerli has served as Director of the University of Bern, as President of the International Geographical Union and as a founding member of the African and Andean mountain associations. He has served as Vice-president and is an honorary member of the Swiss Academy of Sciences, and is a member of six European academies of science, including the Russian Academy of Sciences. He is the recipient, as you would expect, of numerous awards and honours, including the Swiss government's Marcel Benoît prize for scientific achievement, and the Founder's Medal of the Royal Geographical Society in London. There is probably no one in the world today who is as well qualified as Dr. Messerli to speak on his topic today, which is "Mountains of the World — Water Towers for the 21st Century". Will you please join me in welcoming Dr. Bruno Messerli.

Mountains of the World — Water Towers for the 21st Century

Bruno Messerli, Institute of Geography, University of Bern, Bern, Switzerland

Abstract

Research into mountain hydrology has a long history, but only the Rio Conference in 1992 created a real breakthrough for a new awareness about the mountains of the world and their natural and human resources. In 1997 and 1998, mountains as water towers for a thirsty planet drew special interest from UN institutions, which led not only to International Year of Mountains 2002 and International Year of Freshwater 2003, but also to greater co-operation between science and policy.

The particular hydrological characteristics of mountain areas include disproportionately large discharges compared to those of the surrounding lowlands. Mountains account for 20–50% of total discharge in humid temperate regions, while in semi-arid and arid areas, the contribution of mountains to total discharge is 50–90%, with extremes of over 90% (e.g. Nile, Colorado, Orange, Syr Darya, Amu Darya, Rio Negro, etc.). Moreover, discharge from mountainous areas is highly reliable and causes significant reduction of the coefficient of variation of total discharge. These findings were quantified and used to elaborate an overall assessment of the hydrological significance of mountain areas. The dryer the lowland, the greater the importance of more-humid mountain areas.

Locally and regionally differentiated changes in temperature, precipitation, snow cover and glacier storage are likely to alter discharge from mountain-dominated territories with respect to timing, volume and variability, and will influence runoff characteristics in lowlands. Catchments that are dominated by snow are particularly sensitive to climate change, and will be most affected by shifts in discharge patterns.

Growing demands on limited water resources ensure that mountain water resources will play an increasingly important role in the 21st century. But we need more and better data, especially for the mountains of the tropics and subtropics — and this means for the developing world, where water scarcity immediately leads to food shortage. The scientific community has the responsibility to analyze the consequences and complex interactions of climate, water and land-use changes, but also of increasing population and its impact on watershed management and agriculture and forestry policy, in order to develop adequate long-term strategies on water-resource management in the mountains and highlands for the surrounding lowlands.

1. Development of a Global Policy since Rio de Janeiro 1992

The strong orientation of the Rio Conference towards the environment and development provided the setting for an intervention in the PrepCom 1991 in Geneva and that of early 1992 in New York to ensure the inclusion of a Mountain Chapter in Agenda 21. This was enthusiastically supported by the delegates from the Himalayas, the Andes and East Africa, who had experienced international co-operation through the International Centre for Integrated Mountain Development (ICIMOD, founded in 1983 in Kathmandu, Nepal), the African Mountain Association (founded in 1986 in Addis Ababa, Ethiopia) and the Andean Mountain Association (founded in 1991 in Santiago, Chile). The new chapter was unanimously accepted in 1992 at the so-called Earth Summit. However, its importance was not properly understood by many political delegations. Rather, it was assumed that natural hazards, land-use problems, agriculture, forestry and all aspects of development and conservation were part of national policies and national competences which could hardly be classified as having international let alone global importance.

This perception changed for the better at the UN special General Assembly for the evaluation of Agenda 21 in New York in 1997, five years after Rio. The initiatives of the Food and Agriculture Organization of the UN (FAO) as the officially designated task manager of the Mountain Chapter of Agenda 21, of UNESCO and UNU with their mountain research and development programs, of the foundation of the Mountain Forum 1995 and of many local to regional non-governmental initiatives were fundamental in providing greater awareness for the mountains of the world. But most important was to rethink the global significance of mountains between 1992 and 1997. As a result, the book *Mountains of the World — A Global Priority* (Messerli and Ives 1997) and an attractive brochure with the title "Mountains of the World — Challenges for the 21st Century" (Mountain Agenda 1997) were presented to that special UN General Assembly in New York in 1997. It was at this point that the political delegates began to understand the global significance of mountains. The expression "water towers" was used for the first time, and it was also clearly said that cultural and biological diversity, vital recreation areas of an ever more urbanized world population, sacred places in many cultures and religions, privileged regions for protection, and especially water resources, have not only local or national importance but, even more so, international regional to global significance.

Only one year later, in 1998, water problems were the main topic on the agenda of the UN Commission for Sustainable Development (UNCSD) in New York. For this commission meeting, a new attractive brochure with the title "Mountains of the World — Water Towers for the 21st Century" was created and presented to the national representatives of the UN member countries (Figure 1; Mountain Agenda 1998). Presenting a global overview of mountain water resources was still very difficult, due to missing data and a lack of effective methodical approaches. But case studies from Europe, Africa, Asia and the Americas showed very clearly that almost all the major rivers of the world have their headwaters in mountains; probably more than half of humanity relies directly or indirectly on the fresh water that accumulates in mountains. This message was well understood in the global political arena: the mountains of the world were no longer merely local and national problems, they had become globally significant in and for the 21st century. Based on this new understanding, the decision for an "International Year of Mountains 2002" was taken shortly after the UNCSD meeting. Finally, as a great surprise, the General Assembly decided in the year 2000 to declare 2003 "International Year of Freshwater". These two joint international years on mountains and on fresh water offered the possibility not only to co-operate but also to improve the information for the political community and to encourage the scientific community to take new initiatives and new responsibilities for basic and applied research projects on mountain water resources and mountain watersheds.

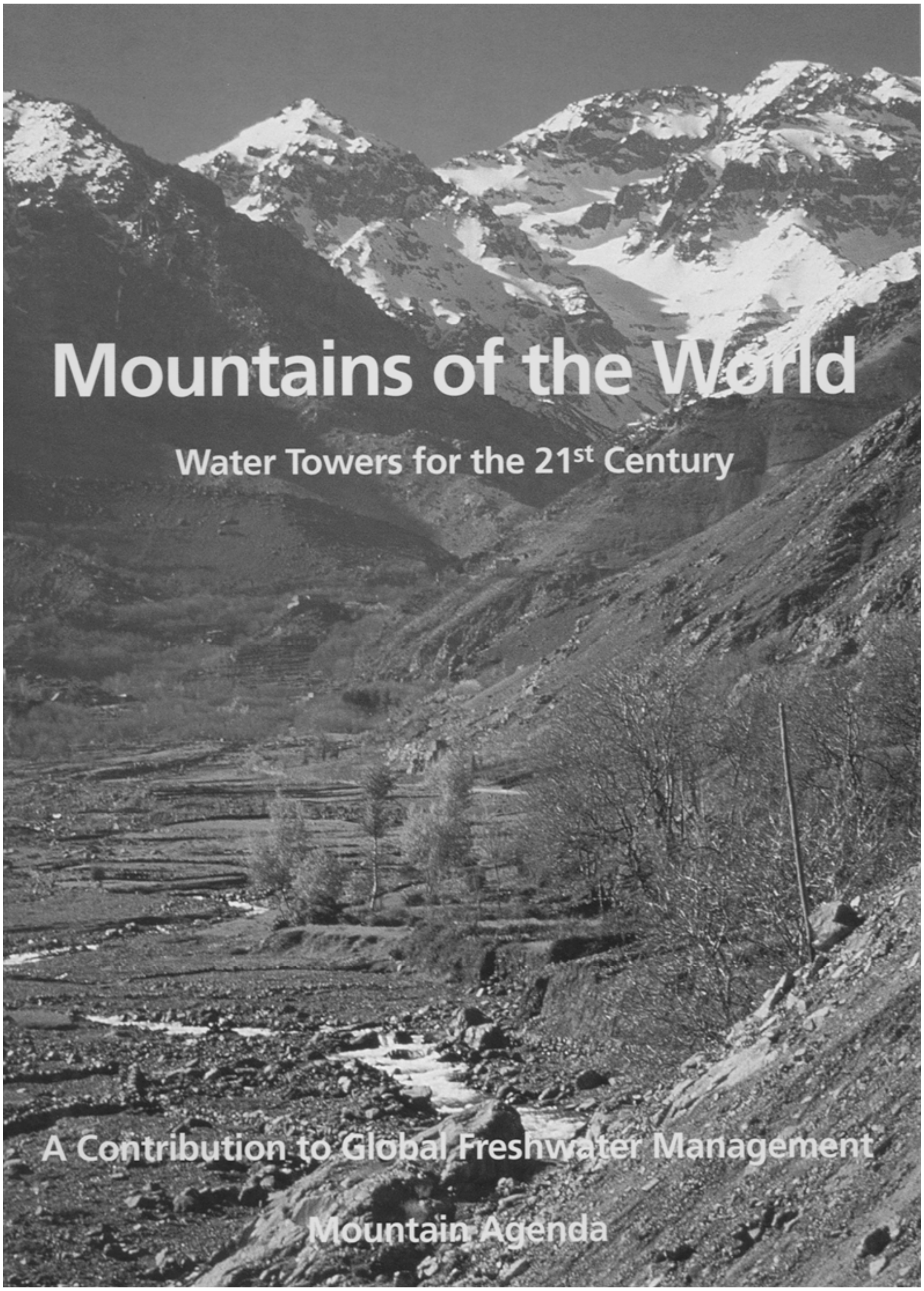

Figure 1. First publication on the hydrological significance of the mountains of the world for the United Nations Commission on Sustainable Development (UNCSD), for the 1998 spring session on "Strategic Approaches to Freshwater Management". Front cover: Jebel Toubkal (4165 m), High Atlas, Morocco — a water tower for the intensively irrigated land-use systems in the valley bottoms and surrounding lowlands (Mountain Agenda 1998)

Besides the official UN policy decisions, there have been and there will be a lot of international institutions and initiatives with a focus on mountain water resources. For example, major international conferences on Headwater Control have taken place since 1989, focused on field-oriented, grassroots movements. This organization published together with UNU and the International Association of Soil and Water Conservation the so-called Nairobi "Headwater Declaration for the International Year of Freshwater 2003" (UNU 2002), but without any quantification of mountain water resources. Another example is the UN "World Water Assessment Programme", but even at the third World Water Forum, held in Kyoto in 2003, mountain water resources did not appear on the preliminary program and it was only thanks to a last-minute intervention by UNESCO (2003) that it became one of many symposia at a huge conference.

In summary, the five years from Rio in 1992 to New York in 1997 proved to be the time that was necessary to upgrade the significance of mountains and their resources from the national to the global level. The following years — from New York in 1997 to the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002, International Year of Mountains 2002, International Year of Freshwater 2003 and finally the International Decade for Water for Life 2005–2015 — were the decisive years to think not only about longer-term strategies and initiatives but also about better co-operation between policy and science from the local to the global levels.

2. Hydrological Significance of Mountains and Highlands

Mountains and highlands play a fundamental role for the available fresh water in the surrounding lowlands. However, as far as quantification of this significance is concerned, there is a good deal of uncertainty in the scientific world (e.g. Rodda 1994). A recently published study estimated the proportion of mountain discharge to total global discharge at 32% (Meybeck et al. 2001), while other studies indicate figures between 40 and 60% (Bandyopadhyay et al. 1997). From a regional point of view, mountain discharge can represent as much as 90% or more of the total discharge of a catchment (Mountain Agenda 1998). On a global scale, few measurement series exist for discharge in mountainous regions and the periods they cover are extremely limited. This restricted database does not measure up to the high degree of spatial and temporal heterogeneity of discharge conditions in mountain areas. This means that in order to assess the hydrological importance of mountains, we have to take into consideration the increasing uncertainty and generalization from the local to the global levels. Additionally, discharge data in water-scarce regions have a high strategic value and are frequently kept secret. This makes basic scientific studies more difficult and mitigation of conflicts over water resources quite impossible.

Basic Knowledge Gained in the European Alps

The European Alps may serve as a model region for studies in mountain hydrology because of the reliable and detailed data available. In the case of the Rhine River, a clear contrast in the discharge pattern between the mountainous upper section and the lower reaches of the river can be detected as a result of the change in the feeder supply from snow in the mountains to rain in the downstream areas. In an average year, discharge in the mountainous Swiss section of the Rhine above Lake Constance contributes 34% of the total discharge at Lobith, close to the river's mouth in the Netherlands, although the mountain catchment area within Swiss territory represents only 15% of the total watershed. The discharge contribution of this alpine Swiss section clearly surpasses 50% in the summer months, when the melting of snow and glacier ice produces high and reliable discharge volumes (Viviroli and Weingartner 2004*a*).

The mountainous part of the Rhine River plays a distinctive role in the hydrology of the whole basin because of higher precipitation, lower evaporation and, consequently, more effective runoff generation in the Alps as compared to that in the lowlands, especially in the summer months. This is illustrated in Figure 2, showing the resulting water balance components for two sub-catchments of the Rhine basin: the climatological water balance (precipitation minus evaporation) in the alpine sub-catchment is markedly higher because of higher precipitation and lower evaporation than that in the upper Rhine catchment (Karlsruhe) about 550 km downstream. Together with seasonal storage in winter, this mountain influence predominates between May and August, when melting of snow and glacier ice produce significant runoff. This summer runoff from the Alps arrives downstream at a time of negative water balance, thus compensating for the smaller and partly negative water balance term (Figure 2). In the higher central Alps, annual precipitation of 2088 mm for the period 1969–1990 was measured, meaning 1711 mm runoff and 382 mm evaporation and suggesting that 82% of the precipitation is available for runoff as well as seasonal and long-term storage (Schädler and Weingartner 2002). But high stabililty and decreasing variability with increasing mean altitude are also important aspects of runoff in mountain areas. The influence of snow (nival-regime types above approximately 1550 m mean basin altitude) and of glacial-regime types (above approximately 1900 m mean basin altitude) becomes decisive, in contrast with the more irregular precipitation processes at lower altitudes (Vivroli and Weingartner 2004*b*).

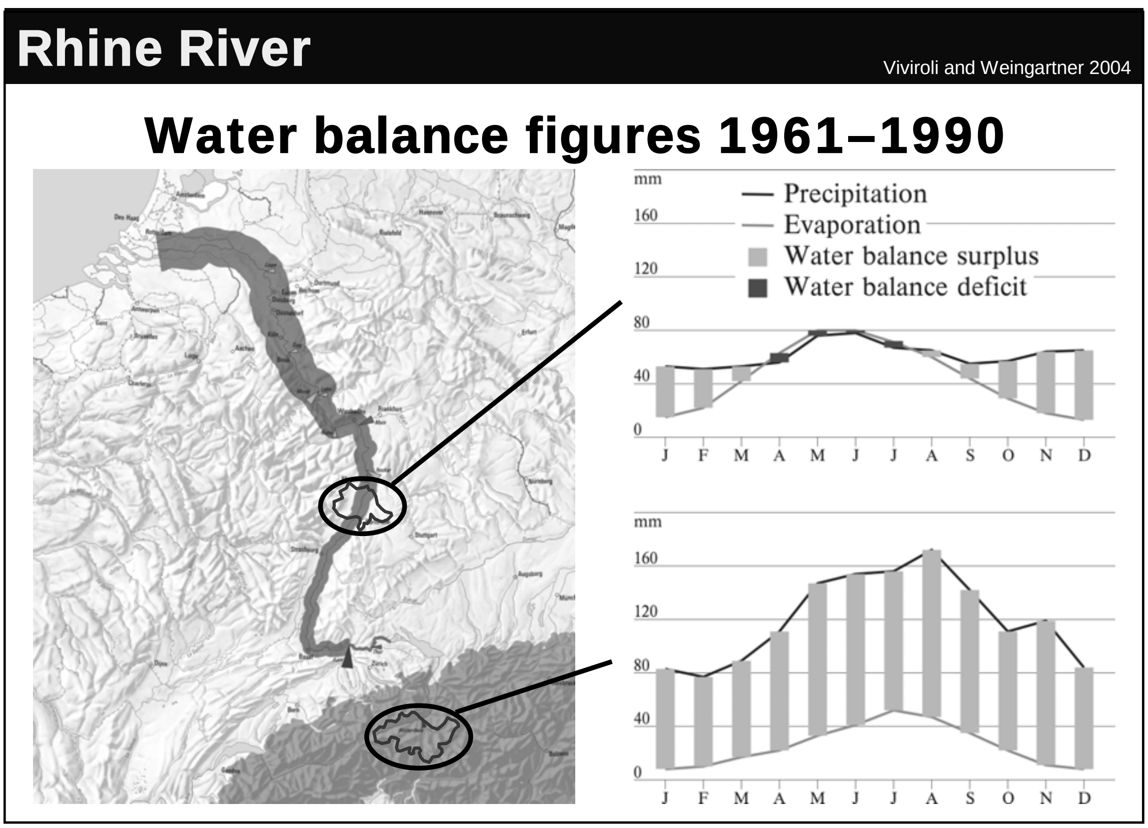

Figure 2. Mean annual water balance 1961–1990 for two selected sub-catchments of the Rhine River, at Felsberg in the Alps (mean altitude 1989 m, area 321 km²) and at Karlsruhe in the upper Rhine valley (mean altitude 177 m, area 1944 km²) (Viviroli and Weingartner 2004*a*; GRDC 1999)

Extending the view to the European Alps in their entirety, Table 1 examines the four major streams that drain the Alpine arc. As observed on the Rhine River, runoff formation is disproportionately high in relation to relative catchment areas. Situated in a humid temperate climatic zone, the Alps play a remarkably important role for western Europe, with a mean contribution of 26 to 53% of total discharge and 36 to 80% of summer discharge. This raises two questions: What would Europe look like without the Alps? And, more important, if the mountains have such great importance in the humid temperate zone, what would be their hydrological significance in the most critical and vulnerable arid and semi-arid regions, which cover more than 40% of the land surface and which are seeing a rapidly growing population in the semi-arid areas of the developing world?

	Mean alpine contribution to total discharge (%)	**Summer alpine contribution to total discharge (%)**	**Alpine share in surface area (%)**	**Disproportional influence of the Alps**
Rhine	34	52	15	2.3
Rhône	41	69	23	1.8
Po	53	80	35	1.5
Danube	26	36	10	2.6

Table 1. The hydrological significance of the four main rivers of the Alps for western Europe (Viviroli and Weingartner 2004*b*)

General Knowledge Gained in the World's Mountains

In sharp contrast to the large temporal and spatial variability of hydrological processes in mountain areas, the availability of long-term measurement series for higher altitudes is very limited on a global scale and especially for the mountains of the tropics and subtropics. Public access to data is further hindered in regions of frequent water scarcity for political reasons, especially in South Asia. On the basis of knowledge gained from studying the hydrology of the Alps, a data-based approach to assess the hydrological significance of mountains was taken using discharge data provided by the Global Runoff Data Centre in Koblenz, Germany (GRDC 1999). The pattern of mean monthly discharge, changes in specific discharge with increasing catchment size, and the coefficient of variation in mean monthly discharge proved to be particularly suitable parameters for assessing the hydrological significance of a mountainous region. More than 20 river basins in various parts of the world were selected for case studies on the basis of climatic and topographical criteria and availability of data (Viviroli et al. 2003). The selection of case studies aimed at covering a wide range of climatic zones and the most important mountain ranges. The inner tropical area containing the two major rivers the Amazon and the Congo was omitted because high tropical rains also in the lowlands clearly dominate the hydrograph and override mountain influences. In addition, however, the polar and part of the subpolar regions are not dependent only on mountain water resources, because snowmelt in the big plains of the northern continents also has a strong impact on the total amount of discharge.

The most restricting criteria proved to be the presence of accessible, reliable and representative data, with the gauging stations being suitably distributed across the river course. The interrelation between mountain and lowland discharge for each case study was examined through a gauging station above an altitude of 1000 m which served as the “mountain station” and a second one in the vicinity of the river mouth which served as the “lowland station”. However, it was carefully checked that the “mountain station” was in an area with mountain relief in order to exclude plains at higher altitudes. Rivers influenced by major dam storage were also excluded. To assess specific discharge patterns along the rivers, all available stations were used. Regions without suitably located stations were excluded from the study. In addition, regional precipitation and temperature conditions were taken into account in order to incorporate the discharge regime into the climatic context of the region.

First of all, the particular hydrological characteristics of mountain areas are manifested by disproportionately large discharge, typically about twice the amount that could be expected from the areal proportion of the mountainous section. Mountain discharge portions of 20–50% of total discharge are observed in humid areas, as can be shown for the Alps, while in semi-arid and arid areas the contribution of mountains to total discharge amounts to 50–90%, with extremes of over 95% (Figure 3). The Orange (South Africa) and Colorado rivers, the Rio Negro (Patagonia), the Amu Darya (Aral basin) and the Nile are by far the most dependent on mountain discharge. In the Euphrates, Tigris, Indus, Sao Francisco (Brazil), Senegal, Niger (West Africa) and Cauvery (South India) river basins, the rate of mean mountain contribution is lower but still exceeds 50%. In addition, there are months when mountain discharge represents almost 100% of total discharge; seasonal data are therefore of vital importance to the lowland areas downstream. For most of the remaining catchments (Ebro, Rhine, Rhône, Saskatchewan, Columbia and Danube), the mountain contribution remains between 30 and 60%. Exceptions are the Mekong and Orinoco river basins, where runoff contributions from the mountains are less than expected.

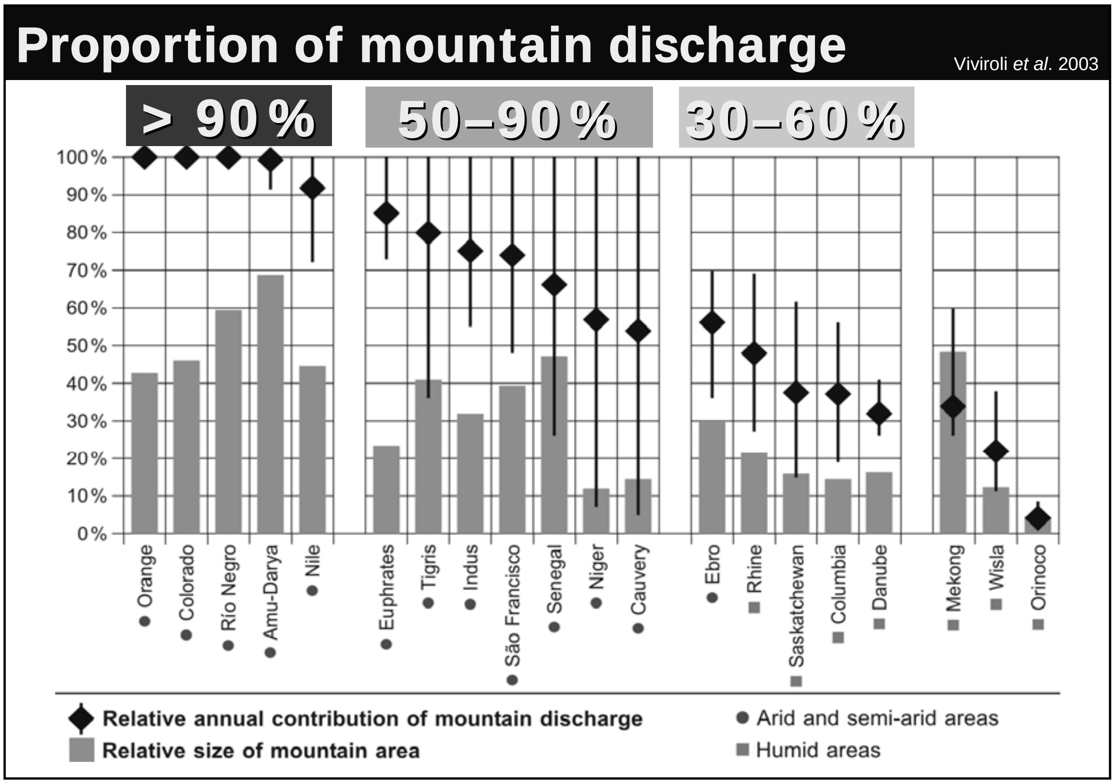

Figure 3. Mean annual mountain contribution to total discharge of fresh water, and proportion of mountain areas (represented by a gauging station in the vicinity of about 1000 m altitude or higher) relative to the entire catchment for the selected river basin. The vertical lines denote the maximum and minimum monthly amount of discharge (Viviroli et al. 2003).

The compensatory effect of mountain discharge on total discharge was estimated through comparison of year-to-year variability of monthly flows at the selected mountain and lowland stations. The difference signifies the reduction in total discharge variability through the influence of the more reliable mountain runoff. This effect generally corresponds with disproportionate mountain-runoff contributions; its magnitude is vast for the Colorado and Indus rivers and is clearly discernible in basins under significant mountain influence. Even for the Orinoco and Mekong rivers, which do not benefit so much from disproportionate volumes of mountain runoff, a clear reduction in runoff variability can be observed thanks to mountain influence (Viviroli and Weingartner 2004*a*).

The Retarding Effect of Snow and Ice Storage

A knowledge of snow-cover dynamics is a prerequisite for all studies of hydrology, climatology and biology in mountain areas. As an example, the spatial variability of snow cover in the European Alps is very high, depending on orientation to the west winds, on the different climatic situations on the north and south sides, and on the change from the more oceanic west side to the more continental east side. Such differences are probably much more pronounced in huge mountain systems such as the Himalayas and the Andes, but there only point measurements of the snow height and water equivalent were investigated, not longer time series on the highly sensitive and dynamic snow cover.

Since 1981, however, archives without any interruption include daily NOAA-AVHRR data covering the whole of the Alps. Since 2001, an operational status has been reached; data with a resolution of 1.1 km² for the entire Alps are available immediately after receipt by the ground station (Wunderle et al. 2002). This example shows that the same methods and techniques could be used for the Himalayas, the Andes or the Central Asian mountains. The Aral basin is a very instructive example for such a snow regime (Spreafico 1997). In the high mountains of the Tien Shan and the Pamirs, annual precipitation ranges from 600 to 2000 mm, with 30% falling as snow. Lowland deserts cover most of the basin and are characterized by less than 100 mm/yr. of rainfall and by high evaporation. Because of snow- and glacier melt, the flows of the two rivers the Amu Darya and the Syr Darya are highest in summer and are characterized by low interannual variability, which is very important for the management of water resources in a densely irrigated land-use system. If we take into consideration that the mountains provide more than 90% of the basin's fresh water, then we understand the high significance of mountain snow cover in the calculation of water resources for the desert lowlands.

Missing Knowledge — Uncertain Assessment of Vulnerability

Runoff generation in mountain areas is characterized by extraordinary heterogeneity in topography, vegetation and soils, by a spatially and temporally differentiated snow cover and especially by extreme events and high seasonal and annual climate variability. Long-range data series are missing for the mountains of the developing world and especially — as mentioned — for the critical zones of the tropics and subtropics. All this means that our knowledge is very limited about runoff generation at different altitudes and under different natural conditions and land-use systems (Gurtz et al. 2003). It would be especially important for semi-arid and arid zones to know how far the recharge of groundwater in the alluvial plains is directly connected to runoff from mountain areas, as can be seen and measured in valley bottoms around the Alps. Taking into account the increasing water scarcity in these regions, especially for irrigation and food production, today's state of knowledge about mountain hydrology is insufficient and makes sustainable water management and an assessment of its vulnerability quite impossible.

3. Climate Change and Its Impact on Mountain Water Resources

The Complex Relationship between Global Warming, Precipitation and Runoff

It is very difficult to determine how differentiated temperature change will affect local to regional precipitation regimes in the mountains of the world. Temperature and precipitation changes must always be regarded as coupled variables. "On a global scale, the term climate change is often equated with the term climate warming. However, the energy cycle of the climate system is intrinsically linked with the hydrological cycle. To a first approximation, it would indeed be more appropriate to equate climate change with climate moistening. The total moisture content of the atmosphere will increase by about 6% per degree warming." (Schär and Frei 2005: 258–259). This interesting statement may show the significance of the hydrological cycle, but also the difficulty to evaluate potential changes. Precipitation will not occur uniformly; rather, changes will be associated with specific geographical and topographical patterns and will vary with the seasons. More specifically, the mid and high latitudes are expected to experience a higher relative increase in total precipitation, in particular during winter, while there is evidence that subtropical and semi-arid regions might experience an increased risk of summer droughts (Weatherald and Manabe 1995). Moreover, heavy precipitation events, which are most important for hydrological processes, are not directly linked to mean precipitation amounts.

Without going into more details of this interesting discussion, we must state that the consequences of global "warming" and global "moistening" still involve a very complex and partly contradictory research process. As an example, we quote the IPCC (2001) report including projected changes of mean annual runoff data for 2050 compared with the values from 1961–1990. Two different general ocean-atmosphere circulation models from the Hadley Centre with a 1% annual increase in CO_2 were used to draft these two instructive world maps (Figure 4). A comparison shows the very different results, especially also for mountain regions such as the southern Rocky Mountains, the Andes and parts of East Africa, Central Asia, the Himalayas and the Indian plains, etc. This means very clearly that we are confronted with serious uncertainties, especially for the developing world in this highly sensitive climatic zone, where mountain water resources play a fundamental role for the adjacent lowlands. Moreover, we should not forget that even slight changes in the temperature regime can have strong impacts on snow cover and on glaciers, which again influence or even change the runoff regime. In this sense, a network of high mountain observatories would have a high priority as indicators or as an early-warning system also for the water cycle and water supply in regions with an uncertain precipitation regime. As a whole, climate change and climate variability have an impact on the human system and also on the most sensitive mountain ecosystems, which in turn have an effect on the human system.

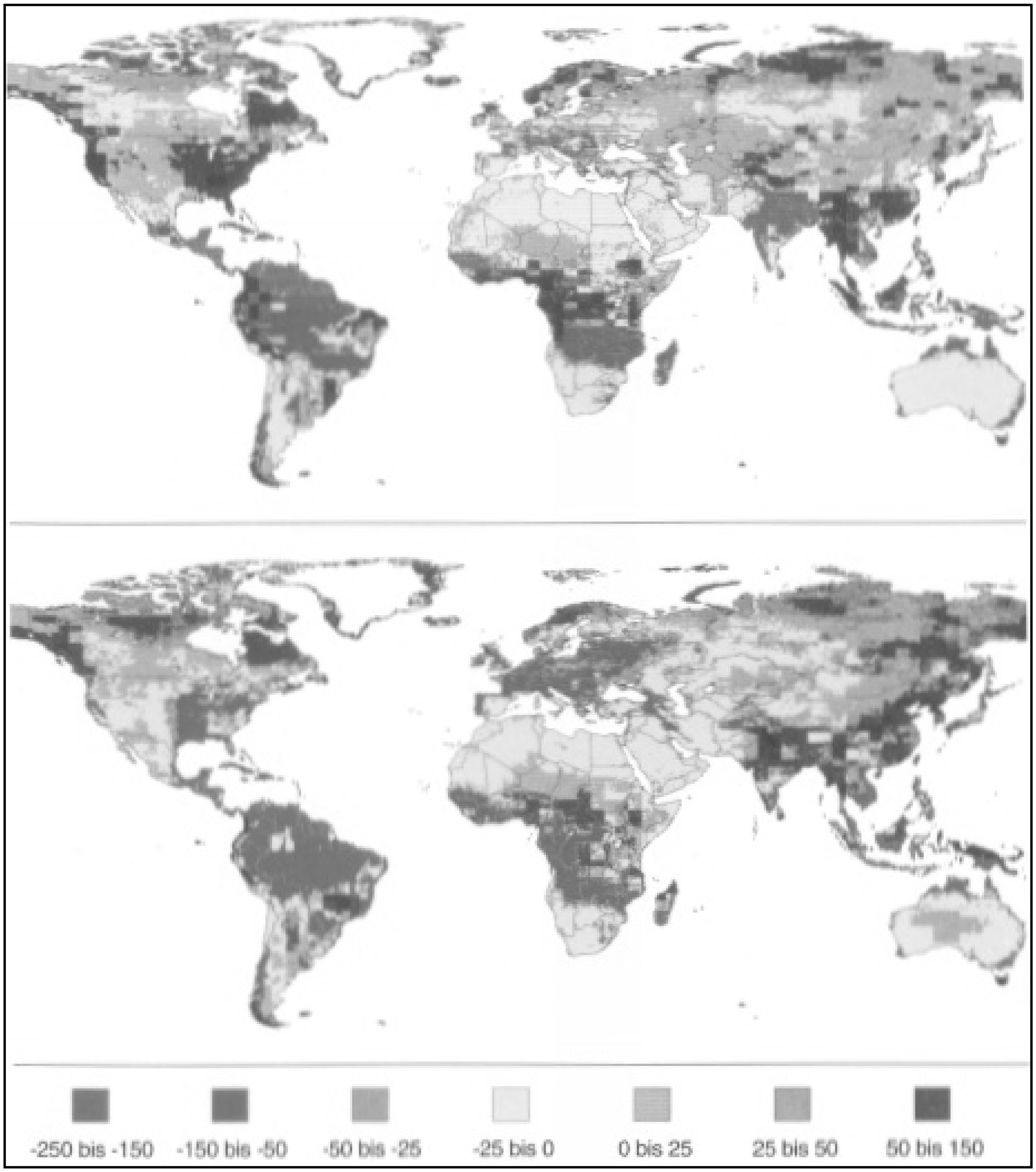

Figure 4. Projected change in annual discharge for the year 2050 in mm/yr., based on two versions of a general circulation model and on an increase of 1% CO_2 per year (IPCC 2001)

Global Warming and Water Resources in Snow-dominated Regions

In a warmer world, less winter precipitation falls as snow and the melting of winter snow occurs earlier in spring. Even without any changes in precipitation intensity, both of these effects lead to a shift in peak river runoff to winter and early spring, away from summer and autumn when demand is highest. Where storage capacities are not sufficient, much of the winter runoff will immediately be lost to the oceans. With more than one sixth of the earth's population relying on glaciers and seasonal snowpacks for its water supply, the consequences of these hydrological changes for future water availability — predicted with high confidence and already diagnosed in some regions — are likely to be severe (Barnett et al. 2005).

On a global scale, the largest changes in the hydrological cycle due to warming are predicted for the snow-dominated basins of mid to high latitudes, but also for mountain areas in almost all climatic zones. As an example, if it is true that approximately 80% of the water used for agricultural, industrial and domestic purposes in the western U.S.A. originates from high-elevation winter-spring snowpacks (Price and Barry 1997), then the consequences of any climate change can be very serious. Some authors project for the western U.S.A. an increase of 0.8–1.7°C compared to present values. This warming is projected to be accompanied by little or no change in precipitation, and this could lead to a large reduction in mountain snowpack and a substantial shift in streamflow seasonality, so that by 2050 the spring streamflow maximum will come about one month earlier in the year. There is not enough reservoir storage capacity to handle this shift in maximum runoff, and so most of the early water will be passed on to the oceans. These hydrological changes will have considerable impacts on water availability (Barnett et al. 2005).

Also, in Canada's western Prairie provinces, Schindler and Donahue (2006) show that climate warming and human modifications to catchments have already significantly reduced the flows of major rivers during the summer months, when human demand and instream flow needs are greatest. All the major rivers crossing the western Prairies originate in the Rocky Mountains, where deep snowpacks and melting glaciers maintain river and groundwater supplies. There are signs that these mountain water supplies are diminishing. The authors predict that in the near future, climate warming — via its effects on glaciers, snowpacks and evaporation — will combine with cyclic drought and rapidly increasing human activity in the western Prairies to cause a crisis in water quantity and quality with far-reaching implications.

In the Australian Alps, snow-cover duration is highly sensitive to temperature changes. A 1°C warming could reduce snow-cover duration by 50% or more at low to moderate elevations, while a 3°C increase would eliminate the snow cover at sites around 1800–2000 m which have a modern (simulated) duration of 100 days (Whetton et al. 1996).

All together, mountains — with their high-elevation snow and ice cover and highly sensitive ecosystems above and below timberline — will play a fundamental role in a changing climate in order to maintain the function of water towers for the more intensively used surrounding lowlands.

Climate Change and Mountain Observatories

Climate variability and climate change are important elements for the assessment of freshwater resources in the mountains of the different climatic zones (Messerli et al. 2004). Figure 5 shows the increase in the mean annual temperature with doubled levels of carbon dioxide, taking into consideration not only a horizontal but also a vertical differentiation of the projected global climate change. The values are zonally averaged, across all longitudes and based on the average of eight general circulation model simulations, comparing the control runs with the 2 x CO_2 simulations. The values are superimposed on a transect through the Americas, from Alaska to Antarctica, which shows the highest points of the mountain ranges as a white line. The mean annual freezing line (from radiosonde data) is shown as a black line. The black dots indicate the GCOS (Global Climate Observing System) stations and their distribution with elevation, planned for the western cordilleras of the Americas. The basic document comes from IPCC (2001); all the other additional and most instructive elements are from Raymond Bradley (University of Massachusetts, Amherst; personal communication).

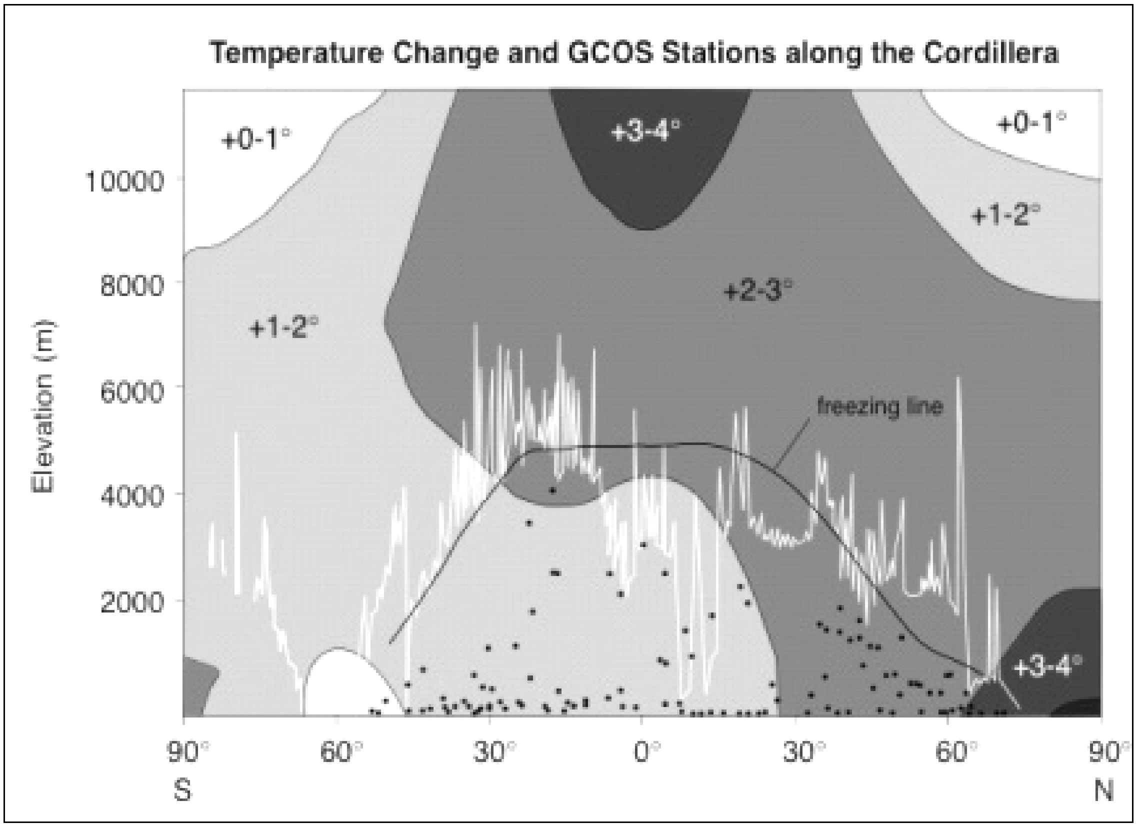

Figure 5. A transect through the Americas: projected changes in mean annual temperature with 2 x CO_2. The white line shows the highest peaks on this transect; the black line shows the mean annual freezing line. The black dots indicate the planned GCOS stations. For further comments, see text. (Raymond Bradley, University of Massachusetts, Amherst, U.S.A., pers. comm.).

This most fascinating figure shows the following: The zone of maximum temperature change which the models simulate extends from low elevations in the Arctic and Subarctic to high elevations in the tropics and subtropics, in the northern and also in the southern hemispheres. It is interesting to see that even the highest peaks do not extend into the zone of maximum warming, but they are still projected to reach the warming zone of 2 to 3°C. This figure is further developed by Raymond Bradley in order to avoid a zonally averaged value for all longitudes around the globe. He simply extracted the data for the mountain regions of the transect through the Americas, based on different models. As a result, the study shows approximately the same pattern, with the same elevation of maximum warming in the tropics and subtropics. These high temperature increases appear to be directly related to enhanced convection in the rising limb of the Hadley circulation, with release of latent heat. These findings have provoked an enduring scientific discussion, but it seems that the discrepancies between surface and lower troposphere temperature trends or between ground measurements at high elevations and radiosonde data can be explained (Seidel and Fee 2003; ProClim-News 2005).

Figure 5 shows very clearly that the existing or planned GCOS stations do not reach — in the critical zone between 30° North and 30° South — the elevation of high temperature change. There are enough mountain peaks, but they are not being used to form a network of observatories which could serve not only as a competent monitoring system but also as an early-warning system. The Mountain Research Initiative (MRI) has taken up this problem and initiated a planning process for a new and longer-term observation and research program in the mountains of the world in general and in particular for the CONCORD (Climate Change: Organizing the Science in the American Cordillera), a transect of selected mountains with well-defined research projects or observatories from Alaska to Tierra del Fuego as a contribution to the ongoing Global Change Programmes.

4. Human Driving Forces and Their Impact on Mountain Water Resources

FAO has used the UNEP-WCMC (World Conservation Monitoring Centre) definition of mountains (FAO 2002; FAO 2003), with six altitudinal classes covering together about 22% of the earth's surface. Areas with an altitude of 2500 m or higher are always classified as mountains. Between 300 and 2500 m, areas are considered mountainous if they exhibit steep slopes or have a wide range of elevation in a small area, or both. The Lofoten Islands in northern Norway may serve as an example: very steep walls of rock more than 1000 m high, beginning just at sea level, the tops covered by snow even in the summer months — altogether an exciting high-mountain impression. No doubt, real mountains also exist below 1000 m.

Vulnerability of Mountain Populations and Mountain Watersheds

FAO used its own unique data bank about population, livelihoods, land-use constraints and vulnerability of mountain people. In a special GIS-based analysis, these data have been classified and integrated into the above-mentioned mountain definition, with a special focus on the developing world (FAO 2003). As a result, FAO estimates the total number of mountain people at 718 million in 2000. Of these, 625 million live in developing countries and in the CIS (Commonwealth of Independent States; former Soviet Union). About 60% of the total mountain area in these countries is located at altitudes below 1500 m, and 70% of the mountain population lives there. By contrast, only 15% of the mountain area is situated above 3500 m, and only 2.5% of the population inhabits these regions. Although urbanization and the growth of mountain cities is important in some regions such as the Andes, more than three-quarters of mountain people in developing countries and in the CIS are still rural (FAO 2002).

FAO estimates that about 40% of the mountain area in developing countries and in the CIS produces less than 100 kg of cereals per person per year. Rural people living in such locations have difficulty obtaining an adequate livelihood from agriculture. FAO has used estimates of their numbers together with other qualitative information to arrive at a preliminary estimate of the number of mountain people who are vulnerable to food insecurity. Based on information currently available, more than half the mountain population in developing and CIS countries — in the range of 250–370 million people — are vulnerable to food insecurity (Figure 6). This estimate of vulnerability should not be confused with FAO's estimates of the undernourished population. Typically, about half of those identified as vulnerable are actually undernourished (FAO 2002). Without discussing all the other factors and constraints that could contribute directly or indirectly to vulnerable food insecurity — such as climatic conditions and extreme events, water availability, soil quality, demographic pressure or emigration, social and cultural aspects, political constraints, difficult accessibility and isolation, lack of education and health services, non-existent integration into a local market or a national economy, etc. — we must accept that food insecurity is not only an important but also an integrating factor in the vulnerability of a society. The consequences of such a situation are serious. Either we have emigration or we have an extension and intensification of the land-use system. Extension means using marginal land and crossing certain ecological thresholds, such as going too high, resulting in the threat of frost, or going too steep, resulting in the threat of erosion. Excessive intensification can lead to impoverishment of soils, to erosion or, with too much fertilizer, to pollution of water sources. In all, food insecurity can be the beginning of destructive impacts on land use and land cover, on mountain ecosystems, and especially on extremely sensitive headwater systems.

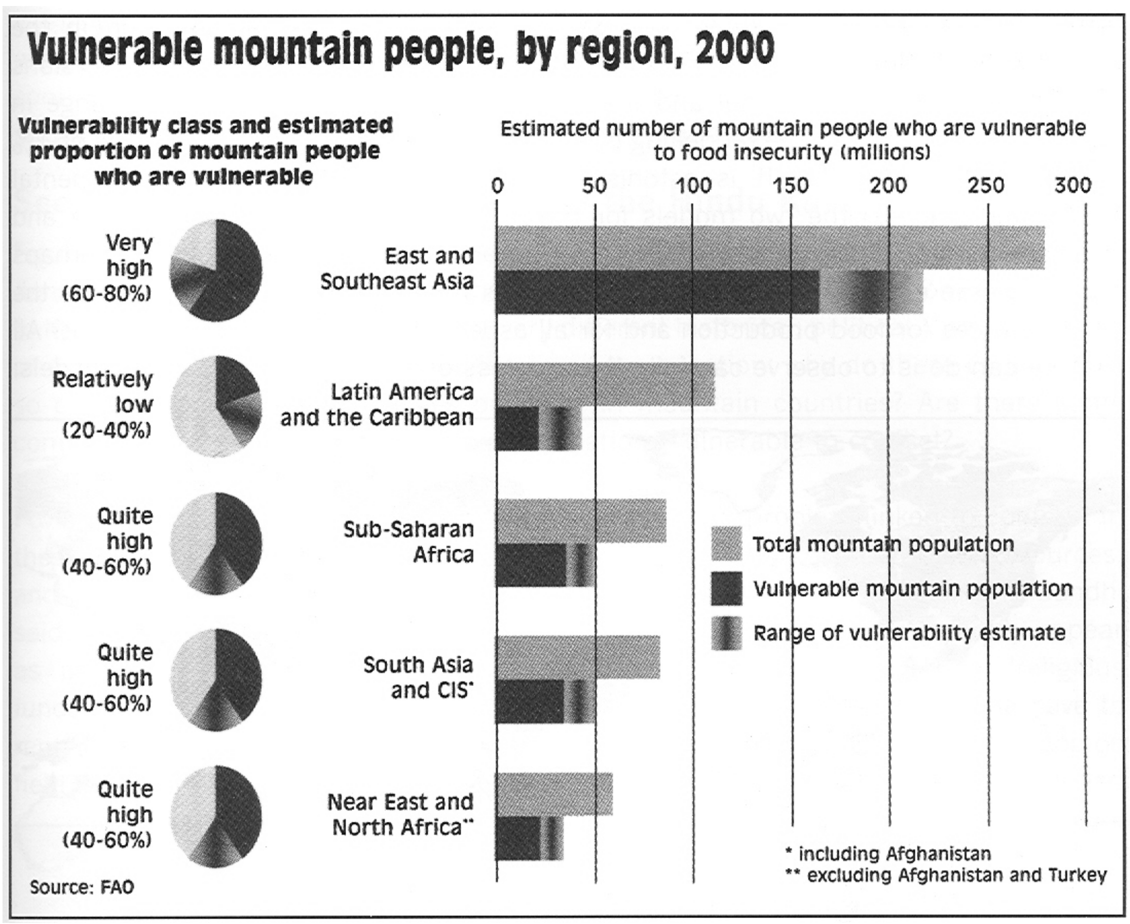

Figure 6. FAO estimates that 625 million people inhabit the mountains of the developing countries and in the CIS and that probably more than half are living in a situation of food insecurity (FAO 2002).

Mountain Watersheds and Human Interventions, from the Past to the Future

In all our future research projects, it is always instructive to pay attention to paleoenvironmental experiences. In about 400 BC, the Greek philosopher Plato wrote: "… and it had much forest-land in its mountains, what now remains compared with what then existed is like the skeleton of a sick man…" (Bury 1961). Looking at Greek history 2400 years ago, we are always fascinated by its cultural highlights but we don't want to see the real-life conditions that must have existed in the mountainous rural areas of the country during this time period. Subsequent generations had to survive in destroyed ecological and hydrological systems; the price for this damage was then and still is very high. What is happening today in some parts of the African mountains happened 2400 years ago in some parts of the Mediterranean mountains.

A look into the future indicates that mountains as water towers are threatened by other types of intervention. Until recently, dams and reservoirs were constructed in the mountains to store water to be used for irrigation in the dry season. But the order of magnitude has begun to change; with new technological and engineering possibilities, the water is no longer stored in mountain areas, it is diverted and transported over long distances. An instructive example is the recent report about the "River Link" megaproject in India (Imhasly 2003). Why should 97% of the Brahmaputra's water flow unused into the Bay of Bengal, when India is suffering from water scarcity? The project should therefore ideally link 37 big river systems. This will require 32 dams, 9600 km of canals, pumps, and power stations, with the overall goal of linking even southern India to the Himalayas with the water from the Brahmaputra and the Ganges.

Another very impressive example is China's huge South-to-North Water Transfer project, from the Yangtze River to the Yellow River on three levels extending west to east with an upper, a middle and a lower canal system. The longest of these canals extends more than 1000 km (Li Guoying 2003). Other examples are Lesotho, which is selling its mountain water to the city of Johannesburg; or Spain, which is discussing a water transfer from the Pyrenees in its north to Andalusia in its south. More projects and more conflicts will arise, especially where water crosses international borders. This is yet another aspect of vulnerability and is also strongly related to ongoing natural environmental changes and human economic and demographic changes, involving far-reaching political decisions and conflicts.

5. Outlook and Conclusions

New initiatives have been taken to improve knowledge about mountain water resources and to create the necessary awareness about the hydrological significance of the world's mountains. On a more practical and development-oriented level, FAO has organized special conferences on Watershed Management and Sustainable Mountain Development on all continents in order to prepare the next generation of watershed-management programs and projects, under the general headline Water Resources for the Future (FAO 2006). On a more scientific level, a hydrological team from the universities of Paris and Bern is working on a global map of mountain discharge, but starting with considerations about their disproportional discharge, then moving on to an earth-systems perspective with incorporation of lowland climates and finally incorporating human demand for fresh water. First and not-yet-published results show that mountain discharge is clearly disproportionally high in all climate zones except for the strictly humid tropics. This is correct for rivers such as the Amazon and the Congo, but not for a peak such as Mount Kenya, situated exactly on the equator: Its mountain rivers play a fundamental role for a vast area with an irregular precipitation regime. This type of climate is common in densely populated subtropical and even humid tropical regions, where vulnerability to seasonal water shortages is high and the hydrological significance of mountains is of special importance (Viviroli et al. in preparation).

Locally and regionally differentiated changes in temperature, precipitation, snow cover and glacier storage are likely to alter discharge from mountain-dominated areas with respect to timing, volume and variability and will ultimately influence runoff characteristics in lowlands. Catchments that are dominated by snow are particularly sensitive to climate change or climate variability and will therefore be most strongly affected by shifts in discharge patterns. When these natural and human driving forces are taken into consideration, it becomes a priority for mountain watersheds to initiate a high-mountain monitoring and research network in the framework of and as a contribution to the Global Change Research Programmes (Huber et al. 2005).

Not only is the global climate changing; in addition, population growth in critical lowland areas will accentuate the pressure on mountain water resources. This may be shown more clearly by the above-mentioned large-scale projects in India and China. According to the World Development Indicators of the World Bank (2001), 65 countries use over 75% of their available fresh water for agriculture, i.e. for food production. Included in this list of 65 countries are Egypt, India and China — all countries that rely on mountain discharge. Even if these data are not very reliable, as the World Bank confirms, the order of magnitude is impressive. If a country has to use more than 75% of its fresh water for agriculture alone, how much is then still available for rapidly increasing urbanization and industrialization? Of course there are possibilities to improve agricultural production systems, but all the same, conflicts between water users are unavoidable. The dependence on scarce water resources for the whole of the development process is alarming, and a feedback effect on mountain resources and ecosystems is inevitable. Perhaps we should keep in mind the following quotation from Lonergan (2005): "If there is a political will for peace, water will not be a hindrance. If you want reasons to fight, water will give you ample opportunities."

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Henry Vaux, Chair, Rosenberg Forum:

We will turn now to our third keynote speaker, who is Dr. Sihem Benabdallah, Associate Professor and Researcher at the Centre for Water Research and Technologies in Tunis, Tunisia. Professor Benabdallah was educated in Tunisia and the United States and holds three degrees in Civil Engineering in addition to her undergraduate training in math and science. Her Ph.D. was earned at Purdue University, and her academic field is hydrologic modelling of watersheds. She is the author of numerous publications on hydrologic modelling and watershed modelling; prior to her current position, she worked as a consultant on hydrologic studies throughout Africa, as well as studies funded by the European Commission. Dr. Benabdallah was a key organizer of an academic exchange in the year 2002 between U.S. and Iranian scholars interested in water. Last year, she was Co-chair of a workshop sponsored jointly by the U.S. National Academy of Sciences and its counterpart in Tunisia which focused on improvements in agricultural water management throughout semi-arid North Africa and the Middle East. She brings to us today both the perspective of a watershed modeller and the perspective of one working in a successfully developing country that is critically short of indigenous water supplies. Her topic is "Upland Watershed Management in the Developing World". Please join me in welcoming Dr. Sihem Benabdallah.

Upland Watershed Management in the Developing World

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Abstract
Managing upland watersheds in developing countries is still a complex process dealing with soil conservation and natural-resource preservation, water-management policies, land-use planning, legal and institutional frameworks, regional economic development, and improvement of living conditions in rural communities. A detailed review of Tunisia's soil- and water-conservation policies over the last three decades is presented in order to show the considerable potential needed by developing countries to balance conservation and preservation of landscapes; food security; and rural-development objectives. In the last few years, conservation priorities have taken a new form in Tunisia based on an integrated agriculture-development approach. Other relevant issues and challenges facing developing countries are also addressed in order to highlight certain constraints and to underline the need to focus on local social and environmental issues.

1. Introduction

The seventh Millennium Development Goal is dedicated to reducing hunger by half by 2015 and to increasing global food production by 60% in order to close the gap in meeting nutrition requirements, cope with population growth and accommodate changes in diets over the next three decades (United Nations 2005).

In fact, water scarcity, coping with uneven seasonal and annual water distribution, and impaired water quality pose serious challenges to economic development (Vorosmarty et al. 2000). For instance, India gets 90% of its rainfall during the summer monsoon season, which makes its efficient management difficult. Because of the seasonal nature of rainfall, many developing countries can use no more than 20% of their potentially available freshwater resources. A small country such as Tunisia receives on average 36 billion cubic metres per year (cbm/yr.). This volume is limited to 11 billion cbm during a drought year and can reach 90 billion cbm during a wet year. Nevertheless, the potentially available surface water is only 2.7 billion cbm/yr., representing only 8% of the country's rainfall.

Further, the world's available freshwater supply is not distributed evenly around the globe, within continents or even within countries. The world's population does not necessarily live in the areas receiving most of the world's annual rainfall. For instance, the Congo River and its tributaries account for about 30% of the entire African continent's annual runoff, while the watershed contains only 10% of Africa's population.

In response to these and other concerns, watershed protection and management has become a policy imperative in many developing countries and more specifically for most of the densely populated regions (Doolette and McGrath 1990). Watershed-management policies necessarily focus on upper catchments because of their dynamic land-water interactions, their human settlements of poor rural communities, their lack of infrastructure and their remaining forests and natural resources.

Thus, the fulfillment of the international commitment stated by the Millennium Development Goals at the local level ought to be coupled with efforts towards effective upland water management — the real asset of the rural population — based on ensuring profitability, enhancing the living environment and also considering the sustainable use of natural resources.

Given the importance of upland natural resources, a wealth of literature pertaining to the review of upland watershed management and dealing with approaches, tools, performances and evaluations has ensued in developed countries. On the other hand, there is not much published concerning developing countries, with the exception of evaluation reports issued by the international donor organizations (World Bank and European Communities Commission). Further, most of the publications concerning developing countries relate to Southeast Asia, Eastern Europe and, to a lesser extent, Latin America and North Africa.

This paper has three main sections. Section 2 provides a brief review of the status of upland watersheds in developing countries. Section 3 presents a detailed historical review of Tunisia's approach to water and soil conservation in dealing with scarce resources; injected social and environmental measures; and a newly developed methodology to ensure sustainable development and improve the well-being of the rural population. A number of the constraints and requirements pertaining to developing countries are discussed further in Section 4.

2. The Status of Upland Water Management

Upland watersheds are the principal source areas for freshwater supplies through streams, water storages, irrigation systems and groundwater aquifer recharges upon which agricultural development and many downstream communities depend. These uplands provide a source of food, natural resources and energy for a growing number of rural inhabitants (Brooks et al. 2003). Even though this may be true for both developed and developing countries, the impact of degraded upland watersheds is more substantial for the poorest and most disadvantaged populations in developing countries.

Mountain watersheds provide 30 to 60% of the fresh water flowing downstream in humid regions, while in semi-arid and arid areas they provide 70 to 95% (FAO 2004). High rates of hill erosion and downstream sedimentation are among the most important issues in the developing world due to tree removal, harvesting of fuelwood, excessive livestock grazing, intensive cultivation of marginal lands, and inadequate agriculture practices (World Bank 1992). For instance, reported soil loss for the Philippines is between 74 and 81 million tonnes annually, affecting between 63 and 77% of the country's total land area (Shively et al. 2004). These challenges are particularly acute in China's southwest, where major and minor rivers, diverse mountain landscapes and chronic poverty are intertwined.

Negative effects include the silting of streams, and consequently increases in the risk of flash floods (UNESCO 1982); the accumulation of silt in coastal habitats that may be located hundreds of kilometres downstream; the reduction of aquatic-ecosystem productivity (OECD 1993); and the accumulation of sediment in reservoirs, reducing the capacity for hydroelectric power generation and the expected life of the structure. In addition, it impacts the water quality for water consumption. These problems are more intense in arid and semi-arid regions, where land degradation can induce desertification, wind erosion, saline water and poor structure and nutrient content of soils.

Further, negatives impacts are observed on site in terms of erosion, channel degradation, and loss of biomass, as well as off-site effects such as siltation of lower dams, loss of river-routing capacity and loss of yields in lower flatlands.

Maintaining healthy upland watersheds in developing countries is crucial, not only to sustainable land management and protection of soil and water resources but also to ensuring the provision of basic needs and the development of decent living conditions for the population.

3. Tunisia's Struggle with Upland Management and Erosion

Located in northern Africa at the eastern extremity of the Maghreb, the water and soil of Tunisia are very prone to degradation due to their physical, geomorphological, hydroclimatic and socio-economic conditions. In fact, about 3 million ha, out of 9 million ha useful for agriculture and grazing, are threatened by erosion, with 1.5 million ha critically affected (Tunisian Ministry of Agriculture 1993).

Faced with these problems, the Tunisian government has made considerable efforts through physical, institutional and legislative measures in matters of soil and water conservation over the last three decades. The Ministry of Agriculture elaborated a National Strategy for soil and water conservation for the decade 1991–2000, based on slope land management and the transfer of surface water, aiming at sustainable agricultural development. Nevertheless, the problems of erosion and water degradation and their consequences continue to be current challenges.

In this section, we will discuss major problems and achievements, as well as challenges and persisting problems.

Several historical sites in Tunisia testify to the fact that the local population was seldom immune to erosion problems. The origin of this upland erosion can be attributed to geographical situation, the succession of several civilizations (Roman [146 BC], Arab, Ottoman, French), climatic conditions, and the lifestyle of the rural population. Even though land erosion is not a new phenomenon, its intensity has worsened. In fact, total land used for agriculture has increased from 1.2 million ha early in the previous century to over 5 million ha today. At the same time, Tunisia's population has multiplied by five. Rural population density has gone up, especially in areas with excessive erosion and low productivity. This demographic increase has induced considerable clearing of the natural vegetation; lands have been put under cultivation and uplands have become overgrazed, accelerating their degradation.

The mountain areas of Tunisia are made up of the final sections of the two Atlas ranges that extend for about 2400 km (1500 mi.) through Morocco, Algeria and Tunisia and are home to most of the forest and endemic plants. The Tunisian mountains are diverse in geology and landscape — from the Mediterranean cliffs, to the *dyrs* on Tunisia's high plateau, to the southern sand dunes and the Sahara Desert.

The Khroumirie and Mogod mountain ranges, which run along the north, constitute the wettest part of the country and contain forests of cork oak, zen oak and the rare *Quercus afares*. These ranges are characterized by dark brown soils developed on sandstone and on non-calcareous clays and by steep and irregular slopes.

In the centre, the High Tell — or Tunisian Dorsal — mountains are the continuation of the Saharan Atlas and are home to *Pinus halipensi* and *Quercus ilex* forests and *Stipa tenacissima* (alfa or esparto grass). At the base of the large mountains, there are calci-magnesic soils consisting of brown, crusted, degraded limestone on hardpan.

The mountains on the high steppes of central Tunisia and the Douirat mountains of southern Tunisia are mainly dominated by *Juniperus*.

In the last decade, the Tunisian Ministry of Environment and Sustainable Development initiated a program to protect what is left of the forests and natural resources through the foundation of four national parks and seven natural reserves situated in mountainous areas.

The mountains of Tunisia are important sources of water, providing about 80% of the nation's water through dams and water transfer, agricultural land, and forests exceptionally rich in biodiversity and home to rare and diverse ecosystems.

The mountain forests are degraded by cattle and human activity, a phenomenon that is particularly serious in the Dorsal mountains and the Kroumirie-Mogod forests. In addition, these areas are fragile, with soft rocks such as argillite and marl alternating with limestone and sandstone.

Climatic conditions are an important factor in the erosion problems of the country's northern and central regions, which are characterized by hot, dry summers and cool, moist winters. Precipitation is very irregular, and rainfall varies considerably from north to south and from year to year. Rainfall is torrential and event-based and can reach 70 mm/hr. in the mountains. High intensities up to 200 mm/hr. have been measured in some exceptional years.

From the 1960s to the 1980s, significant efforts were deployed, resulting in several physical, institutional and legal achievements. Over 1 million ha were dealt with using soil- and water-conservation techniques that varied from the north to the centre, depending on suitability: benches, cords, biological fixing and agro-pastoral management.

However, this work was established based on targeting specific areas in need of urgent intervention for a specific land use, or a degraded upland area. It was also designed to keep the rural population in the interior regions of the country, often through costly development projects and usually without considering the economic aspects. The evaluation of two decades of considerable efforts showed that the engineering approach was not successful in winning the struggle against erosion. Further, the infrastructure implemented by the technicians was rarely maintained or protected by the farmers, which represents part of the failure of this approach (Bachta 1994).

In the early 1990s, new orientations were taken, founded on an integrated watershed-management approach. A national water- and soil-conservation strategy was put in place, with key objectives to be met in the long run by the year 2000 based on progressively involving the rural population in taking responsibility for the conservation of structures, on capacity building of both the administrative aspects and the farmers through technical training, and on promoting private companies for services and encouraging the formation of new co-operative institutions. The main strategy set up the following goals:

- reduction of arable-land loss;
- improvement of soil fertility in order to avoid the decline of production outputs;

- mobilization of an additional volume of 500 million m^3 of water through conservation measures;
- protection of the lifespan of dams;
- attenuation of flood damages caused downstream; and
- enhancement of groundwater recharge.

A program plan was then initiated, aiming at the construction of 1000 hill dams, and 4000 structures for flood control and groundwater recharge; the protection of 600,000 ha through the implementation of conservation measures, and of 400,000 ha with cereal vocation through "soft conservation techniques"; along with the maintenance of 1 million ha already treated. The implementation of these actions was coupled with regional planning covering a number of governorates.

At the institutional level, an administrative unit under the authority of the Hydraulics and Rural Equipment Department was established in 1960 to be in charge of the planning, execution and control of soil- and water-conservation activities. This unit became a sub-directorate under the Forest Management department in the '80s and was recently transformed into a national directorate of Land Conservation and Management with the following goals:

- elaboration of plans and orientations to safeguard natural resources (soils, vegetation and water);
- promotion of technical measures in order to ensure better use of natural resources;
- evaluation of soils resources vocation and follow-up of soil behaviour under the various modes of exploitation;
- monitoring of soil and water though analyses; and
- planning and elaboration of needed uphill-catchment studies; adjustment of anti-erosive work; and follow-up of project implementations launched by soil- and water-conservation programs.

At the legal level, soil and water conservation is governed by several texts, the most important of which is the declaration that water- and soil-conservation structures are public utilities, and by a law for water and soil conservation, instituted in 1995.

It has been noted that the observed failures were not due to the techniques used but mainly due to the approach. In fact, the most modern technology in the world can be useless if it is not understood, accepted and implemented by the local population. A number of socio-economic studies in different parts of the world have shown clearly that each area has its individual set of interrelationships between people and the land they are living on.

Other constraints were due to the social and economic characteristics of the affected areas. In fact, these areas are the most populated areas within the watershed. Consequently, the land is cut into small to medium parcels, which makes anti-erosive actions sometimes impossible to carry out.

A few years were taken to work on the methodology needed to apply the water- and soil-conservation strategy. Initiated in 1997, the new approach was called the Integrated Agricultural and Rural Development Project (PDARI) and based on the realization of production and revenue potential of small agricultural holdings, as well as on the improvement of basic infrastructure available to poor populations. The major project components address soil and water conservation; forestry and pasture development (pasture plantings on private and collective land, and agro-forestry activities); agricultural development for smallholdings (promotion of fruit tree cultivation in some areas, and rehabilitation of irrigated perimeters); upgrading of basic drinking-water infrastructure; and support for women's and community-based development by targeting smallholders and medium landholders practising rain-fed or irrigated agriculture, forest-user communities, and rural women and youth. Thus, the project activities related to soil and water conservation will also affect smallholders living and exploiting the resources.

The participatory approach proposed for these projects is not based on the integrated development approach by micro-basin, as is the case in other countries. It is designed to reach several interest groups not necessarily located in the basin.

Accordingly, programming instruments were set to promote greater involvement by populations in the planning process for development actions through consultative councils at the *imada* (village) and "delegation" (several villages) levels, which were to play a central role in mobilizing populations and in programming and monitoring results. The land-occupation intervention unit is used for undertaking forestry- and pasture-development actions, soil- and water-conservation works, and productivity improvements for agriculture. The authorized user associations bring together landholders to manage and maintain small hydraulic structures and assets with assistance from the government in providing water- and agriculture-related finances, equipment, land training, and market information.

In some locations of the country, NGOs can provide small loans in the context of local savings-and-loan committees within a village-type credit system that has been put in place. Women's issues are provided for through specific mechanisms (financial and training) to promote the economic and social roles of women in rural areas.

The full impact of PDARI activities will only be seen a few years from now. However, observable impacts in areas threatened by erosion include an improvement in the production potential of smallholders and a reduction in silting in small dams and hill reservoirs. In terms of the farmers' assets, land values will increase as land becomes better protected and covered with valuable tree plantings. In terms of community-based development, agricultural training and arts-and-crafts training have given rise to hundreds of micro-projects and several marketable products (rabbits; honey through beekeeping; carpets and rugs; pottery and decorations).

Issues and Challenges

In order to address upland watershed management in developing countries, a wide spectrum of issues related to social, cultural, environmental and economic development need to be underscored. That is not the intent of this section, which aims to simply highlight some of the requirements for upland watershed management in developing countries and to underline the need to focus on local social and environmental issues.

In some parts of the world, the development of large-scale water- and soil-conservation projects does not necessarily provide direct benefits to the small landholder, who must survive within the constraints of his environment. Lebanon, Morocco, Syria and Tunisia have been engaged in a program involving the construction of small uphill dams as water-harvesting systems that provide water-storage facilities containing a few hundred cubic metres. These structures are used for irrigation, livestock watering, domestic uses and sometimes for aquaculture. They protect downstream villages against flooding and erosion and contribute to groundwater recharge.

In Tunisia, this experience was useful in two ways: it helped improve the livelihood of the rural people and it played a major part in protecting the large downstream dams from siltation (Albergel et al. 2004). Case examples of water-harvesting systems are also found in Mexico, India, Iran and Pakistan (Ahmed 2000; Christopher et al. 2000; Agarwal et al. 1997).

Thus, a useful step would be the documentation of alternative models used in developing countries to put principles of water management and soil conservation into action. Several countries are in the process of reforming their water-management policies and could benefit from other countries' success and failures in water policies, plans and programs in the context of their economic feasibility, environmental sustainability, and equity and gender impacts.

It seems that there is a general acceptance of the need to consider social and environmental objectives in water planning generally and in the case of upland watersheds more specifically. However, continued work is needed across several fronts to meet this challenge.

Technical Issues

Some technical aspects in upland watershed management require further study and research on leading topics relating to the following issues:

- Innovations in harvesting, storage and management of water runoff in drought-prone areas, aiming to improve production of crops, trees and rangeland species. This allows stakeholders to build on local capacity for adequate planning, systematic design and sustainable implementation of water-harvesting systems. The application of appropriate techniques for water yield improvement and recharge enhancement are still current issues (ISCO 2006).
- Quantifying erosion extent and impacts through simple measurement and monitoring techniques in a small-scale watershed under arid and semi-arid conditions and low vegetation cover. It should be noted that although some sophisticated approaches to modelling hydrological processes and erosion are available, there is a shortage of appropriate hydrological data for watersheds in general and specifically for upland areas, which precludes a more complex assessment of erosion-sediment relationships in modelling. Adequate databases with extensive measurements and data-collection programs will help in conducting accurate and further assessments on both the scope and the impact of the problems and on the effectiveness of the potential solutions.
- The choice of native and exotic species (trees, plants, etc.) best suited for eroded sites can make a significant contribution to creating micro-zones that can lead the way in economic and social change. Examples in the Maghreb region show that the transformation of the landscape by tree plantation (olive, peach) through government investments has strengthened the producing potential and created micro-zones for the intensification of agricultural production and a local dynamic for agricultural development to bring about real socio-economic change.
- Enhancing soil conservation, soil fertility and farm income through changes in land-use activities which may result from a combination of crops and intercrop activities into crop rotations, different crop-management techniques (irrigation and crop protection), and animal production.
- Quantifying relevant inputs and outputs of land-use activities (i.e. balance of soil organic matter and nutrients; environmental impact of pesticides; labour and machinery

requirements; and economic performance) using different quantitative methods. Special attention should be given when improving current farming systems by intensifying production, putting more pressure on already-deteriorated soils and inducing further problems for river water quality.

Planners and Decision Makers

Upland-watershed management issues are complex, and large amounts of technical, social and environmental information at multiple scales are often required to assist the process. Thus, planners and policy-makers need better tools for understanding landscape-level effects of planning and policy. Sound scientific information is an essential ingredient in sound decisions (Santelmann 2005).

Thus, modern tools for decision-support purposes and spatial analysis, risk assessment, and evaluating the effects of changes in water and land practices, including land-suitability and land-productivity assessment, are of substantial use for developing countries. They contribute to a better understanding of the biophysical themes, ranging from specific soil constraints and climatic parameters, to land-degradation status and population characteristics at national and sub-national levels. Undoubtedly, there will be problems such as data creation, training of users, etc. On the other hand, these tools present promises for enhancing information services for planners and engineers, giving greater insights, more-objective analysis, more ease in data sharing among administrations, and more-comprehensive studies.

From another perspective, it is noted that developing countries rush into setting up national water-management programs with a set of generic principles or goals. This is certainly not sufficient for upland watershed management. The methodology should allow for flexibility in planning and designing the management, development, review and evaluation processes and should be adapted to the specific context and situation. Some of the important variables in a successful upland-watershed conservation plan are the contextual characteristics in relation to conflicts, and agreement on facts, culture and social conditions.

Involvement of the Rural Population

The involvement and participation of local landholders should be integrated as a major component in the design and development of relevant programs for upland watershed management. The case study presented earlier testifies to such a need. However, it seems that there is no single way to institute such a procedure for rural areas. It depends on cultural, social, institutional and political factors. The promotion of participative action in water- and soil-conservation activities supposes the existence of a tradition of public participation in administrative decision-making processes at the institutional level, which is not necessarily the case in developing countries. Further, rural populations represent the lower-income group (poverty, illiteracy, etc.). They are resistant to new techniques and may show a lack of confidence in local administrations and poor civic mobilization for local issues. Hence, participative actions need to be built progressively and may require educational steps and training for both technicians and the rural population in order to define new traditions for making agreements, negotiating, and managing conflicts.

Social and Economic Aspects

Even if the ultimate objective is upland watershed protection, the designed projects should operate within the framework of a rural-development approach that can reconcile the imperative of conserving natural resources with creating conditions for diversifying local monetary revenues (off-farm activities, promoting proximity services, etc.). This framework could be participatory local development. Means of investment involving socio-economic infrastructure, support for community-based organizations and the rapid development of certain revenue-generating activities have a positive impact on the dynamics of local economies which can improve the quality of life for the rural population and enable populations to remain in their villages. Attention is to be paid to the situation of growing off-farm employment opportunities that could result in low levels of labour and capital allocation.

Supported activities to create and strengthen management skills among women, and particularly girls, can also generate new revenue sources and provide an important means to ensure family solidarity.

Conclusions

This paper focused only on local upland watershed management in developing countries. Other important issues related to upstream-downstream planning and implementation which are in need of more attention and better understanding include transboundary upland watersheds and intergovernmental conflicts; and adequate institutional and organizational arrangements and appropriate legislative framework to support watershed-management policies.

Overall, there has been general acceptance among developing countries of the need for considering social and environmental objectives in water-resource management. However, continued work is needed to ensure effective planning processes that balance local social issues, environmental concerns and economic development.

Strengthening the organizational skills of rural populations and their ability to take charge of infrastructure upon completion can enhance soil- and water-conservation and forest-development activities. Public awareness is a must for people to co-operate in facing water- and soil-conservation challenges.

Within a context of a development vision, further research in the field of hydrology, soil and water conservation, and upland watershed management is needed to consolidate the currently available information.

In addition, there is a need for comprehensive monitoring programs and evaluation systems, and for processes to capitalize on local instruments and approaches from past experiences.

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SESSION ONE

Helen Ingram, Session Chair:

It's interesting and therefore gratifying to me when I look at this session I'm asked to chair to recognize that it's exactly the kind of session I would have recommended. It asks the question: Water-resources management in upland watersheds — for whom and for what? When I first began to do water-resources research in 1967, it was assumed that watershed development was done for the public interest and for everybody; these miracles were being delivered to us by experts and scientists, and what they thought about it went pretty well unquestioned. From the very beginning, back in 1965, it occurred to me that at least the environment was being ignored. As I looked closer, it became clear that a lot of indigenous people and a lot of people in upland watersheds who were being flooded out by dams also had very little voice in the decision-making process. When I was invited to conferences, I would get to say such things at the very last session, after all the engineering and then my senior and wiser colleagues, the economists, talked about costs; finally, we would talk about justice and equity. It's a wonderful thing that "Why?" and "For whom?" is being put front and centre.

That said, I'll now introduce Holger Hoff, who is an environmental scientist from the University of Potsdam and who also works at the Stockholm Environmental Institute, where he is leading a green-blue water initiative to bridge science and poverty alleviation. He is also coordinating the GLOWA Jordan River basin project on water management under global climate change, a project based in Germany. His main objective and what he thinks about a lot is bridging climate science and water, but as you will see, he also considers a lot of very important social issues. Please welcome Holger Hoff.

Challenges in Upland Watershed Management: For What? For Whom?

Holger Hoff, University of Tübingen, Germany; Stockholm Environment Institute, Sweden

Introduction

Water stress in many parts of the world is increasing in terms of water quantity as well as quality. Humans are simultaneously causing this water stress and suffering from it. Human appropriation of surface and ground water; changes in land use and land cover; the release of pollutants into the environment; and other pressures are all contributing to increased levels of water stress. The resulting degradation of water resources and lack of access to safe water threaten human well-being and development, and are intimately linked to poverty in many parts of the world. Aquatic- and terrestrial-ecosystem structure and functioning also critically depend on availability of sufficient amounts of water and its temporal distribution.

In response to the emerging water crisis, a number of initiatives have been launched over the past decades, none of which has been very successful in changing the trend of deteriorating water resources and increasing scarcity, except for individual local successes.

More recently, a new, holistic approach to water management has emerged, under the title Integrated Water Resources Management (IWRM). While this is not a panacea to all water problems, it does provide a useful framework for action by acknowledging the complex human-environment interactions and feedbacks in the water system. IWRM primarily addresses solutions at the river-basin scale. Most important in our context of "upland watershed management" is the link between water and land management, which is expressed in the most widely used IWRM definition by the Global Water Partnership (GWP) (2000): "IWRM is a process which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."

Integrated water and land management also provides the lead theme for the following discussion of "challenges in upland watershed management".

Integrated Water and Land Management: The Green-Blue Water Concept

Whereas water management has traditionally been focused on so-called blue water — i.e. water in rivers, lakes and groundwater — for use in irrigation and municipal and industrial water supply, increasingly now the role of "green water" for human well-being and for maintaining ecosystem functioning and services is recognized (Falkenmark and Rockström 2004).

Green water is the water infiltrated into the soil from precipitation. It provides a large natural storage of water, similar to groundwater but accessible to natural and agricultural vegetation. This green-water storage by far exceeds that of man-made reservoirs in size. Human appropriation of green water is almost an order of magnitude bigger than the appropriation of blue water

(Falkenmark and Rockström 2004). Green-water storage and the green-water fluxes between soil, vegetation and atmosphere depend largely on land management and vegetation cover. Effective land management can improve the productivity of green water (mostly be reducing unproductive losses), which can contribute significantly to alleviating water scarcity in many regions where renewable blue water is already fully exploited.

The hydrological effects of land management or changes in vegetation cover are often not fully recognized, let alone quantified. At the global scale, the dominant type of land-cover change has been the replacement of natural vegetation — often forests — with agricultural land, and in many cases the additional introduction of irrigation. Initial global assessments indicate that the cumulative hydrological effect of large-scale deforestation, in particular in southeast Asia, in Amazonia and in southwestern and central Africa, is a decrease in evapotranspiration (ET) by about 3000 km^3/yr. compared to a potential natural vegetation cover. Irrigation, on the other hand, results in about 2600 km^3/yr. of ET, the most prominent regions being southeastern China and the Indo-Gangetic plains (Gordon et al. 2005).

In order to understand the magnitude of these anthropogenic changes in water-vapour fluxes, it is worthwhile to compare them to global blue-water withdrawals for municipal and industrial uses, which amount to about 1300 km^3/yr. (Falkenmark and Rockström 2004).

While the opposite effects of deforestation (reducing ET) and irrigation (increasing ET) seem to almost cancel each other out at the global scale, the two processes have different regional distributions. Therefore, at the local to regional scale, deforestation or irrigation in upland watersheds can significantly change downstream water availability.

Given that the replacement of forest with agricultural vegetation (without irrigation) often results in an ET reduction in excess of 100 mm/yr. (Gerten et al. 2005), runoff, infiltration and total water availability can increase significantly in a watershed when forest cover is reduced — and vice versa.

The lower transpiration of agricultural vegetation, compared to forests, is explained by the facts that trees:

1. have deeper roots than other vegetation, which can tap additional layers of soil moisture;
2. cause higher interception losses due to their height and higher surface roughness; and
3. have no fallow period during which transpiration is reduced to zero.

Despite this clear physical explanation for the higher water losses to the atmosphere from forested areas compared to other vegetation, which has been confirmed in a number of field and modelling experiments (Calder 2005), there is still a widespread misconception that afforestation would increase the water-holding capacity of the landscape and hence increase water availability in the watershed ("forests acting as sponges").

Many watershed programs around the world are building on this misconception. An example at a large, national scale is the very ambitious Indian national forest policy, which has as a target a forest cover of 33% of all land, from a current value of 22%, through a number of initiatives such as the Joint Forest Management Programme, Afforestation Programmes, the *Forest Conservation Act*, etc.

The green-blue water concept, which emphasizes precipitation as the key water resource to be managed, rather than river runoff or groundwater only, can promote a better understanding of water-land interactions and eventually lead to improved upland watershed management that is based on scientific evidence rather than popular beliefs.

Upland Watershed Management and Downstream Effects — What Are the Links?

Integrated Water Resources Management (IWRM), as defined by GWP (see above), implicitly recognizes the link between upland management and downstream effects ("IWRM … promotes the coordinated development and management of water, land and ….). However, despite increasing recognition of the new IWRM paradigm, water planning and management is still mostly disconnected from land-use planning and land management. Land-use planning around the world does not generally take into account hydrological downstream effects.

The key links between upland watershed management and downstream effects are:

- direct fluxes of blue water (surface or ground water) towards the lower reaches of the watershed;
- changes in water quality downstream, e.g. nutrients, salts, other pollutants; and
- upland erosion causing sediment loads that e.g. reduce the storage of reservoirs.

Downstream communities, irrigated agriculture, industries, hydro-power production and other users depend on a reliable water supply from the uplands. So do aquatic ecosystems.

In situations where basins are reaching "closure", i.e. the blue-water resources are fully allocated, upstream measures such as soil conservation or rainwater harvesting, which reduce runoff, or improved water infrastructure, allowing higher blue-water withdrawals, can reduce downstream water availability.

From a development and poverty perspective, technological upgrading such as stronger pumps that can access deeper groundwater, may also be at the expense of the poorest, who cannot afford more-sophisticated equipment to exploit diminishing resources. Communal downstream water resources may be negatively affected in closed basins if private equipment is used to exploit upstream resources to the maximum (Calder 2005).

As described in the previous section, win-win solutions in closed basins can be found in reducing non-productive green-water flows, i.e. evaporation from bare soil surfaces or other surfaces.

Other opportunities are provided by upstream-downstream arrangements where overall, basin-wide water productivity is increased through reallocations of water, e.g. from crops to higher-value products. Compensation of the lower-value producer or sharing of benefits or knowledge may be the way forward if water resources are already fully exploited. The sharing of knowledge can be of particular importance in rural-urban or transboundary contexts, where capacity upstream and downstream can be quite different.

It should be emphasized that the upscaling of biophysical and also socio-economic upstream-downstream effects and relationships to the full-basin scale makes quantifications more difficult and increases uncertainty. In order to fully assess the cumulative or larger-scale effects of upstream water and land management, a range of higher-order effects has to be taken into account, e.g. impacts on ecosystem services, biodiversity, flows to the coastal zone, etc. Also, bidirectional interactions between land surface and climate can become relevant at a larger scale.

Climate change also affects upstream-downstream relationships and associated water stress. Adaptation to climate change or mainstreaming of climate adaptation into IWRM is only just beginning to be addressed by water managers around the world.

The impacts of even small climatic changes may be large and potentially disastrous, given the non-linearities in the water system when it comes to the translation of precipitation into runoff, infiltration, or groundwater recharge. De Wit (2006) shows that precipitation reductions of about

10%, as projected for southern Africa over the 21st century, may translate into reductions in drainage of up to 50% and more.

Climate change and its effects on water resources brings another perspective into the upstream-downstream discussion: while climatic changes such as reduced precipitation, increasing ET and higher variability affect the whole basin, changes in upstream snow, ice or glacier cover may critically affect downstream livelihoods and ecosystems. For example, the water draining from the Himalayan glaciers ensures a continuous water supply in the dry season to hundreds of millions of people in the Indo-Gangetic plains. As much as 70% of the Ganges' summer flow comes from glaciers (Barnett et al. 2005). The melting of these glaciers, as with most other glaciers around the world, has already accelerated; due to further warming, the runoff of the Ganges may increase by 30%–40% over the coming decades, potentially causing more flooding in northern India and Pakistan. In the long run (after about 40 years), however, most glaciers will have disappeared, and subsequently runoff will decrease drastically. The runoff of the Indus and the Ganges is projected to decrease by more than 50% compared to the current situation, with corresponding reductions in water availability (Hasnain 2004).

The responsibility for "upland management", in this case for the Himalayan water towers, lies with all greenhouse-gas emitters.

Upland Watershed Management: The Jordan River Case

In the case of the Jordan River, upstream-downstream relationships are immediately also political in nature, since its headwaters are partially in Lebanon, Syria and Israel, while Israel, the Palestinian Authority (PA) and Jordan are riparians of the lower Jordan. Respective contributions to the annual natural runoff of the Jordan River are (Phillips 2006):

Jordan: 530 million m^3 (MCM)
Syria: 435 MCM
Israel: 160 MCM
PA: 155 MCM
Lebanon: 120 MCM

Any proposals for improved upland watershed management will immediately be judged in the political context, while upstream-downstream compensation schemes would have to work across borders.

In the Jordan River basin, water productivities or water use vary considerably between upstream and downstream riparians, due e.g. to different irrigation or waste-water-reuse technologies, so that transfers of benefits and/or knowledge through co-operation could increase the basin-wide benefits considerably. According to Sadoff et al. (2002), the different categories of benefits from improved water and land management are:

1. benefits to the river (e.g. ecosystem restoration);
2. benefits from the river (e.g. water for irrigation);
3. benefits of reduced costs (savings from reduced tensions and conflict can be much higher than investment cost-management measures); and
4. benefits beyond the river, if co-operation over water resources has spillover effects, e.g. in terms of increasing economic integration (see virtual-water trade below).

The potential for rain-fed agriculture in the Jordan River basin follows the steep regional climatic gradient. While the northwestern part of the basin enjoys rainfall of up to 1000 mm/yr., the eastern and southern parts of the basin receive less than 200 mm. Not only do any improvements in upland green-water management, in particular in rain-fed agriculture, increase the flow of blue water (runoff and groundwater recharge) for the benefit of downstream users; in addition to that, productivity increases in rain-fed agriculture can also reduce the pressure on irrigated agriculture and subsequently allow some reallocations to other, non-agricultural uses. Again, co-operative transboundary agreements and sharing of knowledge on improved upland green- and blue-water management, e.g. through rainwater harvesting and supplementary or deficit irrigation (see e.g. Oweis et al. 2004), can reduce water stress and political tension at the same time.

Climate change is projected to become a major driver of increasing water scarcity and potentially also conflicts over water resources in the Jordan River basin over the coming decades. A number of recent studies have identified the eastern Mediterranean as a hotspot of climate change (Arnell 2004; Milly 2005; Lionello 2006), with expected:

- decreasing overall water availability; and
- increasing intra- and inter-annual variability and frequency/intensity of droughts.

Adaptive regional water management, as well as upstream-downstream agreements on sharing of blue-water resources or co-operation on upland watershed management, needs to take these projections and the associated uncertainties into account; this has not yet happened in any agreement over water resources in the region. Science can help here to provide "climate-proof" solutions to transboundary agreements.

The GLOWA Jordan River Project is an interdisciplinary science and application project that addresses for the first time integrated green- and blue-water management under global change conditions, through the development of quantitative scenarios and decision-support tools (Hoff et al. 2006). It has repeatedly been emphasized that hardly any other region in the world depends so much on imports of food or virtual water, due to extreme water scarcity, as does the Jordan River region. More than two thirds of the overall food requirements of Israel, Jordan and the PA are met by imports, and hence rely on water used abroad for food production (Hoff et al. 2005). These food and virtual-water imports are largely from outside the region, e.g. from Europe and the U.S.

Given the large differences in per capita renewable water resources (and hence capacity for food production) within the region (Gaza Strip, 14 m^3/yr.; Jordan, 151 m^3/yr.; Israel, 244 m^3/yr.; Lebanon, 1219 m^3/yr.; Syria, 1346 m^3/yr. [WRI database 2006]), there is considerable potential for co-operation through intra-regional (i.e. upstream-downstream) virtual-water trade from water-rich (upstream) to water-scarce (downstream) countries, exploiting the comparative advantages of each. The overall net benefits of such co-operation schemes would quite likely far outweigh the net benefits from expensive "hard path" infrastructure schemes such as the Red Sea–Dead Sea canal, which is nothing but a downstream alternative to better (co-operative) upstream management. Unfortunately, such agreements between Israel, Lebanon and Syria are not likely under the current political situation.

How Can Upland Watershed Management Be Made More "Downstream-friendly"?

As described before, upland management and resulting changes in stores and fluxes of green or blue water affect downstream water resources. The most prominent example of this principle entering national legislation is South Africa's *National Water Act* from 1998, which levies streamflow-reduction activities, such as forest plantations. With this taxation of certain land uses, a user-pays principle is introduced which recognizes the upstream-downstream relationships of green and blue water. An assessment of the water requirements for different land uses concluded that all commercial tree plantations in South Africa combined reduce the nation's surface runoff by 1.4 billion m^3 per year, or 3.2%. As a consequence of this resource use, South Africa's *Water Act* requires timber growers to apply for permits before establishing new commercial tree plantations.

Along the same lines, a designation of sugar cane plantations as streamflow-reduction activities is also under discussion in South Africa.

The promotion of integrated water and land management at the river-basin scale, paying attention to the natural upstream-downstream pathways of water, can also be interpreted as an application of the soft-path approach by Gleick (2003). This approach recognizes that the traditional hard-path approach of structural measures and engineering solutions, with its focus on supply management, is no longer an option for basins experiencing acute water scarcity. Instead, taking into account green water in upland watershed management emphasizes the need to keep ecosystems ("natural infrastructure") and their water-related services intact and to include external environmental and socio-economic costs and benefits in the overall balance; see direct and indirect uses of green and blue water in Falkenmark and Rockström (2004).

These principles are beginning to be put into operation in some pilot projects where upstream land managers (mostly farmers) are compensated for short-term losses when managing water and land sustainably and in a "downstream-friendly" way, and encouraged to maintain or enhance beneficial management schemes.

Payments for Environmental Services (PES) had been established previously, e.g. for carbon sequestration or erosion reduction; now initial schemes are being tested for providing hydrological services to downstream users. Upstream-downstream relationships are often such that (financially) stronger individuals, groups or institutions are located downstream of the poorer rural population living in the upper watersheds. This setting, which increases the feasibility of PES schemes for upland watershed management, can be found, for example, in South Africa, where often the large, commercial farms are located downstream. Another example is China, where the big and economically powerful cities are located in the lower parts of the major rivers.

Some initial PES schemes include (Emerton et al 2004):

- The upper Arenal (Río Chiquito) watershed in Costa Rica, where upland farmers have been compensated for the conservation and sustainable management of forests and for reforestation. In contrast to the previously described generally negative effect of forests on downstream water yield, cloud forest can deliver more water during dry periods than other land uses, due to: i) the higher absorptive capacity of forest soils compared with e.g. compacted soils under cattle pasture; and ii) additional water intercepted by the trees from clouds. In this special situation, cloud forests can produce more water for the watershed than other land cover. Moreover, other services, such as carbon fixation, biodiversity protection, and provision of scenic beauty, are also acknowledged in this scheme.

- Similarly, compensation for protecting the Sierra de las Minas Biosphere Reserve cloud forests in Guatemala is also expected to provide additional water supply, in particular for irrigated agriculture.
- The Paute hydroelectric scheme in the Andean highlands of Ecuador, which rewards the assumed benefits provided by upland forest management, i.e. maintaining river flows and limiting sediment yield.
- Mantadia National Park in Madagascar, where the establishment of an upland national park and a buffer zone with subsequent conservation of forests is expected to provide flood attenuation and reduced losses from floods.

An example of a water-quality-protection initiative through agreement with upland watershed managers is the New York City Watershed Agreement, which protects 1900 square miles of land. New York City agreed to provide US$35.2 million for farmers in the upstream Catskills catchment to purchase or build pollution-abatement devices, e.g. fencing to improve cattle feeding, or riverside tree planting. Upstream benefits of this well-known scheme include increased farmers' income due to city funding, and higher farm productivity in nine out of ten cases due to the improvements made on their properties. Downstream water consumers benefit by avoiding the hard-path solution of building a $6-billion water-filtration system (NYC Watershed Program).

An example with private-sector involvement in a PES scheme comes also from Costa Rica, where the national government and Energia Global, a private hydroelectric company, compensate upstream landowners when they maintain or increase forest cover, in order to reduce upland erosion and subsequent downstream siltation of reservoirs. This scheme is not funded by the private company, however; the government of Costa Rica has established a fund to help pay for these services, which largely consists of a 5% tax on fossil-fuel sales.

Beyond reservoir siltation, this scheme is also expected to increase stream regularity by increasing forest cover. Payments ($48 per hectare) are based not on the value of the hydroelectric services but on the approximate equivalent of the opportunity cost of foregone land development, which is primarily cattle ranching (Chomitz et al. 1998).

What Are the Difficulties with These Schemes?

Despite the enormous potential and promising future of such PES schemes with respect to putting into operation the IWRM principles, they also come with a number of shortcomings and flaws that require further testing and improvement in order to really deliver the expected services.

First of all, the direct and immediate effects of any measure in upland watershed management are difficult to measure, given the complex interplay of abiotic and biotic factors that determine flows of water, constituents and water-related benefits between upstream and downstream sections of the basin.

Also, there can be considerable delays between the implementation of upland measures and the resulting hydrological response and beneficial downstream effect, e.g. groundwater changes or erosion reduction.

Furthermore, any upscaling from plot-scale experiments to the full river-basin scale complicates the detection of effects, and requires an integration over the cumulative primary and higher-order effects from all upland measures (Kabat et al. 2004).

Climate variability and change can further complicate the detection of these effects, and will often closely interact with land-use-change effects.

Given the limited number of field and modelling studies on downstream effects of different upland management measures, PES schemes — whether nationally implemented or part of development co-operation — are still largely based on beliefs rather than scientific evidence; see the "trees hold water in the landscape" belief described above (Hayward 2005).

Beyond these biophysical aspects that need careful study before judging the effectiveness of PES schemes, there is a — possibly even wider — range of socio-economic factors that further complicate the picture:

The motivation of upland watershed managers, i.e. farmers, is not sustainable resource use or abstract concepts such as improved water productivity, but maximization of farm income.

Water and land rights play an important role in resource use. If water rights exist, they usually specify withdrawals rather than consumption, so water users will want to maximize productivity or minimize the outflow of blue water towards downstream users.

Given the difficulty of quantifying the downstream effects of upland measures, e.g. in terms of blue-water or sediment yields, private downstream users are usually reluctant to fund PES schemes. If a scheme thus remains dependent on public funding (which was only meant to support the kick-off phase), it may not be sustainable in the long run.

Payments themselves should be coupled to performance, but that requires reliable monitoring and indicators for the success of PES schemes. Leaving aside the issue of expected vs. real downstream effects which was addressed above, the monitoring of upland farmers' compliance with the land-management obligations into which they have entered may also be difficult. Generally, monitoring from within the area or community is recommended. Remote sensing may provide an additional means of monitoring actual land and water use.

A less successful example of a PES scheme also comes from Costa Rica, from the Arenal region. In that case, the proposed combination of government payments for reforestation and the elimination of ranching subsidies did not provide enough financial incentive to landowners to reforest steep slopes. The economic returns from logging and then running livestock exceeded the potential compensation for stewardship. Adding to that, the electricity-generating company downstream determined that the increased water yield resulting from the deforestation outweighed the costs of sedimentation. So no agreement on a sustainable PES scheme was possible (Chomitz et al. 1998).

Given these difficulties, the quantification of green-water fluxes — i.e. the ET losses from the watershed — for different land uses and land-management measures seems to be a more reliable basis for PES schemes than trying to understand and quantify streamflow changes. As described above, streamflow generation is a rather complex and non-linear response to interactions of land and vegetation changes, modulated by climate variability and change, with all the associated uncertainties (Kabat 2004; Hayward 2005).

Green Water Credits — A Pilot Project in Eastern Africa

Green Water Credits (GWCs) are based on the green-blue water concept as previously described. GWCs are payments, in cash or in kind, made to rural people in upland watersheds for specified green-water management activities.

Upstream, GWCs provide cash income, which can help to diversify — not replace — existing sources and livelihoods, e.g. by way of increasing the productivity of rain-fed farming. Downstream, GWCs contribute to water security, flood abatement, improved water quality and increased environmental flows (Dent 2005).

In eastern Africa and in Africa in general, the vast majority of farming is rain-fed, not irrigated. From the upstream-downstream perspective, a shift to irrigated agriculture in the uplands is not without problems: water consumed upstream is no longer available downstream. In particular, if downstream uses are more productive, a basin-wide IWRM approach may not favour the development of major irrigation schemes in the uplands.

The more sensible approach in many cases will be to minimize non-productive evaporation, in particular by improving rain-fed agriculture, possibly with some supplementary irrigation. Part of that can also be rainwater-harvesting schemes, as long as the harvested water would otherwise be lost to evaporation.

A GWC pilot project is currently being implemented in eastern Africa, which largely depends for its water supply on the major water towers around Mt. Kenya. This area is undergoing rapid land-use change, e.g. marijuana cultivation replacing thousands of hectares of forest cover. Deforestation in this area is generally associated with erosion and with siltation of downstream reservoirs. Goals of the GWS pilot project include:

- a quantitative understanding of upstream-downstream links, including upscaling by using a set of hydrological and water- and land-management models;
- the identification of downstream beneficiaries, e.g. hydro power, municipal water users, irrigators;
- the identification of "upland managers", in particular farmers;
- the development of PES schemes that compensate for possible reductions in income when implementing or continuing downstream-friendly measures; and
- possibly also testing remote-sensing applications to monitor the success of PES schemes, in terms of land cover as well as ET.

Given the uncertainties in hydrological responses to upland management measures, as described above, PES schemes may be operated better at regional or national scales rather than with direct reference to local-scale effects.

As for the funding mechanisms for PES schemes, public funding — including development co-operation funds — may be required for a number of years before private funding (e.g. hydro power or city water supplies) will pay for these schemes. Some non-marketable services may continually depend on public funding.

Conclusions

Water (and food) security in many parts of the world depends on upstream catchments, in particular the "water towers" at the headwaters of the basin. Upland watershed management and land-use changes can have severe impacts on humans and ecosystems downstream, in particular in water-scarce regions. These impacts are often not well understood, let alone quantified. Consequently, planning and management at the river-basin scale is often based on beliefs about upstream-downstream links rather than on scientific evidence (see the beliefs about forests in upper catchments).

Given the uncertainties in science itself about upstream-downstream hydrological links, the green-blue water concept can enable a shift to management of the primary water source, i.e. precipitation, partitioning it into evapotranspiration, runoff and infiltration and emphasizing the latter two processes as important for downstream water supply. The green-blue water concept also acknowledges the hydrological services of ecosystems and provides a basis for their economic valuation.

In this context, climate change needs to be taken into account as potentially compounding existing water scarcity, and increasing variability and uncertainty in water supply. Hence, adaptation to water-related climate risks has to be mainstreamed into IWRM in many dryland regions around the world.

Payments for environmental services apply the user-pays principle. As part of IWRM, downstream water users increasingly will need to compensate upland managers (i.e. farmers) for positive external effects of their activities, in particular increases in water yield and overall water-related benefits.

The new Green Water Credits initiative in eastern Africa is an application of the green-blue water concept, integrating biophysical and socio-economic aspects of upstream-downstream linkages. It develops, tests, and monitors payments, e.g. from downstream hydro-power producers to upstream farmers, for a management of upland watersheds that ensures river flows and reduces erosion and sediment loads downstream.

Eventually, such schemes may also be applicable in transboundary situations.

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Helen Ingram, Session Chair:

Next we'll hear from Pedro Arrojo. Dr. Pedro Arrojo Agudo is a researcher in the Department of Economic Analysis at the University of Zaragoza in Spain. His presentation on "Water Management in Alpine Regions" will focus on the failure of traditional public policy to achieve sustainable water management in Europe and elsewhere. Dr. Arrojo Agudo will conclude with a summary of a new water ethic presently being promoted within the European Union. Both his analysis of the failure of "hydrological structuralism in the 20th century" and his pronouncements on the European Declaration for a New Water Culture, signed by 100 European Union scientists in 2005, will put into relief important aspects of our search for a better and more durable water ethic. Please welcome Dr. Arrojo Agudo.

Water Management in Alpine Regions

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1. Historical Antecedents

1.1. Hydraulic Structuralism in the 20th Century

A comparison of Spanish and American hydraulic history may seem pretentious given the vast size difference between the two countries. Nevertheless, it is quite interesting to observe how, despite different cultural and historical realities, parallel processes exhibiting profound similarities have emerged since the end of the 19th century. Therefore, we will use the experience of both countries as a reference for a water-management model that has dominated the entire world over the course of the 20th century (Arrojo et al. 1997).

The fascinating history of the colonization of the North American West shows water to be one of the main protagonists in how the colonization process was organized. The first colonies introduced by Spanish missionaries along the California coast between Los Angeles and San Francisco benefitted from the introduction of Arab irrigation methods with their refined drainage techniques.

Later, in the American Midwest, Mormons used their legends and beliefs to make the introduction of irrigation a centrepiece of their colonization strategy. Their vocation as "God's chosen people" was to transform the desert between the Green and Snake rivers into a new American Promised Land. At the end of the 19th century, they controlled approximately 2500 hectares of irrigated lands in the middle of the desert (Reisner 1993). After successfully irrigating alluvial areas (with good natural drainage), they met with failure in the steppe regions, where salinity and drainage problems sorely tested their scarce knowledge of irrigation. But they were soon applying the Arab drainage techniques used in the irrigation systems of the Spanish missions in California.

The repeated failure of private initiative to construct the great waterworks made possible by civil engineering led to the application of Powell's thesis to the effect that the projects should be implemented using the financial and management capacity that a modern, well-organized state could offer. In 1902, the federal government of the United States launched the first public program of great irrigation works through the newly formed Bureau of Reclamation. In less than half a century, thousands of great dams were built, generally in mountainous regions, along with tens of thousands of kilometres of large canals through some of the most rugged topography and inhospitable deserts, the result being that millions of hectares were irrigated on behalf of the "public interest" through public financing.

Another use that would justify the construction of large dams in the general interest was hydroelectric power. Beyond its economic value, hydroelectric power production became a military priority due to the aeronautical industry's need for aluminum. In fact, American military supremacy during World War II is largely attributable to its capacity to produce hydroelectric energy in order to satisfy the aluminum industry's voracious appetite for aluminum to build combat aircraft.

In Spain, hydraulic-engineering traditions have their historical roots in the ancient Roman Empire, although it was in medieval Muslim Spain that cultural developments in Al-Andalus would foster the most advanced engineering, drainage and irrigation techniques of the era.

By the 18th century, the French Enlightenment would lead to more advances in civil engineering in the area of major navigation canals, which in Spain would stimulate progress with regard to irrigation-related objectives. Important projects such as the Imperial Canal of Aragon, the Castilla Canal, the Murcia Canal and the construction of major dams permitted the implantation of irrigation systems over tens of thousands of hectares.

But it was during the 19th century that the development of hydraulic engineering established the foundation for modern hydraulic structuralism. A range of laws encouraged the private sector to take the initiative with regard to irrigation and regulation works (Pinilla 1997). Nevertheless, the few attempts that were made failed in Spain, as they had in the United States. These projects required large investments and long-term amortizations which rendered the private-finance model impracticable.

Costa's Regenerationist Movement, except for multiple contextual differences, would generate theories, approaches and projects similar to those proposed over the same time period by Powell in the United States. In similar fashion, Costa defended the introduction of public initiative as a key to promoting large-scale irrigation and water-control works. In 1902, the same year in which the first public, large-scale irrigation plan was drawn up in the United States, the Plan Nacional de Aprovechamientos Hidráulicos (National Plan for Hydraulic Development) was approved in Spain. Soon, water management was organized by catchment basin, and the Hydrographical Confederation of the Ebro River became the first catchment basin agency in the world.

Nevertheless, in 1936, the Civil War and the victory of fascism marked a hiatus in Spanish social, cultural and political life, preventing the implementation of Regenerationist hydraulic plans for almost two decades. In the 1950s, these plans were reintroduced, thus giving rise to a sort of "hydro populism" in the service of the regime which became quite popular.

After the death of Franco, cultural inertia combined with existing interests would prolong both the existence of a hydraulic bureaucracy and its attendant power structures, as well as that of old ideas and structuralist strategies (Diaz Marta 1993).

Consequently, as a result of having made the development of large hydraulic works a priority irrespective of the political ideology of the government in power, Spain is currently one of the countries with the most hydraulic infrastructure per inhabitant and per square kilometre in the world, with 53,000 hm^3 of reservoir capacity — the same as that of California, which is similar in size (Arrojo et al. 1997).

1.2. The Crisis of the Structuralist Model and of Supply Strategies

By the 1960s in the United States, congressional representatives of the eastern states (who contributed the major part of public funds) began to protest against the large investments in hydraulic megaprojects in the western states. As a result, cost-benefit analyses and the refilling of government coffers depleted by these investments within reasonable time periods became requirements. Nevertheless, repeated failures to comply with these commitments called into question a management model that had held sway for half a century.

Throughout this period, the Bureau of Reclamation (a civil institution) and the U.S. Army Corps of Engineers (a military institution promoting civil-works projects) became all-powerful lobbying and pressure groups. The extensive and frequently shady dealings involving construction and hydroelectric power, along with agricultural- and urban-land speculation in connection with massive hydroelectric projects, led to the invention of the term "pork barrel" to refer to the system of public financing of large-scale hydraulic works in the United States.

The disappearance of salmon in the great rivers along the Pacific coast and the flooding of emblematic natural areas began to weigh on the public conscience. Public pressure, for example, blocked the construction of Echo Dam on the upper Colorado River but did not, on the other hand, prevent the construction of Glen Canyon Dam. In 1963, millions of Americans reacted with consternation to images of the flooding of 320 km of the emblematic Grand Canyon of the Colorado and its tributaries in order to produce electricity.

Tenacious criticism of the financial accounts, on the one hand, and increasing ecological sensitivity, on the other, would make the system totter on its foundations. In 1978, President Carter, confronting powerful lobbies dominating the Capitol, vetoed the projects on the so-called "hit list", which was essentially a long list of large-scale hydraulic projects; these were to be definitively abandoned. Thus, the heralded change in the approach to water-management strategy was made explicit. Dozens of large dam projects intended to supply Los Angeles, such as the Klamath River, or the Columbia project with its 2000 km of canals and 450 km of tunnels, etc., were set aside (Reisner 1993).

In Spain, while Franco was in power, the regime's ruling families, along with large electric and construction companies, turned large-scale hydraulic projects into private business opportunities based on the use of public funds. In an authoritarian regime in which criticism was impossible, bureaucratization and corruption profoundly degraded the model.

Unlike in the United States, where major urban areas above a certain size were never flooded (with the exception of Hispanic and Indian settlements), in Spain the construction of more than 1300 large dams resulted in the flooding of numerous inhabited valleys, leaving hundreds of towns, especially in mountainous regions, under water (Arrojo et al. 1997). In addition, a large number of fluvial ecosystems experienced serious ecological degradation, leading to the extinction of species as emblematic as the sturgeon, salmon and eel. Furthermore, water quality and the regenerative capacity of fluvial ecosystems were seriously compromised, as a result of which the consequences of a clearly unsustainable water-management model became manifest.

In the '90s, the announcement of a National Hydrological Plan (PHN) that would involve the flooding of 200 valleys gave rise to a public protest movement against the construction of new dams which gained momentum as a result of the proposal to construct large dams along the Ebro River. Beyond the directly impacted, this movement mobilized more than a million citizens against the PHN and in favour of a New Water Culture (Nueva Cultura del Agua) between 2001 and 2002. This massive mobilization resulted in the blockage of European funds intended to make the execution of these proposed large-scale works possible. After the elections, under the new government and within the legal framework of the new EU Water Framework Directive, the repeal of the Ebro dam project closed the process in a way similar to the Hit List veto in the United States (Arrojo 2003).

2. Values at Stake in Alpine Regions

Water and aquatic-ecosystem management implies the management of resources that change depending on the characteristics of the fluvial ecosystems and on the surface area of the catchment basin in which they are found. In headwater regions, which usually coincide with alpine areas, the most important values that come into play with regard to water management are:

1. the regional value of valleys for population settlement;
2. environmental values tied to landscapes and mountain ecosystems;
3. the hydroelectric potentiality of high-elevation waters;
4. values and uses tied to high water quality;
5. the opportunity value inherent in the orographic potential for constructing control works;
6. recreational and emotional values frequently connected to the development of services;
7. the value of downstream irrigation;
8. values, environmental uses and services downstream, along with their economic benefits; and
9. the relationship between ethical values and the maintenance of an equitable distribution of socio-economic resources at the inter-regional level.

2.1. The Regional Value of Valleys for Population Settlement

The World Commission on Dams, in its final report, published in London at the end of the year 2000, recognized that although they had precisely calculated the millions of cubic metres which could be stored in more than 50,000 large dams constructed in the world over the course of the 20th century, they were unable to calculate how many people had been forced out of their homes and towns when regions were flooded by these dams: "The overall global level of physical displacement could range from 40 to 80 million…." (WCD 2000).

From my perspective, what impresses me most about these figures is not so much their magnitude, but rather the lack of knowledge and level of imprecision surrounding them. Declaring "from 40 to 80 million" involves the recognition that it is simply not known — a "hydrocaust" carried out stealthily and silently.

The major part of these displacements occurred in mountainous regions where the affected populations are usually considered marginal. The WCD report itself underscores that such calculations refer only to those people directly affected by flooding of their homes, whereas it is noted that the number of people forced out of their homes as an indirect consequence of dam construction is much higher than the number forced out as a direct consequence.

The greatest affliction borne by the mountainous regions as a result of the impact of large dams is, without a doubt, the loss of social networks, both in the flooded valleys themselves and in other areas connected to and dependent on the flooded regions. Frequently, the flooded valleys integrated entire regions as a result of having constituted central cores with their attendant health services, schools, commerce, etc. Although we are discussing water management in mountainous regions, the most precious and scarce resource is usually the habitable regions themselves — in other words, the valley bottoms rather than the water.

Mountain populations often consist of socially and politically vulnerable minority groups. Difficult communications and hard living conditions have created distinct and relatively closed ways of life which have favoured the conservation of identity markers and cultural values whose preservation is extremely important not only for the communities themselves but for society as a whole. Nevertheless, these elements of social and cultural identity are as fragile as they are valuable. The breaking up of regional valley settlements usually results in a diaspora and in the destruction of the community as such, and therefore in the irreversible disappearance of those values. For this reason, economic compensations and resettlement in other areas (which are not even guaranteed in many cases) do not assure the continuing cohesion and survival of these communities.

In many cases, as we shall see below, the ecological impact of hydraulic policy on rivers located in headwater regions has had its most severe socio-economic consequences on riverbank communities downstream.

2.2. Environmental-resource Values Connected to Mountain Landscapes and Ecosystems

Mountain regions have historically been poor. Severe climates and rugged relief combined with transport difficulties have hindered both agricultural, economic and other development (e.g. in industry and commerce) while keeping populations low. For thousands of years, nature set limits to growth and the land's inhabitants respected and wisely managed these limits in a sustainable way. This permitted the conservation of ecosystems in their unspoiled state, while in other regions — such as grassland areas — human settlement was characterized by a harmonious and sustainable relationship with the natural environment.

With industrial and urban development, these lands were abandoned by migrants leaving for the cities. Mountain regions came to be considered inhospitable areas with little value to society as a whole. Nevertheless, the accelerated environmental degradation experienced in urban areas, and even in a large number of rural areas, has generated a growing appreciation for the role of mountain areas in conserving environmental quality and promoting health. In summary, the contradictions inherent in the unsustainability of our development model have led to the emergence of an appreciation for ecological and aesthetic values related to mountain landscapes in regions that until recently were marginalized and abused.

In many countries, mountain areas constitute a priceless repository of pristine natural heritage, as a result of which national parks, biosphere reserves and other entities set up to protect the integrity of this heritage from the encroachments of our destructive consumer society abound. A large number of these threats are connected to water management in high-elevation basins: the wholesale construction of large dams to regulate water flows; the proliferation of hydroelectric mini-plants; and the construction of ski resorts using artificial snow are examples of these.

In this general context of relatively well preserved natural environments, the best-preserved aquatic ecosystems tend to be rivers, lakes and wetlands in the headwaters of catchment basins. The obvious dependence of middle- and lower-elevation river sections on high-elevation river flows means that the conservation of headwater regions has ramifications that extend far beyond the importance of conserving the ecosystems they host.

When we discuss the importance of conserving headwaters, we are referring not only to water quality and to aquatic ecosystems in their unspoiled state, but also to resource values connected to the conservation of regions, forests and vegetative cover, taking into account their interconnectedness with rivers, lagoons and aquifers. The extent to which these regions are conserved will influence erosion intensity, runoff and the rate of percolation feeding aquifers in their role as natural river regulators.

Lastly, it is necessary to underscore that ecological dependence is not unidirectional, from the headwaters down to the middle- and lower-elevation river courses; in fact, the way in which these lower courses are managed also has an important impact on higher regions, especially with regard to the conservation of migratory fish species such as salmon and eel.

2.3. The Hydroelectric Potentiality of Water at High Elevations

Above and beyond their ecosystem and environmental functions, river flows in fluvial headwater regions store high levels of potential hydroelectric energy. This high level of energy results, first of all, from the potential energy these waters have with respect to sea level, and, in addition, from their low contamination levels and low concentrations of dissolved salts. We will analyze the ramifications of these characteristics in the next section. This potential energy can be exploited as hydroelectric energy offering a source of renewable energy with high opportunity value. It can be characterized as high-quality energy for three fundamental reasons:

- greenhouse gases are not produced;
- it is renewable; and
- it is a variable source whose production is concentrated during peak hours.

Nevertheless, although this energy source is characterized as clean, the infrastructures required to produce it create an environmental impact that is not generally seen in a positive light. In many cases, at issue are large reservoirs whose societal and environmental impacts are well known; in other cases, what is at issue are the mini-plants that frequently result in the drying-up of long stretches of riverbed in mountainous regions, or at least in their ecological degradation and the loss of many uses such as fishing, bathing, whitewater rafting, etc.

2.4. Resource Values and Uses Connected to High Water Quality in Mountainous Regions

In the upper reaches of fluvial basins, water quality tends to be high because it has not yet received contaminating spills or saline drainage. In arid regions such as the Mediterranean, the saline content of river flows is particularly important. Declines in water quality related to salinity, resulting from both human intervention and natural processes such as salt leaching into the drainage from areas of brackish water, negatively affect the use value of this resource. This progressive decline in river-flow quality from its essentially pure state in headwater regions down to its final mixing with sea water in estuaries involves a measurable decrease in energy in all cases due to the energy required to restore the water to its pristine state using reverse osmosis.

The productivity problems engendered by saltiness in irrigation waters are well-known; in addition, the range of possible uses presented by such water is drastically reduced. Without a doubt, the extent to which water quality is an important resource value reaches its maximum expression in the willingness of consumers to pay for drinking water. The high market value attached to mineral water reflects the increasing importance of health as a value. As is well-known, this high-quality water generally originates in fluvial headwater areas. The tendency of multinationals to appropriate springs is indicative of a business approach that revolves around marketing this water.

2.5. The Opportunity Value of Orographic Potential for Setting up Control Works

The rugged relief found in mountainous regions has constituted a value that has played an extremely important role in hydraulic policy as practised over the course of the 20th century. As one would expect, it is in these territories that one finds the reservoir basins and closed drainage basins that permit the highest ratio of dam regulatory capacity to unit price invested. Along with these factors, the fluvial regime itself and the intended uses of the river flows constitute key determinants of control efficiency. In sum, what is involved is an opportunity value derived from the minimization of unit regulatory costs.

As one would expect, the construction of more than 50,000 large dams over the course of the 20th century in the most suitable closed drainage basins has resulted in the imposition of the law of diminishing marginal returns as marginal costs increase. The study on the evolution of the control efficiency of dams in the United States published in 1984 by the United States Geological Survey is highly significant. After undertaking a detailed study of the 100 largest dams in the United States constructed between 1920 and 1960, the report concluded that the volume of flow regulated as a function of the physical capacity of these reservoirs decreased by a factor of 35.

In this sense, the opportunity value of alpine regions as areas favourable for these types of regulation projects has been decreasing as new-project costs have increased and control efficiency continues to decrease.

2.6. Recreational and Emotional Values Frequently Connected to the Development of Tourist Amenities

The increasing appreciation of environmental and scenic values in mountainous regions centres particularly on rivers that have become key areas for the construction of tourist infrastructure. Activities such as canoeing, whitewater rafting, canyoning and sport fishing have changed realities and perspectives for many mountainous regions. In many cases, beyond these types of activities, rivers are coming to define regional identity while becoming key tourist attractions.

Often, these values are intangible and difficult to measure in monetary terms in a consistent way. Nevertheless, in many cases, the activities and services promoted around mountain rivers permit the painting of an accurate portrait of economic activity through an analysis of the profits generated by these activities, or through a calculation of the consumer surplus achieved using methods such as "cost of trip". The scientific-technical articles quantifying these environmental intangibles related to recreational and emotional values published over the last two decades reflect an increasing appreciation of their importance as society has become more aware of these values.

In many cases involving large dams, the monetary quantification of these types of impacts has resulted in calculations of environmental costs similar to the size of the investment budgeted for the construction of the dam itself (Arrojo et al. 2000).

2.7. The Resource Value of Irrigation Downstream

Especially in arid and semi-arid basins, irrigation possibilities have encouraged economic and social development. As was explained in the beginning, since the start of the 20th century, the technical capacity to control massive river flows by means of large dams (McCully 2004) has made possible the cultivation of approximately 300 million ha, according to the FAO. Another 130 million ha are irrigated using subterranean water (Llamas et al. 2005). Irrigation in these regions and climates not only doubles crop production but also guarantees harvests (freeing them from the effects of variations in rainfall) and permits crop diversification.

However, the introduction of new irrigation works, which until a few decades ago was considered an engine for development, is now being questioned for a variety of reasons:

- As marginal costs increase, the law of diminishing marginal returns calls the profitability of these types of projects into question.
- The steep decline in the profitability of agriculture, accelerated by processes of market liberalization, has caused the negative inflationary differential in the sector to surpass the growth in productivity (Arrojo 1998).
- The sustainability crisis affecting aquatic ecosystems, and its grave social and environmental consequences, as a result of the construction of large dams in mountainous regions.
- The degradation and salinization of the soil in irrigable regions, which now affects 20% of the world's irrigable land area according to calculations published by the World Commission on Dams in its final report (WCD 2000).
- In addition, the "up for bid" models characterized by massive public subsidies, on which has depended the development of large-scale irrigation, has promoted inefficient use, with the result that these projects have lost economic rationality.
- Lastly, in each case it is necessary to carefully analyze the societal values at play, beyond the increases in productivity associated with irrigation. In many cases, these transformations have involved land redistribution, thus generating profound changes in social and economic structures. In other cases, under the guise of the common good, the interests of rich and influential corporate sectors have been favoured. This is illustrated in the case of the Dez Dam (McCully 2004), the largest dam built in Iran during the '60s. The project aimed to irrigate 80,000 ha and benefit thousands of small-scale growers. However, the Shah decided that foreign agriculture and livestock companies (Chase Manhattan Bank, Bank of America, Shell, John Deere & Co., Transworld Agricultural Development, etc.) would achieve more efficient production for export. Seventeen thousand peasants were driven from their lands.

2.8. Values, Tasks and Social-environmental Services at Stake Downstream

Due to the reign of hydraulic structuralism throughout the 20th century, there has been a tendency to disregard the social and environmental impact produced downstream by the large hydraulic infrastructures. Rivers have been viewed as simple H_2O canals instead of as living ecosystems. What was overlooked from this perspective is that rivers not only direct vast quantities of water draining out of basins, but also direct large solid and nutrient flows. In addition, there has been a tendency to ignore the importance of the biodiversity harboured by riparian environments. And lastly, there has been a tendency to underestimate the grave socio-economic impacts produced downstream by these hydraulic works, especially on poor communities whose way of life is strongly connected to ecosystems and fluvial cycles.

The direct and indirect impacts of the unsustainable exploitation of rivers, lakes and wetlands on food-producing regions worldwide have been and continue to be serious, especially with regard to the natural productivity of protein-rich foods. It should be noted that fish is one of the principal sources of protein in the majority of underdeveloped or developing countries. It is often said that fish is the poor man's protein. In Africa, this source accounts for more than 20% of animal proteins, on average; in Asia, it accounts for almost 30% (ICLARM 1995). For many poor, inland communities around the world lacking access to coastal fisheries, the availability of freshwater fisheries is a key to their survival.

Throughout the 20th century, the construction of large dams has been one of the key factors contributing to the drastic reduction of river fishing grounds, with the resultant extinction of many species of fish and molluscs essential to the diets of riverbank communities. Some well-documented cases worth mentioning, among many others, are the Urra River in Columbia (WCD 2000); the Singkarak project in Sumatra; Lingjintan in China; Theun Hiboun in Laos; and Pak Mun in Thailand (Dave Hubbel 1994). In all these cases, large reservoirs created serious obstacles to nutritional subsistence for thousands of persons in poor riverbank communities.

But it is not only river fisheries which have been seriously affected; coastal fisheries, whose dependence on rivers has been definitively established, have suffered as well. The case of the Aswan Dam on the Nile River is paradigmatic. A year after the overflow weirs of the dam were closed, the sardine and anchovy harvest fell by over 90% in the eastern Mediterranean. Today it is known that theses species, amongst others, spawn in the estuaries of large rivers, taking advantage of the high concentrations of continental nutrients that result from the increased springtime river flows. These nutrients fertilize marine life — especially in enclosed or semi-enclosed seas, which are generally poor in plankton. A similar breakdown occurred in the Sea of Cortes (in Baja California) as a result of the diversion of the Colorado River to irrigate the Imperial Valley and to buttress urban development in the Los Angeles–San Diego corridor in the United States (Postel 1996).

We find another example of this in Southeast Asia, where Thailand's accelerated industrial growth is motivating the construction of a system of large dams and interbasin diversions from the upper Mekong in order to provide cheap electricity and water resources to the new giant, Indochina. This group of megaprojects threatens to cause serious ecological breakdowns, with disastrous impacts on riverbank communities. It is estimated that 52 million people depend on the Mekong, from which they derive both agricultural products and fish for their nutritional sustenance (Moreth 1995).

Serious modifications in the natural cycle of many of the world's great rivers due to the construction of headwater dams have eliminated traditional forms of agricultural production tied to fluvial cycles that raised water levels at low elevations. This has seriously compromised basic food production for thousands of people. Such impacts have been particularly significant in African countries such as Niger, Chad, Nigeria, Sudan, Senegal and Mali, among others. In northern Nigeria, the construction of the Bakalori Dam over the Sokoto River led to the disappearance of 53% of traditional crops linked to the cycles of river flooding in the plains of the middle and lower basins; destroyed the grazing lands that served as a base for livestock in the zone; and seriously affected the aquifers, depleting vital water reserves during periods of drought (Adams 1992). As indicated in reports published by the World Commission on Dams, similar cases have occurred along the Senegal River, as a result of which nearly 800,000 people experienced difficulty with traditional crop cultivation; near the Sobradinho Reservoir in Brazil, with negative consequences for 11,000 peasant families; and near the Tarbela and Kotri dams in Pakistan, with the resultant loss of traditional grazing lands along nearby floodplains (WCD 2000).

As shown in a large number of studies (Abramovitz 1998), traditional systems of food production in which fishing, livestock, forestry and agriculture are wisely combined not only are more sustainable but also produce more food than systems dependent on large dams in high basins.

In spite of its seriousness, much of the socio-economic impact does not emerge in official statistics. The reason for this is that the harvests derived from these food sources, wisely managed in a sustainable relationship between rural communities and their surroundings, traditionally go to local markets and self-sustenance. From the point of view of market rationality, it is usually claimed that such modes of production suffer from low levels of economic efficiency. Nevertheless, if the social and environmental values at stake are taken into account and if we adopt objectives that include sustainability and fairness, that so-called inefficiency becomes a high level of ecological-social efficiency. It is necessary, in short, to discern objectives when it comes time to define parameters of efficiency. When the objective is to resolve social and environmental problems rather than to produce more market value, it is necessary to define indicators of ecological-social efficiency. In this sense, the preservation of the social fabric and of traditional forms of production in the rural environment while, in general, offering these communities opportunities that permit them to evolve without losing their identity and cohesion, tends to be highly efficient (Arrojo 2005).

2.9. Ethical Values Promoting Inter-regional Equity in Relation to Socio-economic Development

As previously indicated, mountain regions have been considered poor areas with scarce potential for economic development and demographic growth. From this perspective, the decision has often been made to sacrifice entire valleys, even when still inhabited, in order to exploit these regions as simple storage areas for regulating volumes of water destined to promote the development of regions and cities downstream.

Hydroelectric production has rarely been used to generate industrial development in mountain regions themselves. The establishment of unified tariff models has even prevented lower energy-transport costs from leading to lower costs in the vicinity of turbine locations. As a result, primacy has been given to the concentration of industrial development in remote urban areas.

With regard to agrarian development, it is evident that rugged relief offers few opportunities whereas the plains located in middle- and low-elevation basins have traditionally offered favourable areas for implementing large-scale irrigation works.

Lastly, the need for vast quantities of water for urban-industrial uses has turned mountainous regions into high-quality-water storage areas for this urban development.

For decades, all these demands have guided water-management strategy and planning models favouring large regional imbalances. Mountainous regions have ended up being sacrificed for the benefit of others in the name of the omnipresent “general interest”.

Currently, as we have been putting forth, these management models and approaches have entered into crisis, not only for ethical reasons related to inter-regional equity, but also because the social, environmental and economic values we are currently beginning to apply in mountainous regions and in river basins require new models of sustainable management and of participative government quite different from those that were the norm over the major part of the 20th century.

3. The Need for a New Ethical Approach

It is evident that the values coming into play are quite diverse. Because of this, when the value of water is spoken of in generic terms, we run the risk of opening an obscure and confusing debate in which, assuredly, fertile ground for demagoguery will be created. Although water is a well-defined chemical compound — H_2O — what is important is to distinguish its diverse roles, clarifying the values that come into play and the diverse ethical categories that such values give rise to (Arrojo 2005).

3.1. Functions, Values and Rights Involved

If we think about other natural renewable resources, such as wood, we do not encounter as many problems. Beyond clarifying under what circumstances we should extract it from nature so as not to destroy the health of the forest, the management of the lumber obtained does not cause controversy. Once we have determined the restrictions imposed by the need to manage a forest in a sustainable way, it seems reasonable to manage the lumber extracted in accordance with the exigencies of the market. The key to this relative simplicity lies in the fact that the value of the wood is consistently exchangeable for money, whether it is used to build ships or to manufacture chairs, table or closets.

In the case of water, the roles and values involved are more complex and affect ethical categories at a different level. The European Declaration for a New Water Culture, signed in Madrid by 100 scientists from different European Union countries at the beginning of 2005, proposes the establishment of four ethical categories (FNCA 2005):

- **Water-life:** Water for life, related to basic survival functions of both human beings and animals in their natural habitat, which should be recognized and prioritized in such a way that ecosystem sustainability is guaranteed, with universal access to adequate amounts of quality water constituting a right.
- **Water-citizenry:** Water for the common good, as an instrument for safeguarding health and social cohesion — related, for example, to water supply and sanitation services in connection with the social rights of citizens.
- **Water-business:** Water for economic growth, for legitimate economic activities connected to productive work, in connection with the right of every individual to improve his or her standard of living. This water use is to be granted a third level of priority, given that it would be unethical to allow such uses to interfere with water rights and uses pertaining to the previous categories.
- **Water-crime:** Water for illegitimate business activity, with consequent destructive withdrawal practices, toxic spills and other socially unacceptable practices; such uses should be avoided, and prosecuted to the full extent of the law.

If we reflect on the diverse set of values and rights at stake which stem from each of these categories, we will understand that they correspond to different spheres from an ethical point of view.

3.2. Deficiencies and Errors Associated with the Current Neo-liberal Approach

In our opinion, Daly is right when he argues: "Some claim that human-created capital and natural-resource capital can be exchanged, and that, consequently, the idea of a limiting factor (for production) is not applicable. Nevertheless, I think it is quite obvious that human-produced capital and natural capital are essentially complementary and only marginally exchangeable."

Using less-technical language, the Spanish saying that "only fools confuse value and price" encapsulates the same judgement using different words. In summary, unlike wood, water engenders uses and values which are not manageable by way of simple economic exchange relations because these uses and values cannot be consistently replaced by capital goods. In this sense, it is essential to differentiate these uses and to distinguish the diverse ethical categories with respect to value and right which are connected to them, in order to set priorities and establish suitable management criteria.

Nevertheless, based on the neo-liberal principles that substantiate the reigning model of globalization, different water uses tend to be seen as economic utilities that can be replaced by capital goods and, therefore, expressed in monetary values to be managed within the context of market dynamics. Despite the fact that this is the reasoning applied in general by the World Bank (BM) and the World Trade Organization (OMC), their water policies are, in fact, filled with serious contradictions. On the one hand, in the name of economic rationality, developing countries are subjected to intense pressure to privatize their water-supply and -sanitation services, thus giving rise to serious social and political conflict. On the other hand, the World Bank nevertheless maintains the basic components and scripts associated with its old strategies of "up for bid" in the general management of water's diverse productive uses (related to agriculture, industry and energy). Without a doubt, vested interests behind hydraulic megaprojects around the world are still very influential, both at the level of large multinational construction and hydroelectric companies and at the level of domestic political and business networks. For this reason, the World Bank itself, despite the contradictions entailed, is still willing to finance these types of "up for bid" strategies based on the subsidized promotion of large-scale hydraulic projects, thus flying in the face of economic rationality.

3.3. The Need for a New Water Culture Based on New Ethical Principles

The surmounting of the "domination of nature" paradigm by way of the "sustainability" paradigm will require profound cultural changes. It requires that we accept the challenge of managing the biosphere based on ethical principles of equity for the sake of posterity. This means recovering the holistic perspective embodied in the Aristotelian concept of "economy" and going beyond the narrow mercantile approaches that dominate the reigning model of globalization.

Above all, however, it means recognizing the diversity of values and the different ethical levels which come into play. Within the range of values identified, those connected to fundamental ethical principles — such as the right of a community to its traditional living areas, or a society's right to conserve the ecological integrity of its aquatic ecosystems — should be given priority.

In fact, the third generation of human rights currently being debated includes communities' rights to peace and to healthy ecosystems. The World Commission on Dams, in its final report, acknowledged that many of the community evictions carried out to construct large dams have amounted to transgressions of human rights.

Beyond respecting these basic ethical principles, another goal is to recover emotional and identificative values connected to the landscape, and to recover environmental services, along with values related to enjoyment and quality of life which are offered to us by rivers, lakes and wetlands when they are in an ecologically healthy state.

4. New Ecosystemic Management Models and Their Repercussions in Fluvial Headwater Areas

The most advanced water laws, such as the EU Water Framework Directive, incorporate the challenge of implementing new models of ecosystem management, thus advancing beyond traditional approaches to water management in which water is seen as simply a resource. Going back to the comparison with wood, in the same way that we have progressed from the simple exploitation of forests to new policies of sustainable forest management, we can extend this sustainable-management approach to rivers, lakes and wetlands as live ecosystems.

The restoration and conservation of the ecological health of our river courses becomes a paramount objective. This involves the imposition of severe restrictions on traditional hydraulic policies, especially in mountainous regions with regard to the conservation of fluvial biodiversity and the maintenance of consistent river flow cycles.

In addition, an ethical commitment to respecting mountain peoples' right to live in their valleys correlates strongly with notions of democratic government. This commitment is buttressed by our moral obligation to redress a long history of injustices and imbalances suffered by mountain regions as a result of our historical hydraulic policies.

Beyond the restrictions imposed by the need to respect the aforementioned ethical principles, the old strategy of "up for bid" associated with enormous public subsidies is now tending to give way to strategies that involve management of the demand in keeping with the New Water Culture that is so necessary at this time. Without a doubt, this is another argument that renders the construction of large-scale hydraulic infrastructures less important. In fact, the majority of new projects only demonstrate viability when they count on enormous public subsidies, because a cost-benefit analysis always brings up a negative balance sheet (Arrojo 2004).

In conclusion, the aforementioned arguments in favour of sustainability, economic rationality and democratic governability tend to close a loop and open another one based on new objectives and strategies.

Mountainous regions have come to be perceived as natural areas of great value in which conservation policy plays a growing economic role in the form of a developing tertiary sector. Fluvial-headwater regions have been acknowledged as highly valuable parts of our natural heritage, with the result that they are now protected by specific laws such as the American *Wild and Scenic Rivers Act*.

Even from a strictly economic point of view, rivers whose headwater basins are well conserved become much more valuable as rivers than as water, in the same way that a tourist beach is more valuable as a beach than as a sand quarry for construction.

There is increasing social pressure to limit mini-plant turbine rights while requiring the maintenance of minimum flow volumes along watercourses in order to guarantee not only riparian-habitat conservation but also the viability of other activities such as whitewater rafting which become more advantageous than hydroelectric production from both an economic and social standpoint.

Viewed from a perspective based on new management models, the scarce availability of water resources for economic uses should be seen as an unavoidable property of water to be managed rather than as a tragedy to be avoided by way of public subsidies and ecosystem degradation. In the water-business category, criteria with regard to economic rationality should be imposed based on the principles of full-cost recovery. The opportunity value of the resource should be included in the costs to be borne by the user.

Lastly, the value of water quality in headwater basins is increasing the value of their springs as strategic resources for drinking water. This is leading to processes of privatization which need to be carefully evaluated.

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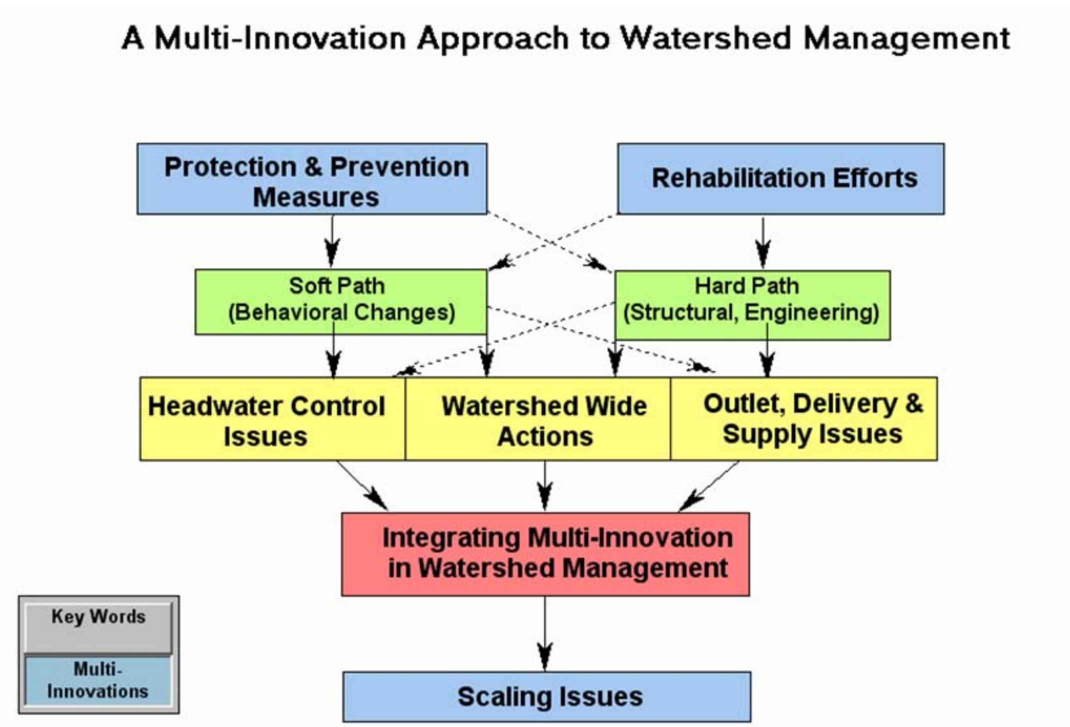
Helen Ingram, Session Chair:

Next we have a commentator, Hans Schreier, whom some of us met before. He's a professor at the Institute for Resources and the Environment at the University of British Columbia. He's a specialist in watershed management — particularly land, soil and water relationships and the interconnections between land use, deposition and water pollution. Some of us got to hear a wonderful presentation he made about that as his work in the western Rockies, but he has also worked in the Himalayas and the Andes. He's a very notable scientist, as Henry let us know. In reading his biography, I also was very impressed that he cares a lot about education and has a course over the Internet and that he believes that mountains are bellwethers for the future.

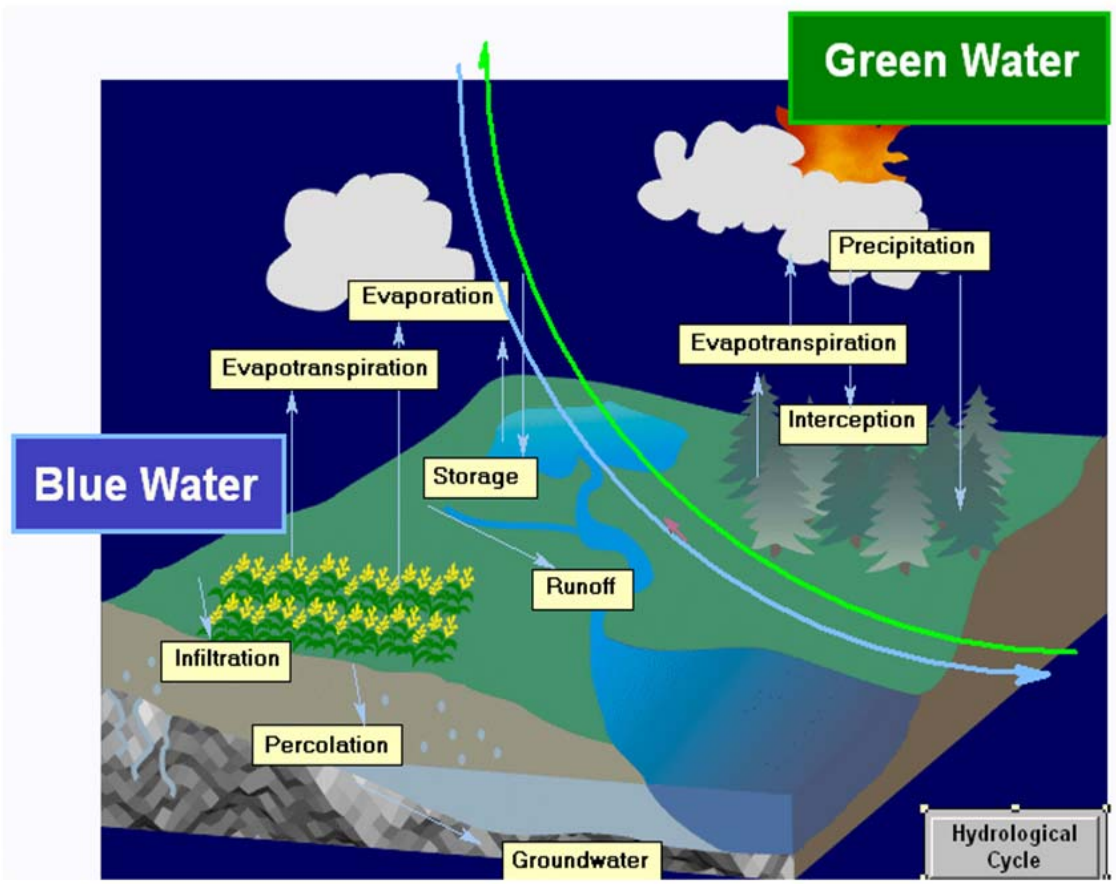
Hans Schreier, Session Discussant:

Thank you very much. I'm supposed to be provocative to stimulate discussion. The theme is: how to manage headwaters to maximize benefit for the lowland people, how to compensate the upstream people for the services provided, and how to allocate enough water for the environment. Those are the themes that were supposed to be discussed. The key words I got out of the presentations today are: green water versus blue water; the hard versus the soft approach; structural development versus equity; virtual water and the water footprint; payment for environmental services; and Green Water Credits. I'm trying to summarize this in one diagram — protecting and preventing measures, versus rehabilitation efforts. The rehabilitation efforts are mostly engineering: the hard approach, hard path. The other parts are mostly the soft approach: behavioural changes, management changes and land-use changes. And we need to work in the headwaters, we need to work watershed-wide and we still need to work on the end of the pipe. So we need an integrated approach, and we can't just simply work in the headwaters, but the headwaters are the key.

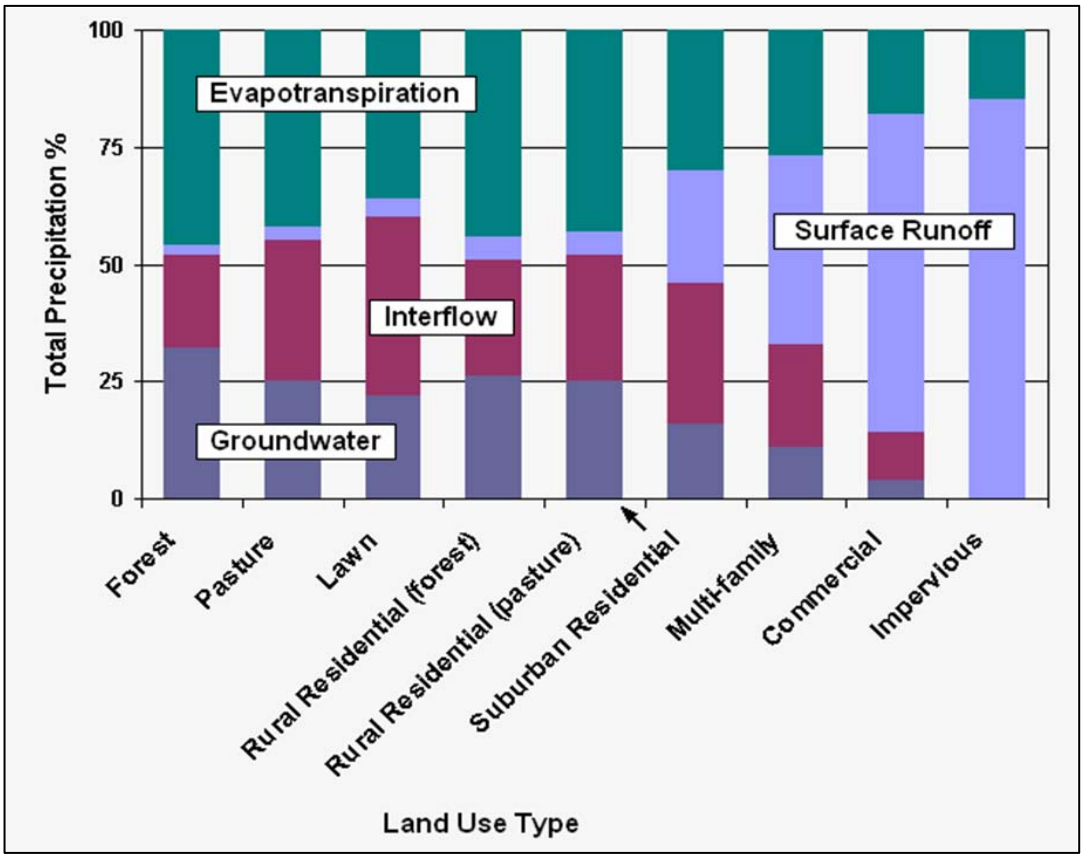


The problem we have is scaling; several presenters mentioned scaling. It's extraordinarily difficult to go from the headwaters downstream, because the processes are totally different. If you look at sediments, going to the Himalayas, the sediments from Mount Everest will take tens of thousands of years before they're in Bangladesh. They erode at the top, and at the bottom it's mostly bed resuspension. It's a totally different process and we can't extrapolate very easily.

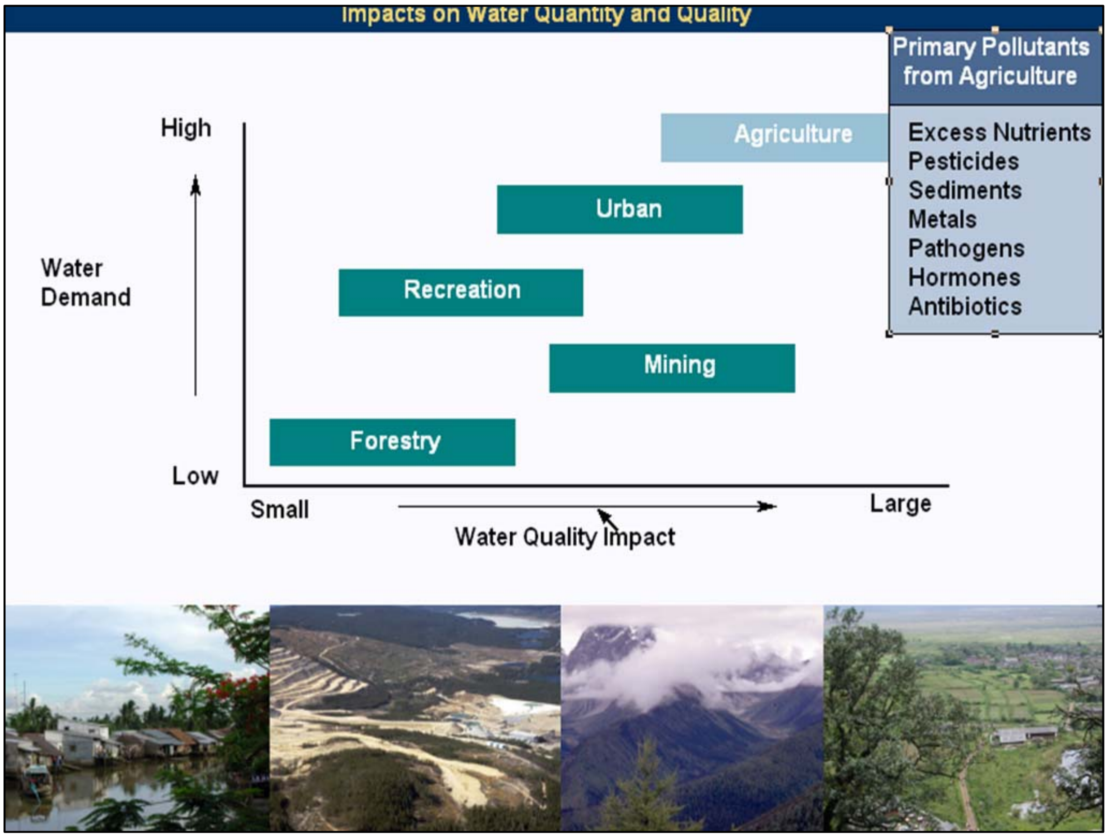
So let's go quickly to some of these different issues, such as the issue of green water versus blue water. Here is my picture of green water versus blue water. We have managed the blue water, but we haven't managed the green water; we do such crazy things as, in California, growing cotton and rice in the middle of the desert — the most inefficient way to use water.



Not only that, but when we change the land use, we change the hydrological cycle, big-time: On the left-hand side, you see what happens to the rainfall when it hits a forest in the headwaters. And as we move from the forest to a completely urbanized environment, you can see what happens to groundwater flow, surface runoff, interflow and evapotranspiration. Massive changes with land use. So this is a big topic for the headwaters, because if we change the land use, we change the hydrological cycle.



If we look at water demand and water quality, you can see that agriculture and urbanization are the biggest users and the biggest polluters. And so we need to focus on these two, and this is going to be the big challenge. So the main problem we're going to face is the water demand from agriculture versus the water demand from urbanization — and, for the first time, the water demand for environmental services for the ecology. And these are all in conflict right now. These are obviously the big issues we have to face, because in my view these are the global topics: massive urbanization, massive agriculture intensification. They need more water, and it's at the expense of the environment.

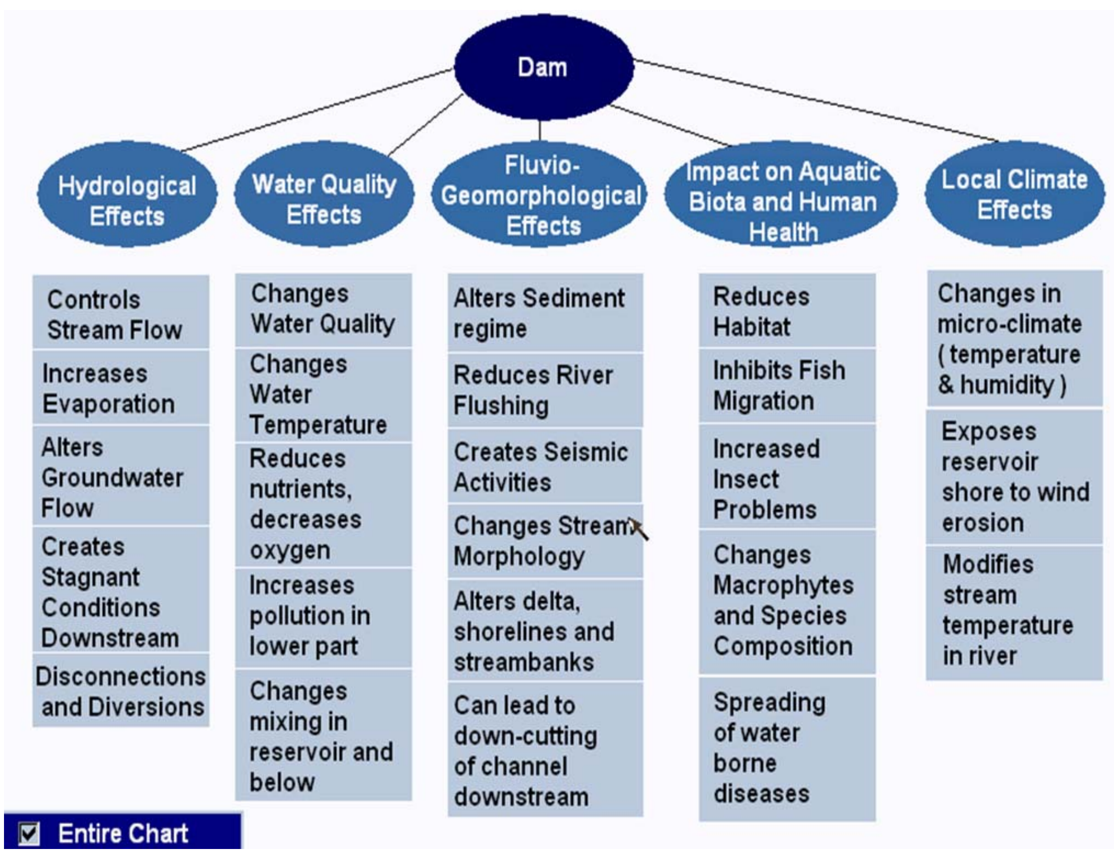


Before we go to the headwaters, this [the traditional approach] is what we have been doing, this is what we're good at. And I'm suggesting that we should take a 180-degree shift and do exactly the opposite. We've created all these impervious surfaces, we've compacted all the soils; well, we should do the opposite: we should minimize the impervious surfaces and we should reduce the compaction. We've minimized buffer zones around rivers; we should maximize buffer zones. We've drained all the wetlands; now we're creating wetlands because they're the best storage and the best filtering systems. We've dealt with piping of storm water; and now we say that we should detain the storm water. We treat the waste at the end of the pipe; and now we're saying: source control, then you don't have to treat it at the end. We've expanded water supply whenever we are short of water; and now we're talking about water-demand control — water-smart. We deal with single pollutants; we should start looking at interactions. We've used water for human activity; and now we have to start thinking about water for environmental services. Flood irrigation is the most common way; we should now be innovative in irrigation. We heard a good presentation on managing blue water; we should now manage the green water. And, finally: governments are hopeless at managing water; we should have public involvement.

Let's go to the headwaters, very quickly. Nice forested watershed, well managed: you get one of those incredible 500-mm storms in the Himalayas, and all hell breaks loose. And now, you're going to have a legacy from this which will take centuries to recover. And as you notice, most of this stuff happens in forests, which we always say is the best thing to do in headwaters. So some of these events are far too difficult to handle.

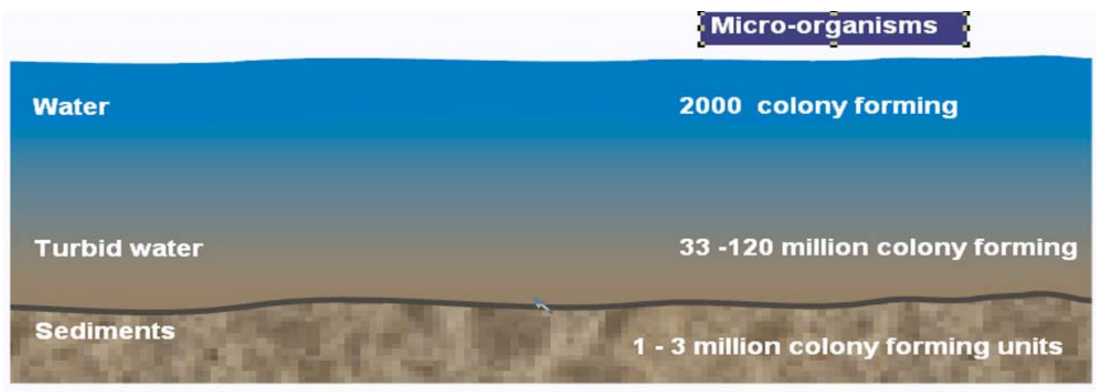
What we're asking is: Can we infiltrate enough water in the headwaters so that we can use it over longer terms and overcome the dry periods? This is not easy, because if you infiltrate too much, you create instability, and if you don't infiltrate enough, you're going to have runoff. My colleague calculated what happens when you compact the soil by 10% through management. A 10% increase in soil compaction is the equivalent of all the water flowing in streams in Canada over a one-year period. And so we need to really work on the infiltration balance so that we can use it, because everywhere I work, there is a dry season and there is a wet season.

We talked about structural things; we talked about dams. This is a summary of what dams do. They have all kinds of impacts, fairly complicated impacts; and in many parts of the world, we have dammed the dams. But with what we're doing now, we'll probably need more dams because of climate change. So when you build dams, this is what happens upstream, this is what happens downstream, and this is often what happens in the reservoirs during the dry season. So we've created all kinds of massive environmental problems, but we've never really addressed those; and as energy becomes more scarce and the demand for green energy increases, I suspect that we'll need to build some more. But we need to build them differently.



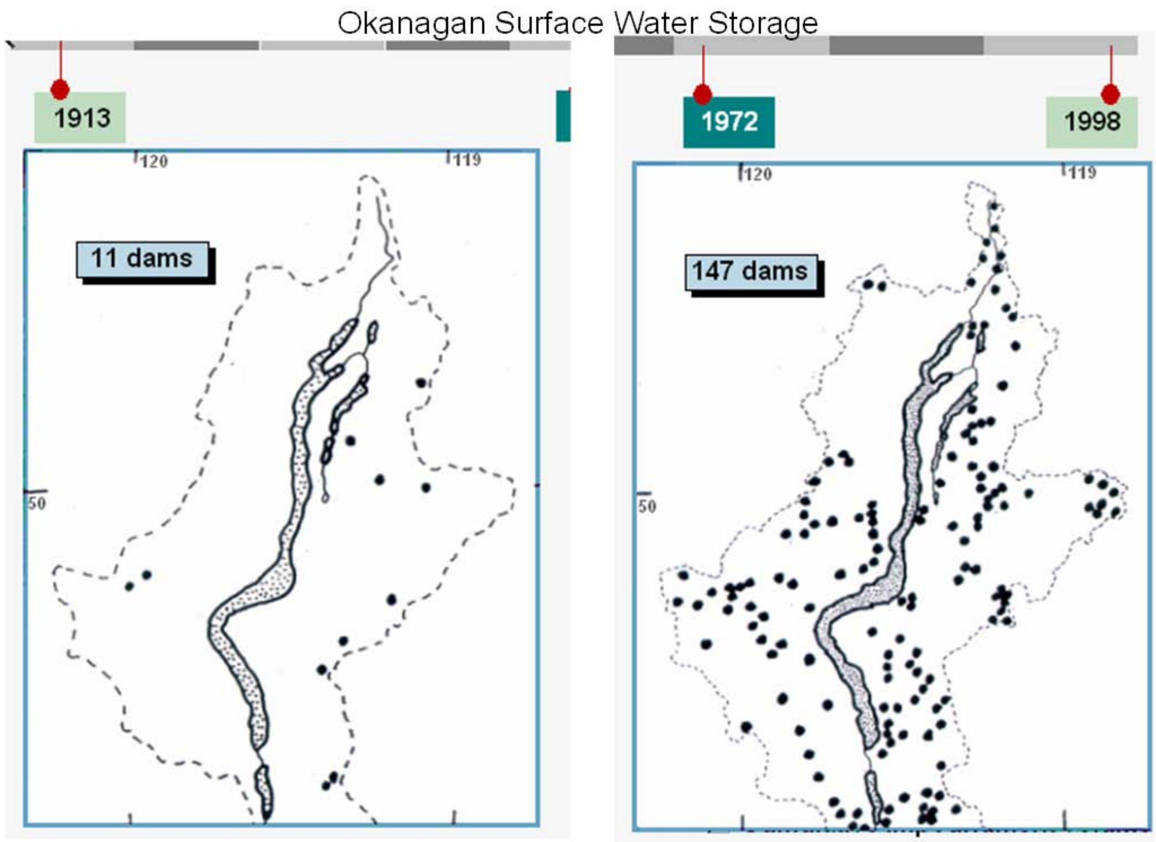
If we do very extensive logging — you can see the logging here and you can see the landslides. It doesn't matter where you go, whether it's here in Canada or in the Philippines or in other parts, land-use management is a really big issue. Logging roads are probably the key things that create impervious surfaces. British Columbia has about 250,000 km of paved highways, but we have *500,000* km of logging roads and mining roads. These are not well maintained; they create massive amounts of sediments, which is going to be a big problem. If you go into the headwaters and you do these kinds of things, you're going to have all kinds of problems.

Sediment is not only a nuisance, it is also a big health concern. When you look at where the pathogens like to hang around, you'll find very quickly that they don't particularly like to be in the water column and they don't like to be in the bed sediment; they like to be in the suspended part of the sediment. Why? Because the suspended part is made up of clay particles, they're negatively charged, they have holes, the bacteria can sit in there, and it doesn't matter how much chlorine you put in there, they're protected. So if you can stop the sediments, you can help yourself dramatically with regard to health impacts for drinking water.

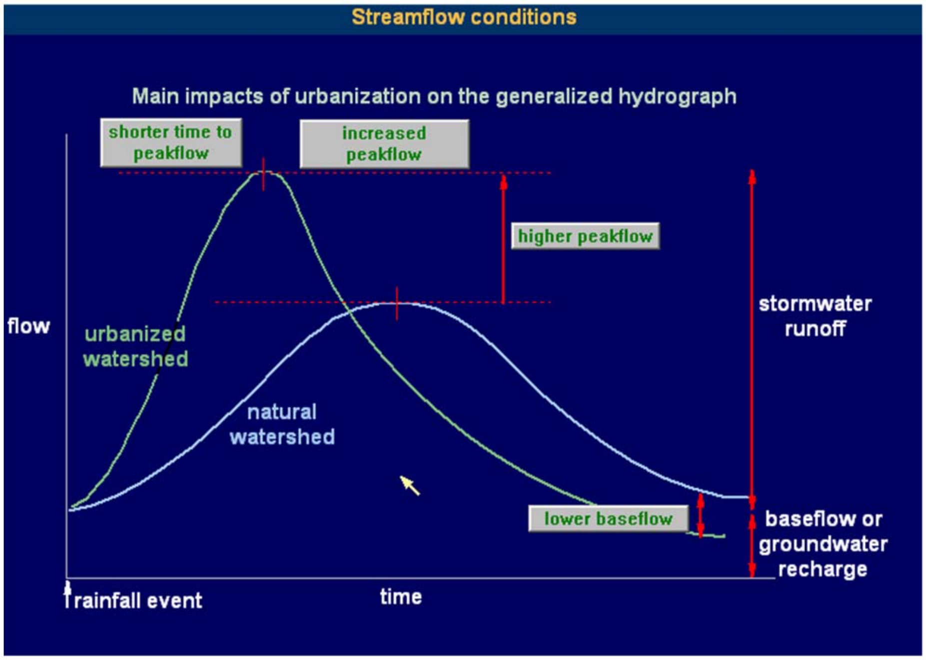


The importance of sedimentary particles in the water as a nursery for bacteria

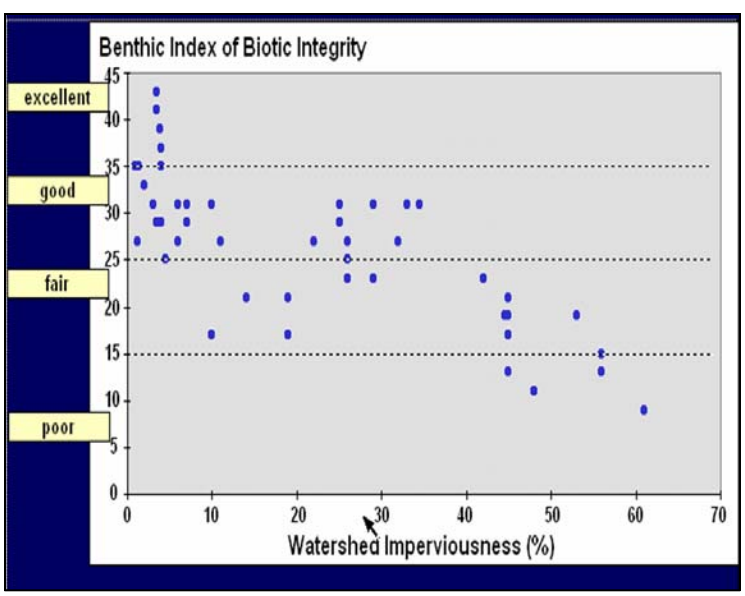
So very quickly, watershed-wide: Just to give you an idea of the kind of stuff we do here in Canada, this is the driest watershed in Canada, the Okanagan basin. In 1913, we had 11 dams. In 1956, we had 45; in 1972, we had 81; in 1998, we had 147. Well, every river is now pretty much fully allocated. And now, the light has come on: demand control. That's the only option we have left, because in a desert, groundwater recharge is minimal anyway. Just to show you how rapidly this thing has changed: we had a population increase over 30 years of 175%; we had a 600% increase in golf courses, the most water-consumptive activity, in the middle of a desert; we had an increase in ski resorts of 100%; we had wineries increase 580%; and we had grape-production and water-storage-system increases. So eventually comes the point where we have to rethink all this supply and start looking at demand.



This is what we typically do when we urbanize headwaters. This is over a 10-year period: we have gone from the forest to completely impervious surfaces. When you do that, you go from a forest response to the hydrograph like this, to a response like this: the peak flow comes faster, the amount of water becomes higher, and the base flow is usually lower.



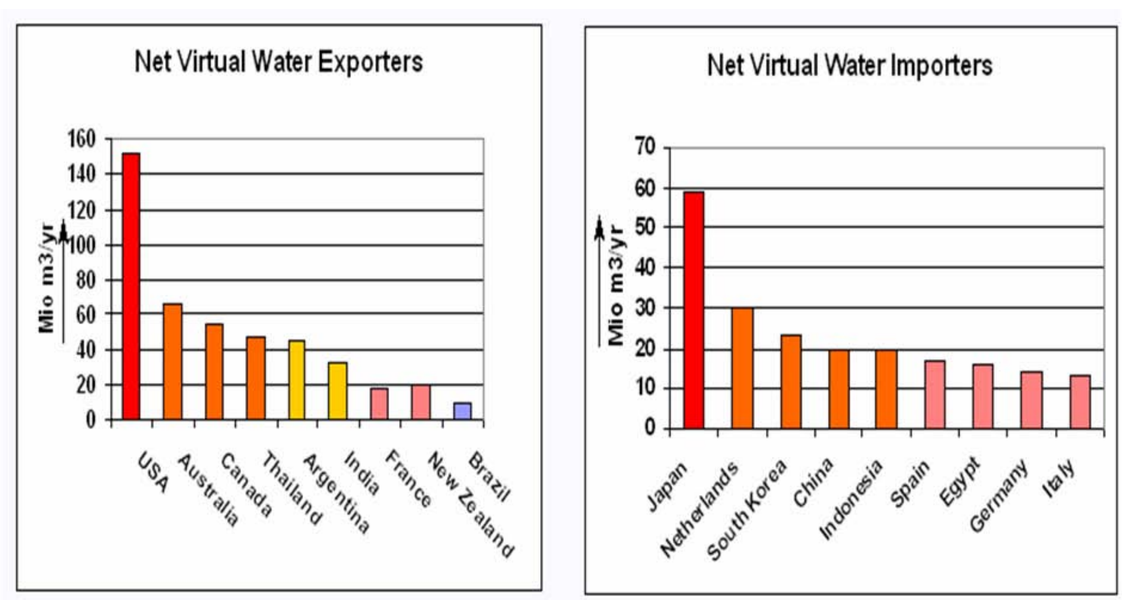
So you create a much more fluctuating water system; but beyond that, we now have found that you also lose biodiversity when you start compacting your soils and paving your upstream watersheds. You can see that there's quite a nice curvilinear relationship; I can show you another one here. It doesn't matter what we look at, if you look at aquatic biodiversity, if you go pretty much beyond 10 to 15% imperviousness, you're going to lose your biodiversity. So what we need to do is make sure that headwaters never go beyond about 10% imperviousness, in order to preserve biodiversity.



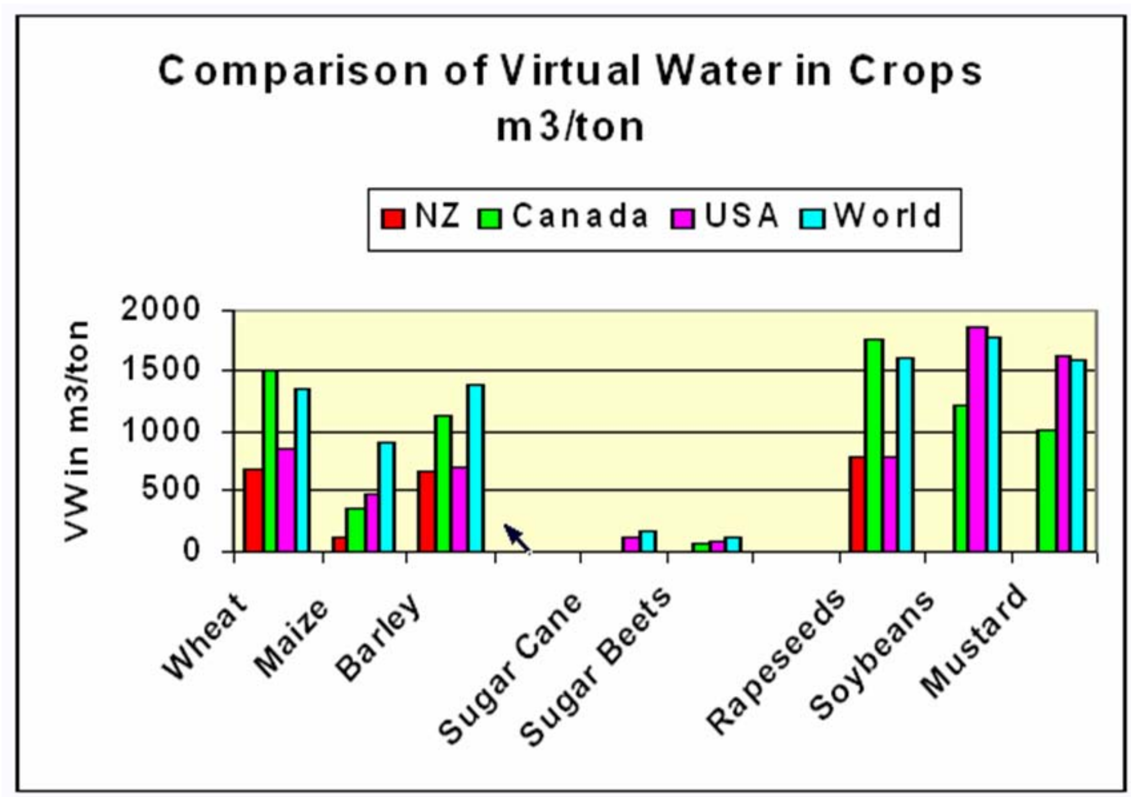
Everywhere I work, there is not enough water at one time of the season. So we have to go into water harvesting big-time, as we heard, and we now have all kinds of wonderful, very cheap systems where we can store the water during the monsoon for low-cost drip irrigation in the dry season. And we can even do roof water harvesting. All these systems are very cheap, they're relatively environmentally friendly, and they're perfectly suited for poor farmers to make an income.

Now I want to talk a little bit about virtual water, because that came up; this is very fascinating to me. Have you ever calculated how much water it takes to maintain your daily diet? Twenty-four-hour food consumption? If you look at the water needed to maintain your North American diet, it takes about 5000 litres per person per day. And if you're in the Third World, it's about half, which means that if the Third World aspires to reach our diet, we're going to need twice as much water to do that. So, we could calculate the actual water footprint, and we could calculate virtual water, and this might be a very interesting way to look at watersheds. Virtual water is simply the water needed to produce the product. So if it's a crop, it's the water needed to produce the crop; if it's a bottle of wine, there's some additional water in order to produce it.

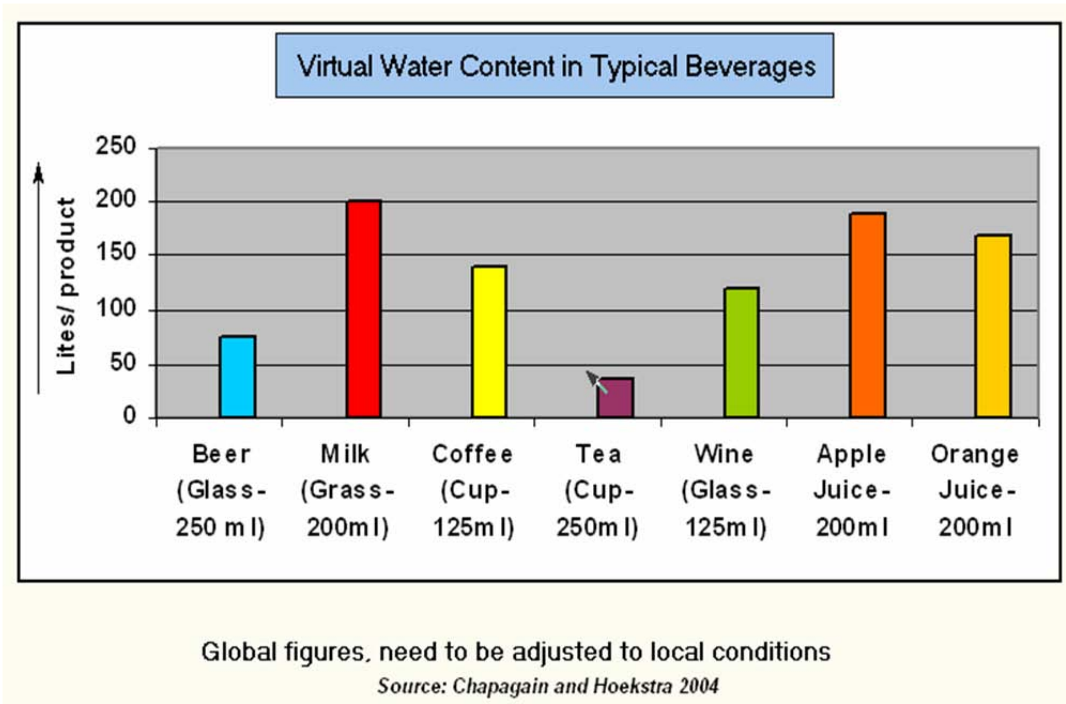
UNESCO has commissioned some interesting work on the virtual-water trade; you heard about coffee. Well, we can now look at who are the virtual-water exporters and who are the virtual-water importers. You can see that the U.S. is the biggest exporter — followed by Australia, Canada, Thailand, Argentina, India, France and New Zealand — and the greatest importers of virtual water are Japan, the Netherlands, South Korea, China, and so on. As the Chinese change their diet, they're going to need more virtual water; they're going to buy products that are more water-intensive. So we could do this in a very efficient way in headwaters, because it is nonsense to do this on a global, countrywide basis; on a countrywide basis, you use averages, and averages are like your head in a fridge, your feet in the oven, and the bellybutton is perfectly at temperature.



We can actually calculate who is more efficient at growing all this stuff. When you look at maize, you can see that the New Zealanders seem to be far more efficient than us; and if you look at rapeseed, the Canadians seem to be doing quite well. So we could look at every crop and do this on a watershed-wide basis. We did this for the driest watershed in Canada and the wettest watershed in Canada, and then we looked at the averages, and it's all over the map. So this might be an interesting concept to consider when we do water balances, because we can only do water balances on a watershed basis.



I put this up just to provoke you, because you're going to have coffee. A cup of coffee takes a 140 litres of water to produce. And then if you look at milk, and apple juice and orange juice and wine, they're very, very water-consumptive. So my suggestion to you is that you either become a teetotaller, or you start drinking beer. That's the only way you can be water-efficient.



We can do this kind of headwater management: This is probably the most intensively used landscape on Earth; we grow four crops per year on a continuous basis, and there are 13,000 fields that can get water delivered by indigenous systems in a three-week period when the monsoon rain starts, to grow crops. Now, this means that everybody has to collaborate, because if one part fails, the whole system will go. And so headwater control has to be extremely sensitive to these kinds of risks.

We talked about payment for environmental services, and we need examples for that. Well, we have a good example on compensation for hydroelectric power, where the downstream people pay for the upstream people, in the Columbia Basin — probably the only one good example. That's easy to calculate, because you can quantify hydro power. We have a situation such as that of New York City, where they pay the farmers to maintain the management in the headwaters for their drinking water. And everybody thought this was great; they invested a billion bucks to prevent all these things from happening. Well, the news release a few months ago said, Sorry, we'll have to build a treatment system because we get these intensive storms and in spite of our best management practices, we have too much sediment and it's creating a lot of health issues.

Water allocation for the environment: South Africa has some really interesting legislation — very progressive legislation — but they have huge problems implementing it, because it's not easy to calculate environmental services. And here is my challenge to Professor Hoff: The Green Water Credit sounds great, but how do you actually calculate a value for environmental conservation? The economists have all kinds of wonderful ways of doing that, but let me assure you that this is not very easy.

So, let me jump to conclusions, because I've got about two minutes. We need completely new leadership in water governance; we have archaic legal systems; we lack monitoring; we have crisis-management attitudes; we lack capacity to enforce; we lack priority; and we have little willingness to initiate new innovations. We need incentives; we need pricing, as we heard; we need community involvement; and we need stewardship-support programs.

So here is what, I suppose, you could think about in your discussion: Governments need to change the way they manage the structure of all the management, and they need a much more collaborative approach. Watershed-wide management is critical, and there is a need to integrate activities between upland and lowland. The water focus needs to shift from expanding supply, to demand; so we need to move from the hard to the soft path. We need to learn adaptive management because of climate change; we have limited response capabilities, and no single option will work. We need new ways to address the water for environmental services; the focus should be on payment for environment services; virtual water; and water footprint. And we need a massive public-education program to bring science into the mainstream of public debate. And now that I've offended you, I should go into hiding; I leave you with that.

Conclusions

1. Governments need to change the management structure of water We need a much more collaborative approach.
2. Watershed wide management or IWRM is critical and there is a need to integrate activities (Upstream-Downstream)
3. The water focus needs to shift from expanding Supplies to reducing Demands (this means changing social behaviour) Shifting from the Hard to the Soft Path approach
4. We need to learn adaptive management to deal with increased variability and uncertainty from Climate Change
5. We will have limited response capabilities, hence no single option will work effectively (Multi-Innovation Approach)
6. We need new ways of addressing water for environmental services (The focus need to be on PES, Virtual water and water footprint)
7. We need a massive public education program to bring science into the mainstream of the public debate.

Helen Ingram, Session Chair:

All right, I'd like to see some name tags turned on the side. Might I suggest that in what you say, you not address a single member of the panel but instead introduce a broader topic that will allow some discussion.

Bob Sandford:

I would like to ask Holger this question, if I could, please. Can you tell us what, in your opinion, are the public-policy steps that need to be followed in order to institute a program that makes payments for environmental services, including the provision of hydrological environmental services to downstream users?

Holger Hoff:

Well, as I indicated, as a project, this is just in its beginnings, so I cannot talk from experience on this. We have just started directing with our partners in the Tana basin in Kenya, and what we find is that there is limited willingness to go these ways. So our first step is to try and show the underlying mechanisms from the hydrological side and then also in terms of the interactions between hydrology and vegetation which make these upstream-downstream links. First explain why there is an upstream-downstream link, and then I think we have to be somewhat pragmatic — not to try and really calculate the exact cost of a certain intervention or the exact benefit, but to be more pragmatic and just try to find out what it takes to make people change their behaviour upstream. I don't think I can be much more specific in that, because we haven't gone through this full exercise yet. I expect major difficulties along the way in terms of acceptance and in terms of translation into policies, but we are not there yet so I cannot respond to that in more detail.

Helen Ingram, Session Chair:

I can't resist adding that it seems to me that Professor Arrojo presented a set of criteria that related to equity and fairness and political acceptability, and it would be very interesting to take your proposal and to run it along that as an access.

John Pigram:

I am depressed. I come halfway around the world to hear all these sad things that we're doing to water. There hasn't been one positive observation in the last two hours. Surely to God, we're not doing it all wrong. The last speaker put up a slide in which he spoke about dams, and every single aspect of the dams was negative. Why on earth do we build dams? We build them for economic purposes or for flood protection or for some other good, human-orientated use. If we can combine those good, sound, solid, positive purposes with preserving ecological aspects and with paying for it in environmental services, good and well, and we are doing that. We are doing that in all sorts of ways. We're certainly doing it in Australia, and I don't say that we're paragons of virtue, but if we are doing it there, we must be well ahead of the rest of the world. The rest of the world seems to have gone to hell, and I don't think it has. I think we should be positive about this. Don't look at the dark side all the time.

Prachoom Chomchai:

I simply want to add a footnote to excellent papers and comments, from the perspective of the Mekong Basin. The uplands in the Mekong Basin, in Tibet and China, contribute only twenty per cent of the waters of the whole Mekong. The rest of the upland areas are in the lower basin, which means that the snowmelt in Tibet is very small compared to what you get from the lowlands in the lower basin. And in the lower basin, because you have deforestation and sandy soil, you have a water tank there that leaks all the time. Thank you.

Jay Lund:

I liked this session very much. It raises the fundamental questions of why we're doing things, but I'd like to add another question to the list, which is: How? We have a lot of very good and noble ideas that have been expressed and that we often express at these kind of meetings, but how do you integrate the achievement of these good and noble virtues into very real local, regional, national, political and economic systems that often involve the private sector as well? Because, really, water is just a small part of our overall social and economic activity which we have to fit in within these larger institutions. I am very pleased to see the discussion on the Water Framework Directive, because I think this is an innovative approach to the subject, but I'd be very pleased to hear what the panellists have to say on this. How do you do this?

Helen Ingram, Session Chair:

Pedro, do you have a brief response?

Pedro Arrojo Agudo:

Yes. First of all, in 15 minutes, one cannot cover everything, and there are many obvious things on which we agree. Dams are useful for a lot of things, and we cannot live without the dams we have and perhaps other ones. But it's just that there are all the values we must consider now and that change the choice for the future.

Secondly, with respect to what to do. I react at the same time with an example about the comments we had on climate change and perhaps that meaning we need more dams. And I used to say: Drop risk management. The first kind of measure I think we need is improving the status of ecosystems — mainly wetlands and aquifers because of their big inertia — and this means that preserving resilience is one quite important thing: managing in a prudent and clever way the natural inertia of ecosystems when they are well conserved. Secondly, changing annual regulation in the way of managing the reserves we have — natural and artificial, and dams. Instead of annual, we must induce inter- or pluri-annual strategies. We must introduce water banks for drought management, because above all, scarcity is not so much a problem for economic uses, it is a problem for human rights. So water banks could be a good idea, and this was a good idea in California. And finally, why not design and implement appropriate financial strategies. When we have a long drought period, it is not possible to gather enough water, so gather money, and for economic uses that are the majorities, we must employ economic strategies and financial strategies.

The Right Honourable Herb Gray:

I have a question that also relates to the EPCOR presentation this morning. A lot of the comments here are built on the idea that the users of water, especially downstream, will pay in money for the use of water. And my question specifically is: How do you equate that with the fact that many people, including in the North American countries and the better-off countries of Latin America, are poor by those countries' own standards or by international standards, and where will they get the money?

Helen Ingram, Session Chair:

Does somebody have a reaction to that in the audience? Yes, go ahead.

Unidentified audience member:

One thing I always object to is this flat statement that we ought to pay for water what it's worth. My formula would be that for a minimum amount — basic health and sanitation — water should be very cheap, and then a quickly rising price of water as you use more. It isn't the small guys who use a little water who are the problem. What we need to do is to get industries that have lavish use of waters, and all these golf courses that are the blight of the North American landscape, to think about ways to conserve water. Hit the big users with the high price tags, not the little guy.

Mordechai Shechter:

Yes, it's mainly to Holger, of course. As an economist, I liked the idea of Green Water Credits, but I want to draw your attention — and this is also a reaction to Bob's query. A few months ago, I attended a workshop in Pittsburgh organized by the EPA and the Farm Bureau. Those are strange bedfellows. And the subject of the workshop was "Tradable Water-quality Permits". I was surprised because I'd worked in this area before; this didn't deal with theory. It dealt with the practicality. Apparently, there are viable water-quality permit markets in isolated areas in the U.S. and it's spreading. The idea here is very simple: farmers who use good, environmentally friendly management practices can reduce the emission of pollutants into the blue water, in your case, and they're rewarded by being able to sell this saved pollution to other demanders. I'm not going now into the water-market issue, but what I'm trying to say is that if you bring in the green-water concept — which ties in very nicely with the water-quality permits, which is already an ongoing, workable, viable concept — I think you can come up with a tool that will advance your work much further and much more quickly than you thought would be feasible, because the solution is already there, waiting for the addition of the concept of green water.

Rathinasamy Saleth:

Actually, the concept of virtual water, of water footprints, should be used in a relative context. For instance, the water use of wheat versus another crop, or even beer versus orange juice. That makes sense; but in a general context — for instance, water use by coffee — the counter-effects, the opportunity cost was not taken into account. Suppose if a place is not producing coffee, all the water will go into the sea. So it doesn't make much sense. I think this is also true with the water content of lions — African lions, for instance. So I think it should be used in a relative way so that it makes sense; otherwise, it becomes a diluter. Thank you.

Richard Adams:

My comment is somewhat similar to Professor Shechter's and goes back to the excellent discussion of the discussant, Professor Schreier; it relates to this issue of how do we value the units that are going to be traded through whatever the market might be? I think your idea about linking the uplands and the lowlands through some sort of water market is an innovative approach, but having been there and somewhat done that from the standpoint of the U.S. and trying to develop non-point-source pollution-trading credits, which is what the workshop you attended dealt with… The idea is great. It's innovative, but the devil is in the details. So the good news is that there are some techniques we've developed as economists for this. There seems to be a political will to move in this direction. The challenge is still: What is the unit that's being traded? And we have not quite got that right yet, but I don't want to be negative after the speaker who chastised us for being negative. I think there are opportunities here and I encourage you to keep pursuing that, but you're going to have some difficulties when it gets down to coming to a tradable commodity.

And it may not just be the unit that's traded, but also other values that have to be connected, which are perhaps not yet captured.

Peter van Niekerk:

My comment is just an example of where blue- and green-water management has been implemented, and that is in South Africa with water supply to the city of Cape Town. As is typical in a developing world where you have mass urbanization happening and where people improve their livelihoods, there's a rapidly increasing demand for water in Cape Town, and this outstrips the existing resources. Something had to be done, so apart from the water-demand-management initiatives being undertaken, the resolution was a multiple solution. It consisted of another dam. It consisted as well of removing alien vegetation, mostly trees that grow in the mountain catchments. Initially, there was a large expense to remove them, but then it's a fairly modest cost to maintain. Removal has the advantages of reinstatement of the natural vegetation, and greater biodiversity, and it came out that the cost of the removal of those trees and the maintenance of that is but one 10th of the cost of new water supplies. But all of those measures are required.

Sekou Toure:

Most of these concepts really boil down to policies — public policies or sectoral policies in terms of providing the necessary services that we're talking about. In the presentations, there are two or three things I was looking forward to hearing. Maybe one of the presenters can come back to it. When you discuss the notion of payment for ecosystem services — fortunately, this is a good concept; but in reality, as Hans [Schreier] mentioned, I think we are falling short of critical mass to really push these ideas forward. Secondly, the notion of virtual water can be really polluting. It's a good concept, but, as has been mentioned, there are some downsides to some of these things. So if it's not carefully put into its proper context, you can push for something and then five years down the road you say, "Oh my goodness, we're having so many negative impacts from these concepts." And, again, I think we really have to push very hard for this issue or notion of green and blue water here, because a lot of commodities are traded but people have no idea what kinds of inputs go into the production of these commodities. A lot of water is wasted for the production of maybe one pound of something that nobody really needs.

Pedro Arrojo Agudo:

In Spain over the last few years, there has been a big debate about what to do: big transfers of water from the Ebro along the Mediterranean coast, or desalination. The first alternative was the initial one: we must think about flooding villages in the Pyrenees in order to stock water — destroying the Ebra Delta, and then moving the water 800 km, which requires 4.5 kilowatts per cubic metre. That is the energy you need to pump water that is more than 1 km deep. In the end, the full cost is more than one euro per cubic metre. And desalination, with the new techniques, is now around half a euro per cubic metre for better water. I think most of the population is going to the coasts, and on the coasts we have bad water and it's getting worse and worse; we must solve this problem of sustainability, and urgently. We will use more and more desalination with reverse osmosis, which now uses about 3 kilowatts of energy per cubic metre with the most recent alternatives of low-pressure osmosis membranes.

Holger Hoff:

There are a number of problems with this payment for environmental services or schemes that you cannot define very well: What is the benefit downstream? You have difficulties identifying your client and the benefits he receives, convincing the upstream managers and, not least, building the institutions that support this. However, there are some examples, as you were saying, from the water-quality side which maybe we should build upon, and I tend to believe that there are no real alternatives to internalize these currently external effects of upstream management. So one has to go along this way and learn along the way how to do it. And there are no examples of that, at least for Africa and water services. There are no examples set yet. There are a few examples on the Latin American side, so my intuitive response would be, yes, it will take a long time and it will take a lot of convincing of all the institutions involved, but that's the way to go forward, because the problems will be more and more pressing, and this issue of the urgency of the problems is also what I believe is behind the statement that said: We in Australia are doing somewhat better. We heard this morning that in Canada, on the other hand, there are, for example, not enough water meters even installed yet. So to me, a lot of it comes back to the question: How urgent is the issue? And if it's urgent enough, as it is in Australia or as it is also in South Africa, then alternative measures will be installed; and as long as there is still a lot of water coming down the river, this will be delayed.

Helen Ingram, Session Chair:

Peter, I have to ask you about this, because your institute has done a lot of stuff about water markets. Do you want to comment on this at all?

Peter Gleick:

I did want to make a comment about the service question, just to follow up. I agree partly that it's very difficult to quantify and to develop institutional mechanisms to pay for ecosystem services. On the other hand, I also agree that we are actually doing it and sometimes we don't know we're doing it. Pedro's example about desalination is an interesting one. In California, there are twenty desalination plants proposed up and down the coast and we just did an analysis of desalination. Our conclusion is that it's far more expensive for almost all spots in California compared to conservation and efficiency and other sources of supply and water markets; but one interesting exception may be a spot on the central coast where they're required to reduce flows in order to restore ecosystems on the Carmel River. The state has said that the water agency has to cut withdrawals to restore the ecosystem, and so the only alternative they're debating now is building a desalination plant sized precisely to reduce their withdrawal from the Carmel River. Now, the customers will end up paying for it if the plant gets built. In a sense, that's a payment for an ecosystem service. They will pay the price of desalination, if they choose to do this, precisely in order to restore the ecosystem flows; and we don't think of it as paying for ecosystem services, but that's what's going on. Peter's example in South Africa is another one. I think there are innovative ways of paying for these services which may be more traditional in the way we bill for them but which are actually ecosystem payments.

SESSION TWO

Dave Sauchyn — Biography

Dave Sauchyn is a Professor of Geography at the University of Regina, and Research Coordinator for the Prairie Adaptation Research Collaborative. His research interests are future and past climatic change, and specifically the paleohydrology of the interior Plains and adaptation to drought. He is a co-investigator in the Sustainable Forest Management NCE (Network Centre of Excellence) and in a multi-year, interdisciplinary study of the impacts of climate change in northern Chile and the southern Canadian Plains. Dave's other international activities include Canadian leader of a program examining the world's dryland landscapes, and a contributor to the North American Drought Reconstruction Project. Among his affiliations, Dave is Past President of the Canadian Quaternary Association, President of the Canadian Geomorphological Research Group, a national director of the Canadian Water Resources Association, and a member of the national advisory committee for the Climate Change Impacts Scenarios project.

Upland Watershed Management and Global Change — Canada's Rocky Mountains and Western Plains

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Introduction

> No country on Earth has such contrasts of drought and water plenty as Canada. None has so much water ready and available for use. But Canada is learning that national statistics do not begin to portray the complexity of its relationship with its most vital resource.… a new reality is emerging. It is a reality in which water is in increasingly short supply in some places at some times, where water suddenly has a real value rather than being an unlimited resource — and where rivers truly can run dry. (Pearce 2006)

A "myth of abundance" has historically influenced Canadian water policy and management (Mitchell and Shrubsol 1994: 1). So has an explicit assumption that "the hydrological regime is stationary and will continue to be stationary in the future." (Whitfield et al. 2004: 89). There is "limited availability of freshwater in Canada at different times and places" (Quinn et al. 2004: 1). The place and time of least fresh water is the Western plains during recurrent drought. This paper is about the hydroclimate of this region (Figure 1) and specifically how water policy and management might be adjusted to compensate for a long view of the surface hydrology. We examine the hydroclimatic variability from 1600 to 2100 as a context for records from the 20th century, the conventional scientific basis for formulating water-policy and -management strategies.

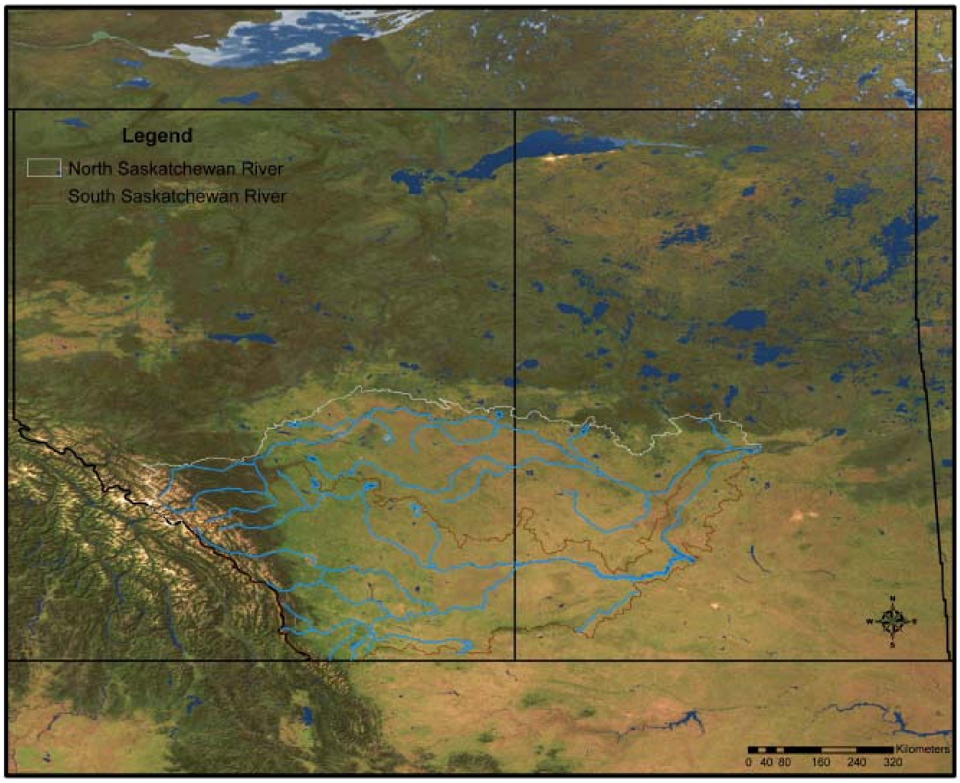


Figure 1. The North and South Saskatchewan river basins shed runoff from the southern Rocky Mountains and across the subhumid to semi-arid Prairie Ecozone of southern Alberta and southwestern Saskatchewan.

Western water policy and management practices reflect the dry climate. In contrast to the accessible surface water and riparian laws of eastern Canada and the eastern U.S., the principles of first appropriation and apportionment developed in the West to guarantee access to water for the first users (irrigators) and to allocate water among jurisdictions (Arnold 2005; Quinn et al. 2004). Apportionment agreements and guidelines for minimum flows ensure water supplies by jurisdiction and for instream flow needs. If natural flows reach unprecedented levels, the uncertainties and assumptions inherent in the calculation of flows for apportionment agreements and to maintain aquatic ecosystems become more significant, implying the question: What is the potential for future low flows resulting in conflicts between users and jurisdictions? (Quinn et al. 2004). In a recent empirical study of the determinants of water-related international relations, Stahl (2005: 270) concluded: "hydroclimatic variability and population density are most influential in arid to sub-humid basins, while socioeconomic and political factors seem to be more important in … humid basins."

In the southern Prairies (Figure 1), first appropriation and apportionment — and, more recently, water-conservation objectives to protect aquatic systems — are policy responses to a subhumid to semi-arid climate. Mean annual water deficits are 35% to 50% in terms of the shortfall of precipitation (P) relative to potential evapotranspiration (PET). The extent of this Canadian dry belt increases by approximately 50% when P/PET is mapped using output from the Canadian

GCM ver2 (emission scenario B2) for the 2050s (Sauchyn et al. 2002). While drought could be more severe and frequent under global warming (Kharin and Zwiers 2000), the expansion of subhumid climate is not outside the geographic range of natural variability, since in drought years (e.g. 1937, '61, '88, 2001) a large part of the Prairies has a P/PET <0.65, although with devastating consequences (Wheaton et al. 2005). Most adjustments to water policy and management practices have occurred in response to these droughts.

Immediately following the driest two years on record, Alberta released its groundbreaking Water for Life strategy (Alberta Environment 2003). The rationale for a provincial water strategy included (p. 5):

> Alberta has been able to manage our water supply while maintaining a healthy aquatic environment because there has been a relatively abundant, clean supply to meet the needs of communities and the economy. However, fluctuating and unpredictable water supply in recent years has stressed the need to make some major shifts in our approach to managing this renewable, but finite, resource.

A "clear set of principles" emerged from consultations to develop the provincial water strategy. They include (p.6):

- All Albertans must recognize that there are **limits to the available water supply**.
- Alberta's water resources must be managed within the **capacity of individual watersheds**.
- **Knowledge of Alberta's water supply** and quality is the foundation for effective decision making.

Applying these principles to science-based decision making will require estimates of the limits to available water supply and of capacities of individual watersheds. Knowledge of Alberta's water supply is incomplete without data on trends, variability and extremes — and thereby limits and capacities — derived from observation and modelling of hydroclimate over time frames that extend before and beyond our short experience with hydrologic systems.

Most sectors, agencies and communities are aware of and concerned about the potential impacts of climate change on water resources, but few are making decisions based on scenarios of trends and variability generated from climate models or from records that extend beyond the length of instrumental records. Operational decisions about reservoir storage, irrigation, flood and drought mitigation, and hydro-power production are based on water-supply forecasts from statistical and simulation models that are derived and calibrated using instrumental data from monitoring networks (Pagano et al. 2005; Chiew et al. 2003). This standard forecasting methodology has limited application to long-term water planning and policy-making because most instrumental records generally are too short to capture the decadal and longer-term variation in regional climate and hydrology.

Whereas water policy tends to reflect mean hydroclimatic conditions (thus the different philosophies and mechanisms between wet and dry climates), water management overcomes differences in water supply between years and places. The management of water in the Western interior is essentially a process of redistributing the runoff from source areas with excess water (i.e. the Rocky Mountains and Prairie uplands, e.g. the Cypress Hills) to the adjacent water-deficient plains that constitute most of Canada's farmland. In most years, the supply of water from the mountains and uplands is high relative to the water deficit on the plains. However, this gap becomes precariously small during years of drought — such as 2001, when there were serious economic consequences resulting in adjustments to water policy and management (Alberta Environment n.d.; Wheaton et al. 2005).

If headwaters are managed for water consumption on the plains, key information for long-range-planning purposes includes the anticipated water supply in the mountains, and demand on the plains. This paper describes research on the stream hydrology and paleoclimatology of this region. This work suggests that current perceptions of water scarcity and variability may be skewed by observation and experience of the 20th century, which may be unrepresentative of both natural and future hydroclimate. The extensive wastage of glacier ice from the Rocky Mountains will have increased local streamflow above the net income of annual precipitation, but it is almost certain that this effect is in decline as the glaciers retreat rapidly towards their Holocene minima (Demuth and Pietroniro 2001). Furthermore, climate-change scenarios suggest that a significantly larger proportion of winter precipitation will fall as rain as opposed to snow (Lapp et al. 2005). This hydrologic regime, with less natural storage, should increase the drought sensitivity of water supplies. According to records and models of pre- and post-20th-century climate as described below, the 21st century will almost certainly include droughts of greater severity and duration than those previously observed and experienced by Euro-Canadians in western Canada.

Recent Trends and Future Projections

A recent study by Alberta Environment (Pietroniro et al. 2006*a*) comprises three major investigations of recent and potential future trends in water resources within the headwater catchments of the Nelson River basin. The first focuses on cataloguing glacial extents within the North and South Saskatchewan river basins (NSRB and SSRB), using legacy Earth Observation data (Demuth and Pietroniro 2001). A second component examines streamflow records for evidence of trends and variability related to changes in glacial extent. The third component involves hydrological modelling of change in flow regime under future climate/glacier-cover configurations. Combined, these analyses provide an assessment of the impacts that climate change may impose on the "water towers" of the Canadian Prairies. In this paper, we summarize the results of these investigations. For a description of the methods of analysis, the reader should consult Pietroniro et al. (2006*a*).

The headwater-study basins contain historic records of streamflow and climate obtained from Environment Canada Archives, and glacier information from the Geological Survey of Canada. Figure 2 illustrates the basins used in the various analyses. It highlights the North and South Saskatchewan drainages (NSRB and SSRB) and all existing and historic Water Survey of Canada Gauges locations up to the year 2001.

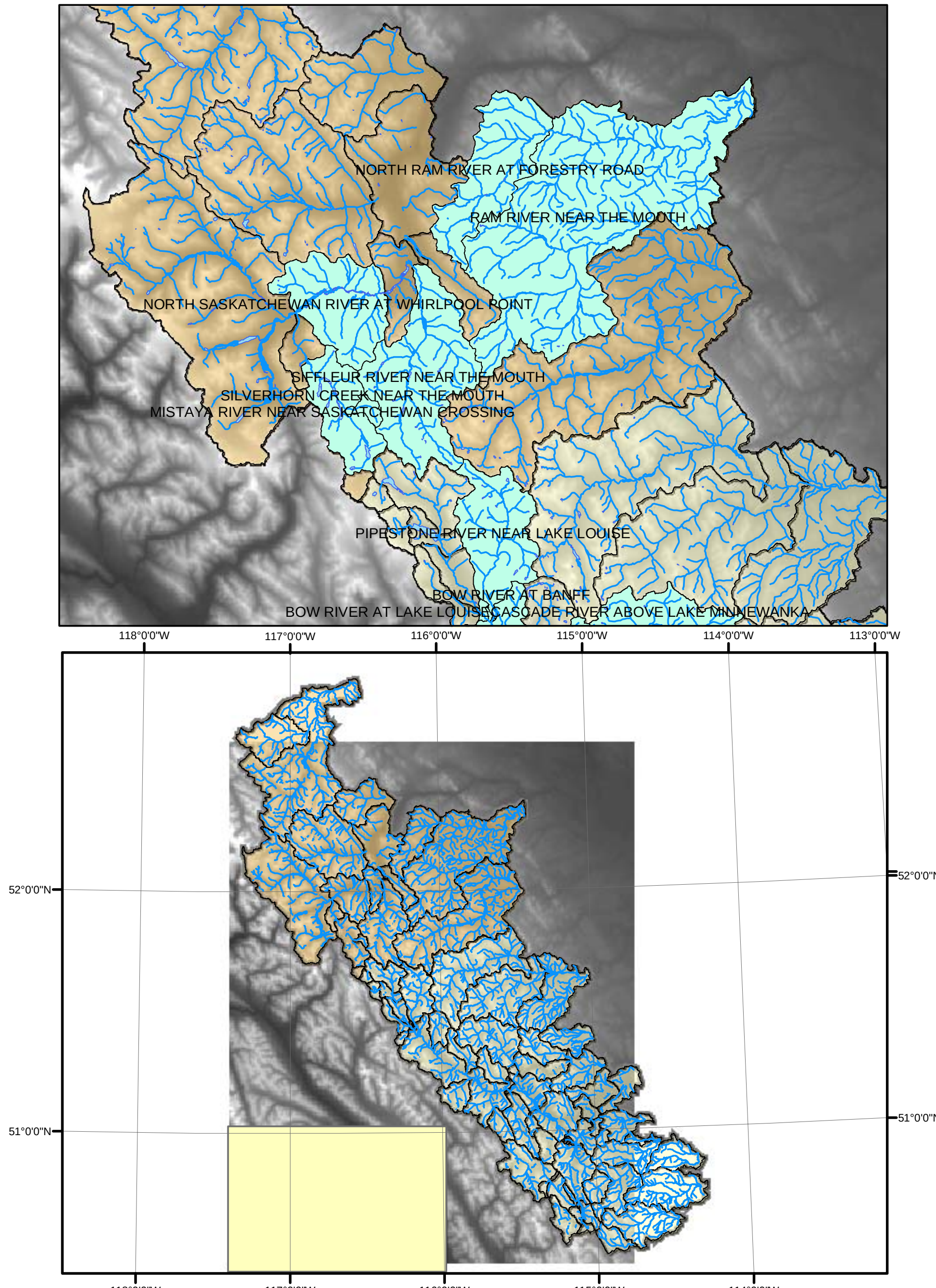


Figure 2. The Nelson drainage headwaters, including the North and South Saskatchewan river basins.

A Changing Glacier Landscape

Documenting land-ice influences on the vulnerability of the water resources of the NSRB and SSRB requires periodic mapping of snow and ice extents. These extents can then be incorporated into hydrological-modelling- and remote-sensing-based glacier-climate-scaling frameworks (Demuth et al. in progress). Landsat satellite images since the 1970s enable repetitive, synoptic and high-resolution multispectral mapping. Glacier extent in the Nelson headwaters was estimated for 1975 and 1998, and changes in area extent were documented. An example of the delineated glacier extent is shown in Figure 3. Total glacier-area change as a ratio of 1975 glacier extent was approximately 50% in the South Saskatchewan River basin and 23% in the North basin.

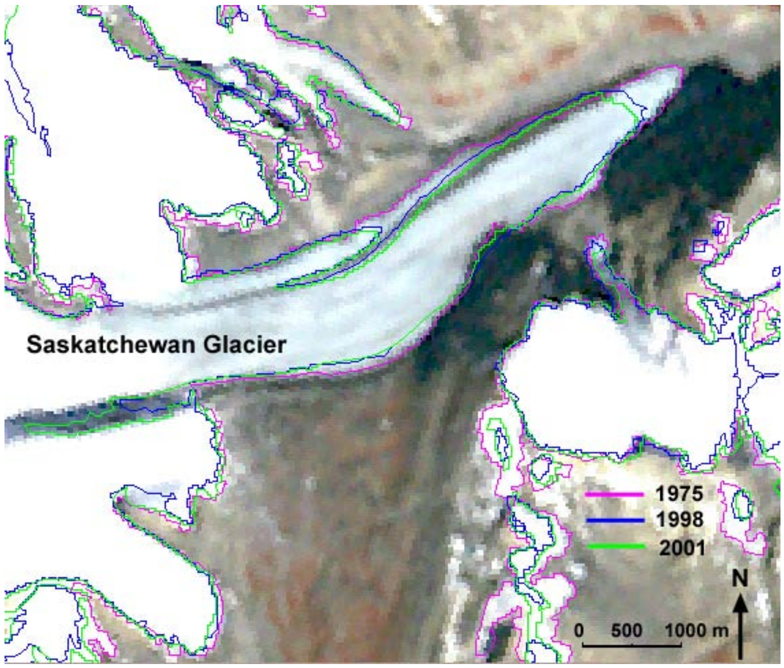
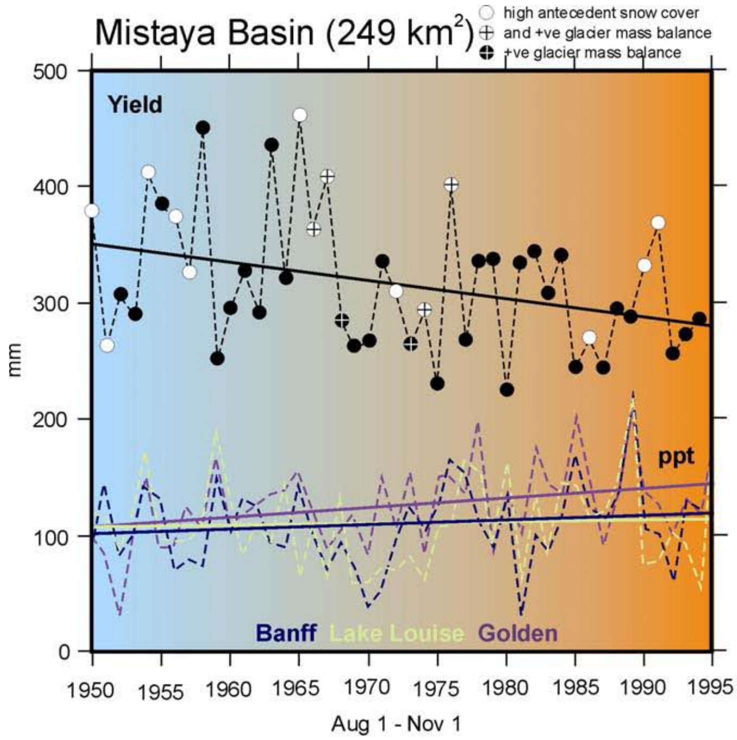


Figure 3. Delineation of the extent of the Saskatchewan Glacier. Note the substantial changes in the tongue of the Saskatchewan Glacier between 1975 and 2001.

Streamflow Trends in Headwater Catchments

The influence of changing glacier cover was examined using parametric and non-parametric statistical-trend analysis of streamflow and basin yield for several reference headwater catchments. During periods of precipitation deficit, basin water yield declines and interannual flow variability tends to increase with continued glacier shrinkage (Young 1991). The extent to which this situation is evolving in the study area was investigated by analyzing longer sequences of historical streamflow data in relation to secular glacier-climate variability (1950–1998) in selected catchments.

The parametric analysis was concentrated on the Mistaya record (initiated in 1950) and the annual transition-to-base-flow (TBF) period from August to October, when there is maximum contribution from glacier ice melt. Figure 4 illustrates the yield from the Mistaya catchment for the period of study. The trend line shown includes all data and depicts declining yields for the TBF period despite evidence that precipitation in the montane is increasing for the same period (Aug 1 – Oct 31). The coefficient of variation (standard deviation/mean) for the streamflow (Figure 4) is increasing over the available record, suggesting that the ability of the glacier cover to regulate streamflow may have been in decline since the mid-1900s.



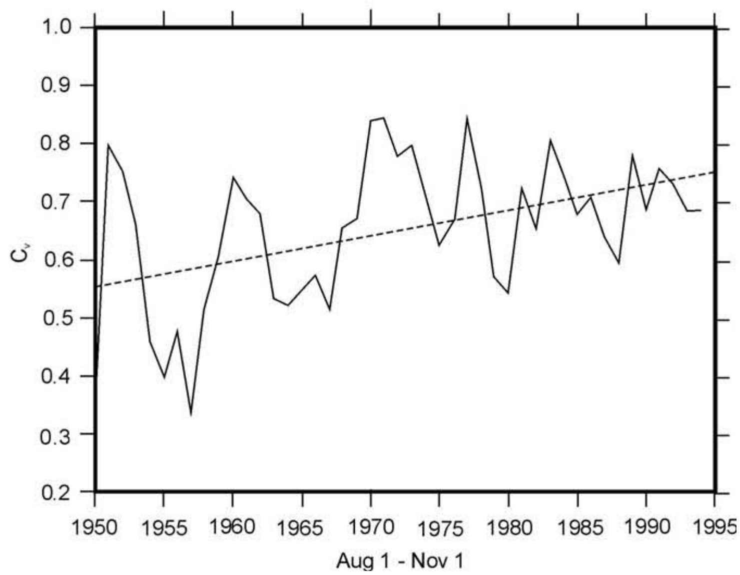


Figure 4. Yield, precipitation and streamflow coefficient of variation (C) for the Mistaya River catchment at gauge 05DA007 over the TBF period

The streamflow regime was also examined using the minimum, mean and maximum daily discharge data available from the Water Survey of Canada (Environment Canada 2000). The TBF change for the Mistaya basin (1950–1998) is quantified using a simple linear-regression analysis, depicted in Figure 5. There is a significant decreasing trend in the mean (r2=0.33) and minimum (r2=0.43) TBF time series, and a weaker increasing trend in the maximum (r2=0.02) TBF time series (Figure 5).

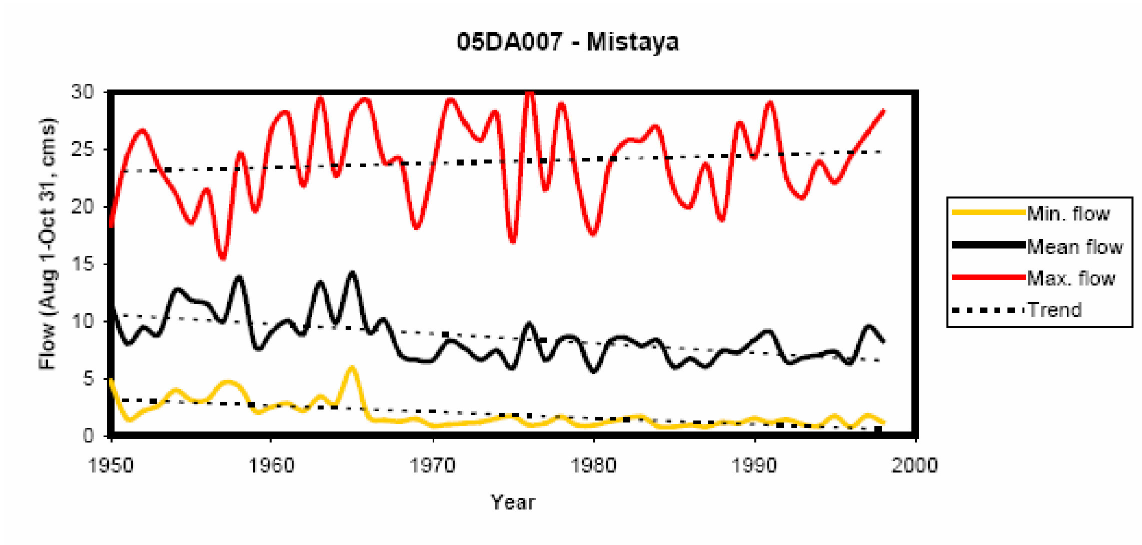


Figure 5. Regression analysis for TBF flow period, showing trends in minimum, mean and maximum flows for the Mistaya basin

The initial inference from this analysis is that significant reductions in the mean and minimum flow regimes and increasing flow variability are the result of extensive glacier contraction to the degree that glacier-melt contributions during dry periods, notwithstanding high antecedent snow-cover conditions, have been in decline over the period of observation.

All historic records available for the headwater region were examined for use in a non-parametric trend analysis of glaciated and non-glaciated headwaters. Selection criteria centred primarily on the length and the completeness of discharge records. Discharge data were obtained from the HYDAT 2003 CD (Environment Canada 2003). Analyses of annual trends were further limited to those stations containing discharge data for all months of the year; those stations containing data for fewer months (e.g. April-October) were used only for analyses of the TBF and/or spring periods and for some observations about changes in monthly trends over the period of record. Spring was defined as March to May, and the TBF period is August to October. Station selection proved exceedingly difficult, since common periods of record of significant duration were never collected. This highlights the importance of systematic and consistent hydrometric-data collection. Nonetheless, a total of 18 discharge stations (5 in the NSRB and 13 in the SSRB) were chosen for Mann Kendall (MK) analysis of streamflow trends.

The results for the 18 stations show that the majority of trends detected are negative, indicating decreasing streamflow patterns. In particular, for the North Ram, Siffleur and Mistaya stations of the NSRB, whose per-cent glacier covers increase from 0% to 2.5% to 8.5% respectively, there is a decreasing trend in TBF as the per-cent glacierization increases. Unfortunately, there is no equivalent comparison for basins with differing glacier extent in the SSRB, and thus the pattern with respect to glacier extent and change in streamflow is less clear than for the NSRB. Overall, 50% of the stations analyzed exhibited no trends in discharge over the periods of record. Interestingly, and perhaps predictably, of those 50% where no trend was detected, 78% were for non-glacierized basins.

Modelling Headwater Catchments

Hydrological-modelling methodology described by Pietroniro et al. (2006*a*) was used to assess both the impacts of future climate variability of flows in the Nelson headwaters and also to assess the feasibility of estimating the glacier contributions through simple sensitivity analysis. The WATFLOOD (Kouwen et al. 1993) model was used; it calibrated well to conditions in the North and South Saskatchewan rivers. Sensitivity analysis showed the important contribution of glacier flow to the headwater catchments and its diminishing influence further downstream. Climate-change projections using change fields derived from the analysis of GCM output for this region were used to assess possible future changes to the streamflow regime (Töyrä et al. 2005). As reported by Töyrä et al. (2005), the ECHAM4 and NCAR-PCM GCMs achieved the lowest errors and highest correlation coefficients and could best model the magnitude of annual and seasonal precipitation and timing of the monthly precipitation in the region. The GCMs could generally replicate the amount of summer precipitation better than in the other seasons, while the spatial pattern of summer precipitation was represented poorly by all models. Winter and spring precipitation amounts were severely overestimated by most models. Nonetheless, the change fields were applied to the WATFLOOD model, and the results indicate lower overall mean annual flows. This analysis was done using the 1998 glacier extent, and no projections of future extent were added to the model.

Model calibration and sensitivity analysis for a subset of years were used to determine optimal parameters for streamflow simulation (Pietroniro et al. 2006*a*). Then the hydrological model was run with a continuous time series for 1961–1990 and 2040–69, standard time slices for constructing climate scenarios (IPCC 2001). The basins used in the continuous simulations are included in Figure 2. The only meteorological forcing of the WATFLOOD model is precipitation and temperature. Data for stations with complete daily minimum and maximum temperatures were extracted from Environment Canada archives, and gridded based on elevation and a linear interpolation between the daily maxima and minima temperature in order to provide lapse-rate-corrected, diurnally varying hourly temperatures. As precipitation is spatially far more variable than temperature, high-resolution spatial precipitation gauging enhances accuracy when modelling channel output (Kouwen, personal communication). Climate stations having daily precipitation records for more than 5 years during the 30-year period were identified.

Results for monthly hydrographs of three headwater catchments in the NSRB showed good agreement between observed and modelled flows (Figure 6). These basins represent varying degrees of glacier cover. In all cases, the WATFLOOD simulation provides reasonable simulation results.

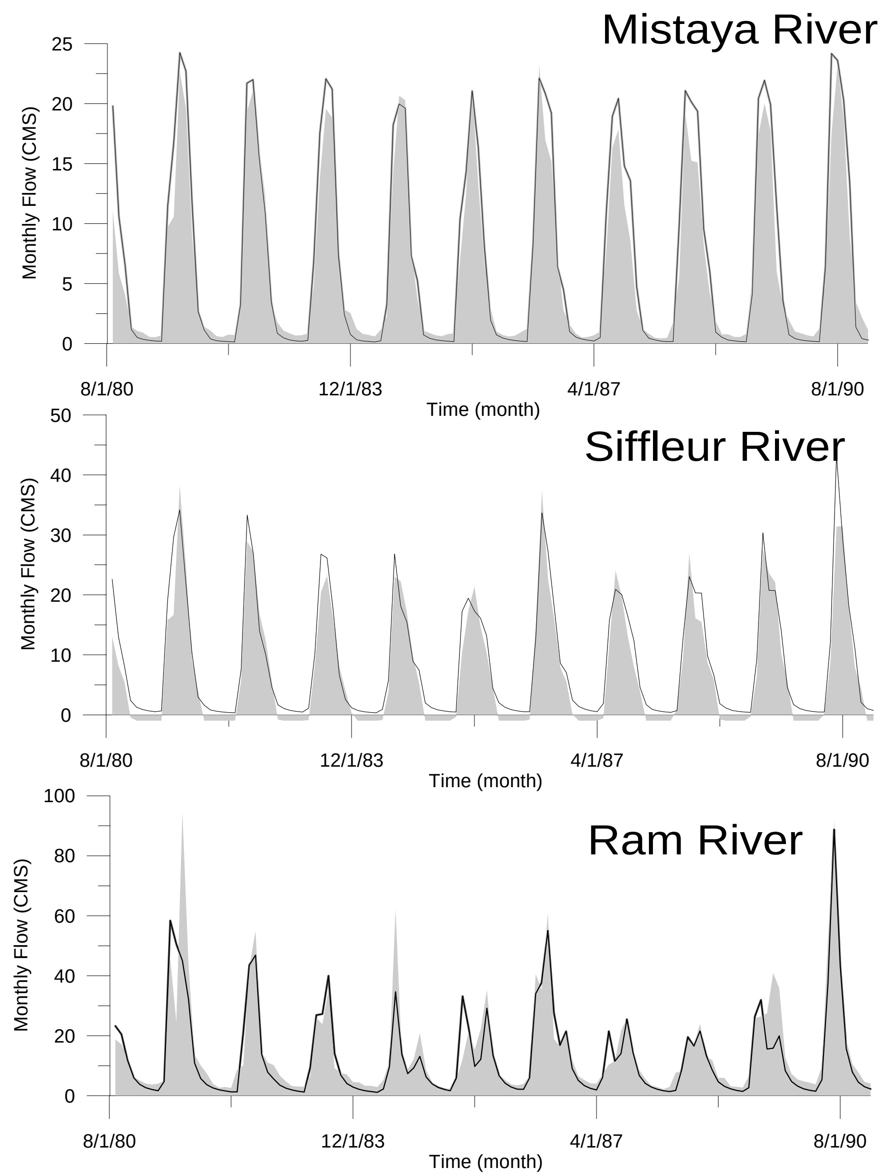


Figure 6. WATFLOOD model results for 1980–1990 in three headwater catchments of the North Saskatchewan River basin. The grey solid portion of the graph represents the observed hydrograph, while the solid black line represents the model output. Model results for the 10-year simulation periods.

A sensitivity analysis of the impacts of glacier melt on total flow used the 1975 and 1998 glacier extents from the Landsat analysis described earlier. In Figure 7, the Mistaya River displays gradually decreasing volumes and variability during the TBF period when moving from the 1975 to 1998 extent. The hydrographs highlighted in cyan show the estimated flows with no glacier extent. There is no change shown in the Ram River basin, simply because it is non-glaciated and the consequences of removing glacier melt from this region are obvious. What this analysis highlights is that basins such as the Siffleur have already experienced deglaciation to the point where future changes in glacier mass will have very little impact on the runoff regime.

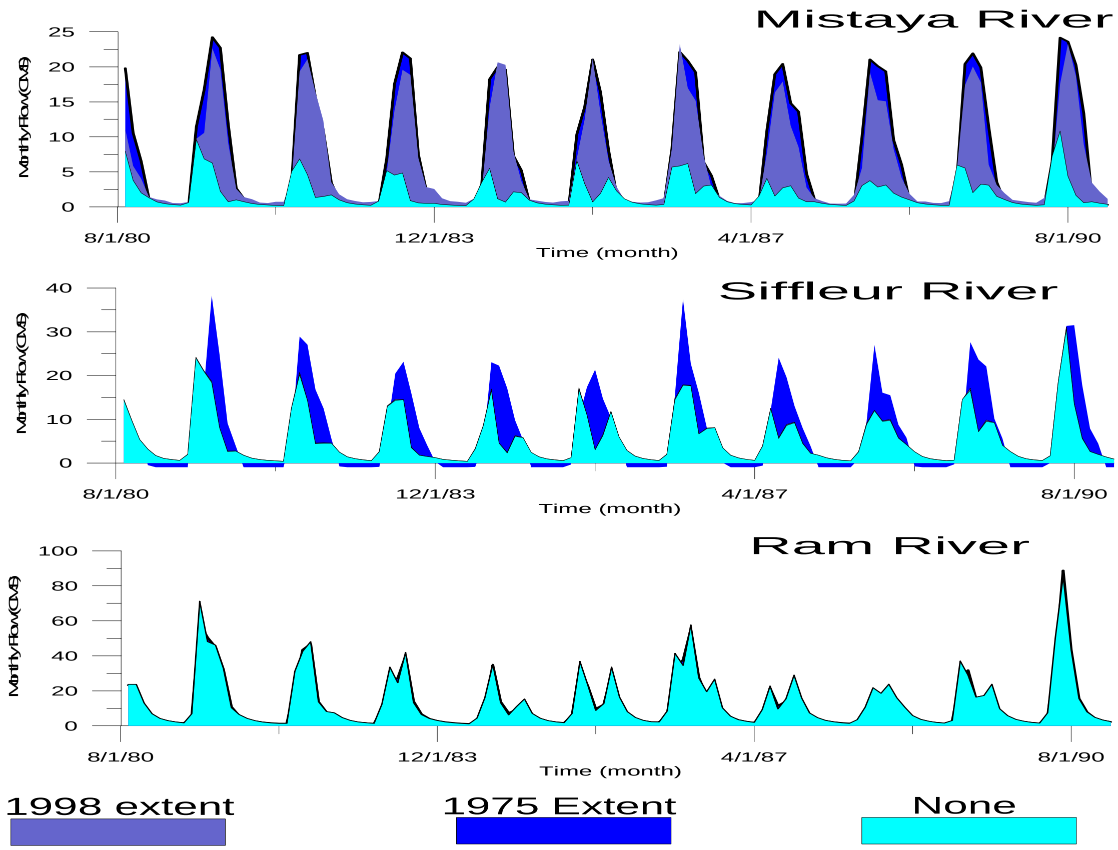


Figure 7. Analysis of glacier contributions to flow using the WATFLOOD model. The hatched area represents the runoff in the basin with no glacier melt. The darker area represents the model simulation with the 1975 glacier extent.

A preliminary climate-change analysis was based on the method outlined by Pietroniro et al. (2006*b*) and the climate-change scenarios described earlier (Töyrä et al. 2005). The potential changes in temperature were applied as offsets, and precipitation was normalized. Spatial gridding of these data produced the anticipated future temperature and precipitation forcing for WATFLOOD. The Hadley Centre and ECHAM models both provided reasonable simulations of the seasonal and annual observed climatology. The WATFLOOD model was rerun using this modified forcing so that current and future streamflow could be compared. Mean monthly flow for the Bow River at Banff shows the influence of changing glacier extent. The 1975, 1998 and "none" hydrographs represent the modelled 10-year monthly flow values using the fixed glacier extents for those years. "None" refers to complete removal of the glaciers from the basin. There is a clear reduction in overall flow volume, and a small reduction in peak magnitude in all three glacier scenarios. The 1998 glacier extent, and the climate-change forcing from the ECHAM and Hadley Centre models, results in similar patterns with a slight change in peak (increase for Hadley and decrease for ECHAM) and a shift in monthly flows to a higher spring runoff. The TBF period shows very little change resulting from climate change alone, and is more influenced by the glacier extent than by the climate warming. This is simply because the glacier extents are fixed for each grid element in the model at a predetermined level. Clearly, changes in precipitation and temperature will have an influence on the dynamic response of the glacier and it is likely that glacier recession will continue. The resulting flow regime for the Bow River headwaters will likely include early and increased spring melt and decreased late-summer flows, as shown in Figure 8.

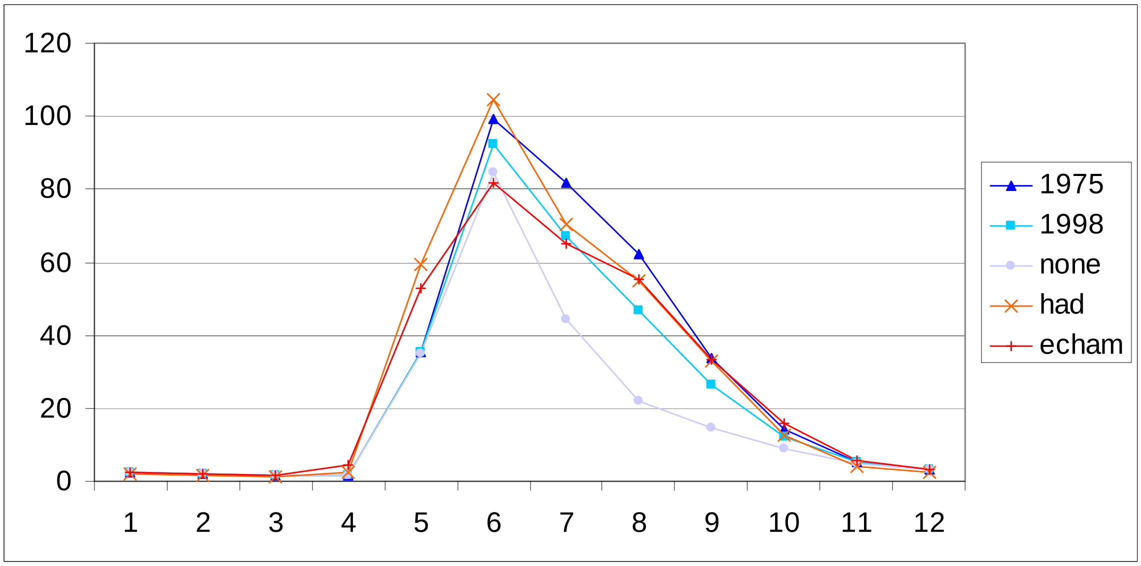


Figure 8. Comparison of 10-year monthly-flow estimates from WATFLOOD for the Bow River at Banff, derived from both climate-change and glacier-change projection

Hydroclimatic Variability

Most drivers of hydroclimatic variation have a periodicity that approaches or exceeds the length of gauge records: "many hydroclimate datasets exhibit inter-decadal variability, where some inter-decadal periods are considerably drier or wetter than others. These wet and dry cycles have significant implications for the management of land and water resources systems, where several decades of sufficient water are followed by droughts clustered over the following decades." (Chiew 2006). Low-frequency variation and sustained departures from mean conditions are observable only with proxy records. Proxy hydroclimatic data can provide water-resource planners and engineers with a context for standard reference hydrology to evaluate baseline conditions and water allocations, and a broader perspective on the variability of water levels to assess the reliability of water-supply systems under a wider range of precipitation and flow regimes than recorded by a gauge.

Tree rings are the preferred proxy for records of climate variability at annual to multi-decadal scales spanning centuries to millennia (Briffa 2000). They are the source of both hydroclimate information and a chronology with absolute annual resolution. Annual variations in tree-ring width reflect daily and seasonal growth-limiting processes. Where available soil moisture limits tree growth, standardized tree-ring widths correlate with hydrometric variables. Streamflow records correlate with moisture-sensitive tree-ring chronologies, because streamflow and tree growth have a similar muted response to episodic inputs of rainfall and snow meltwater. Hydrological peaks are usually underestimated by tree rings, given a biological limit to the growth response to excess soil moisture. Therefore, proxy records do not provide precise volumes of streamflow, yet they capture the timing and duration of periods of high and low flow. Tree rings are an especially good indicator of drought; dry years produce narrow rings.

Until recently, networks of moisture-sensitive tree-ring chronologies have been lacking for western Canada, and streamflow has been reconstructed using just a few chronologies (e.g. Case and Macdonald 2003). Researchers at the University of Regina Tree Ring Lab (www.parc.ca/urtreelab) have collected tree rings at 85 sites to enable the inference of long-term moisture and streamflow variability from a pool of predictor chronologies that capture more of the regional climatic variability. Nearly all of these collections are from open-canopy forests on ridge crests, south- and west-facing slopes, and/or rapidly drained soils. At these dry sites, tree growth is limited by available soil moisture, and therefore our tree-ring chronologies are proxies of summer and annual precipitation, soil moisture and runoff.

Here we present one streamflow reconstruction to illustrate four centuries of hydroclimatic variability and to provide context for the gauge record from the 20th century. The mean annual flow of the Oldman River at Waldron's Corner, Alberta (gauge AA023), was derived by Axelson (2006) from tree-ring chronologies from five sites within 50 km of the gauge. The methods of constructing tree-ring models of streamflow can be found in any technical paper in dendrohydrology (e.g. St. George and Sauchyn 2006). Figure 9 is a plot of reconstructed and observed flow for the period of the gauge record, 1951–2004.

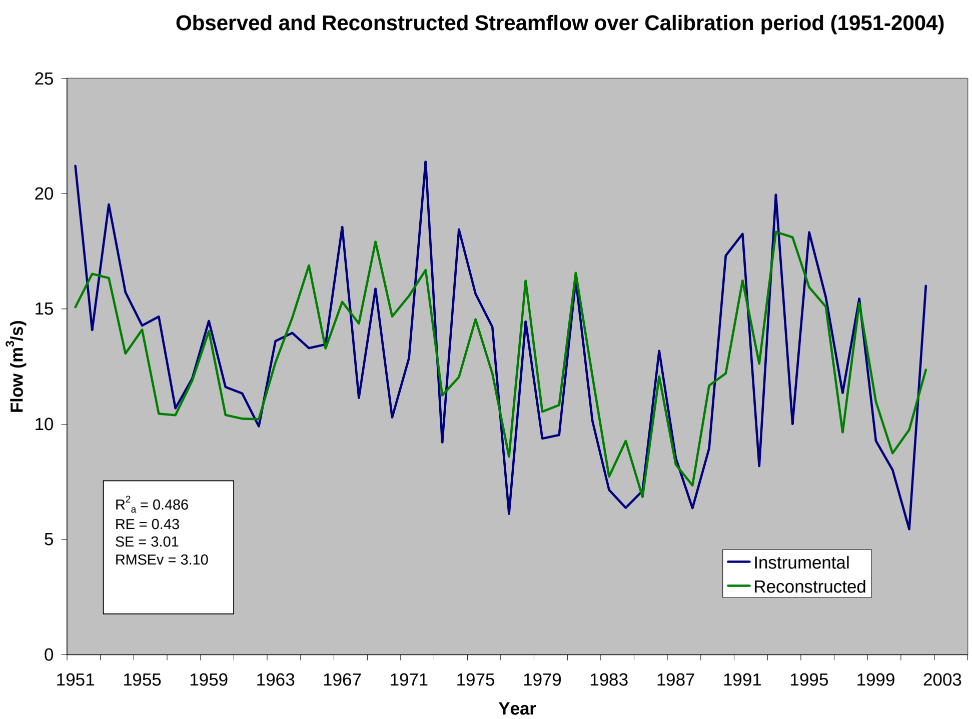


Figure 9. Mean annual flow of the Oldman River at Waldron's Corner, Alberta, for the period of observation 1951–2004. The blue curve is the record from gauge AA023. The green curve is streamflow reconstructed from a tree-ring model. The model predictors are standardized (Arstan) tree-ring chronologies from five sites within 50 km of the gauge.

This plot illustrates the similar variability in the response of the stream and trees to precipitation, especially at lower (decadal) frequencies. The tree-ring predictors account for about 50% of the variance in streamflow. Most of the unexplained variance is attributable to the larger amplitude of observed versus reconstructed flows. On the other hand, the tree-ring records capture the timing of low flows, and thus we are confident that the full reconstruction in Figure 10 spanning 1602–2004 gives the timing and duration of drought.

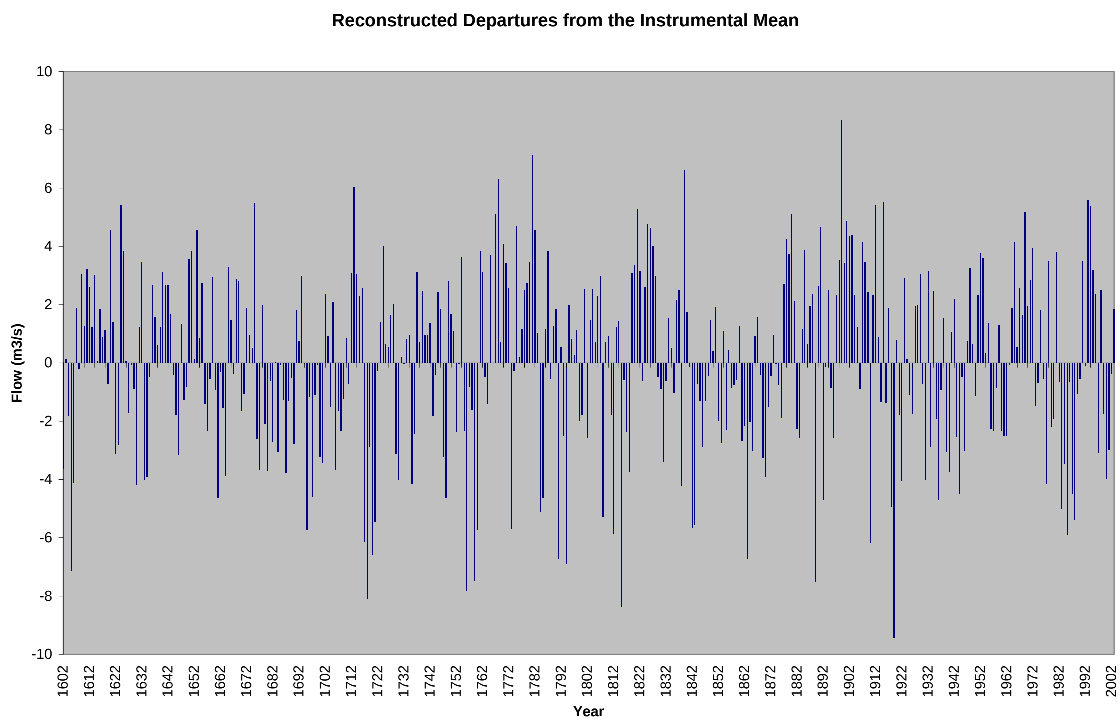


Figure 10. The full tree-ring reconstruction of mean annual flow of the Oldman River at Waldron's Corner for the period 1602–2004. These proxy streamflow data are plotted as departures from the mean of the instrumental record.

The proxy streamflow data in Figure 10 are plotted as departures from the mean of the instrumental record. This record reveals the local impact of the droughts of the 1980s on the flow of the upper Oldman River. This sequence of low flows, however, is certainly not the worst streamflow scenario. For almost five decades between 1830 to 1880, and just before the region was settled by Euro-Canadians, there were only nine years of above-average flow. The regional water balance would have been seriously depleted by these sustained dry conditions. Similarly, in most years between 1640 and 1720, the tree rings record below-average flow. Since these droughts are relatively recent, there are historical observations of the water scarcity and its impacts, including evidence of sand dune activity (Wolfe et al. 2001) from a lack of soil moisture, and flows in the North Saskatchewan River at Edmonton which were so low that furs could not be moved by canoe (Sauchyn et al. 2002, 2003).

Proxy streamflow records reveal periodic shifts in hydroclimatic regime between intervals of dominantly low-frequency variation to intervals of dominantly interannual variation. Large year-to-year variability presents a different challenge for water management from that presented by extended wet and dry intervals. In general, natural and socio-economic systems are able to recover from severe drought of short duration. Sustained drought has cumulative impacts on water balances and ecosystems, resulting in significant, sometimes irreversible impacts. Current water policy and management does not account for sustained dry spells lasting a decade or longer, because droughts of this duration did not occur in the 20th century.

Discussion

The most serious risk to the Canadian plains from climate change is the potential for water scarcity (Schindler and Donahue 2006). Recent trends and future projections include lower summer streamflows, falling lake levels, retreating glaciers and increasing soil and surface water deficits as more water is potentially lost by evapotranspiration. Western Canada is losing the advantage of a cold winter, where the accumulation of snow and ice produces a reliable and predictable supply of spring and summer runoff. Water scarcity would be a significant constraint on economic growth from expanded irrigated lands in the south or oil-sands production in the north. Thus water conservation will continue to be a major adaptation to climate change and variability. This includes water-pricing regimes to more accurately reflect the real costs of water treatment and supply and to ensure that an increasingly scarce resource is properly allocated.

The impacts of climate change on resource economies are necessarily adverse because resource-management practices have assumed a stationary hydrological regime. The realization that hydroclimates are far from stationary has come with the modelling of global warming (climate change forced by greenhouse-gas emissions) and from studies of past climate. The inferred paleosalinity of lakes (Laird et al. 2003), and long, moisture-sensitive tree-ring chronologies (e.g. Woodhouse and Overpeck 1998) reveal shifts in hydrologic regimes at decadal to century time scales. Water use, policy and management were established during a period of fairly stable and reliable water supplies as compared to the recent past (tree-ring and historical evidence of prolonged drought), recent trends (glacier wastage, and declining snowmelt runoff and summer flows), and GCM-based scenarios of precipitation, PET and runoff.

The analysis in this paper of recent and future flows in the North and South Saskatchewan River basins showed the important contributions of glacier runoff to the headwater catchments and the diminishing influence downstream and with time. Overall, the evidence indicates large changes in glacier extent with decreasing streamflow in glacierized basins, but no discernible trend to this point in non-glacierized catchments. Given the uncertainty associated with GCM predictions, hydrological models and current observation networks, it is difficult to quantify the exact magnitude of change. However, it appears that we are experiencing significant reductions in glacier extent and that this is manifest in decreasing streamflow both annually and in the late-summer periods. The changes will likely effect water resources in low-snowfall years, particularly during the transition-to-base-flow period in late summer. However, projected increases in precipitation may very well offset these reductions in mean annual flow, resulting in increasing spring snowmelt peak, but less water availability in the TBF period due to the lack of natural storage. These impacts will be particularly acute in mountain headwater basins. The impacts on the prairies will probably be less severe.

According to the Intergovernmental Panel on Climate Change (IPCC 2001), flow contributions from glacier sources should increase in the short to medium term, and decrease in the long term.

On the eastern slopes of the Rocky Mountains, there already is evidence during critical periods of a reduction in yield with reduced glacier area. This is amongst the strongest signals of the impacts of global warming in western Canada. Underlying this trend is the natural variability in hydroclimate, represented here by moisture-sensitive tree-ring records from the region. These data illustrate the significant multidecadal variability in the hydrologic system and suggest that future surface-water supplies very likely will be subject to a drought of longer duration than the most serious droughts experienced since Euro-Canadian settlement of the region.

Notwithstanding the uncertainty in climate projection, particularly estimates of precipitation, the science presented here has significant implications for water policy and management in western Canada. Agriculture is particularly sensitive to climate variation, and the irrigation sector in southern Alberta and southwestern Saskatchewan is vulnerable given its dependence on streamflow to overcome soil-moisture deficits (Alberta Environment n.d.; de Loë et al. 2001). About 70% of the irrigated farmland in Canada (400,000 ha) is in southern Alberta (Statistics Canada, Ottawa, www.statcan.ca). This is 4% of the cultivated land in Alberta, yet it produces 18% of the province's agri-food gross domestic product. In the South Saskatchewan River basin, about 75% of the allocated water is used for irrigation (Alberta Environment n.d.). This percentage rises to 86 in the Oldman River sub-basin. Between 20 and 30% of withdrawals are returned to the river system.

Irrigation is an adaptation to climate change and variability and the uncertainty of the natural precipitation regime. There is an elaborate network of canals, diversions and dams to store and redistribute the water and overcome the soil-moisture deficit across a large area. Irrigators have considerable adaptive experience given the history of adaptation to climate variability — mostly adjustments of policy and practices in response to drought, and also responses to increased demand and potential conflicts. There have been major improvements in the efficiency of irrigation and water-management systems. Water-rights transfers have been recently introduced to permit the transfer of the right to use water from one type of use, irrigation, to another, such as food processing.

Adapting to climate-change impacts on water resources requires adjustments to practices, policies and infrastructure in order to sustain economic development given shifts in mean hydroclimatic conditions and variability. Management strategies and structures have evolved to limit exposure to a historical range of hydroclimatic variability. Paradigms and practices of water management must be adjusted to manage a hydrological cycle that may be increasingly sensitive to the timing and frequency of rainfall events, with less of a buffer from glacier ice and late-lying snow at high elevations. Sensitivity to drought suggests that our communities and institutions are not adequately adapted to climate variability, even in the absence of climate change that could produce shifts in the amplitude and frequency departures from an average climate. The principles of adaptive, anticipatory and integrated water-resource management, which include monitoring and scientific discovery, would seem to provide the framework for adapting to the greater range of hydroclimatic variability anticipated for the 21st century:

> Adaptive management explicitly accepts indeterminacy, ignorance, uncertainly and risk; the inevitability of surprise and turbulence; and the need for flexibility. It supplements traditional approaches characterized by a belief in rational, comprehensive models of thinking and analysis. [It] simply recognizes that planners and managers have imperfect knowledge and understanding, and that even when trying to be anticipatory and preventive they will

undoubtedly encounter surprises, and require the modification of policies and activities. (Mitchell and Shrubsol 1994: 55)

Knowledge of the current state of the climate system, and systematic tracking of the gradual changes occurring in these large systems, requires large investments in data collection and science. There are important economic justifications for understanding and monitoring progressive changes in support of adaptation. Past trends are really the only systematic way to understand and validate possible future scenarios.

Acknowledgements

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Yuksel Inan, Session Chair:

Thank you, Dave. Right now we will have the second speaker, Richard Adams. He's going to talk to us about the implications of climate change for upland watersheds. Richard is a professor of agricultural and resource economics from Oregon State University. He's awarded as a Distinguished Fellow of the American Agricultural Economics Association. His current research interests focus on the economic effects of air and water pollution and the implications to climate change, agriculture and water resources. He's a member of various governmental committees and has numerous articles in various prestigious journals. The floor is yours.

Climate Change and Water Resources: Potential Impacts and Implications

Richard M. Adams, Professor, Department of Agricultural and Resource Economics, Oregon State University, Corvallis, Oregon, U.S.A.
Dannele E. Peck, Assistant Professor, Department of Agricultural and Applied Economics, University of Wyoming, Laramie, Wyoming, U.S.A.

Introduction

The recurring drought and heat observed over large portions of the western U.S. have generated adverse and costly effects, including lost agricultural productivity in rain-fed regions of the Midwest and the Great Plains, record wildfires in Oregon, Colorado and California, and large fish kills in California's Klamath River triggered by warm water temperatures. Drought has persisted for nearly a decade in some regions of the western U.S., leading to severe stress on water resources. The intensity and frequency of recent droughts, coupled with increased frequency of other extreme weather events such as hurricanes, and rising temperatures observed globally over the past decade have raised concerns that fundamental climate shifts may be occurring in North America and elsewhere.

This paper reviews the current understanding of possible impacts of global climate change on water resources, with emphasis on the frequency and intensity of drought. The focus on drought rather than on long-term climate change more generally is intended to provide managerial and policy relevance to what otherwise is an overwhelmingly complex topic. The physical and economic consequences of drought are discussed, as well as the potential to mitigate the adverse consequences of these events through changes in water-resource management, such as using long-term forecasts and other meteorological information. Examples from empirical research which address water-related problems in upland settings of North America are also provided.

Background

A range of potential effects of global climate change on water resources and agriculture has been suggested (see recent reports from the Intergovernmental Panel on Climate Change [IPCC]). These include increased surface temperatures and evaporation rates, increased global precipitation, increased proportions of precipitation received as rain rather than snow, earlier and shorter runoff seasons, increased water temperatures and decreased water quality. Variability in precipitation patterns is also expected to increase, resulting in more-frequent droughts in the western U.S. and elsewhere (see Adams et al. 1999 for a detailed review of the effects of climate change on agriculture and agricultural resources).

The economic consequences of drought are well-documented. On average, annual costs in the United States due to drought are estimated at $6 to 8 billion (Knutson 2001). Flooding and hurricanes, despite being more publicized than drought, are reported in the same publication to be responsible for only $3.6 to 7.2 billion in annual damages combined, although this estimate will quite likely be higher when damages from the 2005 hurricane season (i.e. Katrina) are included. Some of the economic costs of drought arise from direct physical impacts such as crop failure, municipal water shortages, wildfires, and fish and wildlife mortality. However, indirect effects are also important. For example, water deficits reduce hydroelectric power generation and increase electricity prices. The National Oceanographic and Atmospheric Administration (2002) and Claussen (2001) offer comprehensive discussions of the physical and socioeconomic impacts of drought in the United States.

Water-resource managers, agricultural producers, timber managers and policy-makers can reduce the negative effects of drought through a number of strategies. These include revising water-storage and -release programs for reservoirs, adopting drought-tolerant cropping practices, adjusting crop insurance programs, pre-positioning fire-suppression equipment and supporting water-transfer opportunities. The ability to anticipate and efficiently prepare for future drought conditions is currently limited, however, by imprecise long-term weather forecasts and climate models. Improvements in some forms of climate forecasts, such as those associated with the El Niño–Southern Oscillation phenomenon (ENSO), offer potential for reducing the impacts of both drought and flooding. Nevertheless, the economic costs associated with drought could be further reduced if drought-forecast improvements increased the ability to detect drought further in advance, enhanced forecast accuracy and improved the geographical detail of forecasts to pinpoint drought location, intensity and duration.

Global Climate Change, Water Resources and Drought

The ability of the earth's atmosphere to trap solar radiation and increase global temperature (the so-called "greenhouse effect") has been recognized for at least 150 years. More recently, global climate change has been a topic of intense scientific and political debate. Certain pieces of evidence are unequivocal: carbon dioxide (the most abundant greenhouse gas in the earth's atmosphere) concentrations have been increasing steadily for over a century. Specifically, CO_2 levels have increased 30% since the late 1800s and are higher now than they have been in the last 400,000 years (National Assessment Synthesis Team [NAST] 2000). The decade of the 1990s was also the warmest (on a global scale) in over a century. The average annual temperature of the United States has risen almost 0.6°C (1.0°F) over the 20th century (NAST 2000). The role that humans have played in recent global warming, and whether it is possible to offset that effect in any meaningful time scale, is still debated. The belief that global warming will continue, however, is becoming more widely accepted in the science and policy communities. It is therefore prudent to consider both the impacts of such warming, and mechanisms to adjust to those effects.

Several general circulation models (GCMs) have predicted that U.S. average annual temperatures will rise 3 to 5°C (5 to 9°F) over the next 100 years (NAST 2000). Atmospheric scientists anticipate that numerous climatic effects will arise from these increasing temperatures. For example, precipitation, which has increased in the U.S. by 5 to 10% over the 20th century (IPCC 2001*a*), is predicted to continue to increase in many regions, particularly those at higher latitudes (Frederick and Gleick 1999; Gleick 2000). Two GCMs — the Canadian Climate Centre, and the Hadley Centre in the United Kingdom — have projected specific precipitation changes across the U.S.

These include 25% precipitation increases in the Northeast, 10 to 30% increases in the Midwest, 20% increases in the Pacific Northwest, 10% precipitation decreases along the southern coast of Alaska, and up to 25% declines in the Oklahoma panhandle, northern Texas, eastern Colorado and western Kansas (NAST 2000). Caution should be exercised in using any of these as predictions, given the coarseness of geographical scale in existing GCMs.

Water Quantity, Timing and Quality

Increases in precipitation, given warmer atmospheric conditions, will not necessarily mean more available water at the state or regional level. The higher evaporation rates that accompany rising temperatures are expected to result in less water being available in many regions (Frederick and Gleick 1999). For example, GCMs project global average evaporation to increase 3 to 15% with doubled CO_2 levels (Gleick 2000). Simulation studies suggest that precipitation must increase by at least 10% to balance evaporative losses resulting from a 4°C temperature increase (Gleick 2000). Projections of rising evaporation rates indicate that they will outpace precipitation increases, on a seasonal basis, in many regions (IPCC 1998; Gleick 2000). The greatest deficits are expected to occur in the summer, leading to decreased soil moisture levels and more-frequent and -severe agricultural drought (IPCC 1998; Gleick 2000).

Shifts in the form and timing of precipitation and runoff, specifically in snow-fed basins, are also likely to cause more-frequent summer droughts. More precisely, rising temperatures are expected to increase the proportion of winter precipitation received as rain, with a declining proportion arriving in the form of snow (IPCC 2001*b*; Frederick and Gleick 1999). It is expected that snowpack levels will form much later in the winter, accumulate in much smaller quantities, and melt earlier in the season (IPCC 2001*b*).

These changes in snowpack and runoff are of particular concern to hydro-power generation, irrigated agriculture and commercial and recreational fisheries. For example, if the runoff season occurs primarily in winter and early spring rather than in late spring and summer, water availability for summer-irrigated crops will decline during the crucial spring and summer months, causing water shortages to occur earlier in the growing season. The timing of runoff will affect the value of hydro-power potential in some basins if peak water runoff occurs during non-peak electricity demand. Shifts in runoff, precipitation and evaporation patterns may also intensify interstate and international water-allocation conflicts as water managers struggle to meet the obligations of compacts and court decrees given more-variable water availability and timing in headwater areas.

A shift in stream hydrographs to greater winter flow may also disrupt the life cycle of anadromous species, such as salmon, which depend on late-spring flows to "flush" young salmon to the ocean. Unless reservoir systems are in place to capture and store winter runoff for late-spring or summer use, reduction in summer flows is expected to lead to higher water temperatures. Summer temperatures already exceed the lethal levels for salmonids and other coldwater fish species in some streams in the U.S. and Canada; further warming could lead to more-frequent fish kills, such as those observed recently in the Klamath River, in northern California.

Water-quality impairment is also predicted to increase under climate change (IPCC 2001*b*; NAST 2000; Gleick 2000). Specifically, precipitation is expected to occur more frequently through high-intensity rainfall events, causing increased runoff and erosion. Sediments and pollutants such as fertilizer will be transported into streams and groundwater systems, decreasing water quality

(Gleick 2000). Water quality will also be impaired in areas receiving less precipitation as nutrients and contaminants become more concentrated (IPCC 2001*b*).

Rising air and water temperatures will also impact water quality by increasing primary production, organic-matter decomposition, and nutrient-cycling rates in lakes and streams, resulting in lower dissolved-oxygen levels (IPCC 2001*b*). Increased evaporation rates from open water bodies threaten to increase the salinity of surface water. Lakes and wetlands associated with return flows from irrigated agriculture are of particular concern (IPCC 2001*b*). Water-quality impairment is thus a threat to agricultural water supplies, as well as to fish and wildlife (Adams et al. 1988).

Coastal areas are additionally at risk of water-quality impairment due to saltwater intrusion (Frederick and Gleick 1999). As global temperatures increase, seawater warms, causing ocean density to decrease and sea levels to rise (Solow 1993). Sea levels are also rising in response to the melting of land ice, which includes glaciers and the Greenland and Antarctica ice sheets (Solow 1993). Global sea levels rose 10 to 20 cm during the 20th century (NAST 2000). The Intergovernmental Panel on Climate Change projects a sea-level rise over the next century of 38 to 66 cm (Claussen 2001). Rising sea levels may also affect water availability indirectly by causing water tables to rise. Higher water tables cause surface runoff to increase at the expense of aquifer recharge. Groundwater quality and recharge are impaired by rising sea levels and saltwater intrusion. Radical changes to the freshwater hydrology of coastal areas, caused by saltwater intrusion, threaten many coastal regions' freshwater supplies.

El Niño–Southern Oscillation and Seasonal to Interannual Climate Variability

The possible long-term effects of global climate change on drought and other extreme weather phenomena are based on climate models that are associated with high levels of uncertainty, particularly at the regional or state level. A more immediate and predictable effect of climate change is the anticipated increase in the frequency of ENSO events and the intensity of ENSO-related droughts and floods (IPCC 2001*a*; Gleick 2000).

The El Niño–Southern Oscillation (ENSO) is a natural weather phenomenon resulting from interactions between the atmosphere and the ocean in the tropical Pacific Ocean (Trenberth 1996). The concurrent weakening and strengthening of ocean and air currents causes warm and cold ocean currents to mix, with one covering the other (warm water over cold during an El Niño; cold water over warm during a La Niña) (IPCC 2001*a*). Changes in the thermal profile of ocean currents alter winds, sea surface temperatures and precipitation patterns in the tropical Pacific, and drive climatic effects throughout much of the world (IPCC 2001*a*).

El Niño and La Niña events are associated with both droughts and floods in many regions of the globe. For example, El Niño events cause drier winters in the northwestern U.S., the Great Lakes region, southwestern Mexico and parts of South America but cause increased precipitation in southern California (IPCC 1998). The effects of global warming on the behaviour of ENSO events are uncertain. However, more-frequent ENSO events, as suggested by Timmermann et al. (in Gleick 2000), would increase the variability of precipitation and streamflow in many ENSO-sensitive regions of North and South America (IPCC 1998), leading to greater risk of droughts and floods (IPCC 2001*a*).

The negative economic consequences of ENSO events in North America have been estimated in several studies (e.g. Adams et al. 1995 and Chen et al. 2001 for the U.S.; Adams et al. 2004 for

Mexico). ENSO-related droughts have historically caused billions of dollars in damage annually in the United States, as have ENSO-related floods. Increased drought frequency and intensity under global-warming scenarios threaten to increase these damages unless adaptive measures are taken.

Examples of Water-resource Challenges in the Uplands

Upland areas in much of North America are largely devoted to agriculture or forestry uses. In addition to timber, forested areas produce a range of marketed and non-marketed ecosystem services, such as recreational activities, habitat for fish and wildlife, and the sequestration of carbon. In regions where agriculture is the dominant land use, it provides not only food and fibre but also positive and negative externalities, ranging from open space and carbon-sequestration potential, to air and water pollution. Earlier discussions in the paper highlighted some possible effects of climate change, primarily drought, on these activities. This section provides a more detailed examination of means of mitigating a few of these effects — specifically, the effect of prolonged droughts on irrigated and rain-fed agriculture in Oregon and southwestern Mexico, and the impacts of rising water temperatures on salmonid production in the Pacific Northwest.

Agriculture and Climate Change

Numerous studies have estimated the effects of climate change on agriculture and agricultural resources (see Adams, Hurd and Reilly for a review of these studies). Most of the early studies focused on changes in "average" climate over relatively large regions. More recently, attention has focused on changes in climatic variability which may arise from the general warming of the earth's atmosphere. As noted earlier, this variability is expected to manifest itself as more extreme weather events, such as droughts or floods, or more systematic climate anomalies, such as the El Niño–Southern Oscillation phenomena.

Two recent studies address the consequences and mitigation possibilities for agriculturalists in dealing with two aspects of changes in weather variability. The first (Peck and Adams 2006) estimates the effects of more-frequent and -severe drought on irrigated agriculture in the Pacific Northwest. The other (Adams et al. 2004) assesses the impacts and adjustment possibilities for rain-fed agriculture in southwestern Mexico. Each is described briefly below.

In the first study, Peck and Adams develop a six-year farm model within a dynamic and stochastic decision environment in order to examine the effects of increased drought frequency and intensity on irrigated agriculture. The model is parameterized for a representative mixed-crop farm in eastern Oregon. The farm receives water from the irrigation district's reservoirs, which store spring snowmelt from the mountains. The water allotment for the upcoming growing season is uncertain (known only in probability) at the time a producer makes fall decisions. Producers therefore choose fall activities that maximize expected profit over the planning horizon. The water supply is revealed in early spring, after which spring decisions are made. Fall decisions constrain spring decisions, which creates intra-year dynamics. The farm system also includes agronomic constraints that generate inter-year dynamics. The model is solved for the following four climate scenarios: base case, increased drought frequency (Case 1), increased drought intensity (Case 2) and increased drought frequency and intensity (Case 3). The three climate-change scenarios' relative impacts on expected farm profit and cropping patterns, as compared to the base case, are discussed below.

The following table summarizes the impact of the climate-change scenarios, when responded to optimally, on expected profit for the 6-year period, standard deviation of profit, minimum profit (when 6 years of drought are experienced), and maximum profit (when 0 years of drought are experienced). Note that the probability of a 6-year drought increases from 0.4% to 1.6% when the frequency of drought increases from 4 to 5 out of 10 years.

Case	**Drought frequency** (x of 10 yr.)	**Drought intensity** (water supply in ac-inch/ac)	**E (profit)** (US$1,000) [% change]	**Std. Dev.** (US$1,000) [% change]	**Min. profit** (US$1,000) [% change]	**Max. profit** (US$1,000) [% change]
Base	4	24	1,328	19	1,297	1,349
1	5	24	1,324 [–0.3]	14 [–25]	1,303 [+0.5]	1,345 [–0.3]
2	4	18	1,257 [–5.4]	77 [+310]	1,126 [–13.2]	1,331 [–1.3]
3	5	18	1,248 [–6.0]	15 [–21]	1,224 [–5.6]	1,272 [–5.7]

The impact of increased drought intensity (Case 2) on expected profit, standard deviation and minimum and maximum profit is more severe than that of increased drought frequency (Case 1). Producers adapt to increased drought frequency by reducing the concentration of high-value, fall-prepared crops in any particular year of the planning horizon, which reduces the risk of crop failure in the event of a dry year. Producers adapt to increased drought intensity by decreasing the acres of low-value, fall-planted crops and the acres of crops with low profit per acre-inch of water. These adaptations provide more flexibility in the spring plan, after the water allotment is revealed, and save more water for high-value crops in the event of a dry year. In both cases, producers also shift irrigation technology for some crops from furrow to furrow with tailwater reuse. When both drought frequency and intensity increase (Case 3), expected profit is only slightly less than when drought intensity alone increases. Standard deviation and minimum profit are actually better for Case 3 than Case 2, although maximum profit is not. Producers adapt to Case 3 using a combination of the adaptations seen for Cases 1 and 2. Producers, in summary, are better able to mitigate for more-frequent moderate drought than for less-frequent but more-intense drought. The implication of climate change for agriculture clearly varies depending on the distributional characteristics of the affected water supply.

In the second study, Adams et al. develop a profit-maximizing mathematical model of crop production in five southwestern states of Mexico in order to assess the economic consequences of ENSO events and to identify possible actions by which negative impacts can be minimized. The model encompasses the large number of crops found in the region and is representative of current cultural and agronomic practices in the area. The effects of weather associated with three ENSO states (El Niño, La Niña and Normal) on crop yields are modelled with plant biophysical simulation models. The main behavioural response of producers is to change crop mixes in anticipation of various ENSO states. The advantage of such behaviour is reflected in the difference between profits made using decisions based on events' historical probability of occurrence and those made using decisions based on a long-range forecast of such an event, as is now commonly available from NOAA and Mexican climate agencies.

The results indicate that the three ENSO events affect agriculture in different ways. Specifically, an El Niño results in economic losses across the region amounting to almost $1 billion pesos, whereas a La Niña slightly increases total production and profits. Thus, if El Niño events become more common as a result of climate change, the expectation is for increased economic losses in this region. The results also reveal that a strategy of using pre-season ENSO forecasts in planting decisions can offset some of the expected losses of an El Niño and increase some of the benefits that may follow from a La Niña event. In the case of an El Niño, the use of forecasts to make crop-mix decisions can offset 15 to 20% of the losses associated with the use of traditional crop mixes. These estimates assume that forecast accuracy is approximately 70% (prob. 0.7); lower or higher levels of accuracy will affect the gains from using forecasts. The implication is that the use of forecast information, coupled with flexibility in planting and other cultural decisions, will be increasingly important in dealing with a more variable climate.

Water Quality and Fisheries

The streams that drain upland areas in the Pacific Northwest, western Canada, and Alaska provide critical breeding and rearing habitat for salmonids and other cold-water fish species. Salmon play an important commercial, recreational and cultural role in this area and have been a religious icon for native peoples for thousands of years. Salmon populations are depressed in many parts of the region due to a number of factors, including overharvesting, dams, logging, and water diversions. Some populations within the U.S. are sufficiently depressed to be listed as "endangered' or "threatened" under provisions of the *Endangered Species Act*. Warming water temperature in streams has recently been recognized as another threat to salmonids. Causes of this warming include mismanagement of riparian zones in the uplands, water diversions, and general atmospheric warming.

Continued climatic warming is expected to exacerbate rising water temperatures. In anticipation of this effect, Oregon and other states have enacted temperature standards for the protection of salmonids under the Total Maximum Daily Load provisions of the *Clean Water Act* (as amended). Although the temperature standard may vary by location and season, it is approximately 17°C. The challenge to managers for achieving this standard is that most streams currently exceed it during at least part of the year. In some cases, temperatures exceeding lethal levels (24–25°C) are observed during critical summer and fall periods.

Several studies have examined least-cost ways to meet the TMDL standard for temperature. One study (Watanabe et al. 2006; Watanabe et al. 2005) focuses on a higher-elevation, mid-size stream in eastern Oregon (the Grande Ronde River), while the other (Seedang, Adams and Landers) addresses temperature issues in a larger stream in western Oregon (the Willamette River). Both streams are home to several salmonid species, and both contain stocks of these species which are listed as endangered or threatened. Although their stream locations and geomorphology differ, the studies are similar in that they combine input and models from hydrology, forestry, geomorphology and economics to develop cost-effective management regimes that achieve the temperature standard.

Several findings are common to both studies. First, in some regions of each watershed, it is not possible to meet the standard under any management regime. This calls into question the nature of the standard, given that future climate warming will increase the areas in violation. Failure to meet the standard, however, does not mean that some cooling will not be beneficial. Second, in areas that can reach compliance, a range of management actions are required to achieve the standard in a cost-effective manner, including riparian restoration, streamflow augmentation and river channel restoration to increase hyporheic cooling. Third, the results suggest that targeting of key reaches or areas of the watershed is needed to achieve the standard cost-effectively. This implies that location matters in stream management and that a one-size-fits-all regulatory regime is not likely to be successful or cost-effective today, nor in a warming world with increased climate variability.

Coping with Drought and Other Events: The Case for Climate Forecasts

One step towards preparing for potential increased frequency and intensity of drought, ENSO or other climate events is an improved understanding of potential regional precipitation and evaporation shifts under a changed climate. The accuracy, precision and timing of seasonal or longer-term forecasts are likely to affect their adoption by farmers and other resource managers. Providing reliable year-to-year forecasts of precipitation is difficult; decadal forecasts as provided by GCMs are even more problematic. However, as noted in the previous sections, some types of forecasts, such as those associated with ENSO events, are becoming more reliable (NAST 2000; Trenberth 1996). Adaptation strategies to ENSO events, such as changing crop mixes, are currently being practised in many parts of the western hemisphere.

More-accurate, -precise and -timely forecasts can reduce the risk for decision makers and decrease economic losses due to drought (see NOAA 2002). Current drought-management tools can also be reassessed and revised in light of the more reliable information provided. For example, drought-insurance programs may need to revise coverage conditions and premiums in order to provide efficient coverage in the changed climate. Increased crop diversity on individual farms or in economic regions could also reduce losses during extreme weather events (IPCC 2001*b*). Reservoir capacity, timing of water releases, and safety will need to be reconsidered and updated as well. Voluntary water transfers, with or without climate change, will become an increasingly important tool to mitigate water-distribution problems. Municipalities are currently considering the vulnerability of their fresh surface- and ground-water supplies to drought, pollution and saltwater intrusion, and they may need to consider new protection programs and supplemental water sources. Improved confidence in regional forecasts of climate-change impacts is, however, of primary importance in helping regional managers understand risk levels, identify management priorities and define realistic adaptations.

Summary

Global climate change is likely to increase the frequency and intensity of drought for many regions of the world. Although subject to substantial uncertainty, regional forecasts of long-term climatic change from GCMs do offer a glimpse into possible future climatic conditions. Predicted impacts vary by region but include increased temperatures and evaporation rates; increased but more variable precipitation; higher proportions of winter precipitation arriving as rain rather than snow; earlier and more severe summer drought; and decreased water quality.

Drought currently results in substantial economic losses in the United States annually. These losses, which occur across a range of sectors from agriculture and energy to recreation, have profound effects on local communities. More-frequent or -intense droughts imply increased costs to society unless agricultural producers, water users and others are able to adapt. Improved forecasts concerning future drought conditions, particularly at the regional scale, are necessary for managers and policy-makers to identify efficient adaptive strategies and to reduce the economic costs of drought.

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Yuksel Inan, Session Chair:

Now we have Adèle Hurley as a discussant. She is within the University of Toronto at the Munk Centre for International Studies, where she is Director of the Program on Water Issues. A short biography: In 1980, during the Reagan administration, she co-founded the Canadian Coalition on Acid Rain. After that, she worked on a successful campaign aimed at bringing about amendments to the *U.S. Clean Air Act*. In the 1990s, she was appointed to the Board of Directors of Ontario Hydro, where she served as the first Chair of the Environmental Committee. In 1995, she was appointed by the Prime Minister's Office to serve as Canadian Co-chair of the International Joint Commission. Later, she served as a member of the Canadian federal government's International Trade Advisory Committee Task Force on Environment and Trade Policy. Please welcome our discussant, Adèle Hurley.

Adèle Hurley, Session Discussant:

I found these two papers to be relatively straightforward and largely in agreement. Essentially, the Adams and Peck paper finds that climate change will affect forestry, fishing and agriculture in the Pacific Northwest. Frequency and intensity of droughts will determine our ability to adapt. We don't have much ability to adapt to long droughts; the salmon fisheries will probably disappear.

The Sauchyn, Pietroniro and Demuth paper, while more detailed, reinforces the same key finding: we don't know how to deal with long droughts, and we really haven't planned for any. The extensive loss of glacier ice — as much as 50 per cent in some catchments — means that we have lost our insurance, or backup, when it comes to coping with dry spells. Key indicators point to water towers of the Eastern Slopes producing less water and lower streamflows when water is needed most: a slow-moving emergency for water in the West.

Dave Sauchyn's helpful introduction of tree-ring data, or dendrology, shows that recent Prairie occupants are living in somewhat of a fool's paradise; we're living in relatively wet times. We've yet to experience the droughts that can occur — and when we do, we'll likely experience them with reduced glacier insurance. All of which means that none of us is really ready for long-term aridity.

The paper cautions us to be on the lookout for what might be termed "counterintuitive" phenomena, when trying to assess change. It says: "It appears that we are experiencing decreasing streamflow, both annually and in the late summer. The changes will likely affect water resources in low-snowfall years, particularly during the transition-to-base flow period [TBF] in the late summer. However, projected increases in precipitation may very well offset these reductions in mean annual flow, resulting in increasing spring snowmelt peak, but less water availability in the TBF period due to the lack of natural storage." In essence, climate change + natural variability = vulnerability.

So the question is: How does a society go about limiting its exposure? To some extent, the past is prologue, but not entirely. It would seem somewhat disingenuous to be sitting in Banff, talking about drought cycles, receding glaciers and adaptation options, just a few hours' drive from the oil sands. We know that oil-sands development is occurring at a rate and scale that are unprecedented. Just last week, the outgoing premier of Alberta acknowledged that the province was unprepared for this level of growth. On a national level, the oil sands are going to contribute enormously to Canada's greenhouse-gas emission levels. We have yet to determine where the credits will come from, by which we will offset these emissions. But surely, if we are about to have a valuable discussion about upland watershed management and environmental impacts in the face of global climate change, we need to include a plan, in this part of the world, for controlling the greenhouse gases that are about to engulf us from just up the road.

Who can envy the tough calls that our government officials and politicians are now being required to make? It's hard work, but many people are prepared to help, from across the political spectrum. It is opportunities, such as the one provided here at the Rosenberg International Forum on Water Policy, and science, such as that provided by Rich Adams and Dave Sauchyn, that are helping us to frame the discussion we are about to have, Mr. Chairman — a discussion that, conducted in good temper, is likely to benefit, by viewing receding glaciers and water shortages as incentives for innovative measures to reduce, limit and offset greenhouse-gas emissions. Thank you.

Mordecai Shechter:

I'm glad that climate-change impact on water resources is being explicitly discussed. In retrospect, I think we should have paid more attention to it in previous Rosenberg Forums, and I really should thank Bob Sandford for pushing the idea that we must have it in this conference. That's a footnote. Now one point: I enjoyed the two presentations and I would like both David and Richard to also relate to another concept, which was not mentioned. You both stressed the importance of dealing with variability, and you are absolutely correct. It's not the means and the trends; it's variability. We also know that a lot of work is being done on adaptation — both of humans, and also of ecological societies, which are less capable of adapting, but they could also adapt, although the question is what will come out of the adaptation. The question that I think we economists have overlooked, and that natural scientists have stressed because it doesn't involve cost-benefit analysis, is the concept of precautionary attitude, precautionary policies. I didn't hear that word — because in dealing with variability, it's again not the variability for which we can assess the distribution functions, but the variabilities of which we have complete ignorance. In other words, catastrophes whereby there are non-linearities, as Holger pointed out — due to which humans societies, but certainly natural systems, could completely break down. And this is not easily amenable to economic analysis. I would like to hear from both the natural scientists and Richard, the economist: How would you relate to this issue, which is gaining importance in climate-change deliberations? Thank you.

Dave Sauchyn:

Well, I'm familiar with the precautionary principle and the related concept of no-regrets adaptation, and certainly there's a lot that can be done in terms of making adjustments to policy, practices, infrastructure and public attitudes and behaviour. There are a lot of adjustments that aren't that costly and represent adaptations to climate change; a very good example that's relevant here is water conservation. Water conservation is a good idea for a variety of reasons, and it also represents adaptation to climate change where you expect to be exposed to declining water supplies.

Richard Adams:

This is really an important question, and it's something we really probably could discuss for hours and probably need to over some wine this evening; but, very quickly, I agree that we have various concepts within economics and risk, in decision theory, which give us general guidelines on what to do when confronted with the kind of situation Mordecai is explaining. From a practical standpoint, I think probably the best thing we have going for us in the United States in the short term — at least with respect to one aspect, and that is biodiversity — is the *Endangered Species Act*, because the *Endangered Species Act* basically forces us to save things. Unfortunately, it's on a species-by-species basis, not ecosystems; but that puts, in essence, a floor there that we have to do whatever it takes to protect the species. That's going to become increasingly difficult with a more variable climate, but at least it's focusing attention on the part of scientists and policy-makers on what strategies might be effective in minimizing the probability of extinction, which would be one of those catastrophic events. As far as other issues, I don't think we have anything within the political realm which gives us the leverage to take the kinds of actions that might be needed. So I guess I'm less optimistic in the short term, until there's perhaps a political will to investigate those questions and do some accepting of the fact that we don't live in a static environment. Things are changing, and we need to make decisions in the long term which reflect that change.

John Pigram:

First of all, let me put my position, and I do have one or two supporters. As far as climate change goes, I'm a skeptic. The jury is still well and truly out on climate change, despite the sophisticated models that are put forward. Remember, they are models. They are models and they are based on a lot of assumptions, scenarios, extrapolations, so I want more time before I'm convinced that these predictions are going to come true. But assuming these speculations are half right; then the appropriate response is adaptation. And I'm pleased to hear the gentleman at the end mention a no-regrets approach. It's the first time I've heard it in this forum. It is in my view the one thing anybody who is using water can do. That is to say, you take steps to upgrade your management of water — whether it's in the backyard in your garden or whether it's in your irrigation farm or whether it's in your brewery — which will pay off whether or not climate change occurs. If it doesn't occur, you're still in front. If it does occur, well, you've taken steps to cope with it. And just one final point to the lady here on my left: I'm not a technologist as far as extraction of oil from tar sands, but I do realize the potential of this in Alberta and other places and I do know that it takes some amount of water. But I just would like to raise the point: Does that water have to be first-class water? I would think it shouldn't have to be. In other words, we can substitute lower-grade water to help with the extraction process, whether that lower-grade water is brackish water or even moraine water, and that will help us with our extraction process. Thank you.

Dave Sauchyn:

I'd like to comment on the climate skeptic. With all due respect, John, there no longer are climate skeptics in the community of active climate-change scientists. And I say that because I'm currently involved in the Fourth Assessment of the Intergovernmental Panel on Climate Change. I have the good fortune to be invited to participate. I expect that there probably are other people in this room who are currently involved in the Fourth Assessment, and we all know how influential and rigorous that process is. The report of Working Group I will be released early in 2007 and I've been able to see a draft; the basic conclusion is that there is now 100% consensus among climate-change scientists that, of course, the climate is changing because the climate is always changing, but that there is global warming and that is due in part to human activities. Three weeks ago, I was at a small climate-change workshop, just a few people, in Bozeman, Montana, and we were joined by Bill Ruddiman, who is a very prominent climate-change scientist. He's the author of the book *Plows, Plagues, and Petroleum*, and he said that even five years ago he was a bit skeptical, but he said that all the doubt has been eliminated in the last few years and, as I said, you can't find a credible, active climate-change scientist who will suggest that the climate is not warming.

Richard Adams:

I would agree that we ought to search for solutions to any resource-allocation problem in order to improve our use of that resource, regardless of what the current motivation is; so I would agree, putting aside the issue of climate change, that moving towards a more rational, if you will, management of resources makes sense, and I think the marketplace does have something to say about that as some of these resources become scarce or the prices go up and people have an incentive to conserve. So I'm reasonably comfortable that we will be conserving water and we will move water around to more highly valued uses. My concern, though, is that there are a lot of things we currently seem to value for reasons other than their commodity value which don't get reflected in markets, and to that extent, what are the "no regrets" with respect to those things, such as species preservation? My concern would be that those would not be effectively addressed through a no-regrets strategy that used traditional economic measures.

Domingo Jimenez:

I must say I'm prompted to intervene, having heard the statement from David Sauchyn that we have to accept drought as normal. I think that for us Spanish, it's very interesting to hear that in Canada, because even in Spain, where we have a big drought now, we do not accept drought as normal. I think this is a key issue. I'm very glad that Mordecai mentioned the precautionary principle. Why? Because what we have heard this afternoon is clear. Things are increasing. I mean that we have to act on climate variability, climate change. That, of course, is clear now. We don't know how far, how soon or how fast. So we've got to decide on the conditions of uncertainty. So my question to you is: Wouldn't it be wise to act under those conditions? To go a little away from the red line, to increase our capacity for manoeuvring. When we know that the red line is going to move, and not in a good direction, wouldn't it be fair to move into policies of managing water and the conditions of quality? I think we have heard today many interventions about how we can move to demand management. My feeling is, to be honest, that we could do all that, provided there is the political will. In the end, the market is the result of a political decision. The conditions are that you can do demand management, you can do cost internalization, provided you want it; so the difficulty is not technical, excuse me, it's political. Who ever wants to internalize cost in the price of water? Who wants to manage demand? Water companies? Not many of them want to do that. I have heard of people not interested in subtly reducing demand. So I think it's a key issue whether we really can ask for policies under conditions of quality and move really strongly into demand management, because now the red line, as you have put it today, is moving closer to us. Thank you.

The Right Honourable Herb Gray:

My questions are very much as a layman and I hope the scholars and experts will bear with me. When I listened to the papers, it wasn't clear to me whether they were dealing with climate change that occurs over the centuries, dating back hundreds if not thousands of years, or climate change that is man-made. Dr. Sauchyn's answer to one of the comments suggested that we're dealing primarily with man-made climate change, but I'd appreciate it if the other discussants would clarify that. I ask that because if the climate change we're talking about is man-made, we obviously need more than adaptive measures. We need to do things to change what people are doing to create greenhouse gases and global warming. My second point, which may seem unrelated, is that there are people who say that the world is reaching the "tipping point", when there won't be enough water for growing populations, not just in North America but around the world. On the other hand, when Dr. Asit Biswas gave his lecture in response to being awarded the Stockholm Water Prize, he seemed to say in his remarks that there was enough water, provided it was managed properly.

Richard Adams:

In answer to your first question, there is a literature on adaptations that's quite large, dealing with how we might respond to climate change regardless of the source, whether it's anthropogenically induced or whether it's natural. The literature just presumes — and I'm speaking from the economic literature — that climate will change by certain amounts as simulated by the general circulation models that most of us get our data from. As was mentioned, these are based on models. The models are forecasting change over the next 50 to 100 years, so in some of the economic assessments we do, we put in changes as best we can forecast, of technology and so forth, in the year 2100. You don't want to impose the 2100 climate on the 2001 technology. That would be silly, because we are going to change; there will be technological change. So the way we've done it is just to assume that the climate is changing as it has been forecast to change from the models, and I would leave it up to the modellers, or people who are more skilled in atmospheric science, to tell me what percentage of that is driven by presumed anthropogenic increases versus natural.

The adaptations are what we do in response to it. The other point that you made is a very good one, and that is mitigation. That was the point I was referring to with respect to things like carbon sequestration: things that could be a bridge to get us out of the current situation of carbon dependency until the year 2100 or 2200, when I'm confident, if we're still alive and haven't wiped ourselves out due to something else, that we will have bridged to a different energy base — one would hope hydrogen that's based on something other than extracting it with electricity — but the mitigation that's being discussed in IPCC and other reports does talk about things that can be done to absorb CO_2 under the presumption that it is coming from primarily anthropogenic sources.

In part, your second question had to do with supplies of water, and I think most people who study the demand for water say there's actually plenty of water to go around, or plenty of water if you want to price it at a certain level. The problem with that is there are parts of the world where the people have difficulty paying for water in the sense that we would think of it in the United States or in Canada. So there are probably people in this audience who have much more experience in the other parts of the world in whether water is physically constraining or economically constraining in terms of the ability to produce food.

Dave Sauchyn:

The future climate will be a combination of the climate that would have occurred anyway plus the effect of human beings, and I don't think anybody can tell what proportion of that is due to the greenhouse gases that we produce. But the fact is that climate modellers can only reproduce the current warming if they include the effect of human beings. If you exclude the effect of human beings, then these models show that there should be no warming, or even a slight cooling, when in fact we have a fairly significant warming.

In terms of adaptation, as Richard said, there is a rich adaptation literature. One of the foremost scholars is Barry Smit from the University of Guelph, Ontario, and he's written extensively about this concept of adaptive capacity. Our capacity to adapt, to change, is a function of many things, but they include fiscal wealth, infrastructure, natural capital, intellectual capital, technology. And if you take those determinants and apply them to Alberta, you have to conclude that there are very few places in the world that have the capacity that Alberta has to adapt. It's rich. But it takes one more element besides adaptive capacity. It takes the willpower to change, and that's what seems to be lacking presently: the willingness to apply this huge capacity to the problem of climate change. But I also have to acknowledge — and I'm not doing this because the current Minister of Environment is in the room and the previous Minister of Environment was in the room, but because I've been immersed in climate-change science in western Canada — we do a lot of work with the Government of Alberta, and they have probably the most innovative climate-change programs in Canada, despite the rest of Canadians having an image of Alberta which is largely a function of a single person who makes some outlandish comments. The fact is that there's a huge capacity in Alberta to deal with climate change and its impacts, and I guess I'm a bit impatient, but I'm just anxious for everybody to take that next step and implement all that capacity.

David Schindler:

Just quickly, Dave. I'm interested in the tree-ring work you've done. What sensitivity is there that might give you some sense of not just the annual kind of precipitation but the seasonality of that precipitation — because in agriculture, of course, timing is everything and you may receive less rainfall in a year, but if it arrives at that wonderfully convenient time, you might just luck out. The second part of that is, given perhaps the forecasts on climate change and reduced water supplies, where do we begin the debate on making the choices about what we do with the water we have left? Because I think we all know we can't live without water. I'm thinking that we probably can't live without food either.

Dave Sauchyn:

I find it easier to answer the first question, because it's technical and scientific and I'm always reluctant to enter into political debates except as a private citizen and not as a scientist. The first question — well, I obviously glossed over the technical details and I'd be happy to share them with anybody. And I'm not sure whether I mentioned that the global climate models actually forecast that western Canada will get more precipitation, not less. But a lot of that increases in wintertime and a lot of it is rain. It doesn't really help that much when the extra precipitation falls at that time of year and not as snow but as rain. So even though we might actually have more precipitation, the major impact of global warming seems to be on the distribution, both in time and in space; and that's where people like you, David, will probably have to make the most adjustments — to the distribution of precipitation during the year, among years and from one basin to the other. And I avoided the second question.

Philip Weller:

I was very, very pleased to hear the comment made and the statement put into the discussions that the hydrological system is not stationary. Because for many, many years, river-basin management has been based on the assumption — or the hope, perhaps — that rivers are stationary, that the hydrological system doesn't adjust. We, within the Danube River basin, have dealt with the other end. You focused, I think, in this presentation, on the drought side. In the past couple of years, we've had to deal with the opposite end, which we always have; in the same way that you've talked about drought conditions existing here, we have always had floods. There have always been floods, there always will be floods, and we need to manage and have begun strategies to deal with that in the sense of giving rivers more space. But what I'm interested in is whether trying to adapt at one end, on the flood side, is going to cause problems on the other end, the drought side, and how we get strategies that work together on both sides and allow us to deal with situations that, as all of you have pointed out, are unpredictable and could go either way, depending on the circumstances we're dealing with.

Richard Adams:

Most of the work I have done is focused on drought, but there is a literature that looks at increased frequency of flooding, and I guess an answer that would help temporarily, at least, on both sides is one that reflects the fact that you're likely to have more winter rain and less winter snow. Some people are advocating more reservoirs, more storage; I suppose that if you had more storage, they could do dual purpose, as they do today, for both flood control and water, capturing water for summer use. There is a literature being funded from the United States, primarily by NOAA [National Oceanic and Atmospheric Administration], our sort of weather agency, and they've got some innovative work going on long-range forecasts of floods and so forth. I think the forecasting is still relatively primitive and the economics that's been done on it is probably even more primitive, but there is some literature about flooding and I could talk about that over dinner if you wanted to see some of what those suggestions and adaptations are.

The Honourable John Nilson, Saskatchewan Minister of Environment:

It's been a pleasure to hear all the different perspectives that are reflected here, which I clearly learned about on the bus trip. One of the questions I have and comments I want to make about this particular panel is that you've identified very clearly the need for adaptation to a climate that's changing, and that has some fairly dramatic economic effects on society as a whole — its ability to provide resources, to provide for all of its people. It strikes me that it's a risk-management question and who pays; as a politician, it seems to me that the fallback position is always that somehow government will raise the funds to deal with some of these things, and it's important to hear, I think, both of you say that it's about attitude change, because it can't just be the dollars. But the fundamental question, when you're sitting in a Treasury Board position in the Canadian system or as the Chair of the Finance Committee in a legislature somewhere, is: What kinds of dollars do we need for some of these issues? Are they on the engineering side, or are they more on the education side around conservation? And that's where, being a politician, you try to make choices. So I'd appreciate some comments on that, even though it ventures into the political field.

Dave Sauchyn:

Very good question, John. As you know, institutional and human responses to climate change are of two types: mitigation and adaptation. Mitigation, basically, is controlling greenhouse-gas emissions and sequestering carbon. It's actually fairly simple and straightforward, which is probably why it has received nearly all the funding and all the attention from the public and the media and politicians. It's quite easy to grasp that and get your mind wrapped around the concept of producing less carbon dioxide.

Adaptation, on the other hand, is this very vague concept defined by the IPCC as simply adjustments to just about everything we do. How do you measure that? And how do you measure the success of adaptation strategies? Which is perhaps why adaptation, until recently, was hardly on the agenda; but it's getting increasing attention from government and even from the public.

And I had another thought, which is that if — today, this afternoon — the entire world was to stop producing greenhouse gases, the temperature would continue to increase fairly rapidly to the middle of this century. That's what climate scientists have determined. So we've already changed the climate. The climate system does not respond immediately to carbon dioxide. There is a lag of decades, and so as we continue to produce greenhouse gases, we have modified and produced global warming that's going to last probably centuries, thus the necessity for some fairly immediate response to climate change in terms of adaptation. And as I said, adaptation is adjustment to nearly everything we do, and therefore the solution is diverse. In some cases, it doesn't have to cost very much; in other cases, it's probably an investment in adaptive technologies, which may be a more expensive solution.

Richard Adams:

If I might add something to what David said. If you were a politician, I think it would be very difficult to sell your electorate on embarking on a hundred billion dollars to do something where the benefits might occur in a hundred years. However, I think it would be relatively easy, or I hope it would be, to convince them that in the annual budget — because of the immediate environmental benefits in terms of, for example, ecosystem services — investing in wetland restoration, for example, might make sense. It's relatively inexpensive. The benefits from that are immediate. That has the effect that if climate is changing in the future, then you have that in place: you have additional wetlands; you have additional riparian habitat, as the rancher David was visiting with said he was embarking on. So, not being a politician, I would still think that there are many things we can do in the short term which have immediate environmental benefits, but also have benefits in terms of both mitigating potential climate change and providing for long-term species diversity and other benefits.

Jennifer McKay:

In the Forum tradition, many of you, particularly Mordecai, addressed my question, and David has already hinted that Alberta has got the most resources to achieve an adaptive capacity. My question then is that we need an institutional form that has the precautionary principle embedded, and equity, and we need to work out a way to fund this, and if any of you have any ideas on how that would best look. I'll just give you a bit of information. In Australia, we have the precautionary principle embedded in all state laws, and every water-supply CEO and business manager has to achieve it, has to make sure that decisions are environmentally friendly. When I asked them, what's the most difficult of all the environmental achievements they have to achieve according to the Act, they put that one as the most difficult. And then I asked them, how did it relate to their KPIs [key performance indicators], and it was in exactly the opposite direction. So the question is whether you have any ideas about an institutional form, and is there any place in the world that administers a fitness-for-purpose concept in the use of water — getting water to be used for the highest purpose it can be used for, rather than using potable water to water gardens, as we do in Australia, and for other inappropriate uses.

Richard Adams:

We do a lot of metering of water use within the City of Corvallis, in Oregon, and it becomes increasingly expensive the more you use rather than the less you use, which kind of runs against the fact that there are economies of scale in the provision of water. But nonetheless we charge a very rapidly rising rate to discourage people from using city-treated water for lawns and anything else, and it's somewhat ironic now that in Corvallis, which is a relatively wet area, our lawns are all brown in the summertime. So there are examples of that, and there must be other places around the world in which to do that. In terms of precautionary principle, yes, I think the *Endangered Species Act* is probably the most explicit use of that in the U.S., but most of our environmental regulations have that implicit within those regulations. Now, that doesn't mean that the U.S. will spend anything it takes to do whatever to save a species. There's always some out even within the U.S.A. The minimum it says you shall use is the most cost-effective way to achieve the objective, and there's even a greater, a final out that if the cost is just too expensive — and this probably makes biological as well as economic sense — you don't spend twenty billion dollars to save a species that's going to go extinct in twenty years regardless of what you do. You should spend that money on other species. But in answer to your question, I can't give you a specific set of institutions or way in which that general idea can be enacted and will always work.

Dave Sauchyn:

Jennifer, sorry, with regard to your first question, can you repeat it? I think I have an answer. I have the answer, but no question.

Jennifer McKay:

An institutional form that embeds the precautionary principle, equity principles, along with economics and use — a form that does that, do you know of one?

Dave Sauchyn:

The best advice I've heard for public institutions in industry is that all decision making, all policy analysis, all programming should be passed through a filter of climate change. Everything we do, we should evaluate against a backdrop of: Does this represent an adaptation or a maladaptation to climate change?

Yuksel Inan, Session Chair:

I have to thank all of you, and the audience, for your patience. I'm glad and proud to chair this session, but we do have time constraints. Thank you.

SESSION THREE: Case Study One

Henry Vaux, Chair, Rosenberg Forum:

Our day is devoted to four case studies, and I will introduce to you Ayman Rabi from Palestine, who will be the Chair of the first session, focused on the Jordan River basin. Ayman?

Ayman Rabi, Session Chair:

Thank you, Henry. Good morning, ladies and gentlemen, distinguished guests. I would just like to express my gratitude to the Rosenberg Forum, and to all of you, that we are meeting here to discuss one of the very important issues which will really be a challenging issue for the coming century. Before we start and before I give the chance to our speakers to talk about the case study and adaptation and policies in the different parts of the Jordan River basin, I just want to share with you some background information about the basin.

We are talking about a relatively small basin with a total area of around 4500 square kilometres. Lebanon, Syria, Jordan, Israel and part of Palestine, which is the West Bank, all share the overall basin of the Jordan River. The main tributaries that feed the Jordan River originate in Lebanon, Syria and Israel and meet in the Hula Valley, a bit north of Lake Tiberias. They all flow together and continue to Lake Tiberias, and then from there it continues down until it reaches the Dead Sea. But in the meantime, it joins with the Yarmouk River, from where they continue together as the Lower Jordan River until it reaches the Dead Sea.

Because of the extreme development of this water upstream, there is not much water left in the lower part of the Jordan River. Currently, what we are receiving in this part is almost one tenth of the historic flow of the Jordan River — what used to reach the Dead Sea. This is why the southern part of the Dead Sea is no longer there; it is almost drying up. And we are losing almost 70 cm per year from this northern "lake" of the Dead Sea. So the Dead Sea is really diminishing with time because of the huge abstraction of water which is taking place in the north; there is no more water left to flow down, other than the saline, brackish water and some of the waste water that is still flowing there.

I would like to leave you with this first introduction; I am sure the speakers will give you more detail. But just before leaving you, I want to mention that there have been several international attempts to allocate the water of the Jordan River among the riparian countries. One of the famous attempts was the Johnston Plan, which is very well-known by the people from the region; Eisenhower, the President of the United States, in '53 sent a special envoy, Eric Johnston, in an attempt to divide the water of the Jordan River between the riparian countries. This plan was somewhat finalized on September 30, 1955, and became a kind of base for future partition of this water allocation, but it never materialized on the ground in the way that it was put forward. It is interesting that this information remained classified from '55 until recently. I think it's no longer considered classified information and has just recently been released from the archive of the United States national library, and we could have access to it.

With this, I would like to invite Dr. Alon Rimmer from Israel, who has a Ph.D. from Technion [Israel Institute of Technology], Haifa, in 1993, and he also did post-doctoral studies at Cornell University in 1995 in the field of soil and water physics. He is a senior scientist at the Lake Kinneret Limnological Laboratory. He is also involved in several groundwater and surface-water research and modelling projects in the upper catchment of the Jordan River. Dr. Rimmer, please, the floor is yours.

Systems-hydrology Tools for the Upper Catchments of the Jordan River and Lake Kinneret, Israel

Alon Rimmer, Israel Oceanographic & Limnological Research Ltd., Yigal Allon Kinneret Limnological Laboratory, Migdal, Israel

Abstract
Three studies on major hydrological problems in the upper catchments of the Jordan River and Lake Kinneret, Israel, are reported. By application of a systems approach to each problem, we learned the nature of each system and the major physical laws that govern its operation. The studies were focused on: 1. **identification** of the hydrological system (precipitation-streamflow relations) of the Jordan River sources, which originate from the karstic region of Mt. Hermon; 2. **detection** of three unknown components — evaporation, saline-springs discharge and salinity — of the monthly water-solute-heat balances of Lake Kinneret; and 3. long-term **predictions** of Lake Kinneret salinity, in response to operational changes such as reduced inflows. Each system is presented from the description of the problem, through the mathematical justifications and equations, to the results and discussion.

1. Introduction

Systems Approach in Hydrology

The approaches to the study of hydrological problems can be generally divided into two extreme groups (Amorocho and Hart 1964): (1) the physical-science approach, and (2) the systems approach. The former is also referred to as a basic, or theoretical, approach; and the latter, as an operational, or applied, approach. Aggregations of studies involving the former can be called **physical hydrology**; those involving the latter, **systems hydrology**.

In the physical approach, the primary motivation is the study of physical phenomena and their understanding, while the practical application of this knowledge for engineering and other purposes is recognized but not explicitly required. A physical approach to determine output from a given system would normally require detailed specification of (a) system input, (b) system structure (geometry), and (c) physical laws, together with initial and boundary conditions.

Unlike detailed physical studies of each hydrological structure, the systems approach is motivated by the need to establish workable relationships between measured parameters in the hydrological cycle, to be used in solving practical technological problems. This approach generally holds that the vast complexity of the systems involved in hydrological studies, and the inadequacy of the available knowledge, and of the knowledge likely to exist in the foreseeable future, make the possibility of a full physical synthesis so complicated that it must be discarded for practical purposes. Under these premises, a logical approach would consist of measuring those observed variables in the hydrologic cycle which appear significant to the problem, and then attempting to establish explicit algebraic relationships between them. It is hoped that these relationships hold true within the range of conditions.

In this paper we investigate three hydrological systems in the upper catchments of the Jordan River (UCJR) and Lake Kinneret (LK, also known as the Sea of Galilee), Israel, for the explicit purpose of establishing an input-output relationship that can be used for reconstructing past events or predicting future events. However, in our approach we are concerned not only with the system operation but also, to some extent, with the nature of the system itself (its components, their connection with one another, and so on) and the major physical laws that govern its operation. Thus, our intent is to solve practical hydrological problems and gain some physical knowledge about the hydrological systems we deal with, but at the same time to avoid the difficulties and complexity of the full physical approach.

In all three cases, the physical laws and the nature of the system are combined into a single concept of system operation. It is this concept that constitutes a so-called **grey box**, the intermediate concept between detailed physical analysis and the classic system approach, usually referred to as **black-box**.

A systems analysis model is usually expressed as (see also Figure 1):

$$y(t) = \Phi[x(t)] \quad \textbf{(Equation 1)}$$

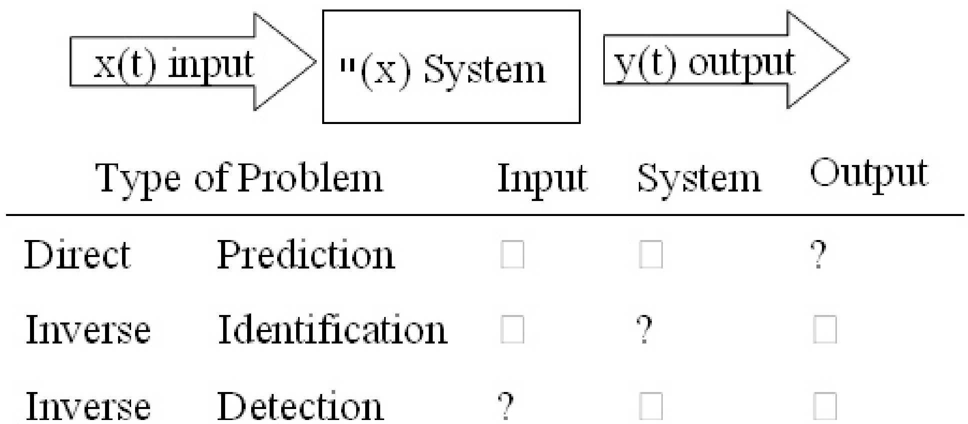

Figure 1. Schematic description of systems-type problems

Here y(t) is the model output, x(t) is the model input, and the system operation Φ(x) represents a set of equations that transfer the input to the output. The problems associated with hydrological systems can be broadly classified into three types (Figure 1; Singh 1988): 1. In the **prediction** problem, the input x(t) and the system Φ(x) are known, while the output y(t) should be predicted; 2. In the **identification** problem, both the input x(t) and the output y(t) are known, but the equations and parameters that describe the system Φ(x) should be identified; and 3. In the **detection** problem, the output y(t) and the system Φ(x) are known, and the objective is to detect the input x(t). The first type is referred to as a **direct problem**, while the other two are known as **inverse problems**. Each of the three hydrological problems that we show here will exemplify one of these three categories, applied for practical purposes to the region of the UCJR and LK.

Study Area

The UCJR, located in the central part of the Jordan Rift Valley (northern Israel, Figure 2a), is the most important surface-water resource in Israel, providing approximately 35% of its annual drinking water, a proportion that is constantly increasing. The area of the drainage basin of the UCJR and its tributaries is ~1700 km², where ~920 km² are in Israel, and the rest of the area is in Syria and Lebanon. The UCJR is the major water source of LK, while the other sources of LK originate from the direct watershed, located in the immediate vicinity of the lake (Figure 2b). The direct-watershed area is ~1100 km², where 750 km² constitute the southern part of the Golan Heights, east of the lake, and the other 350 km² are part of the eastern Galilee Mountains, west of LK. The lake is heavily deployed and supplies ~30% of the water in Israel through the National Water Carrier (NWC). The average area of the lake surface is 166 km², the average volume is 4100 Mm³, and the average residence time is ~8.3 years.

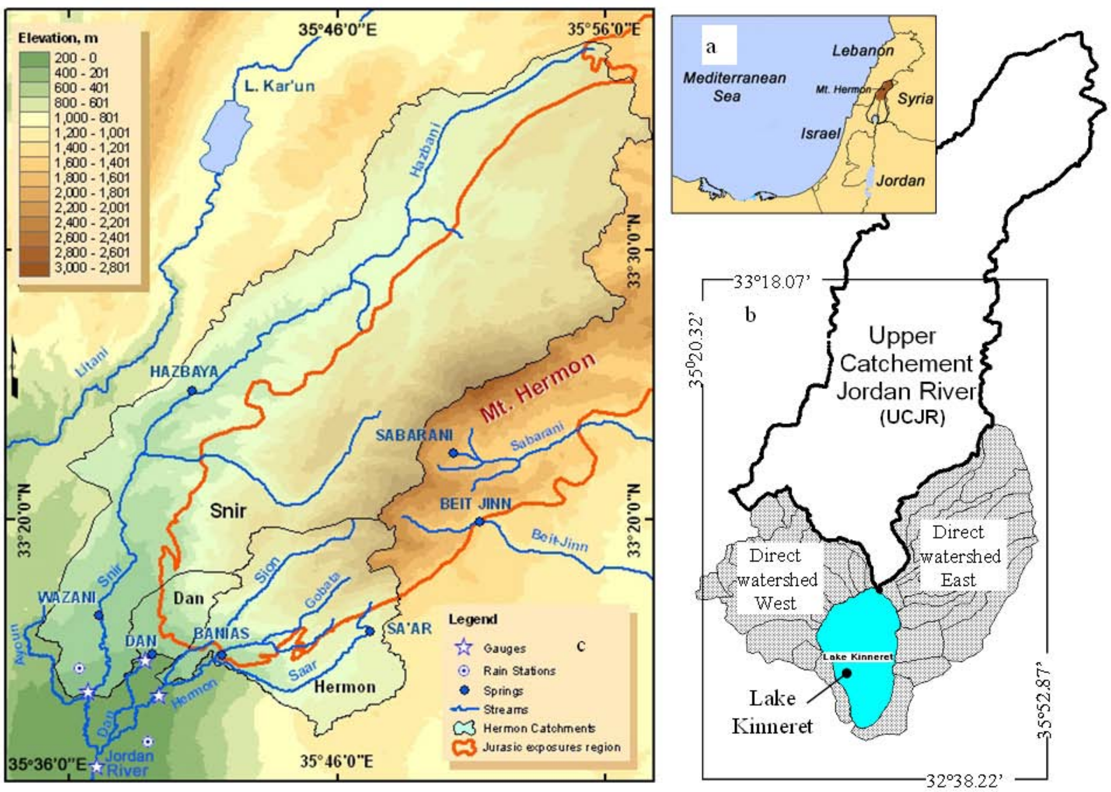

Figure 2. a. Orientation map of the east Mediterranean; b. The direct watershed of Lake Kinneret (dark) and the upper catchments of the Jordan River; c. the Mt. Hermon area and the Dan, Hermon and Senir watersheds

The objective of this paper is to show how systems-hydrology studies were applied to three major hydrological problems of the region (Table 1): 1. **identification** of the hydrological systems of the Jordan River's sources (based on Rimmer and Salingar 2006); 2. **detection** of three important components of the monthly water-solute-heat balances of LK (Assouline 1993; Rimmer and Gal 2003); and 3. long-term **predictions** of LK salinity in response to operational changes (Rimmer 2003).

Table 1. Summary of three systems-hydrology tools for the UCJR and LK

Characteristic	1. Hermon hydrology	2. LK water-solute-heat balances	3. LK salinity
Time interval	day	month	year
Input	Daily extrapolated rainfall and potential evaporation from stations south of Mt. Hermon	Saline-spring inflows, the salinity of the springs, and the evaporation	Annual stream inflows, outflows, evaporation, direct annual rainfall; average stream salinity
Output	Calculated base flow and surface flow components of three streams in the Hermon karst basins	All the measured variables from the water, solute and heat balance, including measured inflows and outflows, and the measured monthly differences between storage of water, solute and heat in the lake	Long-term predictions of solute mass, volume and salinity of the lake
System	Hydrological model for karst environment, including four modules: surface layer, surface flow, vadose zone and groundwater.	A well-known set of physical equations and assumptions which summarizes the mass, solutes and energy balances of the lake	The equations of complete mixing in which solute flux through the outlet is linearly proportional with solute storage
Type of problem	An **inverse problem** of the type **identification**	An **inverse problem** of the type **detection**	A **direct problem** of **prediction**
References	Rimmer and Salingar 2006	Assouline 1993	Rimmer 2003
Objective	**Identify** an appropriate systems model for both the base-flow and the surface-flow components of a karst basin, and get better quantitative understanding of Mt. Hermon hydrology.	Calculate systematically the monthly water-solute-heat balances, and **detect** the three unknown inputs: evaporation, springs discharge and salinity.	Use an existing well-known physical mechanism of complete mixing as a tool to **predict** long-term changes of chloride concentration in the lake.
Applied to the period:	**1969−2005**	**1987−2005**	**1964−2005**

2. The Karst Hydrological System of Mt. Hermon

Description of the Problem

In a karst basin, part of the water from precipitation may enter the earth's surface through high-permeability channels and voids that feed the karst network (preferential flow), and may produce quick and large responses of groundwater discharge to rainfall events. Other parts may infiltrate through low-permeability areas to the soil and contribute smaller changes to the groundwater level (Jeannin and Grasso 1997). In addition, typically for karst regions, large springs may immerge into streams in various locations and contribute a large base flow that is not related to the size of the geographic surface of the catchments.

Some of these characteristics are typical of the hydrology of the three major sources of the UCJR located in the south of the Mt. Hermon range in northern Israel (Figure 2c). Mt. Hermon is an elongated, 55-km-long and 25-km-wide anticline of mostly karstic limestone of the Jurassic period, with thickness >2000 m. Only 7% of the range lies in Israel, while the rest is divided equally between Syria and Lebanon. It is the highest mountain range in Israel. The summit of Mt. Hermon, 2814 m above sea level (ASL), is in Syria. The Hermon high regions (above 1000 m ASL) receive the most precipitation in Israel (>1300 mm $year^{-1}$), restricted to the wet season, from October to April. Snow usually falls on the elevated areas from December to March, and persists on areas above 1400–1900 m ASL (depending on local conditions) until March-June. Rainfall and snowmelt on Mt. Hermon recharge the main tributaries of the UCJR: (1) Dan (255×10^6 m^3 annually), (2) Snir, also known as Hatzbani (118×10^6 m^3), and (3) Hermon, also known as Banyas (107×10^6 m^3) (Figure 3).

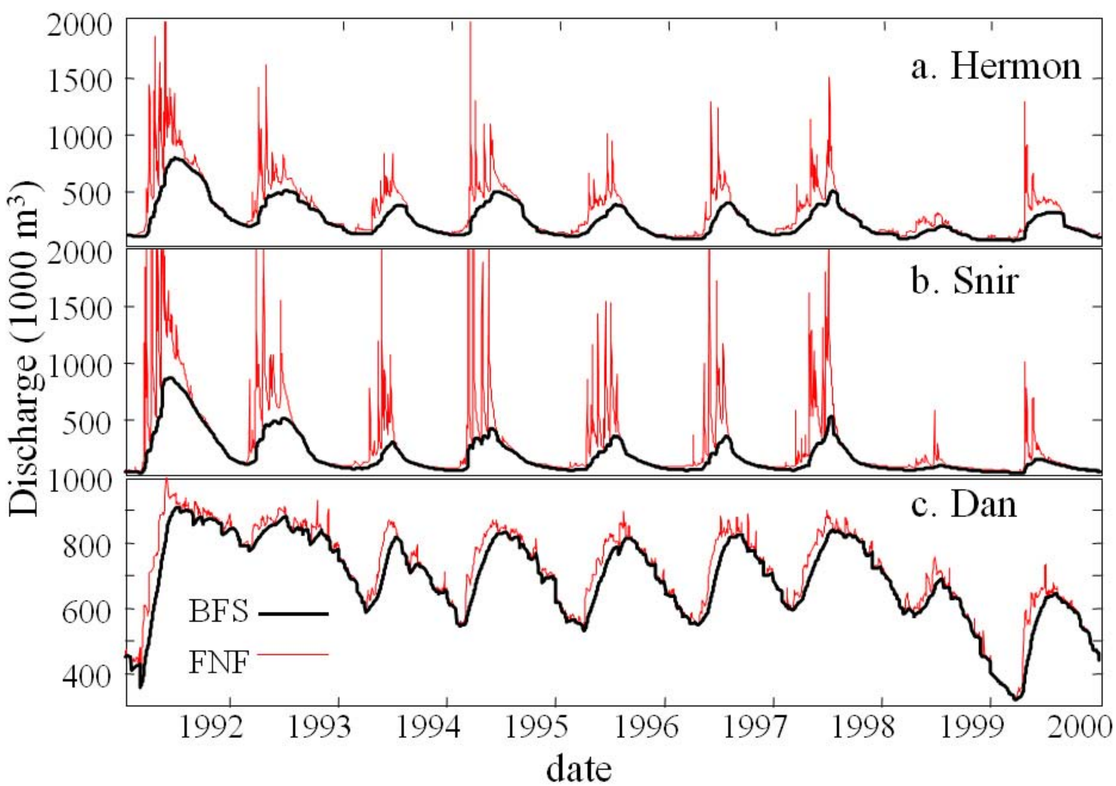

Figure 3. Full natural flow (FNF) of the Dan, Hermon and Senir streams, and the application of the base-flow separation technique (BFS)

Because of the sensitivity of water resources for the entire region (including Syria and Lebanon), and the requirement to keep the status quo, the Hermon area has not undergone anthropogenic changes during the last decades as compared to other major hydrological systems in Israel. For example, no significant land-use changes or pumping have taken place in the entire area. Despite the great importance of this mountainous area, only few quantitative hydrological studies have been conducted (Simpson and Carmi 1983; Gilad and Bonne 1990; Gur et al. 2003). The geological setting of the southern region of Mt. Hermon was partly described in the past (Michelson 1979); however, apart from the delineation of the location of the Jurassic exposures (Figure 2c), which contribute to the knowledge about the extension of the karstic region, and some geological cross-sections (Gilad and Schwartz 1978), knowledge about the geohydrology of the region is limited. The lack of hydrological data is typical of Mt. Hermon and includes the following:

a. The amount of snow and rainfall on Mt. Hermon was never measured systematically because of the difficulties in maintaining a meteorological station above 2000 m ASL. Hence estimations of snow and rainfall in previous studies were based on stations located at lower elevations (Gilad and Schwartz 1978; Simpson and Carmi 1983).
b. A complete water balance for the region is difficult to compute, because the stream and spring flow in the eastern and northeastern Mt. Hermon region is in Syria and Lebanon and there is no sharing of hydrological data between Israel, Syria and Lebanon.
c. The thickness and the borders of the aquifer(s); water-level fluctuations; hydraulic characteristics (i.e. conductivity, porosity); and the local rainfall distribution are unknown.
d. The well-developed karstic landscape causes large preferential flow into groundwater, and relatively little surface runoff. These types of flow increase the complexity of quantitative studies.
e. Finally, the location of different aquifers in the region, and the recharge area of the three main tributaries of the Jordan River are unknown. Moreover, recharge areas are not correlated with the size of the geographic surface of the water catchments.

In contrast to the considerable lack of information from the Mt. Hermon area, there is an excellent database on the hydrology of the Jordan River, south from Mt. Hermon. It includes long-term streamflow data, daily rainfall, daily pan-evaporation measurements, monthly water consumption, and more.

System Type and Objective

The existing data types, and the lack of others, call for a systems-analysis model (Equation 1). In this case, the model input x(t) is long-term time series of extrapolated daily precipitation and evaporation; the output y(t) is long-term predictions of daily streamflow, which can be calibrated versus the measured data; and the unknown is the system operation $\Phi(x)$, representing a set of equations that transfer precipitation to streamflow. The problem of recognizing the main temporal and spatial characteristics of Mt. Hermon hydrology is an **inverse problem** of the **identification** type. The objective of this study (Rimmer and Salingar 2006) was to **identify** an appropriate systems model $\Phi(x)$ for both the base-flow and the surface-flow components of a karst basin and to get a better quantitative understanding of Mt. Hermon hydrology. In the proposed system, special attention was given to a method to deal with the uncorrelated base and surface flows, and to the large-scale preferential flow to groundwater. The model was applied to the three main tributaries that originate from the karst region of Mt. Hermon, which form nearly the entire flow of the Jordan River.

The System, the Mathematical Representation and the Solution

The input

Long-term daily rainfall data (some started back in the beginning of the 20 century) were analyzed. We found clear indications that in northern Israel, average monthly rainfall is nearly a linear function of the elevation. However, the linearity is slightly weaker and less significant during the beginning of winter (October), increases towards the middle of winter (January) and gradually decreases towards the end (April). Measured daily precipitation also verified that the variations between rain gauges and the timing of maximum and minimum precipitations are similar for most rain-gauge stations. A representing rainfall gauge of the entire Hermon region was therefore defined using a combination of elevations and daily rainfall from several gauging stations in the Upper Galilee and the Golan Heights. Potential evaporation estimations were based on long-term (1970−2000) daily measurements of pan A evaporation (Ponce 1989). Unlike precipitation, spatial evaporation was not calculated, because only three locations of long-term measurements were available. The mean seasonal pan-evaporation trend for the UCJR was computed similarly to Viney and Sivapalan (2000). For calculating actual evaporation, we used a simple estimation in which evaporation is a function of "dry days" counted from the day of the last rainfall event.

The output

Daily discharges of the main UCJR tributaries — the Dan, Snir and Hermon (Figure 3) — were measured (1970−2005) by continuous monitoring of the water level in the stream, and calibrated by periodic measurements of stream-velocity profiles. The measured data were corrected for each stream by adding the actual consumptions upstream to the measured data. In the three measured flow time series, base flow was separated from surface (or quick) flow and created six time series, two for each tributary. Base-flow separation parameters were performed with the Eckhardt (2005) method. Results of the separation analysis (Figure 3) were used to calibrate the model output.

The system main equations

A conceptual HYdrological Model for Karst Environment (HYMKE, Rimmer and Salingar 2006) consisting of three surface-flow catchments and four regional phreatic aquifers was proposed as the sources of the surface- and base-flow components of the entire region.

HYMKE is made of four modules (Figure 4): the surface layer (0), the vadose zone (1), groundwater (2) and surface flow (3). In the conceptual model, the earth surface of the entire geographical basin is recharged by precipitation, and dried by evaporation, surface runoff and percolation to deeper layers. The karst nature of the landscape was introduced similarly to Jeannin and Grasso (1997), with a surface layer ("epikarst") composed of a low-permeability section, and a high-permeability section that feeds the karst network. The surface layer is drained continuously as a function of moisture content. Saturation excess is generated when the surface layer is saturated, and then part of the excess saturation is transformed into surface flow (Module 3), while the other part forms a downward preferential flow component. Therefore, the percolation into the vadose zone (Module 1) includes both "slow flow", i.e. Darcy flow that depends on the soil moisture content and hydraulic conductivity, and "quick flow", which is effective mainly during the peak of the wet season. The output from the vadose zone (Module 1) feeds the groundwater reservoir (Module 2). However, the differences between the groundwater discharge patterns require the separation of Module 2 into several groundwater reservoirs. In the case of Mt. Hermon, these are the three reservoirs feeding the Dan, Snir and Hermon base-flow component, and one reservoir that contributes the residual of groundwater to springs in the east part of Mt. Hermon in the area of Syria. Combining the output of the surface-runoff module (3) and the base-flow module (2) for each stream results in the full natural flow of each tributary. The sum of all three tributaries will create the flow in the main stream, the Jordan River.

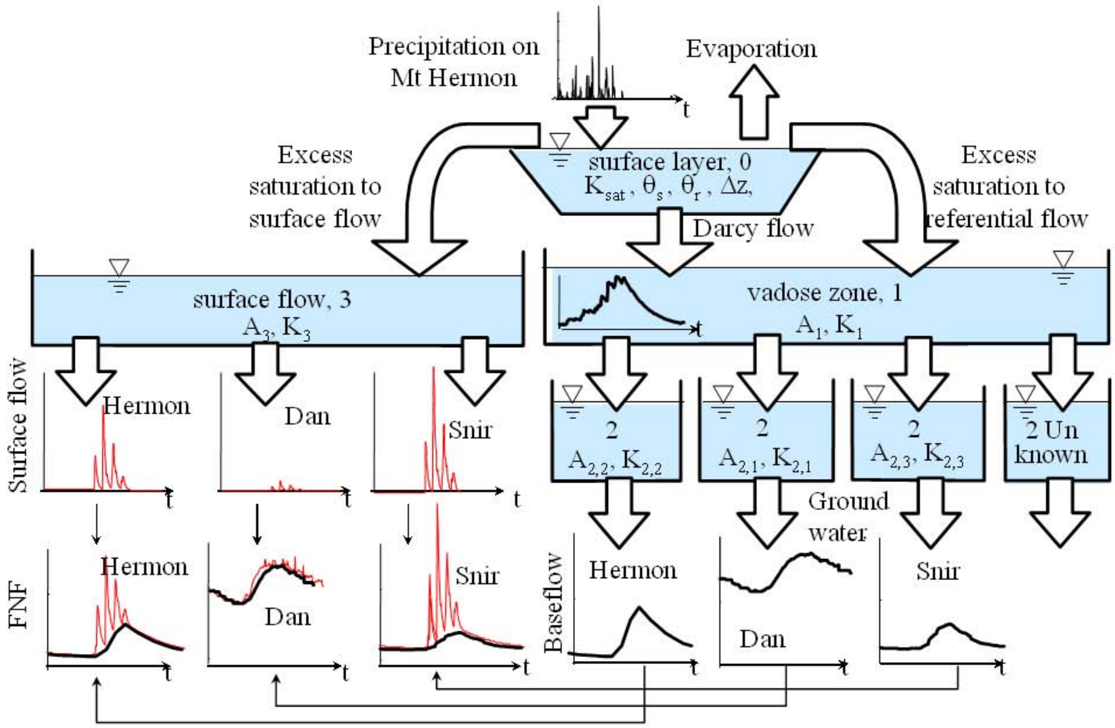

Figure 4. Schematic description of the Mt. Hermon conceptual hydrological model: Module 0 is the surface layer; Module 1 represents the vadose zone; Module 2 consists of four groundwater reservoirs; and Module 3 simulates the surface flow. The calculated base-flow and surface-flow components of each tributary result in their full natural flow.

Module 0 of the surface layer is governed by the mass balance equations:

$$\theta_j = \begin{cases} \theta_{P\,j} & ; \text{if } \left(\theta_{P\,j} < \theta_S\right) \\ \theta_S & ; \text{if } \left(\theta_{P\,j} >= \theta_S\right) \end{cases}$$
$$\text{where } \theta_{P\,j} = \theta_{j-1} + \frac{q_{IN_j} - q_{OUT_j}}{\Delta z}$$
(Equation 2.1)

Here θ is the moisture content ($m^3\ m^{-3}$), θ_P the "potential" moisture content; θ_S indicates saturation, Δz the thickness of the topsoil layer (m); and "j" is the daily index. The daily flux into the surface layer q_{INj} (m) was defined as:

$$q_{IN_j} = 0.001\left(R_j - E_{A\,j}\right)$$ **(Equation 2.2)**

where R_j and E_{Aj} are the daily rainfall and daily evaporation time series in mm (see input description above), and the 0.001 originates from changing units (mm to m). We assumed that the daily moisture of the surface soil to a depth Δz is uniformly wet. Under this condition, q_{OUT} was described with the "unit gradient" assumption, in which the vertical flux, defined by Darcy's law, is reduced to:

$$q_{OUT\,j} = -K_D(\theta_j) \qquad \textbf{(Equation 2.3)}$$

Here $K_D(\theta)$, the unsaturated hydraulic conductivity of the soil (m day^{-1}), is a well-known function of the soil moisture content θ (Mualem and Dagan 1976). Note that while the θ is set on θ_S, the difference $\theta_P - \theta_S$ in Equation 2.1 is the excess saturation. We propose that only the constant part of this component ($0 \le \alpha_{Sk} \le 1$) is contributed to surface runoff Q_S, and the residual, Q_{PR}, flows downward as preferential flow, typical for karst environments. The excess saturation (10^3 m^3) is therefore represented by:

$$Q_{Sk}(t) = A_k \alpha_{Sk} \left[1000 \times \Delta z \times (\theta_P(t) - \theta_S)\right] \qquad \textbf{(Equation 2.4)}$$

and

$$Q_{PRk}(t) = A_k (1 - \alpha_{Sk}) \left[1000 \times \Delta z \times (\theta_P(t) - \theta_S)\right] \qquad \textbf{(Equation 2.5)}$$

Here A_k is the surface area (km^2) of the k's tributary (k=1,2,3), and α_{Sk} can be calibrated versus measured surface flow.

The next modules (1, 2 and 3 in Figure 4) are combinations of linear reservoirs. A linear reservoir has an outflow proportional to the amount of water stored in it. The theory of linear reservoirs is often used in surface and groundwater hydrology as models for the management and control of inflows and outflows in water reservoirs (Singh 1988; Sugawara 1995). The equations for a continuous water balance in linear reservoirs are:

$$\frac{dh(t)}{dt} = \frac{Q_{IN}(t)}{A} - \frac{h(t)}{K} \quad \text{s.t.:} \quad h(0) = \frac{KQ_{OUT}(0)}{A} \qquad \textbf{(Equation 2.6)}$$

where h(t) (mm) is the height of the water level in the reservoir above the outlet, A (km^2) is the reservoir area, Q_{IN} and Q_{OUT} (10^3 m$^3 \times$day^{-1}) the inflow and outflow respectively, and K (to distinguish from K_D) is a storage coefficient with the dimension of time (day).

If $Q_{IN}(t)$, and the coefficients A and K are known, and the initial condition is prescribed by a measured flow $Q_{OUT}(0)$, then Equation 2.6 can be solved numerically or analytically for h(t), and the outflow $Q_{OUT}(t)$ can than be calculated with:

$$Q_{OUT}(t) = \frac{Ah(t)}{K} \qquad \textbf{(Equation 2.7)}$$

The surface-flow module (3) takes as input part of the daily pulse of excess saturation (Q_{Sk} in Equation 2.4) and transforms it into the streamflow by a simple linear reservoir operator (Equation 2.6). The output (Equation 2.7) represents the surface flow for each tributary and is calibrated against the surface component of the separation analysis. The vadose zone module (1) takes as input the other part of the daily pulse of excess saturation (Q_{PRk} in Equation 2.5) and the Darcian flow component (q_{OUT} in Equation 2.3) and transforms them into an input to the groundwater reservoirs. The groundwater module (2) takes as input the output of Module 1, and transforms it into the base flow. This groundwater output represents the calculated base flow for each tributary and is calibrated against the base flow from the separation analysis.

Results and Discussion

The full model (modules 0, 1, 2 and 3) was tested by reconstruction of both the surface and base flow during a continuous period from January 1, 1986, to September 30, 2000, and then was verified by applying the calibrated parameters to the periods January 1, 1970, to December 31, 1985, and October 1, 2000, to September 30, 2004.

Input data includes single time series of daily precipitation which retain both the daily trends of the rainfall in the region and the extrapolated average monthly precipitation of Mt. Hermon. The model did not take into account the type of precipitation (rainfall, snow) because of the lack of information. We also applied the best estimations of potential evaporation, but the parameters of real evaporation had to be calibrated.

Calibration of the surface layer and the surface flow was based on accurate simulation of the days when saturation occurred and excess saturation caused surface flow. The calibrated parameters resulted in correlations of r^2=0.60 and r^2=0.75 between the calculated and the separated surface flow of the Snir and Hermon streams, respectively (Figure 5), while the contribution of surface flow to the Dan was negligible. Model predictions of surface flow were less successful on days of extreme events. This is probably due to the lack of data about snowmelt; the crude assumptions on which the "surface layer" module was based; and especially the assumption of constant division between surface runoff and preferential flow. However, the calibration of these modules may be improved by adding more procedures and parameters.

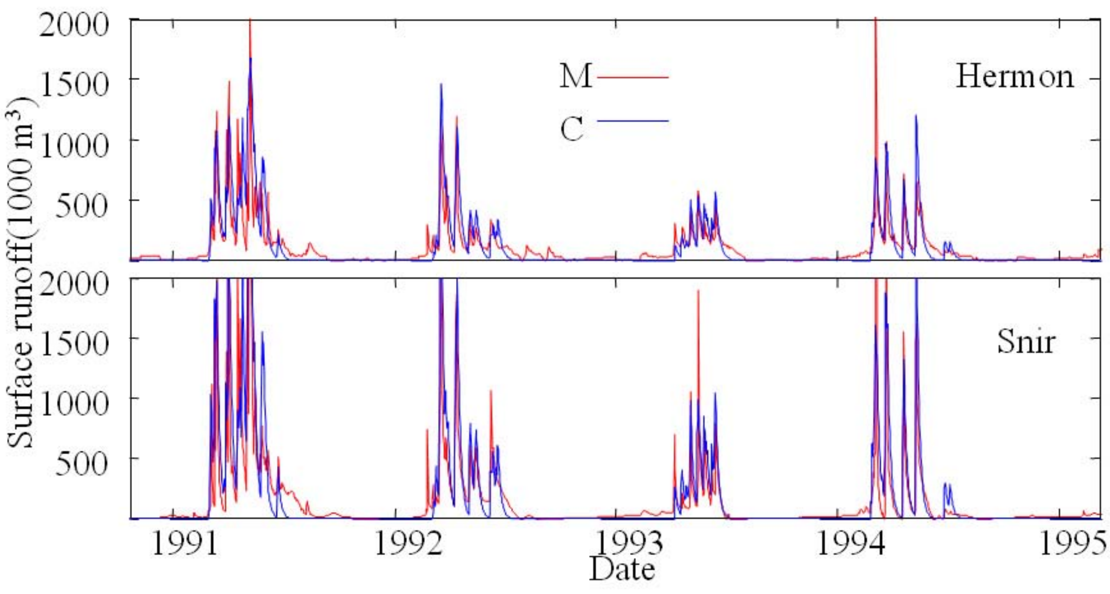

Figure 5. The predicted surface flow of the Hermon and Snir streams (C) compared to the surface flow from separation analysis (M) for the years 1991 to 1995

After calibration of the surface modules was completed, the linear reservoir (Equation 2.6) of Module 2 was solved numerically for $h_1(t)$, using the Runge-Kutta method, with the downward flow and preferential flow from the surface layer as input. The outflow from the reservoir was calculated with Equation 2.7, and the values of the constants α_{Bk} were calibrated to fit the contribution to each groundwater reservoir $Q_{IN2\ k}(t)$ separately. Then, Equation 2.6 was solved numerically for $h_{2\ k}(t)$, using the same method, and Equation 2.7 was used to calculate the base flow of each tributary (Figure 6). The calibrated parameters of these two modules resulted in correlations of r^2 = [0.84, 0.89, 0.77] and Nash-Sutcliffe coefficient (NC) = [0.71, 0.80, 0.21] between the calculated and the separated base flow of the Snir, Hermon and Dan streams, respectively. Figures 7 and 8 show the final steps of the modelling process. In Figure 7, the sum of calculated base flow and surface flow is compared to the FNF of each of the three tributaries, while Figure 8 shows the results for the flow in the Jordan River with r^2 = 0.94 and NC=0.79 for the same period.

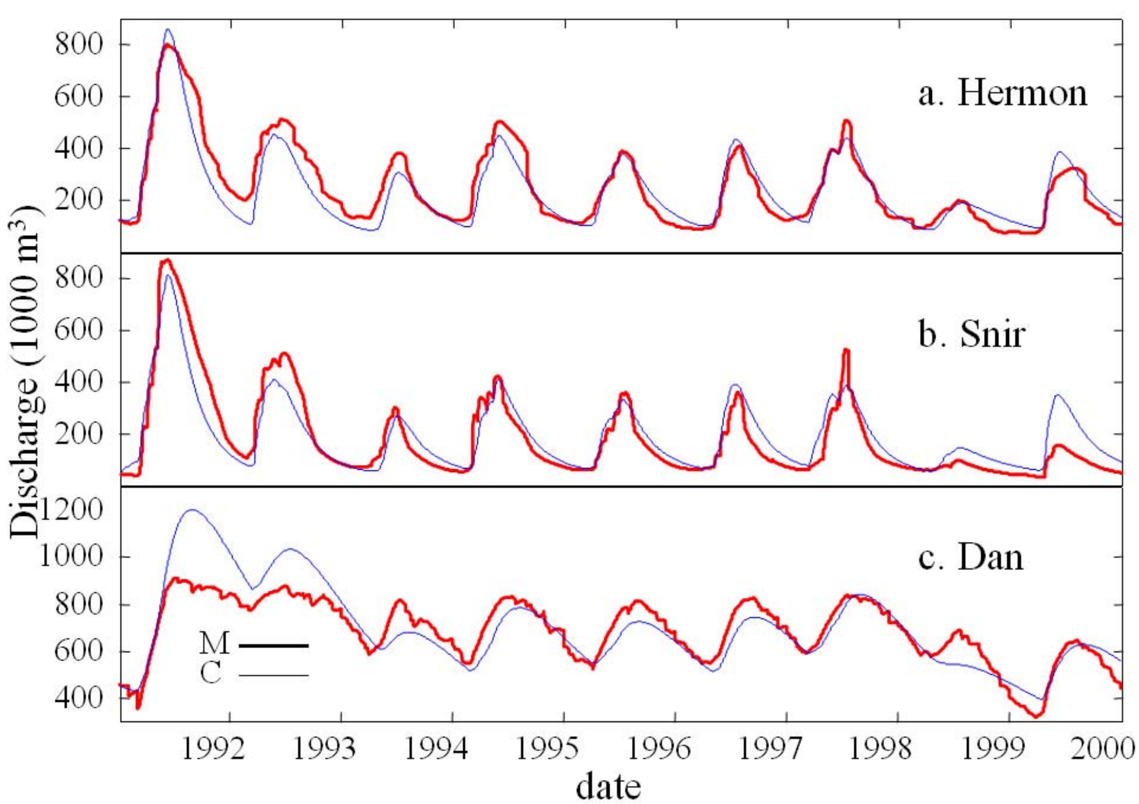

Figure 6. The predicted base flow of the Hermon tributaries (C) compared with the base flow from separation analysis (M) for the years 1991 to 2000

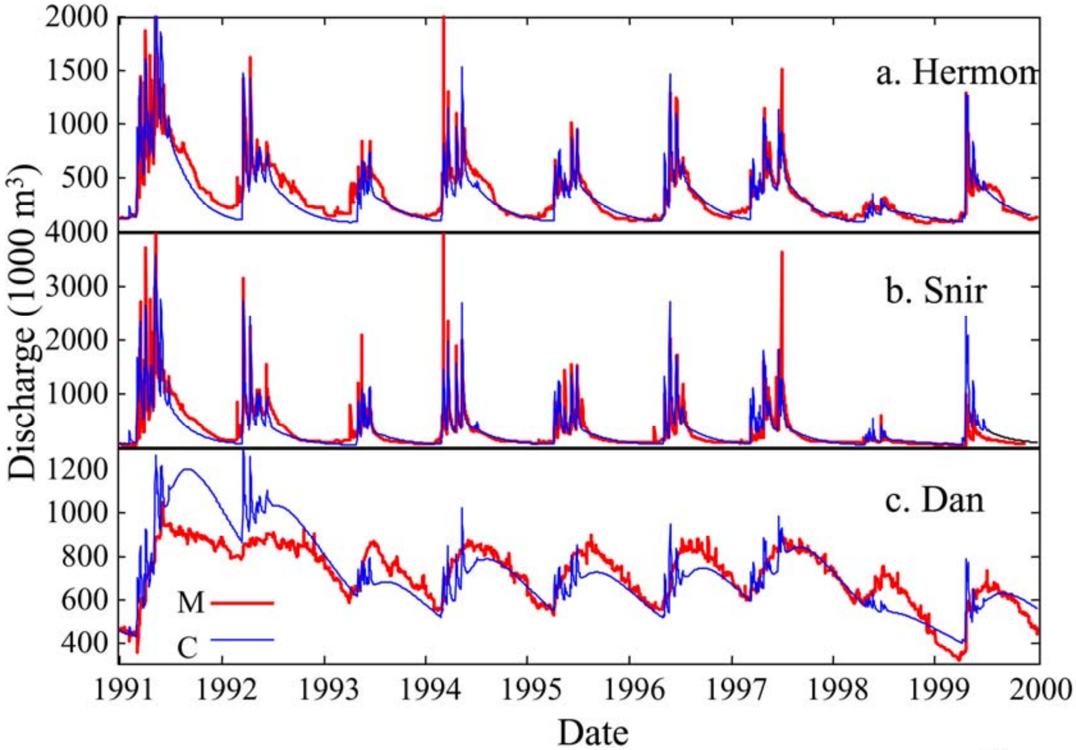

Figure 7. The predicted FNF of the three tributaries (C) compared to the measured flow (M) for the years 1991 to 2000

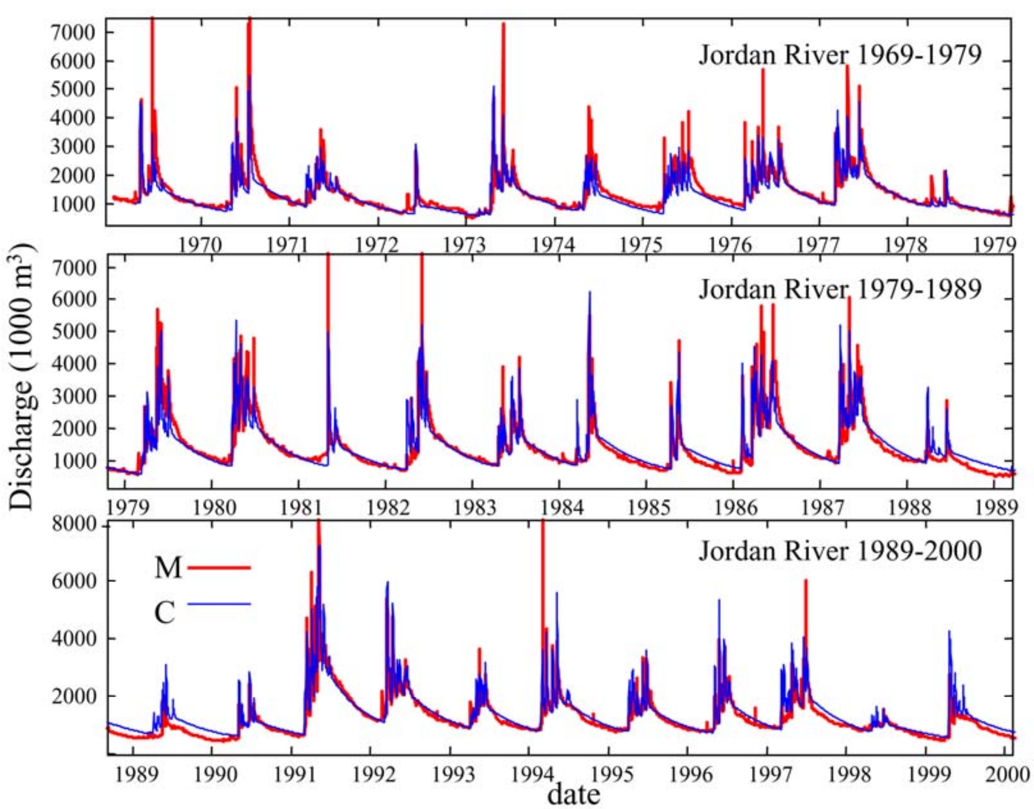

Figure 8. The cumulative calculated full natural flow of the Jordan River compared to the measured cumulative full natural flow from 1969 to 2001

Our approach for a primary but systematic mass balance was based on setting the parameter A_1 on the cumulative area of the three surface catchments of the Dan, Snir and Hermon (A_1=783 km^2). This is a reference point that enables systematic definitions of mass balance. We calculated the representing annual precipitation of the entire Hermon region as ~958 mm. All together, the entire annual precipitation is equivalent to 783 km^2 multiplied by 0.958 m of rainfall, which results in 750 million m^3 (Mm^3). The total calculated potential evaporation was ~1900 mm; however, if the altitude is taken into account, this value may be reduced to 1000−1200 mm annually (National Action Programme, Chapter Two: Environmental Status in Lebanon, www.codel-lb.org/Chapter %20II.pdf). Real evaporation in the model was 226 mm (~177 Mm^3); the calibrated surface flow is only 90 mm (70 Mm^3, compared to 83 Mm^3 from separation); the calculated downward flux includes 275 mm (215 Mm^3) from Darcian flow and 367 mm (287 Mm^3) from preferential flow, which adds up to 502 Mm^3 according to the model, and 393 Mm^3 according to the measured data. The ~109 Mm^3 difference is probably contributed by the east part of Mt. Hermon, such as the Beit Jinn and Sabarani springs in Syria, as was actually suggested by Gur et al. (2003) and others.

Current Use of the System

The Israeli Hydrological Service decided recently to use HYMKE as a decision-making tool that will be operated parallel to other types of models. The model was applied successfully to another karst system (LK regional aquifers). It is now under a continuous process of improvements.

The System of Monthly Water-solute-heat Balances of Lake Kinneret

Description of the Problem

Water, solutes and heat budgets are a common procedure applied on a routine basis to sources of water, and especially to lakes, in order to determine available water, rainfall-discharge relationships, evaporation estimations, lake-groundwater relationships and water-quality issues. The results of continuous, long-term, periodic budgets are essential in order to study the hydrological system of the lake and to determine a long-term operational policy.

Annual publications on the monthly water, solute and heat balances of LK have been carried out and reported on a regular basis by Tahal (Water Planning for Israel Ltd.) since the 1950s, and more accurately from 1963 to 1986. Since 1987, Mekorot (Israel National Water Co.) has been conducting the balances annually. Whereas Tahal separated the solute from the water and heat calculations, according to the Mekorot method (Assouline 1993), all three balances were calculated simultaneously every month. In this procedure, measured properties of the three balances, which are monitored continuously on a monthly (or biweekly) basis, are used to calculate the closing residuals of the balances. The entire procedure is completed for each month when all three equations (i.e. water, solute and heat) are balanced, and the residual of each equation is found and evaluated.

In LK, two essential variables for lake management — the evaporation (Assouline and Mahrer 1993), and the unknown inflows of water and solutes from the saline springs (Rimmer and Gal 2003) — are calculated from the balances. Annual evaporation losses in LK are relatively high (270 ± 30 million m^3 annually or ~1600 mm) (Rimmer et al. 2006), about 36% of the mean annual outflows from the lake. During dry years, when pumping is reduced, evaporation rates can reach

~50% of annual outflows. The annual mean discharge from the saline springs was approximated as ~78 Mm^3 (only 10% of the water inflows) with an average salinity of 1160 mg L^{-1} and an average temperature of 27°C. The annual solute discharge was 78×1160=90,480×10^6 kg Cl^-, or 7540×10^6 kg Cl^- monthly (nearly 90% of the entire solute inflows to the lake).

System Type and Objective

In this system, the model output y(t) is a monthly summation of all the measured variables from the water, solute and heat balances. It includes all measured inflows and outflows, and the measured monthly differences between storage of water, solute and heat in the lake. The input x(t) includes three unknowns: the saline-spring inflows, the salinity of the these springs, and the evaporation. The system operation Φ(x) represents a well-known (Winter 1981; Assouline 1993) set of physical equations and assumptions which transfer the input to the output. This case is an **inverse problem** of the type **detection**, where we look for the unknown input. The objective here is to calculate systematically the three unknowns of the monthly balances. An important aspect of lake budgets is the effect of uncertainty related to the measured and evaluated components involved (Winter 1981). This issue was discussed in detail by Assouline (1993), Rimmer and Gal (2003), and Rimmer et al. (2006), but will not be part of this contribution.

Long-term analysis is essential in particular to define the functional relationship between the periodic changes of water levels in the lake and the discharge from the saline springs (Mero and Simon 1992; Rimmer and Gal 2003).

Mathematical Representation and Solution

When measured values are separated from unknowns (Figure 9), the water balance equation of LK is:

$$Q_{ur} + Q_s - Q_e = \Delta V_L + Q_d + Q_p - Q_{gs} - Q_j - Q_y - Q_r - Q_{mr} \qquad \textbf{(Equation 3.1)}$$

where the monthly measured quantities (Mm^3) at the right hand side of Equation 3.1 are ΔV_L the change in water volume of the lake, Q_d release through the Degania dam, Q_p withdrawal of water by pumping to the National Water Carier (NWC) and by private consumers, Q_j the Jordan River discharge, Q_y water diverted to the lake from the Yarmuch River, Q_r direct rain, Q_{mr} runoff from the gauged part of the direct watershed, and Q_{gs} discharge from the gauged part of the saline springs. The monthly unknown quantities (Mm^3) at the left hand side of Equation 3.1 are evaporation loss, Q_e, the unmonitored saline springs contribution, Q_s, and runoff from the ungauged direct watershed Q_{ur}.

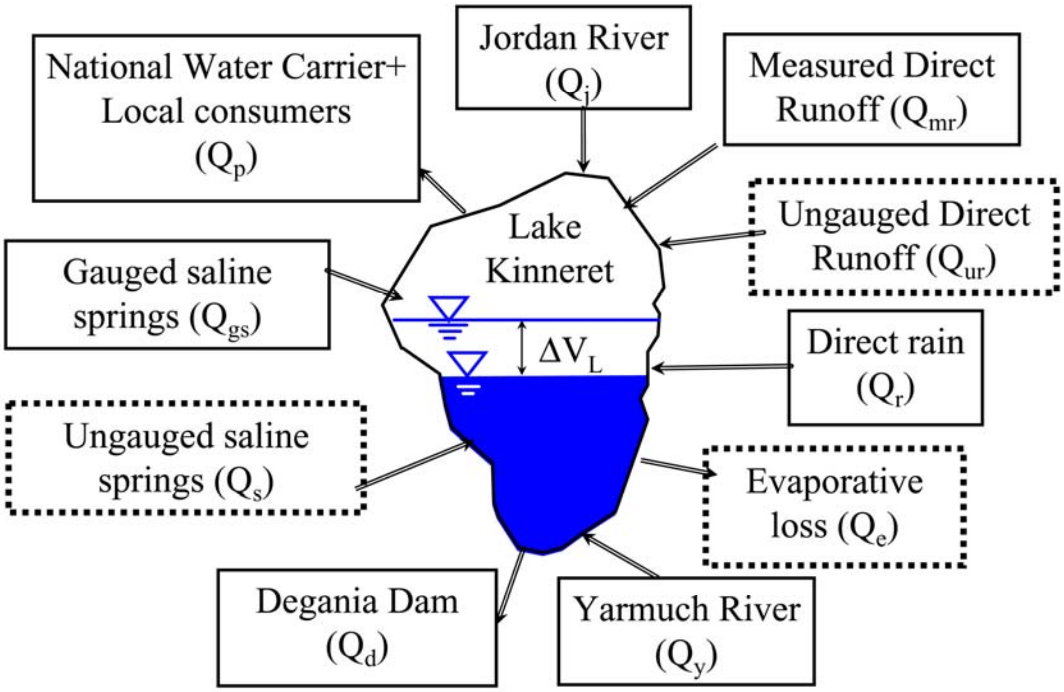

Figure 9. Schematic diagram of water-balance components, including inflows, outflows, and changes in lake volume. The unknown variables are marked with a dashed box.

Using the same procedure for the heat balance of LK results in the equation:

$$T_{ur}Q_{ur} + T_sQ_s - KQ_e = \Delta H_L + \sum_i T_iQ_i - R_n$$
$$K = L(1+\beta)+T_0 \qquad \textbf{(Equation 3.2)}$$

where R_n is net radiation at the surface, ΔH_L the change in heat storage in the lake, T_i the respective monthly mean temperature of the i-th measured component (i- subscript index), L the latent heat of water, T_0 the water surface temperature and β the Bowen Ratio. In terms of Equation 3.1 and assuming that rainfall and water vapour are salt-free, the salt balance equation is:

$$C_{ur}Q_{ur} + C_sQ_s = \Delta S_L + \sum_i C_iQ_i \qquad \textbf{(Equation 3.3)}$$

where ΔS_L is the change in salt storage in the lake, and C_i the respective monthly mean chloride concentration of the i-th measured component (i- subscript index).

Denoting by W (for water), H (for heat) and S (for salt) the results from the operations on the measured components as they are expressed on the right-hand side of equations 3.1,2,3, the expression of the system of equations to be solved is:

$$\begin{bmatrix} 1 & 1 & -1 \\ C_{ur} & C_s & 0 \\ T_{ur} & T_s & -K \end{bmatrix} \begin{bmatrix} Q_{ur} \\ Q_s \\ Q_e \end{bmatrix} = \begin{bmatrix} W \\ S \\ H \end{bmatrix}$$ **(Equation 3.4)**

Equation 3.4 could not be solved without further assumptions. First, based on occasional measurements during floods in the ungauged basins, C_{ur} and T_{ur} are assumed to be practically equal to the measured C_{mr} and T_{mr}; second, Q_{ur} was evaluated (and denoted by Q_{ur}^*) by assuming a simple proportion between runoff fluxes from neighbouring gauged and ungauged watersheds; and third, a linear relationship between C_s and T_s was fitted (Mero 1978). Under these three assumptions, the system in 3.4 becomes:

$$\begin{bmatrix} 1 & -1 \\ C_s & 0 \\ f(C_s) & -K \end{bmatrix} \begin{bmatrix} Q_s \\ Q_e \end{bmatrix} = \begin{bmatrix} W - C_{ur}^* \\ S - C_{ur} Q_{ur}^* \\ H - T_{ur} Q_{ur}^* \end{bmatrix}$$ **(Equation 3.5)**

Equation 3.5 holds three unknowns inputs — Q_e, Q_s and C_s — and therefore it has a unique solution. If a linear relationship between C_s and T_s is presented:

$$f(C_s) = T_s = aC_s + b,$$ **(Equation 3.6)**

the solution of 3.5 leads to the evaluation of the three detected inflow variables.

$$Q_e = \frac{\left(H - T_{ur} Q_{ur}^*\right) - a\left(S - C_{ur} Q_{ur}^*\right) - b\left(W - Q_{ur}^*\right)}{b - K}; \quad Q_s = W - Q_{ur}^* + Q_e; \quad C_s = \frac{S - C_{ur} Q_{ur}^*}{Q_s}$$

(Equation 3.7)

Results and Discussion

Solution of equation 3.6 results in the monthly evaporation from the lake (Q_e), the monthly inflows of the saline springs (Q_s), and the average monthly salinity (C_s) of the entire inflows of the springs. The entire process can be repeated from one month to another in order to create the time series that complete all three mass balances. With this procedure, the mean annual evaporation for 1968−2002 was calculated as ~1450±130 mm, with maximal evaporation during July (>185 mm) and minimum during February (<50 mm) (Figure 10).

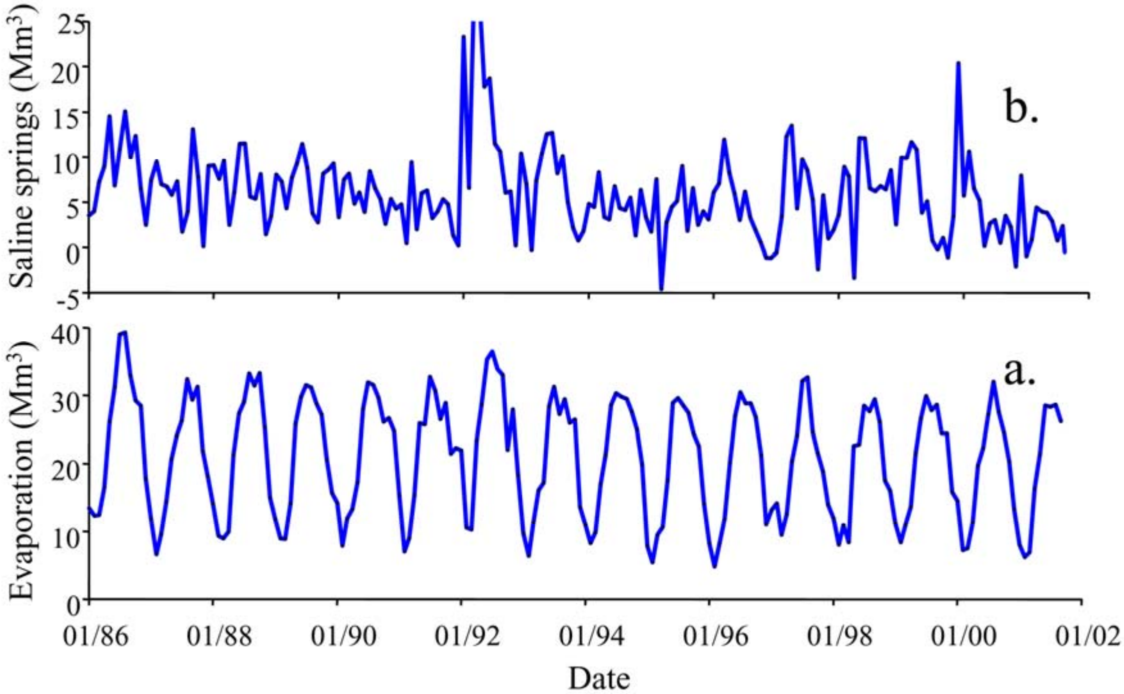

Figure 10. The residual of the Lake Kinneret water balance for the years 1986−2001: a. monthly evaporation; b. monthly discharge from the ungauged saline springs

While the calculated evaporation is easy to approximate with the water and energy balances method, the solution of the other two variables in Equation 3.7 (Q_s and C_s) often results in non-physical values such as negative spring-flow discharges (Figure 10), and/or negative, or extremely high values of spring salinities, caused by the noise in the calculated S time series. In order to minimize the effect of noise, it is proposed to solve the mass-balance equations with the following procedures (Rimmer and Gal 2003): First, it is essential to solve the problem with as long time series of W, S and H as possible. Second, it is recommended to replace the time series S with a smoothed series, S^*, which contains only a few negative values and which is much more stable than the original S_k series. Third, it was found that if a constant C_s=~1160 mg L^{-1} was assumed, there was a good closing of the entire lake mass balances. Note that according to the typical salinity-temperature relations of the Kinneret saline springs (Equation 3.6) $T_s=0.002\times C_s+25.1$ (T_s is the temperature), the salinity of $C_s \cong 1160$ mg L^{-1} is equivalent to a temperature of 27°C. Using the temperature of 27°C for the entire saline-springs discharge in a one-dimensional LK energy model (DYRESM) over 10 years, resulted in the best estimation of the lake temperature (Gal, pers. comm.).

The time series that complete the water, solute and energy balances are demonstrated in Figure 10. The results were used to clarify issues of the salinization mechanism, which had been under debate for several decades. We found a positive relation for both water and solute discharges of the saline springs with lake levels — i.e., there were high fluxes of groundwater, and high leaching of solute during rainy winters, indicating that the major salinization mechanism of the lake is leaching of brines by groundwater (Gvirtzman et al. 1997; Rimmer and Gal 2003). In addition, we examined the monthly solute flux against the monthly water discharge. We found that the solute mass increases with the water discharge, in agreement with the conclusions of Moshe (1978) and

Benoualid and Ben-Zvi (1981) but in contrast with model results reported by Simon and Mero (1992). We also showed that there is a positive relationship between annual solute influx and annual depth of precipitation, and therefore concluded that rainy winters cause higher fluxes of the groundwater to the lake, and higher quantities of solute — a conclusion that brought an important understanding to the dispute on LK's salinization mechanism (Goldschmidt et al. 1967; Mero and Mandel 1963; Gvirtzman et al. 1997).

Current Use of the System

The water-heat-solute balance system is continuously used by the Watershed Unit of Mekorot (1987 till today) to calculate and publish the annual summary of changes in LK hydrological variables.

The System of Lake Kinneret Salinity

Description of the Problem

Increased lake salinity is a growing problem in arid and semi-arid regions. Operational management, which is based on a reliable hydrological understanding, has the potential to control lake salinity. This is the case of LK, where saline water flows into the lake through on-shore and off-shore springs, causing the salinity of the lake to be relatively high (180−300 ppm Cl^-). The history of LK salinity has been documented since the beginning of the 20th century (Dalinsky 1969). In 1964, the Israeli National Water Carrier (NWC) became operative, and the chloride content began to drop from ~390 ppm Cl^- (Figure 11); this trend was enhanced in January 1965, when the Saline Water Carrier (SWC, a canal that diverts the northwestern-shoreline saline springs from the lake) was fully operated. Lake salinity dropped significantly between 1965 and 1968, and this was further enhanced by the exceptional winter of 1968−69 (inflows of 200% compared to an average year). The lowest lake salinity, 192 ppm Cl^-, was reported in May 1988. It then increased to 250 ppm Cl^- following three dry winters, and decreased to ~210 ppm Cl^- following the exceptionally rainy winter of 1991−1992. From the end of the winter of 1993−1994 to the winter of 2001−2002, the annual average lake salinity has increased and the annual average lake level has decreased constantly.

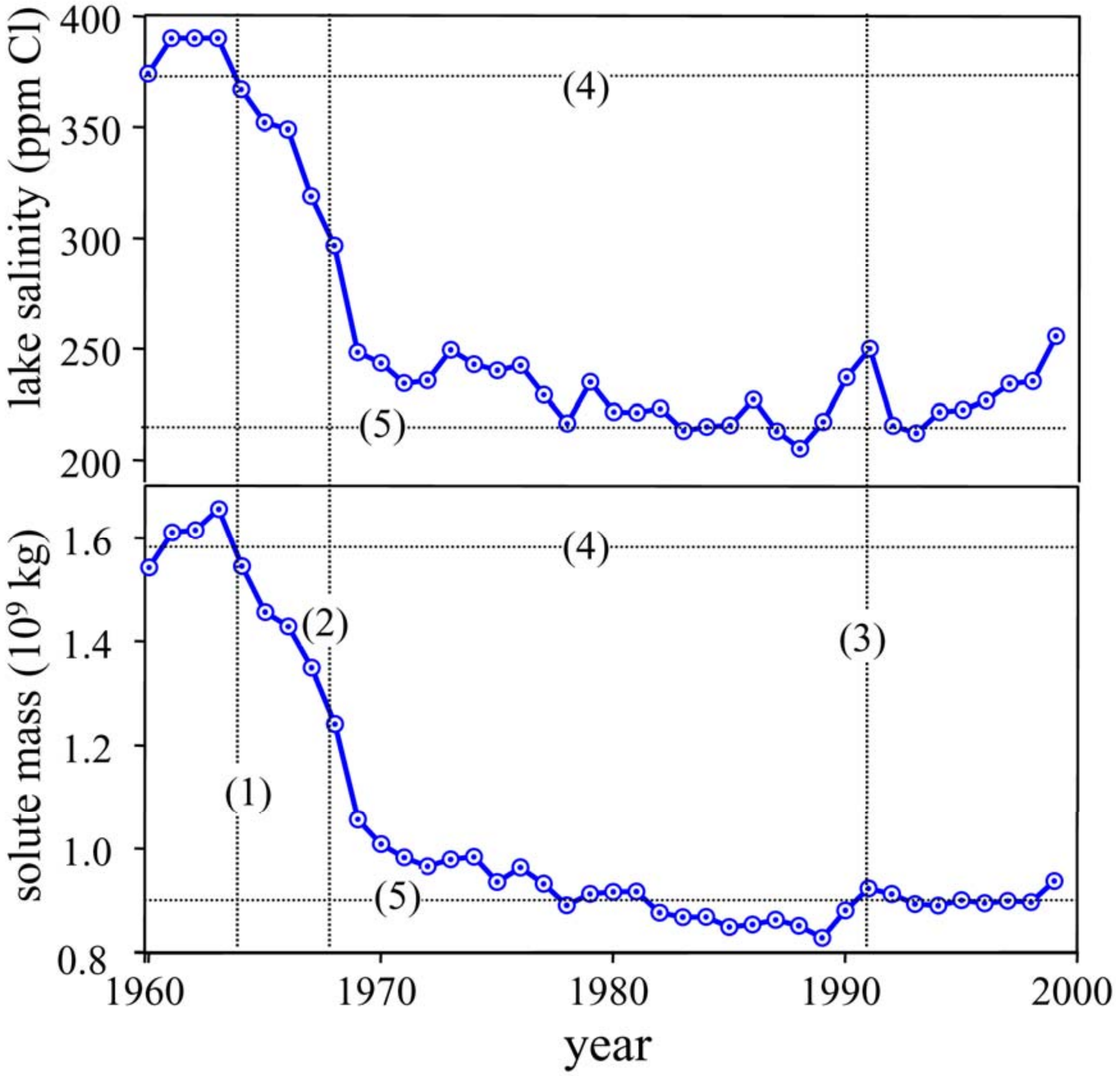

Figure 11. Lake salinity (top panel) and solute mass in the lake (bottom panel) at the beginning of each year (October 1), for the years 1960−1999: (1) operation of the Saline Water Carrier (SWC); (2) the winter of 1968−1969; (3) the winter of 1991−1992; (4) high lake salinity during the years 1960−1963; (5) expected lake salinity with the diversion of the saline springs by the SWC

The most significant variable in the analysis of LK salinity is the solute mass inflow to the lake. Ben-Zvi and Benoualid (1981) calculated the annual average total inflow of solute to the lake as 161×10^6 kg for the period 1960−1979. Simon and Mero (1992) calculated an average of 159.4×10^6 kg×year^{-1} for the period 1960−1986, with a standard deviation of 18.7×10^6 kg×year^{-1}. Rimmer (1996) calculated the solute mass inflows to the lake for the years 1968−1996 in four groups: 1. the springs diverted by the SWC (~38×10^6 kg×year^{-1} from Tabgha and ~17×10^6 kg×year^{-1} from Tiberias); 2. the measured springs that flow to the lake (~12×10^6 kg×year^{-1}); 3. the unknown springs (~78×10^6 kg×year^{-1}); and the surface-flow contribution (~15×10^6 kg×year^{-1}). His annual average solute inflow (~160×10^6 kg×year^{-1}) was in agreement with previous estimations.

Several policies for the operation of the lake have been examined in the past, using models to predict the expected changes in lake salinity. F. Mero developed in the late ’70s a model for the effect of operational aspects such as pumping and saline-springs diversion (Mero and Simon 1992). Ben-Zvi and Benoualid (1981) developed a model that connected the semi-annual solute inflow, water discharge, and rainfall. Assouline et al. (1994) suggested a monthly based model for the same purpose. Berger (2000) further developed Assouline's model into a general operational model for the LK system. All the proposed models were lake-wide numerical models based on statistical analysis of data of water discharge to the lake, and solute discharge from the saline-springs system.

The proposed systems approach model is a lake-wide model for the salinization mechanism, based on the main components of the solute balance. However, unlike previous statistical models, it proposes that with the appropriate assumptions, LK's salinization mechanism can be described by a simple, physically based model (complete mixing) and therefore can be solved analytically. The solution allows us to easily examine the influence of each component of the solute balance on expected salinity changes. Predictions of changes in lake salinity were demonstrated for the cases of controlled increase or decrease of saline-springs discharge to the lake, and for the changes in water quantity allowed to flow into or be pumped out of the lake.

System Type and Objective

The **input** data x(t) of this hydrological system represent long-term annual stream inflows, outflows, and evaporation, direct annual rainfall, and average stream salinity; the **system operation** $\Phi(x)$ represents the equations of complete mixing (CM). The theory of CM is often used in geochemical analysis of water resources (Lerman 1979; Varekamp 1988). In a CM model, solute flux through the outlet is proportional with solute storage (Figure 12). The **output** y(t) is the long-term predictions of solute mass and volume of the lake, based on the input. This problem exemplifies the **direct problem** of **prediction**.

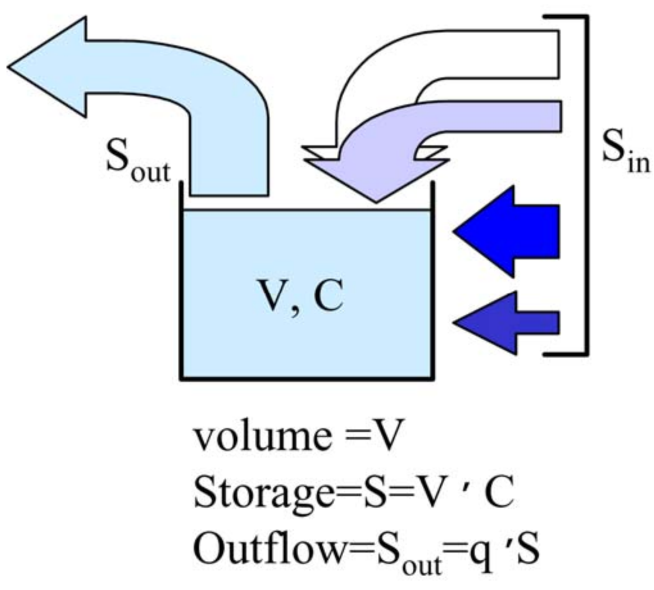

Figure 12. The complete mixing concept: C is the salinity of the lake (ppm Cl^-), V volume (Mm^3), S the solute mass in the lake (kg), S_{in} and S_{out} the inflow (tributaries, springs) and outflow (pumping and water release) of solute, respectively (kg × $year^{-1}$).

The objective of this work was to verify an existing well-known physical mechanism, and to use it as a tool to predict long-term changes of chloride concentration in the lake. The theoretical mechanism was tested against special cases of long-term salinity changes in LK in the past, and then was used to predict the long-term influence of future operation policies on lake salinity.

Mathematical Representation and Solution

The equation for the continuous water balance in the lake is:

$$\frac{dV(t)}{dt} = Q_{in}(t) - Q_{out}(t) \qquad \textbf{(Equation 4.1)}$$

where V is the volume of the lake (Mm^3); t is time (year); Q_{in} ($Mm^3 \times year^{-1}$) the inflow discharge; and Q_{out} the outflows ($Mm^3 \times year^{-1}$). As with the water, the solute balance of the lake can be written as:

$$\frac{dS(t)}{dt} = S_{in}(t) - S_{out}(t) \qquad \textbf{(Equation 4.2)}$$

where $S = C_{lake}V$ is the solute mass in the lake (kg), represented by multiplying the average chloride concentration C_{lake} (ppm Cl^-) by the lake volume V (Mm^3); S_{in} is the incoming solute flux (kg × $year^{-1}$); and S_{out} is the solute outflow flux (kg × $year^{-1}$) through pumping and water release.

The incoming solute flux, S_{in} (Equation 4.2), may be written as a product of total water flux Q_{in} and a single, averaged solute concentration, $\overline{C}_{in}$:

$$S_{in}(t) = Q_{in}(t)\overline{C}_{in}(t); \qquad Q_{in} = \sum_i Q_i; \qquad \overline{C}_{in} = \frac{\sum_i Q_i C_i}{\sum_i Q_i} \qquad \textbf{(Equation 4.3)}$$

where i is the index of inflow sources. It is assumed that a mechanism of complete mixing can be applied to the lake, and therefore the concentration of solutes in the outflows is equal to the average lake salinity, i.e.:

$$S_{out}(t) = Q_{out}(t)C_{lake}(t) \quad ; \quad C_{lake}(t) = \frac{S(t)}{V(t)} \qquad \textbf{(Equation 4.4)}$$

Substituting equations 4.3 and 4.4 into Equation 4.2 results in:

$$\frac{dS(t)}{dt} = Q_{in}(t)\overline{C}_{in}(t) - \frac{Q_{out}(t)}{V(t)}S(t) \qquad \textbf{(Equation 4.5)}$$

Equation 4.5 may be written in the form:

$$\frac{dS(t)}{dt} + q(t)S(t) = S_{in}(t) \quad ; \quad s.t.: S|_{t=0} = S_0$$
$$q(t) = \frac{Q_{out}(t)}{V(t)} \quad ; \quad S_{in}(t) = Q_{in}(t)\overline{C}_{in}(t)$$

(Equation 4.6)

The S_0 in Equation 4.6 represents the initial solute mass in the lake, and q stands for the ratio of outflows to lake volume, which is the water renewal rate, or the reciprocal of water residence time (Wetzel 1983). Assuming a constant long-term operation policy within the computational time period, with constant outflows, inflows and a steady lake level (i.e. q and S_{in} are constants), the solution of Equation 4.6 is then given by:

$$S(t) = \frac{S_{in}}{q} + \left(S_0 - \frac{S_{in}}{q}\right)\exp(-qt)$$ **(Equation 4.7)**

The expression $(S_0 - S_{in}/q)$ is the lake-system full response to changes in solute and/or water inflows and outflows. If this expression is zero, lake solute mass remains constant; if the expression is negative, lake solute mass increases, and vice versa. We are particularly interested in the solution of Equation 4.6 over periods in which S_{in} (representing the degree of control, and the natural fluctuations of the saline-springs inflows) and q (representing the policy of pumping, and overflow from the lake) change in steps (i=0…n) from one period to another. For this type of step change, we can also use the solution of 4.7 as explained by Rimmer (2003).

Results and Discussion

This system was tested and verified mainly for the years 1964−2000, as the LK salinity data for this period are more reliable than data from previous years. Moreover, monthly water and solute balances of the lake (Water Planning for Israel 1968−1986; Mekorot 1987−2005, see above) support the reliability of these data.

Steady state

Mean annual net inflow (total inflow, including direct rainfall evaporation) of water for the entire period was 490 Mm^3; mean annual outflows (not including evaporation) were 498 Mm^3; and mean lake volume was 4020 Mm^3. The time taken for lake salinity to reach a steady state can be estimated by calculating the mean q. Applying the calculated mean $\overline{q} = 0.12$ (residence time $= 1/\overline{q}$ =8.3 years) to Equation 4.7 results in a change of 70% in the system response during the first 10 years, and a change of 91% in the system response during the first 20 years. A steady state can therefore be considered after nearly 3/q (~25) years. By then the solution in Equation 4.7 nearly reduces to the expression $S(t) = S_{in}/q$. Taking, for example, $S_{in}=160\times10^6$ kg×year^{-1} as the annual mean solute inflow to the lake without the diversion of the SWC (Simon and Mero 1992), and using q=0.12, the calculated solute mass in the lake at steady state was ~1333×10^6 kg, and the calculated salinity (with V=4020 Mm^3) was ~330 ppm Cl^-, similar to the average measured values prior to 1960. As a result of the operation of the SWC, which diverts an average of ~55×10^6 kg×year^{-1} from the lake, the average annual inflow was reduced to $S_{in}\cong105\times10^6$ kg×year^{-1}. The calculated solute mass in the lake for steady state is then ~875×10^6 kg, and the expected calculated salinity is ~218 ppm Cl^-. Similar values have been measured in the lake since 1980 (Figure 11).

Lake salinity changes in time

The most obvious example of long-term salinity changes is the period 1964−1987, following the operation of the SWC in 1964. The duration of this period is nearly 3/q years — i.e., at the end of this period, lake salinity is close to reaching a steady state. During these years, lake solute mass decreased from 1550×10^6 kg to 861×10^6 kg, and lake salinity decreased from 367 to 212 ppm Cl^-. The natural exponential decay of solute mass and the reduction of the salinity of the lake are illustrated in Figure 13a. Special attention needs to be drawn to the exceptionally rainy season of 1968−69. This season contributed a relatively high (~160×10^6 kg) solute mass to the lake. Nevertheless, this season contributed more than twice the annual average inflows, and the value of q was 0.302, compared to an average of 0.127 for the period 1964−87. As a result, lake solute mass dropped significantly faster than the predicted exponential decay. On a 23-year scale, however, the exponential decay represents the salinity changes well.

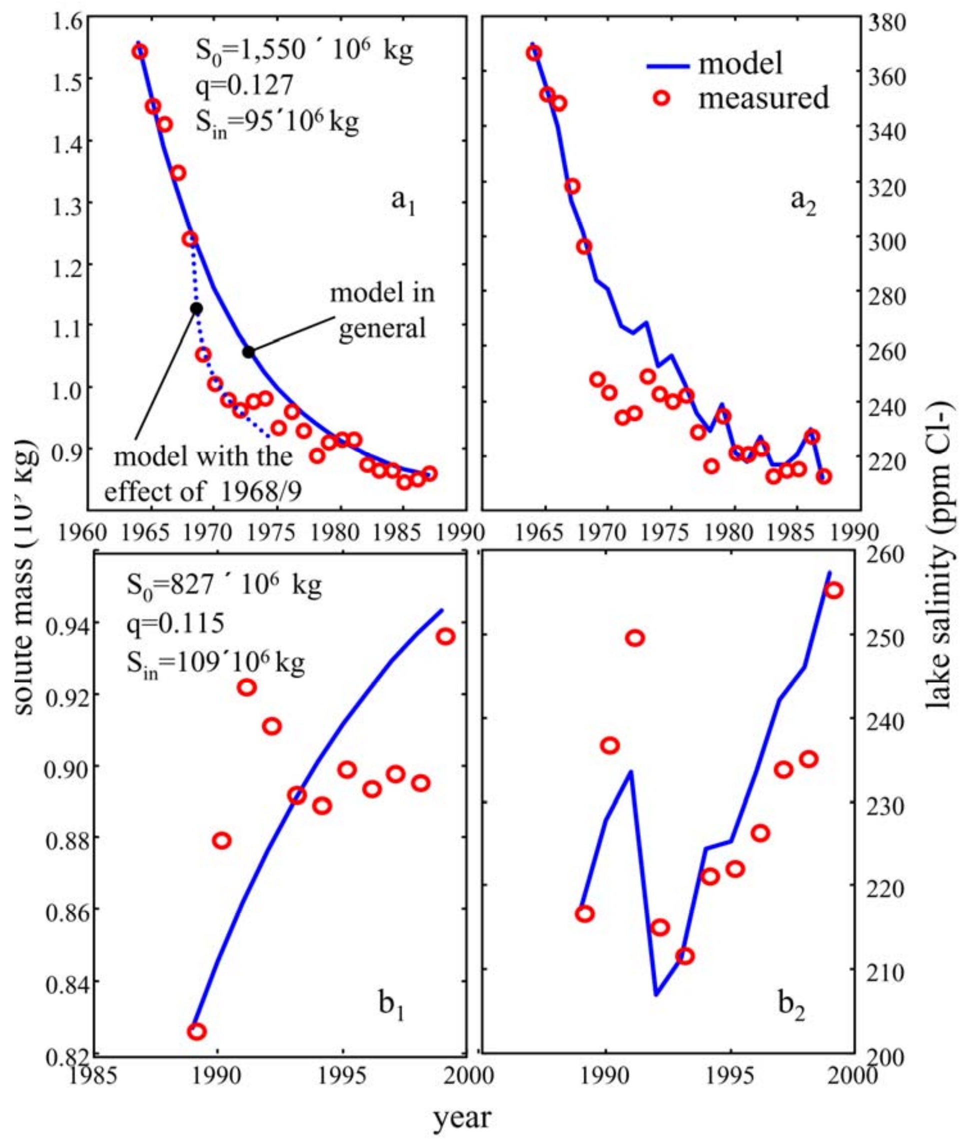

Figure 13. Changes in solute mass (left) and in the salinity of the lake (right): a. from 1964 to 1987; b. from 1988 to 1999

Another example is the period 1989−2000, illustrated also in Figure 13b. The annual solute balance shows an increased discharge from an average of 95×10^6 kg during the years 1970−1989, to nearly 109 ×10^6 kg in 1989−2000. This change was explained by the less effective usage of the SWC, and the solute inflows increase during the rainy winters of 1991−92 and 1992−93. These two reasons together added ~14×10^6 kg Cl^- to the average solute inflows during this period. In addition, lake volume varied significantly, from ~3600 Mm^3 in 1991, to ~4200 Mm^3 in 1992, and back to 3600 Mm^3 in 1999. Applying Equation 4.7 to this period with the calculated average annual values (q=0.115; S_{in}=~109×10^6 kg) resulted in an exponential increase of the solute mass and a fairly good description of lake salinity despite all the major changes in the hydrology of the lake.

Predictions

The purpose of this section is to demonstrate the use of Equation 4.7 to predict the long-term influence of future operation policies on the lake's salinity.

Change in saline-springs discharge: Two procedures can cause a change in solute inflows to the lake. The direct control of solute flux can be achieved by an increase or decrease of the diverted discharge into the SWC. An indirect method to change solute inflows is by increased pumping from the eastern Galilee aquifers (Rimmer et al. 1999; Gvirtzman et al. 1997). Using the first approach, the diverted discharge can be measured directly — unlike with the second approach, in which the effect on the saline-springs system can be evaluated only by calculations of lake solute balance. In the following, it is assumed that the average S_{in} can be controlled.

Prediction of salinity changes as a result of changes in the diverted amount is straightforward: First, the starting year t_0 and the appropriate initial lake solute mass S_0 were determined; second, a new solute inflow S_{in} was calculated; third, the mean q value of the lake was determined for a given lake level and cumulative outflows; fourth, Equation 4.7 was applied for future years; and finally, the approximated solute mass was divided by the lake volume, V. The calculated results for this procedure, with C_{lake0}=280 ppm Cl^-, and Q_{out}=500 Mm^3, were plotted on the same axes for two lake levels (V=3600, 4020 Mm^3); and five solute discharges S_{in}=[70,90,110,130,140]×10^6 kg (Figure 14a). The parameters of this prediction are therefore q=[0.138, 0.124] and S_0=[1008, 1125.6]×10^6 kg for V=3600, and V=4020 Mm^3, respectively. The predictions for 10 years are a decrease in lake salinity to ~180 ppm Cl^- for S_{in}=70×10^6 kg, and no decrease for S_{in}=140×10^6 kg. It is shown that the reduction in lake salinity for the same S_{in} is faster for a lower volume, because the leaching effect on the solute mass, determined by q, is higher when the lake volume is smaller.

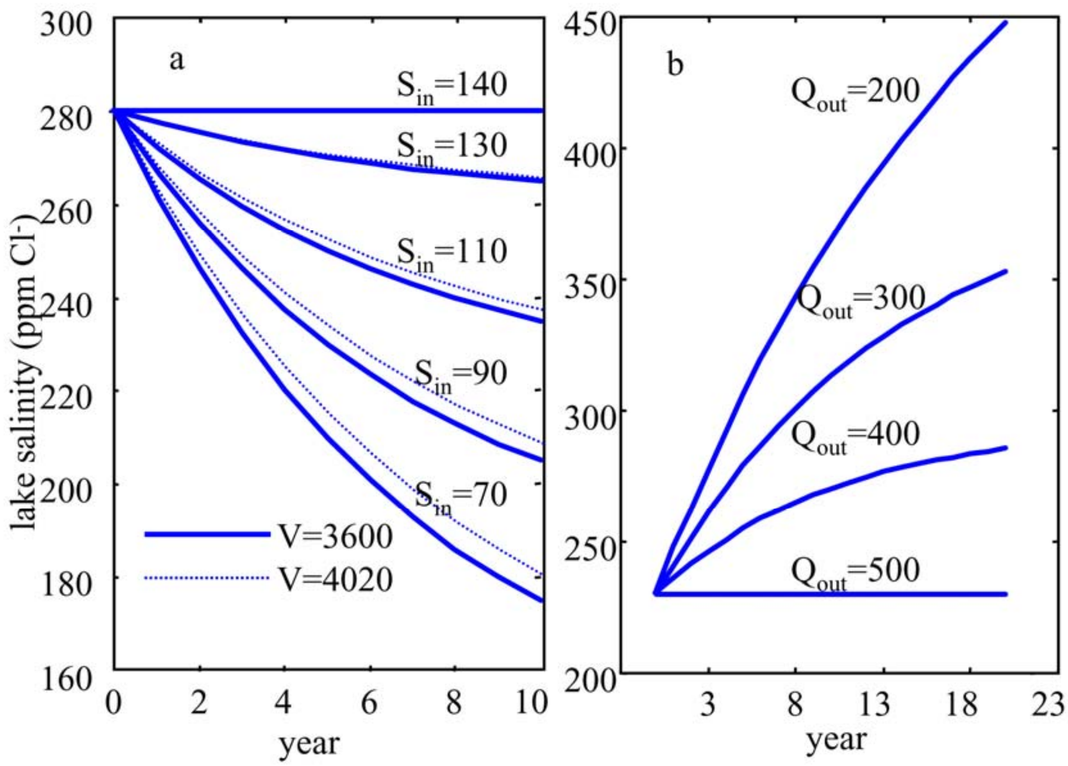

Figure 14. a. predictions of changes in lake salinity for five solute discharges (S_{in}=70, 90, 110, 130, 140×10^6 kg). Predictions were calculated with Q_{out}=500 Mm^3 and initial salinity of $Clake_0$=280 ppm Cl_- for two lake volumes 1. V=3600 Mm^3 (solid line), and 2. V=4020 Mm^3 (dashed line); b. predictions for 20 years of changes in lake salinity as was calculated for four average outflows Q_{out}=200, 300, 400 and 500 Mm^3, with initial lake salinity C_{lake0}=230 ppm Cl^-; V=4020 Mm^3 (S_0=924.6×10^6 kg) and S_{in}=115×10^6 kg

Change in inflows from the Jordan River

Significant variations in the salinity of LK are also expected as a result of changes in the average quantity of inflows from the Jordan River and the streams from the LK direct watershed. The results for 20-year predictions in the case of reduced water inflows and outflows, with C_{lake0}=230 ppm Cl^-; V=4020 Mm^3 (S_0=924.6×10^6 kg) and S_{in}=115×10^6 kg were calculated for four average outflows Q_{out}=[200, 300, 400, 500] Mm^3. The q values are therefore 0.049, 0.074, 0.099 and 0.124, respectively. A significant change in lake salinity is expected as a result of the decrease of q, explaining the increase in salinity of the lake in dry seasons, and the desalinization of the lake during very rainy seasons.

Current Use of the System

The above CM approach was used to explain a long-term increase in the salinity of Lake Biwa, Japan. The system is now improved and includes stochastic components (Rimmer et al. 2006). It is planned to be applied by the Israeli Hydrological Service for long-term salinity predictions for LK.

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Ayman Rabi, Session Chair:

Thank you very much, Alon, for this very interesting presentation. I think it is really useful. I would now like to introduce Engineer Yousef Ayadi from Jordan. Engineer Ayadi received his PSE degree in Engineering from Cairo University, Egypt, in 1971. He's Director of Planning within the Ministry of Water and Irrigation, Jordan Valley Authority, and has many publications in water-management issues in the region. Please, Engineer Ayadi, the floor is yours.

Policy and Adaptation in the Jordan Valley

Yousef Hasan Ayadi, Director of Planning, Ministry of Water and Irrigation, Jordan Valley Authority, Hashemite Kingdom of Jordan

Abstract

The Jordan Valley Authority (JVA), under the Ministry of Water and Irrigation, is entrusted with the integrated socio-economic development of the Jordan Valley. During the last 30 years, JVA has completed numerous infrastructure projects in the Valley which have changed the lifestyle of its inhabitants, reversed rural-to-urban migration and even attracted others to settle in the area. Presently, JVA is focusing its efforts on water- and land-resource development, management and protection, in addition to tourism development and promotion in the Jordan Valley.

Jordan's water strategy and policies were summarized, the institutional set-up in the Jordan Valley was discussed and the 20 adaptive measures used to apply these policies were introduced. A modern water-control centre using an advanced Supervisory, Control and Data Acquisition System (SCADA) was installed in the Valley to monitor and control water-management activities, and a Water Management Information System (WMIS) was developed in order to provide the necessary decision-support tools for optimum water distribution of the limited water resources to satisfy agricultural and domestic water users. The WMIS modules help system managers to develop seasonal water-management strategies, to follow up monthly and daily water-management activities and to balance available water supply and water demand. Water tariffs were introduced, with an increasing block structure to encourage farmers to reduce water consumption and save irrigation water. A participatory water distribution management approach was implemented to encourage farmers to form water-user groups that suit their particular situations in order to share the responsibility of irrigation water distribution with the JVA. This approach became possible after the amendment of *Jordan Valley Development Law no. 30/2001*, which allowed the participation of the private sector in the operation and management of the irrigation system in the Jordan Valley, as reflected in the JVA Strategic Plan for the years 2003–2008.

Keywords: Jordan Valley, JVA Mandate, Strategic Plan, Water Management Information System, SCADA, JWC, Red Sea–Dead Sea Water Conveyance Project.

1. Background

The Jordan Valley (JV) is part of the Great Rift Valley, which extends from southern Turkey to the Horn of Africa. In the Hashemite Kingdom of Jordan (HKJ), it extends for about 400 km from the Jordanian border south of Lake Tiberias in the north, to the Gulf of Aqaba in the south. According to the JV development law, it extends westward to the western Jordanian border and eastward to 300 m above sea level north of the Dead Sea and 500 m above sea level south of the Dead Sea. The Valley is 5 to 10 km wide, and its floor varies in elevation from –212 m south of Lake Tiberias, to –417 m at the Dead Sea, and rises to +250 m in central Wadi Araba before dropping down to sea level in Aqaba.

The variations in temperature, humidity and rainfall produce distinct agro-climatic zones. Annual rainfall starts in October and ends in May, most of it falling from December to February. The northern area receives about 400 mm/year, while the southern areas receive 100 mm/year. In dry years, precipitation drops down to 200 mm in the northern area and to 50 mm at the Dead Sea, whereas in wet years these same locations receive up to 650 mm and 250 mm respectively.

The salient variations between northern, central and southern parts of the JV are also clear in terms of water availability, water quality, soil type, and cropping pattern. Water resources in the JV are scarce and deteriorating, which severely constrains agricultural production. The annual available water resources in the valley are estimated to be 300–350 million cubic metres (MCM), while the annual demand exceeds 500 MCM. The agricultural land that could be irrigated represents about 60%–70% of the irrigable land in the valley due to the lack of water resources, and the gap between supply and demand is increasing due to the competition between municipal and industrial (M&I) water users and irrigation water users.

The Jordan Valley can be considered a natural greenhouse with the relative advantage of producing off-season fruits and vegetables. Although its area represents less than 5% of the HKJ area and its population less than 6% of the country's population, the valley produces more than 60% of the Kingdom's fruits and vegetables.

Figure 1. Jordan Valley mandate north of the Dead Sea

Figure 2. Jordan Valley mandate south of the Dead Sea

2. Water Resources in the Jordan Valley

2.1. Surface-water Resources

Water resources in the JV are characterized by scarcity, variability and uncertainty. One of the main sources of water in the JV is the Jordan River. The lower Jordan River originates at the outlet of Lake Tiberias and discharges into the Dead Sea, and it forms the north-south axis of the valley, with several tributaries flowing from east and west of the river.

The Yarmouk River is the major lower Jordan River tributary, and its waters are shared with neighbouring countries located upstream and downstream of the river. The main eastern tributaries of the lower Jordan River sub-basin are the Zarqa River and the side wadis of Arab, Ziglab, Jurum, Rayyan, Kufranja, Rajib, Shueib, Kafrein and Hisban.

The east Dead Sea sub-basin includes the wadis of Mujib, Wala, Zarqa-Ma'aeen, Karak, Hasa, Ibn Hammad and other inter-catchments. The south Dead Sea sub-basin includes the wadis of Feifa, Khneizerah, Ad Dahil, Fidan, Musa, Dana and As Siq.

Total surface-water resources currently available in the JV amount to about 337 MCM/yr., of which 217 MCM/yr. are in the northern part of the Valley and 120 MCM/yr. are in the south.

2.2. Groundwater Resources

Groundwater is scarce in the JV. There are three main well fields producing about 45 MCM/year: the Mukheibeh well field (25 MCM/year), the Wadi Arab well field (12 MCM/yr.), and the Kafrein well field (8–12 MCM/yr.).

2.3. Treated Waste Water

There are 22 waste-water treatment plants (WWTP) in Jordan, producing about 80 MCM/yr., of which 60 MCM flows down to the Jordan Valley, with Khirbet Al-samra discharging to the Zarqa River being the largest with a flow of about 50 MCM/yr. Figures 2 and 3 summarize the currently available water resources and demands in the JV areas north and south of the Dead Sea.

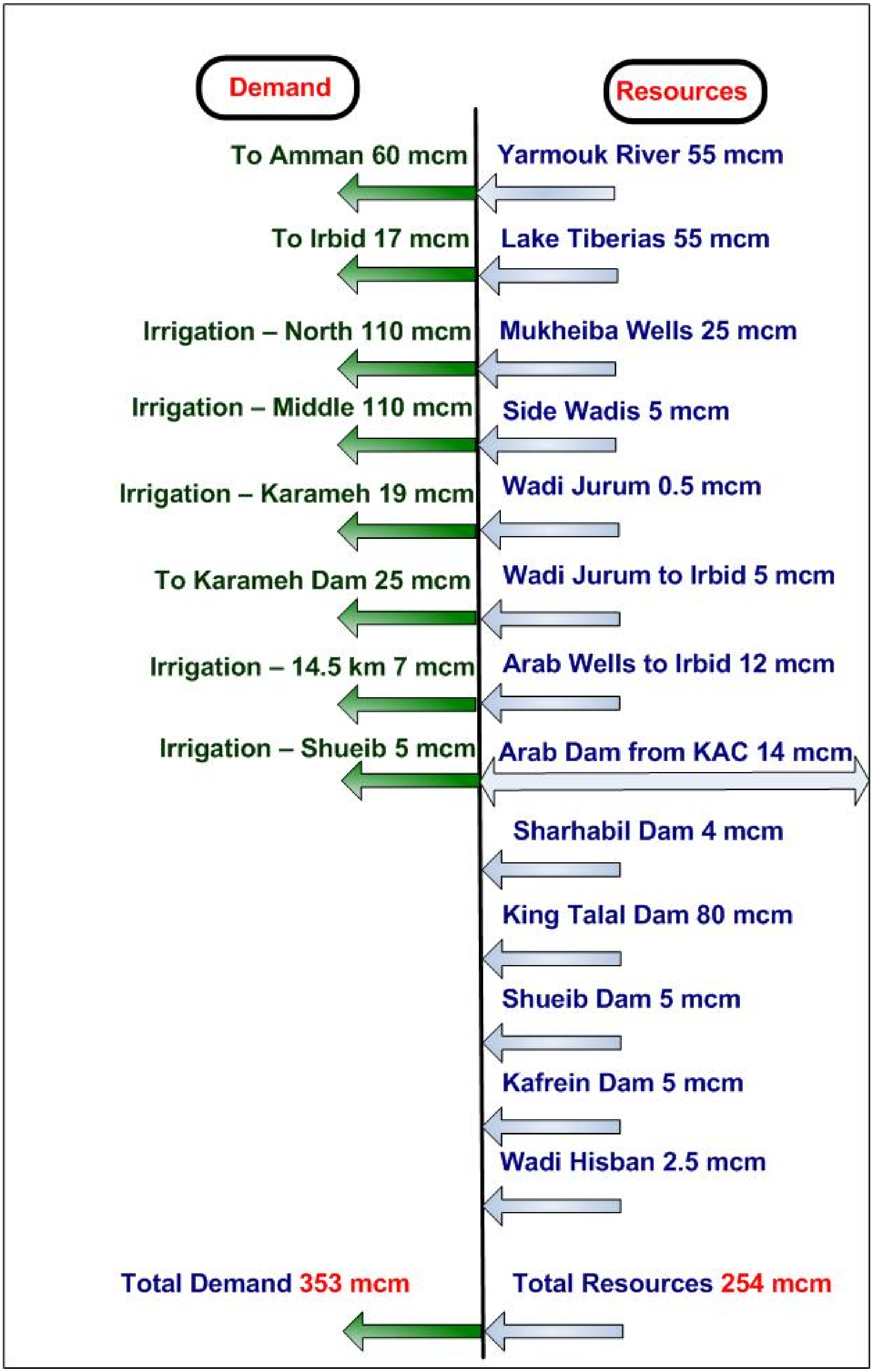

Figure 3. Current demand and resources north of the Dead Sea

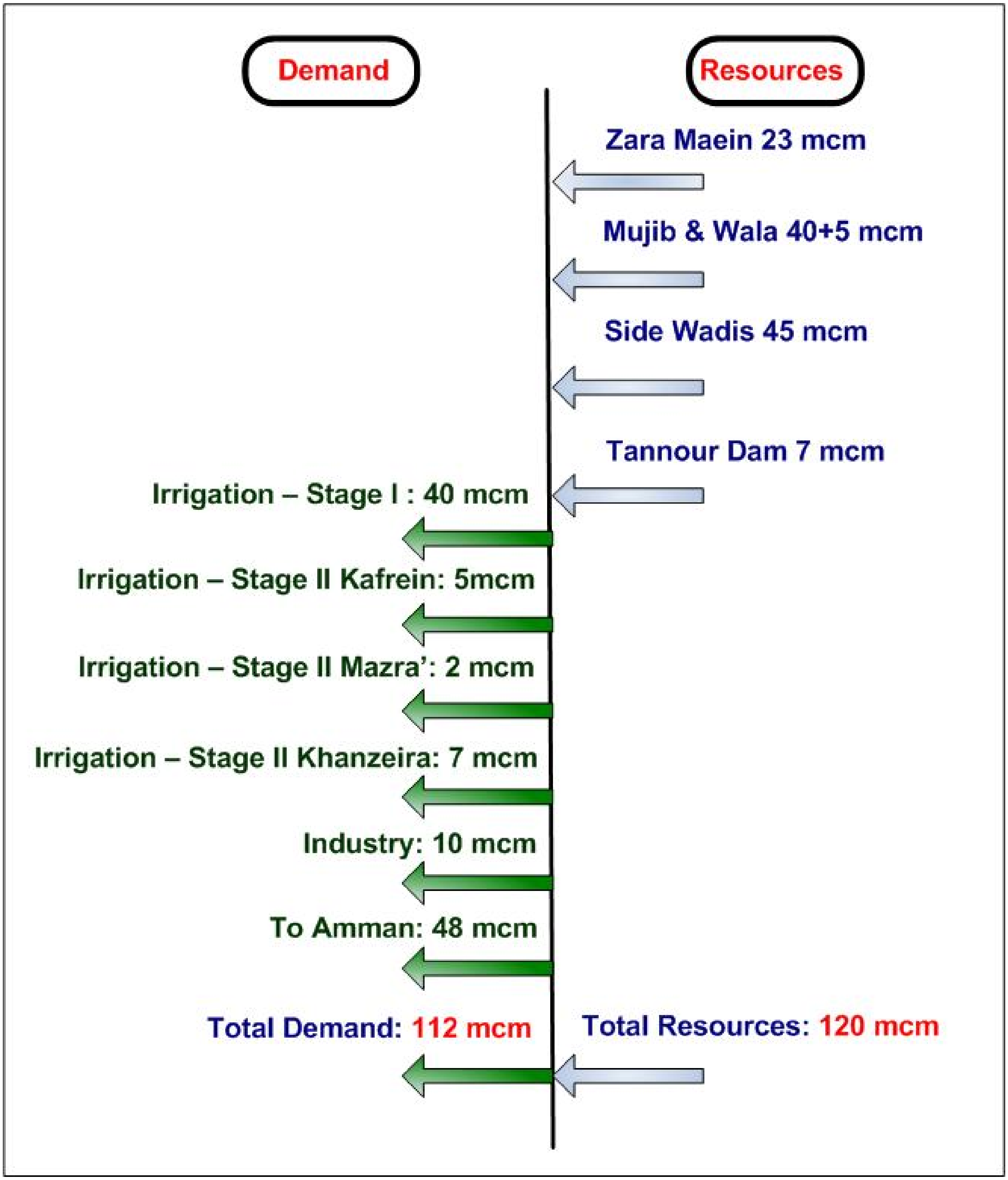

Figure 4. Current demand and resources south of the Dead Sea

3. Infrastructure Development in the Jordan Valley

In the early 1950s, the Jordanian government, through the Jordan Valley Authority (JVA) and its predecessor organizations, started to implement the development of infrastructure and irrigation projects in the Jordan Valley.

In 1958 the construction of the East Ghor Canal (now King Abdullah Canal) allowed the conveyance of water from the Yarmouk River to irrigate lands in the JV. The first phase was 70 km long, ending at the Zarqa River and irrigating 12000 ha. The canal was later extended by 8 km and then 18 km, and finally by 14.5 km in 1989 for a total length of about 110 km.

Other irrigation projects were constructed and irrigated directly from other water sources — such as the North East Ghor (NEG) project, which is supplied by the reservoirs on Wadi Arab and Wadi Ziglab, in addition to Wadi Jurum water, to irrigate 4200 ha; the Zarqa Triangle project, which is supplied from the Zarqa River via the Zarqa carrier to irrigate 1650 ha; and the Kafrein/Hisban project, which is supplied from the Kafrein Dam and Wadi Hisban to irrigate 1660 ha. These projects increased the total area equipped with irrigation infrastructure to about 31000 ha.

South of the Dead Sea, Stage I of the Southern Ghors irrigation scheme was constructed in the period 1983–1985 to bring about 4750 ha under modern drip irrigation. Recently, another 900 ha were developed in Ghor Mazraa, Fefa and Khneizerah.

In parallel with irrigation projects, the developed agricultural land in the JV was divided into farm units of 3–4 ha each which were distributed to farmers in the JV.

Dam construction started in 1967 with the building of the Sharhabil (Ziglab) Dam (4 MCM) and continued with the Shueib Dam (1.5 MCM) in 1968 and the Kafrein Dam (increased to 8.4 MCM in 1994). The King Talal Dam was constructed in 1977 (increased to 75 MCM in 1987), and the Wadi Arab Dam was constructed in 1986. The construction of the Karameh Dam (53 MCM) started in 1994 and was completed in 1997.

In addition to the dams in the north, three dams in the Southern Ghors — the Mujib (35 MCM), the Wala (9.3 MCM) and the Tannour (16.8 MCM) were recently completed. Two conveyors from the Mujib Diversion were also recently completed to convey water northward (48 MCM) to the city of Amman and southward (12 MCM) to the Dead Sea industrial complexes and to the agricultural areas in the Southern Ghors.

The Al-Wehda Dam (110 MCM) is being constructed on the Yarmouk River and is expected to be completed by the end of 2006.

Other dams are planned on the Karak, Ibn Hammad, Meddain, Qai, Whaideh, Rahmeh and many other sites, pending the availability of financing.

The total storage capacity of the dams is currently 218 MCM, and will amount to 328 MCM after the completion of the Al-Wehda Dam.

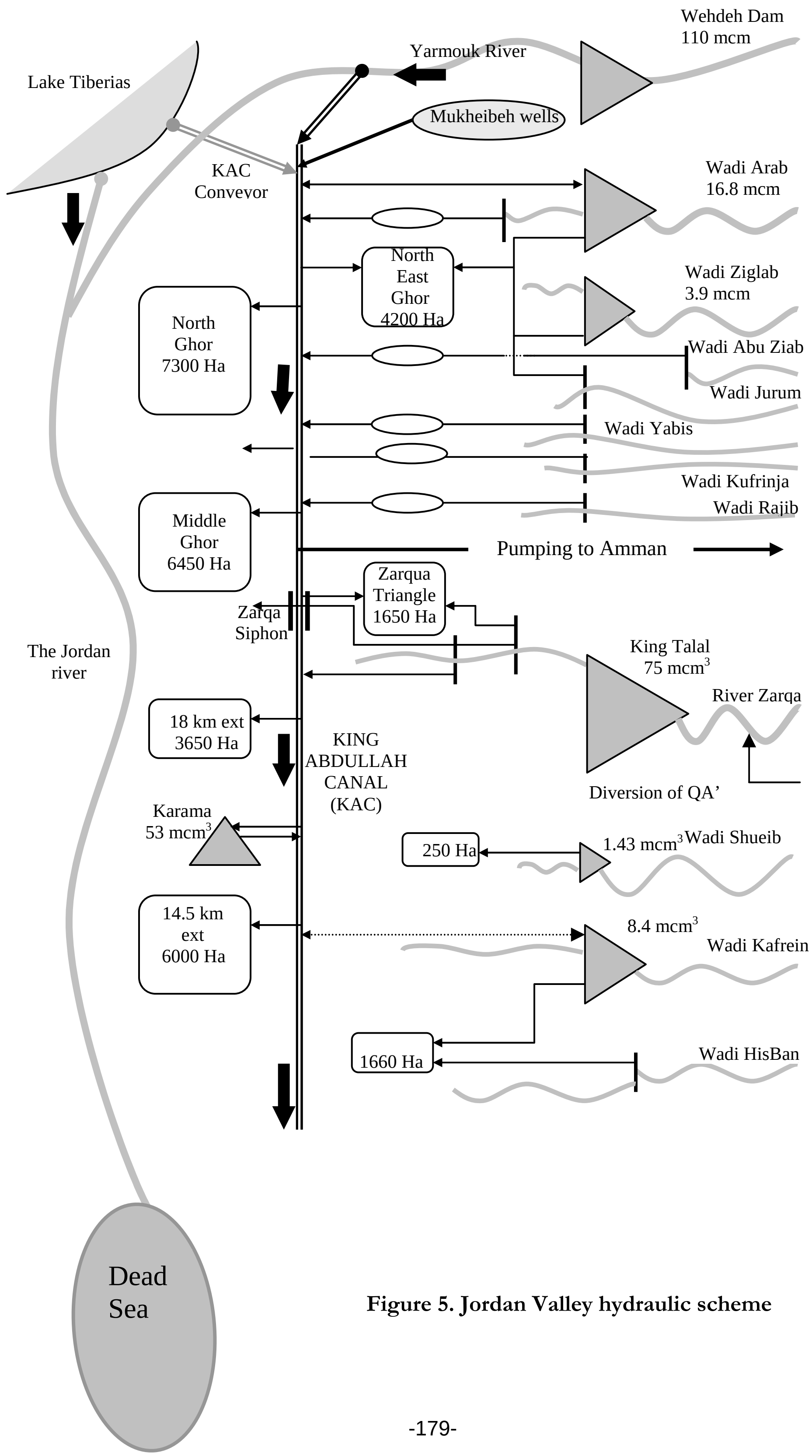

Figure 5. Jordan Valley hydraulic scheme

4. Water-sector Strategy and Policies

The Ministry of Water and Irrigation (MWI) published the Jordan Water Strategy in 1998 and developed a set of policies related to irrigation, groundwater, waste water and utilities. The following are the main features of the water strategy and accompanying policies:

4.1. On Resource Development

- Water is a national resource and shall be valued as such at all times. A comprehensive national water data bank will be established and kept at the Ministry of Water and Irrigation and will be supported by a decision support unit. It will be supported by a program of monitoring and a system of data collection and of entry, updating, processing and dissemination of information and will be designed to become a component of a regional water data bank.
- The full potential of surface water and groundwater shall be tapped to the extent permissible by economic feasibility, while addressing social and environmental impacts. Investigation works of deep aquifers shall be conducted to support development planning. The interactive use of ground- and surface water with different qualities shall be considered. Assessment of the available and potential resources shall be conducted periodically.
- Waste water shall not be managed as "waste". It shall be collected and treated to standards that allow its reuse in unrestricted agriculture and in other non-domestic purposes, including groundwater recharge. Appropriate waste-water treatment technologies shall be adopted with due consideration to economy in energy consumption, and quality assurance of the effluent for use in unrestricted agriculture. Consideration shall be given to blending of the treated effluent with fresh water for appropriate reuse.
- Marginal-quality water and brackish water sources shall be enlisted to support irrigated agriculture. They shall be enlisted, along with sea water for desalination, to produce additional water for municipal, industrial and commercial consumption. Technology transfer and the findings of advanced research in genetic engineering shall be introduced to the extent possible for this purpose.
- A long-term plan shall be formulated for the development of resources, and a revolving five-year plan shall be derived from it and updated as necessary. The revolving plan shall be compatible with those formulated for other sectors of the economy. A parallel investment plan shall accompany the development plan.
- The priority criterion for project implementation and for additional water allocation shall be based on economic, social and environmental considerations. A "critical path" shall be established for the allocation of each new source of water. Consideration shall be given to the sustainability of the allocation in light of the national water balance situation and the economic, social and environmental opportunity cost of forgone alternative uses of water.
- First priority will be given to allocation of water to satisfy basic human needs; as such, the first priority shall be given to the allocation of a modest share of 100 litres per capita per day for domestic water supplies. Expensive additional water shall be allocated for municipal purposes as a first priority, followed by tourism and industrial purposes.

4.2. On Resource Management

- Priority shall be given to the sustainability of use of the previously developed resources, including resources mobilized for irrigated agriculture in the Jordan Valley and other established uses. Special care shall be given to the protection of water from pollution, depletion, and quality degradation.
- Mining of renewable groundwater aquifers shall be checked, controlled, and reduced to sustainable extraction rates. Mining of fossil aquifers shall be planned and carefully implemented.
- Resource management shall continually aim at achieving the highest possible efficiency in conveyance, distribution, application and use. It shall adopt a dual approach of demand management and supply management. Tools of advanced technology shall be adopted to enhance resource-management capabilities.
- A dynamic regime of demand and supply shall be instituted and updated. A minimum cost of operation and maintenance shall be targeted. The production costs of future industrial, commercial, tourism and agricultural projects shall be evaluated in terms of their water requirements per unit of production.
- The interactive use of multiple resources shall be targeted in order to maximize usable flows and maximize the net benefit from the use of a unit of water.
- Human-resource development shall rank high on the priority scale. Continuous education, on-the-job training and overseas training programs shall be organized and implemented. Over-employment shall be trimmed to reach optimum employment levels compatible with efficient management entities elsewhere in the world.
- The management of waste water shall receive attention with due regard to public-health standards. Industrial waste water shall be carefully monitored to avoid degrading the quality of the effluent of waste-water treatment plants which is destined for reuse.

4.3. On Legislation and Institutional Set-up

- Periodically review institutional arrangements and legislation in effect in order to appraise the adequacy of the status quo through changing conditions and times. Institutional restructuring shall take place to match changing needs.
- Update legislation whenever necessary to respond to emerging needs, including the need to improve performance efficiency. Laws in effect shall be enforced with due diligence.
- Introduce and enhance the participation of stakeholders, and legislate for their involvement whenever necessary.
- Assure co-operation and coordination among public and private entities involved in water development and management.

4.4. On Shared Water Resources

- The rightful shares of the Kingdom shall be defended and protected through bilateral and multilateral contacts, negotiations and agreements. Peace water and waste-water projects, including the scheme for the development of the Jordan Rift Valley, shall be accorded special attention regarding construction, operation and maintenance.
- Due respect will be given to the provisions of international law applicable to water sharing, protection and conservation, and those applicable to territorial waters.

- Bilateral and multilateral co-operation with neighbouring states shall be pursued, and regional co-operation shall be advocated, preferably within the provisions of a Regional Water Charter.

4.5. On Public Awareness

- The public shall be educated through various means about the value of water to them and to the well-being of the country for the sustainability of life and for economic and social development.
- Challenges in the water sector are to be faced not only by the water administration but equally if not more by the public. The water-conservation roles to be played by the different sectors of society shall be defined and assigned.
- Facts about water in Jordan shall be disseminated, along with information about the cost incurred to provide the service and about the mounting pressure of population on water resources. The introduction, adoption and use of water-saving and -recycling systems and devices shall be promoted.
- Economic measures shall be adopted to reinforce public awareness. Such measures as demand management and efficiency improvements within supply-management techniques shall be employed.

4.6. On Performance

- The performance efficiency of water and waste-water systems and the management thereof shall be monitored and rated, and improvements in performance shall be introduced with due consideration to resource economics.
- Human-resource performance shall be continually appraised in order to upgrade capabilities and sustain excellence. Incentives for excellence shall be introduced in compliance with the needs for dedication.

4.7. On Health Standards

- The setting and enforcing of national health standards shall be enhanced and sustained, especially with regard to municipal water supplies.
- Concerns for public health and the health of workers shall be a focus in programs dealing with the reuse of treated waste water.
- Laboratories for controls shall be maintained and properly equipped.

4.8. On Private-sector Participation

- The role of the private sector shall be expanded. Management contracts, concessions, and other forms of private-sector participation in water utilities shall be considered and adopted as appropriate.
- The concepts of BOT/BOO [build-operate-transfer/build-operate-own] shall be entertained, and the impact of such concepts on consumers shall be continually assessed, and negative impacts mitigated.
- The role of the private sector in irrigated agriculture shall also be encouraged and expanded. Emphasis shall be placed on social benefits in conjunction with private investments.

4.9. On Financing

- Recovery of the cost of utilities and the provision of services shall be targeted. Recovery of operation and maintenance costs shall be standard practice. Capital-cost recovery shall be carefully approached. The role of water tariffs shall be considered as a tool to attract private investment in water projects.
- Cost recovery shall be linked to the average per capita share of the GDP and its level. It shall also be connected to the cost of living and the family consumption basket. However, profitable undertakings in industry, tourism, commerce and agriculture shall be made to pay the fair water cost.
- Until full cost recovery is attained and national savings reach levels capable of domestically financing development projects, project financing will depend on concessionary loans, private borrowing and/or BOO and BOT arrangements.

4.10. On Research and Development

- Efforts will be made to encourage and enhance indigenous water research targeted at improving resource management, enhancing the understanding of resource economics and adapting the research findings from other environments to local conditions, including but not limited to crop water requirements, minimizing evaporation and controlling evapotranspiration, and the like.
- Emphasis will be placed on liaising with international institutions in order to keep abreast of modern technological advances and to facilitate technology transfer and adaptation.

In addition to the above, a Water Demand Policy is being prepared. The Irrigation Water Policy will be annexed with two additional policies on Water Allocation and Irrigation Equipment.

A Groundwater bylaw was issued to monitor and organize groundwater abstraction, and instructions were issued to organize and protect the use of irrigation water.

5. Legislation and Institutional Set-up

5.1. JVA Mandate

The Jordan Valley Authority (JVA) was established in 1977 with a broad mandate for the integrated development of the Jordan Valley, encompassing all aspects of life. In 1988 the JVA became part of the Ministry of Water and Irrigation (MWI). Its mandate includes:

A. The development and use of water resources in the Jordan Valley for purposes of irrigated agriculture, domestic and municipal uses, industry, hydro-power generation and other beneficial uses, for the protection and conservation of these resources and for the implementation of all works related to the development, utilization, protection and conservation thereof, including:

1. Conducting studies required for the evaluation of water resources, including hydrological, hydrogeological and geological studies, drilling of exploratory wells and installation of observation wells.
2. Planning, design, construction, operation and maintenance of irrigation projects and related structures and works of all types and purposes, including dams and appurtenant works, pumping stations, reservoirs and water-conveyance and -distribution networks,

surface and subsurface drainage works, flood-protection works, and roads and building needs for operation and maintenance.

3. Soil surveys and classification, the identification and reclamation of lands for use in irrigated agriculture, and the division of such lands into farm units.
4. The settlement of disputes arising from the use of water resources.
5. In coordination with the Water Authority of Jordan, organizing and directing the construction of private and public wells.
6. The development and improvement of the environment and of living conditions in the Jordan Valley, and the implementation of related works including:
   - Setting rules and regulations for areas of land outside town and village borders on which construction of buildings is permitted — setback lines, rights of way, etc.
   - The development of land zoning to define land use: residential, industrial, agricultural, etc.

B. The planning, design and construction of farm roads.

C. The development of tourism in the Jordan Valley, including construction of tourism and recreational facilities.

D. The social development of the Valley inhabitants, including the establishment of private institutions in order to help them contribute to the improvement of the Valley and to the achievement of development objectives.

E. Additional development activities as requested from the Cabinet.

During the last 30 years, JVA has completed numerous infrastructure projects, including electricity, telecommunications, roads, schools, health centres and governmental and residential buildings, in addition to its core activities in land- and water-resource development.

JVA has invested significant effort and resources to improve the infrastructure on the east coast of the Dead Sea in order to attract investments in tourism and for the development and care of religious and archaeological sites in this region of the country, the most important of which is Jesus Christ's baptism site on the Jordan River.

Presently, JVA is focusing its efforts on water- and land-resource development, management and protection, in addition to tourism development and promotion.

Jordan Valley Development Law no. 19/1988 was amended (no. 30/2001) to allow for larger farm unit areas and thus more economically feasible agriculture, and to allow for private-sector participation, which opened the door to farmer participation in water management.

A five-year Strategic Plan for the period 2003–2008 was developed to cope with the new government policies and JVA's future role. The Strategic Plan is also seen as a tool to improve the level of service JVA offers to its customers and to improve JVA's operational efficiency and cost recovery. It is centred on the following four main goals:

- water-resource development and management
- water supply and distribution
- land development and management
- organizational-performance improvement and development

Each of these goals has a number of objectives, which in turn were developed into a number of strategies. Finally, specific actions were developed for each strategy, the implementation of which will ensure the successful realization of the Plan's goals.

5.2. Water Management

Water-resource scarcity and fluctuation, the complexity of the Jordan Valley hydraulic scheme, and competition between water users, require JVA to use modern water-management procedures in order to cope with the challenges. A clear division is made between water-supply and water-distribution activities, as detailed below:

5.2.1. Water distribution

Activities related to water distribution — mainly operation and maintenance of the irrigation networks — are under the responsibility of four Directorates. The Directorates depend on Stage Offices to organize water distribution among farmers, open and close farm turnouts and follow up on billing and accounting operations. The organization between Directorates and Stage Offices is shown in Figure 6. The water-distribution turnouts are represented in Figure 7 for the Northern Ghor, Figure 8 for the Middle Ghor, Figure 9 for the Karama area, and Figure 10 for the Southern Ghor.

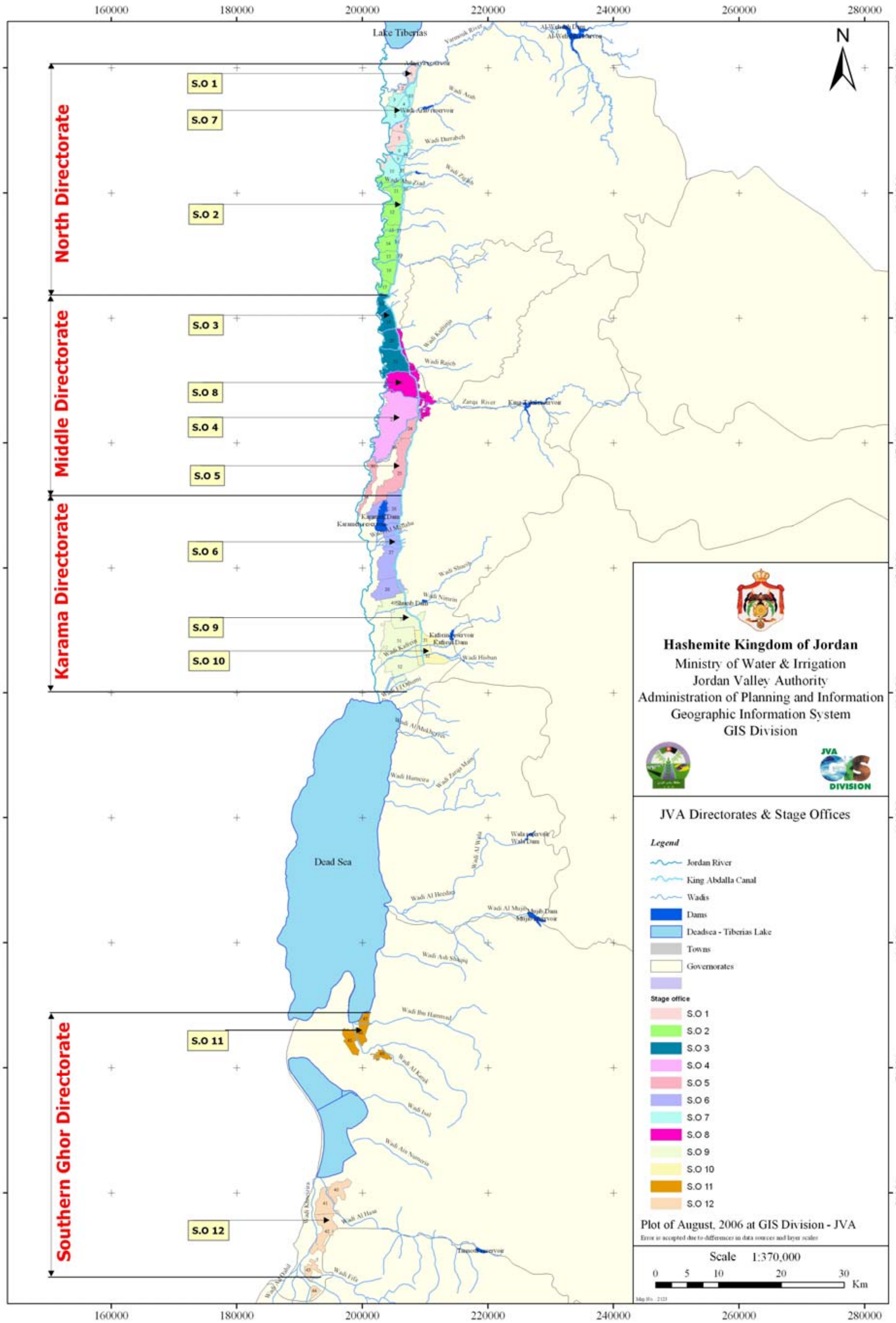

Figure 6. Jordan Valley operation and maintenance administration

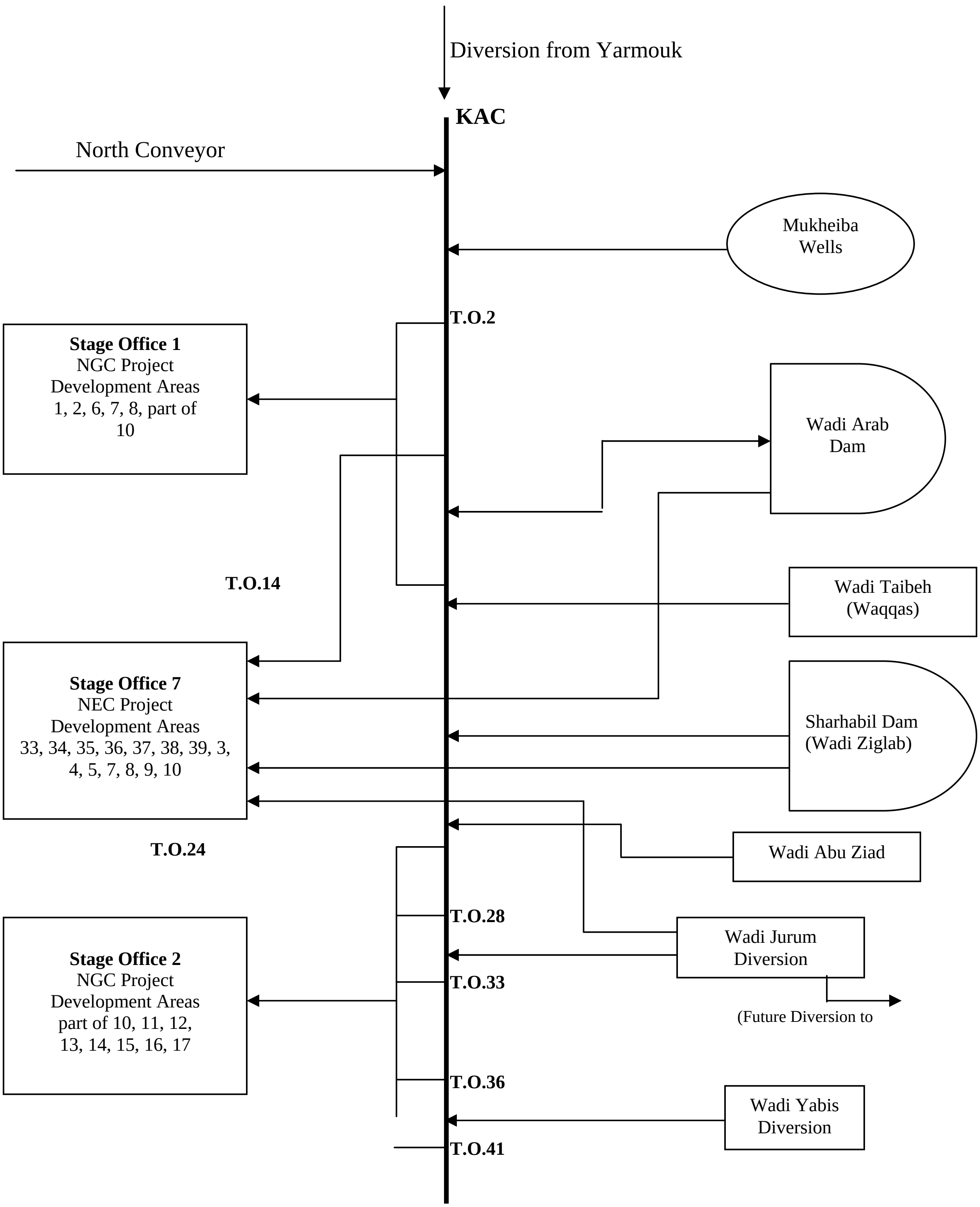

Figure 7. Irrigation scheme in the North Directorate

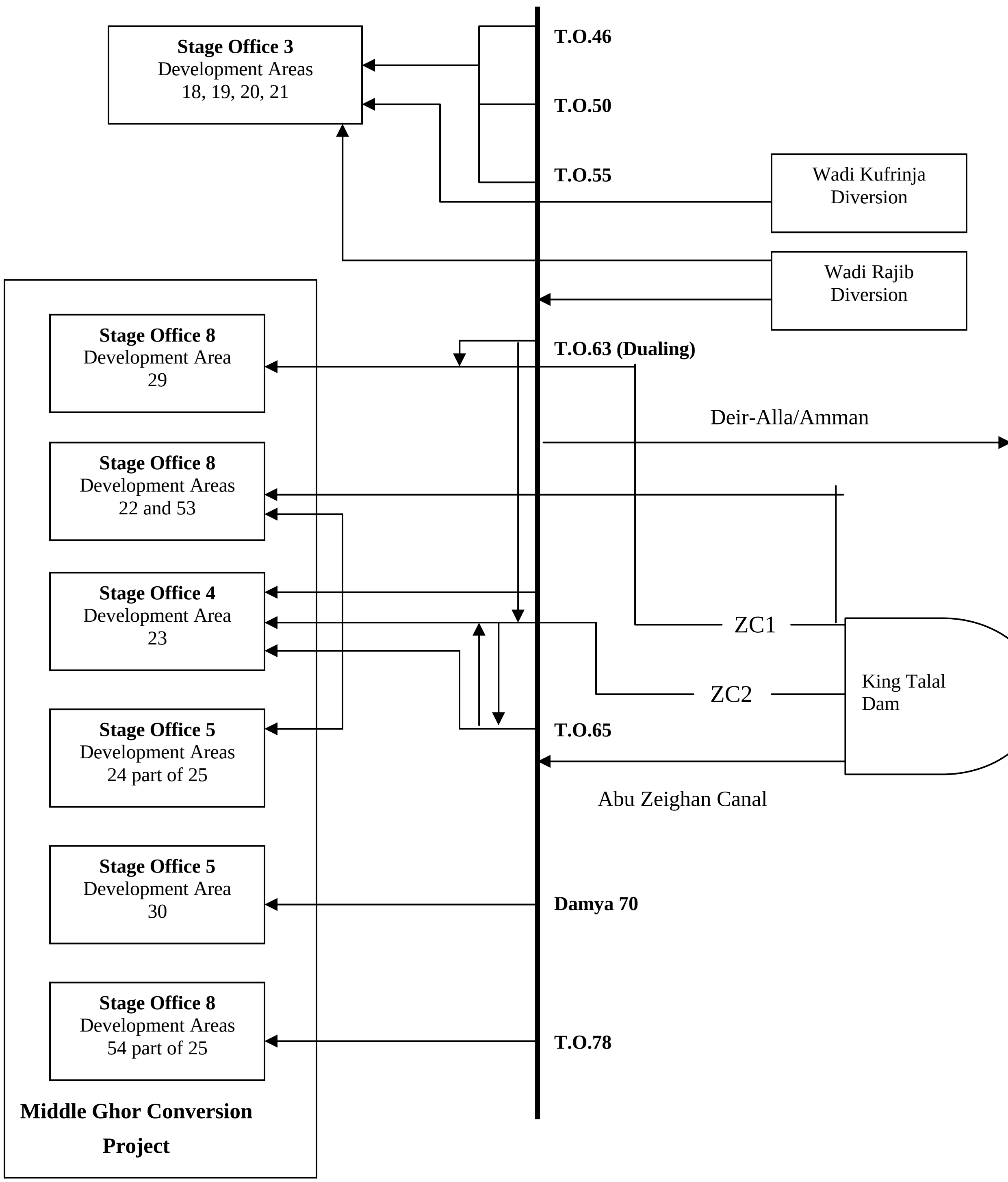

Figure 8. Irrigation scheme in the Middle Directorate

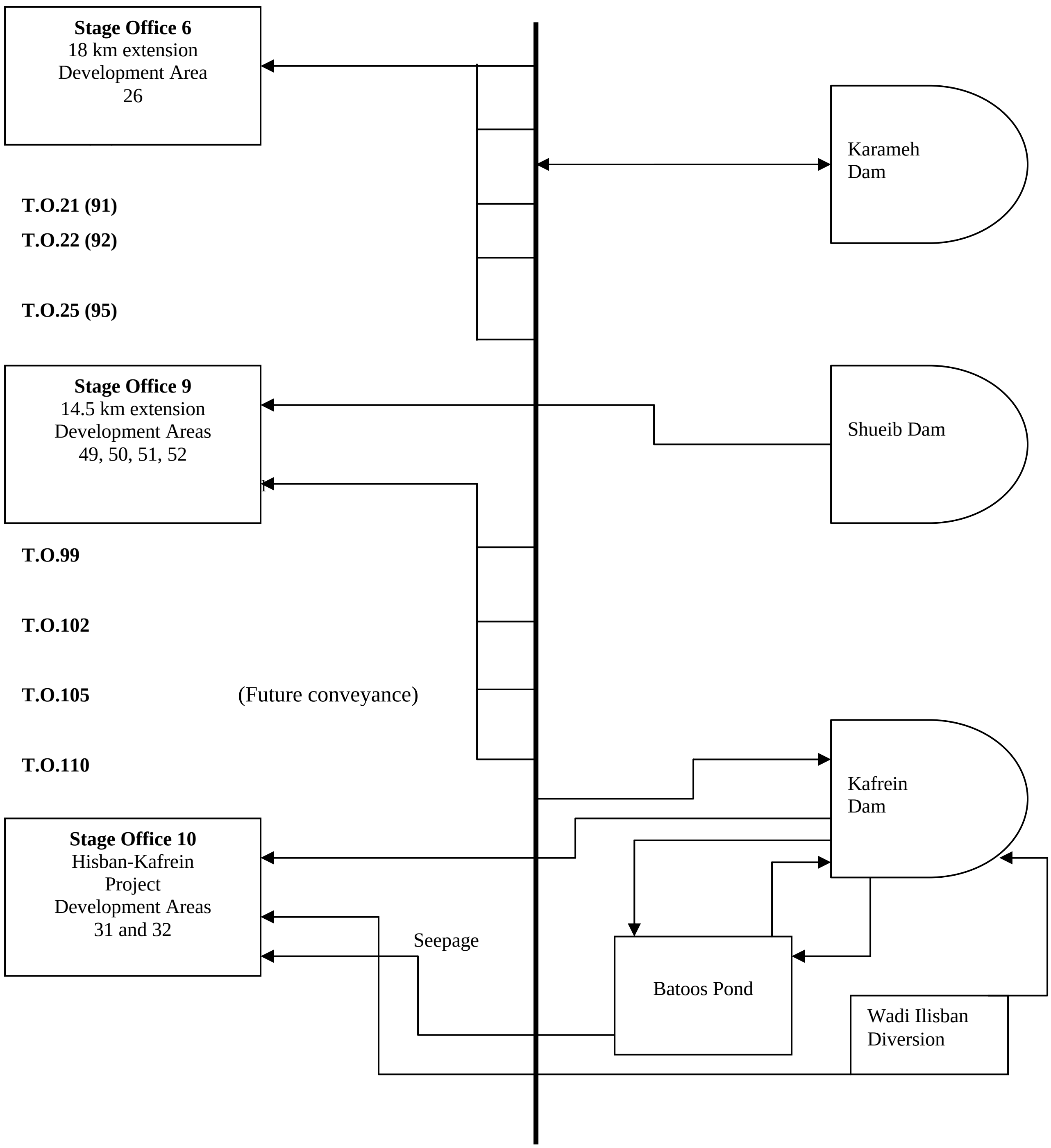

Figure 9. Irrigation scheme in the Karama (South) Directorate

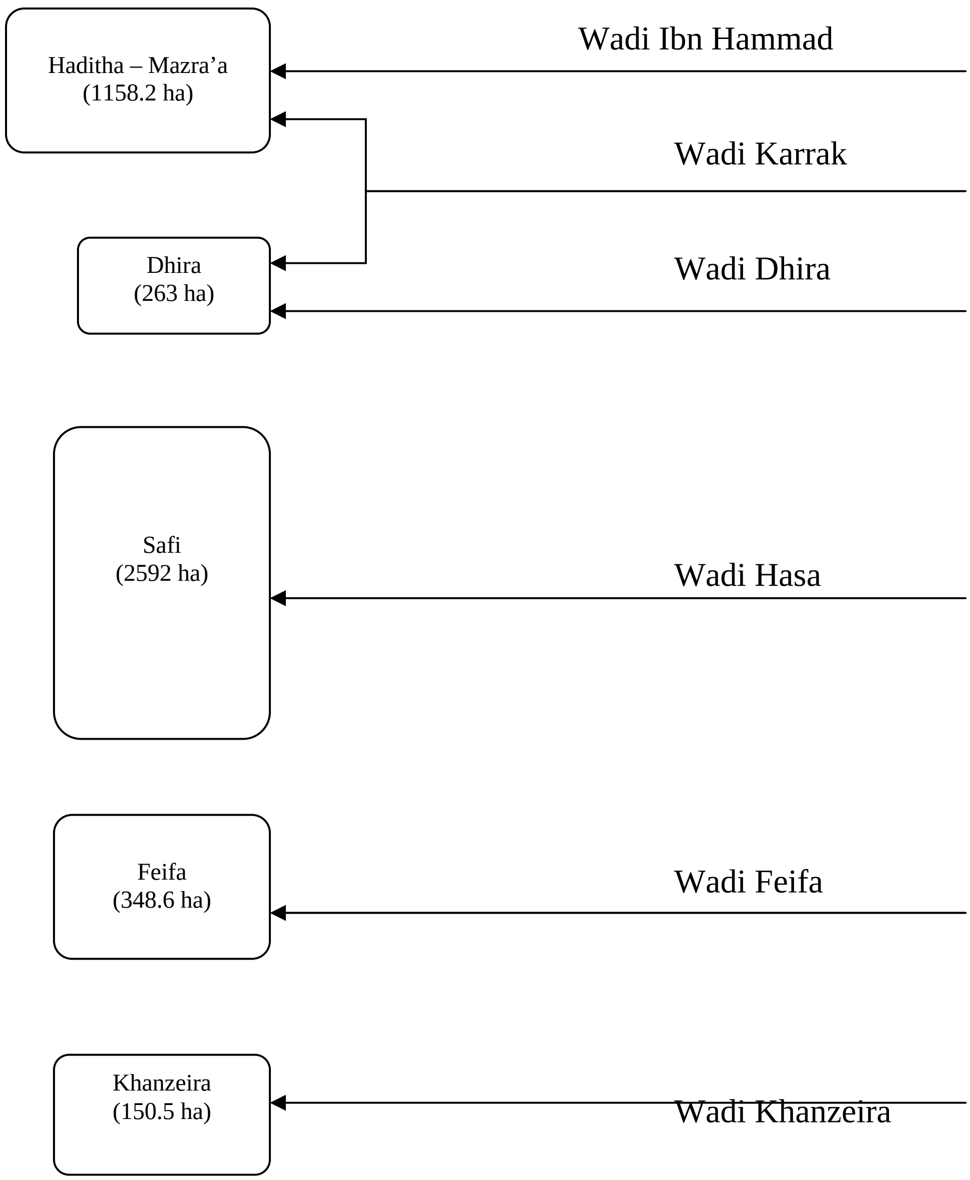

Figure 10. Irrigation scheme in the Southern Ghors

5.2.2. Water supply

Water supply is performed by the Control Division, under the responsibility of the Water Control and Management Directorate, which is under the direct supervision of the Assistant Secretary General for Operation and Maintenance. This division is located at the Deir Alla Control Center, in the Jordan Valley, which houses the Supervisory Control and Data Acquisition System (SCADA).

The following activities are performed at the Deir Alla Control Center:

- Water management strategy: definition of monthly target volumes for each reservoir and monthly water allocations to each Stage Office.
- Daily water balance in order to ensure that water requests stay within the amount of available resources. According to this balance, decisions are made regarding the release from dams or pumping to dams, transfer from the King Abdullah Canal northern section to the southern section and management of shortage situations.
- Control of the King Abdullah Canal through the adjustment of check-gate settings.
- Revision of quotas for crops and irrigation suppliers and feeders according to the current water situation, and proposing reduction percentages in cases of water shortage.

6. Adaptation Activities

The main factor that JVA considers in water management is the availability of water resources, which is far less than what is needed for the different uses. The following adaptive activities are performed to face this situation:

1. The conversion of surface irrigation channels to pressurized pipe networks. Each farm unit was equipped with a Farm Turnout Assembly (FTA) including a pressure regulator and a flow-limiting device that limits the flow to 6–9 litres/second. It should be noted that the flow at the farm gate was 20 litres/second when the open-channel networks were used, before the conversion to pressurized systems.
2. The rehabilitation of King Abdullah Canal (KAC), which is the main water conveyor in the Valley, reduced losses and improved its operational conditions. A water-measurement network was installed along KAC, and a SCADA system was used to monitor and automatically control water flow in the canal from a Control Center located in the JV.
3. A computerized Water Management Information System (WMIS) was introduced to help in making decisions to balance water resources and demands and to optimize water distribution to farm units. The system allows for the calculation of seasonal, monthly and daily water balances and for the setting of reservoir target volumes and operational efficiencies of the different sections of the hydraulic network.
4. Pilot projects were introduced with the help of donors to illustrate how to optimize water use inside the farm units by the use of tensiometers to help identify the exact time of irrigation according to crop needs. An Irrigation Advisory Service (IAS) was also instituted to help farmers use these devices and schedule their irrigation frequency. Universities, research centres and non-governmental organizations (NGOs) are involved in the activities at the pilot areas.
5. A hydraulic simulation model (EPANET) is used to stabilize pressure and flow in each irrigation line from the water source to the FTAs. As a result, the pressure was stabilized to 3

bars throughout the irrigation network, and the flow at the FTAs was adjusted to 6 litres/second, thereby increasing equity and farmer satisfaction in addition to raising the efficiency of irrigation water use.

6. Farmers were also encouraged to change their irrigation systems at the farm-unit level from surface to micro-irrigation (drip and mini-sprinklers) and to introduce advanced technologies to maximize irrigation water-use efficiency (crop per drop).
7. Good Agricultural Practices (GAP) are introduced and many farmers are certifying their products for export to external markets. Cash crops such as Charentais melon, strawberry and early grapes are being planted to maximize the benefits from irrigation water.
8. Farmers were encouraged to form water-user groups of different forms (water committees, local water councils and water-user associations) according to geographic zones and social characteristics. Around 40 per cent of Jordan Valley farmers participate in one way or another in these groups, at 16 different locations along the Valley. The main function of these groups is their participation in irrigation-water distribution activities. Farmers now open and close their FTAs according to the irrigation schedule, thereby alleviating this burden from JVA. In addition, there has been a significant reduction in water losses and illegal water use due to these self-controlled water-distribution activities.
9. Guidelines were issued to help farmers in using best practices to irrigate certain salt-tolerant crops with brackish water (slightly saline), which is available mostly in the shallow aquifer north of the Dead Sea. The brackish water is used directly to irrigate salt-tolerant crops, or it can be blended with fresh water or even water desalinated by small reverse-osmosis units by some farmers (23 private desalination units were already installed in the JV).
10. Guidelines for the use of reclaimed water in an environmentally safe and economically viable manner were prepared by JVA to help farmers to apply best practices in using the reclaimed water, whose use is on the increase for irrigation in the JV due to the lack of fresh water and its diversion for municipal purposes. Programs are being conducted to monitor surface water, groundwater, soil and crops. The results of these monitoring programs are analyzed and used to take mitigation measures to remedy any negative effects from using reclaimed water.
11. Water tariffs were introduced, with an escalating, categorized structure that encourages farmers to reduce consumption and save irrigation water. The bills for low-income, vegetable-growing farmers are normally in the lower tariff category, while the bills for those who consume larger water quantities are in the higher categories. A fixed rate is charged on the monthly water bill to cover the cost of FTA maintenance. Water sales for agriculture and industry cover most of the operation and maintenance costs of JVA.
12. In cases of severe drought, farmlands are rented from farmers by JVA to save water, and farmers are compensated for losing their planting season. Irrigation-water rationing has become a general practice in the summer season, and summer vegetables are banned in some areas due to the lack of irrigation water.
13. Licences for planting banana and citrus trees are no longer issued to farmers, as these are high-water-consuming trees. Farmers with already-existing licences are given the water requirements when water is available, but in cases of drought a minimum amount of water is given to these trees to keep them alive.

14. The Jordanian-Syrian Committee for the utilization of water from the Yarmouk River basin meets regularly to coordinate the utilization of the basin's water according to the agreement signed between the two countries.
15. The Joint Water Committee (JWC), which was formed after the signature of the peace treaty between Jordan and Israel, meets regularly to follow up on the implementation of the water annex (Annex II) in the Peace Treaty.
16. A water conduit was built from the Dajania Gate, at the southern outlet of Lake Tiberias, and the King Abdullah Canal (KAC) to convey an amount of water similar to that stored from the Yarmouk River in the Lake in wintertime, to the KAC in the summer, in addition to the water quantities that were agreed upon in the Annex and other agreement-implementation protocols.
17. A diversion weir was constructed on the Yarmouk River in Adasiyeh to control and regulate the flow of the Yarmouk to both sides.
18. The Al Wehda Dam is being constructed on the Yarmouk in the Maqarin area, on the border between Jordan and Syria, in order to store flood water and to regulate the base flow of the river at that site.
19. Several studies were conducted to supply Jordan with an additional 50 MCM/yr. of drinkable water, as stipulated in the agreement between Jordan and Israel, and the issue is still under discussion.
20. Finally, great emphasis is being put on the implementation of the feasibility study of the Red Sea–Dead Sea Water Conveyance Project, which aims to save the Dead Sea, an international heritage whose level is decreasing dramatically due to the diversion of the freshwater resources that used to feed it. In the project's later stages, the difference in levels between the two seas will be exploited to generate electricity and to desalinate sea water.

Ayman Rabi, Session Chair:

Thank you very much, Engineer Ayadi, for this very interesting presentation. I would now like to call on our discussant, Mr. Moneef Zou'bi, who is post-graduated from Loughborough University in the U.K. He has been Director General of the Islamic World Academy of Sciences since 1998. He has an interest in IT and in environmental-science and technology policy studies, and he previously worked for several consulting firms. He has published over 30 papers on water policy and has co-edited 10 books, including a very well-known reference on the subject of water resources, in 1995. Mr. Zou'bi, please, the floor is yours.

Moneef Zou'bi, Session Discussant:

Thank you, Ayman. Good morning. Henry Vaux is a man you cannot say no to; when I received his kind invitation to join as a participant and a discussant, I had to oblige, and I thought that I should try to do my very best to undertake this task he has assigned me, of looking at the two papers that were presented this morning.

Having read and learned a lot from the papers of the two eminent speakers who preceded me this morning, I also thought I would not do either paper justice by attempting to present a three- or four-minute summary of each. The two papers have very adequately addressed the topic in question. Now, I allowed myself a little academic freedom in terms of trying to focus on the broader issue, and to attempt to provide the bird's-eye-view, so to speak, of the Jordan River basin. And this was reinforced, in fact, by discussions I've had with the vast majority of participants here, who, I sense, were probably quite eager to evaluate and study the broader policy issues concerning the Jordan River basin. I just hope that the few comments I'll make this morning will prompt you to interact with the panel in a typical Rosenberg Forum fashion.

Let me first mention some of the natural and environmental highlights of the lower Jordan River valley, for those who have not visited that part of the world. The Jordan River is the world's lowest; it flows to the lowest point on the surface of the earth — the Dead Sea, which is around 400 m below sea level. It is an important wetland habitat, sustaining diverse vegetation and fauna. It is the cradle of early human migration out of Africa, and the site of early human settlement based on the cultivation of wild wheat, first undertaken near Jericho, in the Jordan Valley.

Let me also propose to adopt the definition, or a definition, for watershed management, courtesy of an excellent book published by the U.S. National Academy of Sciences in 1977 — and I think Professor Vaux was very much involved in the production of the book at that point — and that is to say that watershed management "is the art and science of managing the land, vegetation and water resources of a drainage basin to control the quality and quantity of water for preserving human welfare and nature". This is probably the basis of my following comments.

Now, varying the hydrological cycle through diverting water that flows into the main body of rivers — in this case, the Jordan River — has brought about undesirable, probably disastrous, environmental consequences. In the case of the Jordan River, the management of Lake Tiberias as a major water-supply reservoir, and the diversion of the Yarmouk River have resulted, as already mentioned by Mr. Ayadi and Dr. Ayman this morning, in only 10% of the 1.3 billion cubic metres of water that used to annually naturally flow down the Jordan River to the Dead Sea, actually being discharged into the river. And that has resulted in sections of the river drying up in the summer, and the demise of river habitat. The historic river has become a shadow of its former self. Indeed, recently, a small yet highly sophisticated water-treatment plant was built on the eastern shores of the river to ensure a reasonable quality of water for the pilgrims who flock to the historic location of the baptism site from all over the world.

The capture of winter floodwaters of the Jordan River on either side, and of its tributaries, as well as the discharge of untreated sewage into the river, and the lack of co-operative mechanisms in place to promote sustainable development to allow residents of the Valley to benefit and prosper from its natural and cultural heritage, has resulted in the integrity of the lower Jordan River being seriously undermined. Without immediate intervention in terms of river rehabilitation, the damage will be irreversible.

Ecological rehabilitation of the river is a commitment agreed to by the governments of Jordan and Israel under the 1994 peace treaty between the two countries. Agreements between the Israelis and the Palestinians set out similar requirements. The irony is that despite the valley's potential to attract significant tourism, for example, the residents have not benefitted yet from such potential revenue. The people of the Valley are amongst the poorest in their respective countries.

At the macro level, let me remind you that the water use varies through the region; Israel's use is greatest — probably twice as much as Jordan's, estimated at more than 2300 million cubic metres per year. Usage on the West Bank and in the Gaza Strip is lowest, equivalent to one 10th of what we use in Jordan. Mr. Ayadi has just given us an update as to what the current situation is, so I'll not go into that. Instead, I'll move quickly on to say that the combination of resource overuse and contaminated sources means that freshwater scarcity in the Jordan River basin has reached a critical level. The 1997 United Nations study entitled "Comprehensive Assessment of the Freshwater Resources of the World" says that if present rates of population growth and agricultural and industrial development continue, then within 20 to 30 years, all of Israel's and Jordan's fresh water will be needed for drinking-water demands. Agricultural applications will receive only treated sewage water, and industry will have available only costly desalinated water. And desalination, as you know, in our part of the world, especially in Jordan, is probably out of the question, as we have no energy resources.

Currently, approximately 350 million cubic metres of reclaimed sewage waste water is used in the region, mostly by Israel, followed by Jordan. Needless to say, that large-scale use of reclaimed waste water is itself unsustainable, because it can result in high mineral filtration of soils and surface- and ground-based freshwater sources.

It wasn't until the mid-'90s that the shared-use approach was productively considered. The Israel-Jordan Treaty of Peace of 1994, and the Agreement on Cooperation in Environmental Protection and Nature Conservation between Israel and Jordan of 1995 are our bilateral agreements, calling for a co-operative approach for sharing and developing the Jordan River. The 1994 Israel-Palestinian agreement, and then the Interim Agreement on the West Bank and Gaza Strip, address co-operative water and sewage development. The 1996 Declaration of Principles for Cooperation among the Core Parties on Water-related Matters and New and Additional Waters is a multilateral agreement signed by Israel, Jordan and the Palestinians.

The peace treaty acknowledges the insufficiency of freshwater resources for the region and calls upon the parties to act "in the spirit of cooperation" in resolving short-term water shortages. Proposals integrated into the treaty anticipate joint construction and management of a storage dam on the Yarmouk River, and the co-operative management of the groundwater of Wadi Arab, south of the Dead Sea. Specific allocations of water from the Yarmouk and Jordan rivers informally incorporate into the national equitable-utilization principles. The treaty traditionally provides for a joint water committee which is currently in existence, as has just been mentioned by Mr. Ayadi.

Now, despite the consensus reached in these agreements in co-operative management, joint conservation and equitable sharing, little practical movement in addressing the water-scarcity problem has been taken over the past seven years. The few scientific and independent studies undertaken during the last few years assert that to avoid critical water scarcity in the Jordan River basin, reforms must be implemented on several fronts. The basin of the Jordan River must continue towards a genuinely co-operative and integrated multinational and multi-use scheme of regional water sharing and development. The water basin is widely accepted as the natural and rational unit for the management and planning of river development, rather than the artificial management units imposed by political boundaries. Basin-wide management is also a cornerstone of equitable-sharing and -utilization principles and is integral to the International Law Commission Convention on the Law of the Non-navigational Uses of International Watercourses of 1997. However, neither classical nor modern international law principles of *transboundary* water sharing have been embraced in the region.

Finally, Mr. Chairman, and in concluding, I think that if the governments of the region are really serious about giving life back to the Jordan River, they need to take immediate action and seek outside help, in both advice and monetary terms. Thank you very much.

Ayman Rabi, Session Chair:

Thank you very much, Moneef. This is certainly very interesting. We have almost a half-hour for our discussion. Pedro, please go ahead.

Pedro Arrojo Agudo:

I must thank you specifically a lot, Dr. Moneef Zou'bi, because at the end, the main problems emerged and I think that the Jordan case is very clear — a good example of how to kill a river in order to grow cotton in the desert, stressing the situation of the majority of people living within the basin. I don't want to oversimplify, but this is a very basic issue. It's an example of how to deal with the river as a simple channel of water: a channel of water, but no more. So I ask you, what about the other values? What about the aquatic ecosystems; what about the cultural values and the heritage, even holy heritage, holy spaces for all the regions in the area, such as the Dead Sea? How about social values, how about the ethical dimension? What about the economics? I have directed a doctoral thesis on the economics of Jordan. That is, I think, the system with the most unreasonable economic management in the world. It's not reasonable, the economic use that we are doing, the human beings, in this valley. For the future, on the coast, where the population is growing, I'm sure that desalination will be very useful and that most of the water we are extracting from the river will need to remain in the river and for the basin; but for this, we must change perhaps the political approach — so the contribution, the peace solutions and the collaboration must be the future. Thank you.

Ayman Rabi, Session Chair:

Thank you, Pedro. Any response from the panel?

Yousef Hasan Ayadi:

As I said in the first part of my presentation, we are downstream residual users, which means that water comes to us from the neighbouring countries; unfortunately, this water is decreasing every year. Before I came, I took the average for the Yarmouk for the last five years, and it was about 55 million cubic metres per year. The historical average of the Yarmouk was around 400. That is the Yarmouk; if we are talking about the Jordan River, we are not taking anything from the Jordan River. Now as regards the socio-economic aspect, we in the Jordan Valley Authority are in charge of the socio-economic development of the Valley, which means that we are building schools, we are building health centres, we are developing the land, we are promoting tourism. So we are dealing with all aspects of life for the inhabitants of the Valley, and this was actually reflected in the number of inhabitants. Whereas I can say that after the 1967 war, the valley was almost empty, now we have around 300,000 inhabitants in the Valley. So our development activities have a socio-economic dimension.

Alon Rimmer:

I won't go into politics but I want to say that problems like this, as you mentioned, can be solved after what we know are bigger problems. You can see from the history of the region that when the atmosphere was an atmosphere of peace — let's say, before 2000 — there were many plans of reviving the Jordan River, basically the lower Jordan River. I was myself part of one of these programs, but these programs wouldn't work without the big picture being solved. So we can talk here through the night, but until the big problems, the political problems, are solved, the environmental problems will be pushed away.

Holger Hoff:

We've had a description of extreme water scarcity in the basin. Could it be that, along the lines of adaptation which were discussed yesterday, the responses also need to be equally extreme or radical? We heard that the per capita water availability is about the lowest anywhere in the world. We know that the population increase is about the highest anywhere in the world. We know that if any region in the world will be faced with less water availability due to climate change in the future, most likely it will be there, and we have heard that water productivity is about at the limit to which you can get it with all the technological means that you have exploited already. Now, there's still about 60% of the water going into agriculture and to what you might call low-value use. At the same time, Engineer Ayadi suggests a 10-billion-dollar scheme of providing new water through desalination; and similarly in Israel, there's a proposal to build a whole chain of desalination plants with 500 million cubic metres a year to make up for the deficit. Why is that preferable to reducing agriculture further?

Domingo Jimenez:

Not to comment about the framework, the conditions for change, in this specific case, but I think the Jordan River case is a very interesting one. I would just like to hear some comments too about what I find to be a different interpretation of the situation. When Mr. Ayadi said that you were turning challenges into opportunities — bringing water from the Red Sea to the Dead Sea and then producing electricity, travelling from the … [undecipherable] … our plants, and then coming to desalinization. Then I heard from the discussion of Mr. Zou'bi that desalinization was out of the question because of the energy needed. So have you made any balance about how much electricity you will generate if you try bringing water to the Dead Sea, and how much could we use for desalinization, whether that could be an available opportunity or a win-win approach — notwithstanding this alternative, of course, of reducing agriculture, which I think is a very interesting question.

Yousef Hasan Ayadi:

The desalination question needs an answer, that's for sure. But in the case of the Red-Dead issue, there is a 400-metre difference in levels between the Red Sea and the Dead Sea. This difference will be used to let the water fall directly on the membranes and to produce the fresh water. So there will be no cost for energy in this case.

Ayman Rabi, Session Chair:

Do you want to respond to the first question, Holger, about why reducing agriculture is…

Holger Hoff:

Yes, if I understand the first question — that the cost will be, you said, 10 billion dollars for the project. The study has not been done yet. There was a brief feasibility study for the project in 1997−98. Now, by the end of this year or the beginning of the next year, I think, the World Bank will start tendering for the feasibility study of the project; it will be a 10-month study and it will show the real cost. We think that the cost of bringing the water from the Red Sea to the Dead Sea will be around one billion. Then the other phases will not be for tomorrow; they might be for the year 2020.

Moneef Zou'bi:

Regarding Dr. Holger's question concerning agriculture and the water used for irrigation and agriculture production. I think that you probably know — you've been to Jordan many times — that there is a social element attached to this, and although the farming community in Jordan has been decreasing in size over the last thirty years, still it forms a backbone of the local economy in a number of areas. So there is a social element in terms of really maintaining the agricultural sector, although in terms of water resources and water use, it probably may not be the best option. Secondly, very quickly, and you probably know this as well: our farmers have actually done what the government has asked them to do in terms of adapting and using new technologies and strategic crops and so on and so forth, so they've really done very little wrong in terms of following the guidelines of the government. So that's working in their favour. Thank you.

Prachoom Chomchai:

I simply want to offer a piece of information on the Mekong and raise a few queries. The lower Mekong contributes 80% of the water from the Mekong, and our first task, which started in '57, was to try to get to know the river better by collecting streamflow and rainfall information. We are now at the stage where we can model the lower river completely so that we could now do flood forecasting and lower-river forecasting for use by the member countries. My basic difficulties with modelling are related to the three questions we are raising. First, there are gaps in information; the further you go back in the past, the less reliable the data. And both the gaps and the reliability of data are important for modelling. Also, the question of stability: the Mekong River, by geological standards, is still very young and is changing all the time; you can see that there is much more sedimentation than before. Of all these three or four difficulties, how reliable are your models and how far can we go into modelling? Thank you very much.

Alon Rimmer:

The modelling in the cases I showed is modelling for practical purposes. There are a lot of hidden assumptions in every model that we build. The advantage of these models is that they give answers to some questions which are immediate and you can relate to something; otherwise, you might end up developing models for years and years and whenever somebody asks you what will happen, you will say, "Just give me another three years and I will give you the answer." So the purpose of the type of model I was showing is actually really for practical purposes, and for that purpose, you need to make assumptions, you need to know that you made the assumptions and you need to let others know what the assumptions are.

The Right Honourable Herb Gray:

First of all, I was going to raise the question of the World Bank, and I am very glad that this has been noted. We should be, all of us in our various ways, keeping in touch with the World Bank to see if we can provide some useful expert input. Second of all, I want to know if any of the participants from the panel have anything to say about what I understand to be a long-standing non-governmental organization offered by the world environmental group Friends of the Earth, and their efforts not only to develop a project to save the Dead Sea but to at least try to mobilize local municipal and civil-society groups in the lower Jordan Valley; I think they had a conference at Petra, and I understand that there are circles of mayors that are meeting. Do you think that this has any value, or do the mayors have too limited a role under their governmental structure to have an impact on the issues that have been discussed this morning?

Moneef Zou'bi:

Friends of the Earth, at least, has been very active in terms of raising the awareness of the public as to the current, very uncertain future of the Jordan River basin. In fact, this is one of the publications — *Crossing the River Jordan*. It is a very useful publication if you want to get first-hand information on the cultural as well as the hydraulic and various other facts about the situation on the ground; it's there on their Web site, FOEME, Friends of the Earth Middle East. Their efforts are very commendable. Thank you.

Yousef Hasan Ayadi:

Just a little addition about the work of civil society in the region. Of course, there are also many other groups who work on this particular issue and they're also coming around to discussing problems related to the Dead Sea, problems related to water scarcity, and the overall problem in a more integrated way; their voices are also heard. However, coming back to your first point — whether the mayors are really influential or not — I don't think it's something the mayors can do at this particular stage. The point here is that we have to raise as much awareness as we can and we have to form lobby groups and pressure groups from all different parts of society in order to really influence higher policies so that we can actually release a little bit more water to the Dead Sea to save it from being dead. Thank you.

Peter van Niekerk:

I just have a very simple question, and that is: What do you do with the water that is now collected from the saline springs? How is that disposed of? Is it treated and then used again, or what happens to it?

Alon Rimmer:

About 60,000 tons of chlorides, so that means other components as well, is diverted from the lake and is taken now by a canal to the south of the lake, and then it is poured into the lower Jordan. Plans are — and I can tell you that I've known these plans for maybe 15 years — to take this water, to desalinate it, and to add it into clear and treated sewage water and then to create some kind of decent stream to go into the lower Jordan. But these are plans, and maybe this is where the money should go in order to keep a safe Jordan River, and to revive it, as was said before.

Mordecai Shechter:

Concerning the Red-Dead Sea project. Now, I'm not against desalinization, and I think that this backstop approach will come on line in time, but our situation is like Alice in Wonderland. We have to keep running faster just to stay in place, and there is always the temptation to find easy solutions. And in this case, I am concerned about this Red-Dead Sea canal, with its uncertain environmental impacts. It's clear to everybody here that out of the five case studies, when you consider the Jordan case study — whether you talk about upland or down-land or lowland or midland watersheds — all of the others pale in comparison to the severity of what we're talking about here, because the climate-change models we have been working with point to the fact that we may end up with a sub-Saharan situation in this area by the middle of this century.

So I believe — and this is also based on studies we've carried out in the past — that the first order of business is for the governments and for societies in the area to sort things out for themselves before they go out and try to look for miracle solutions to the situation. Foremost, it's my own country: Israel. There is a need to make more-rational use of the available sources, including water for nature. Now, Holger was right; it might very well imply that for agriculture — which in the case of Israel, a developed country, doesn't contribute much to the GNP anyhow — we will have to change our ways of life. And would I lessen agriculture? We talk about adaptation; I like very much the kind of adaptation measures you mentioned, Ayadi, but before we go for the easy solutions, we have to make hard choices, and this is where I believe, I'm afraid, that we are lacking. I would like the speakers to respond to that. Thank you.

Yousef Hasan Ayadi:

Again, as regards this Red-Dead issue, we are now facing a real environmental problem in the Dead Sea area. As Ayman said, the level is going down every year by seventy centimetres and sometimes even one metre, which means that the Dead Sea itself is diminishing. This results in what we call sinkholes. Because the water goes down in the sea, the groundwater itself in the area goes down; this phenomenon of sinkholes is now taking place around the Dead Sea. These sinkholes are very large holes that happen abruptly, suddenly, at the farms of the farmers, and sometimes we have issues involving real danger because of that. We have to face this environmental catastrophe. How? There is no other way than to raise the level of water in the sea, and there is no other way except bringing water from the outside, and we have found that the easiest way is to bring it from the Red Sea.

Consuelo Varela-Ortega:

My question relates to what Moneef was just saying: the importance of the farming sector in countries such as Jordan or Syria, for instance — and also, in this framework, to the adaptation measures that were explained by Mr. Ayadi, which I think were extremely interesting. The first element is an economic element, so to speak, which is a quota system that is obviously imposed on the farmers, a maximum amount of water that can be used. The second is the technological aspect, which is the development of new technologies, modern technologies, to reduce losses. The third is the social and institutional aspect, which is the formation of the encouragement, the formation of the water users associations. I would like to know, in this framework, what has been the role so far of the water users associations — that is, what is the role that they play, if any, in the control and enforcement of the quota system? How are the decisions taken? Because we know that if there is bottom-up involvement among the farmers, they could play a crucial role in the enforcement of these quota systems. Syria has a very similar situation in some of the very water-scarce basins. So whether the farmers are directly involved in the roles of controlling those water quotas, I think is crucial; I would like to know what is your experience so far in the involvement, and also if they are paying any fees.

Yousef Hasan Ayadi:

Regarding the participation of farmers in water management, I would like to say that in the past, when the irrigation systems were simple, the farmers themselves managed their canals. The issue happened after 1960, when the King Abdullah Canal was installed and there were large farming developments in the valley; at that point, the Authority itself took the responsibility of managing the whole irrigation scheme, which means that at each irrigation branch and at each farm gateway, a ditch rider has a schedule and he has to go through the whole line, from the beginning to the end, and open the gates in the morning and come back and close them in the evening. This took the farmers out of their historical responsibility of water management. This mistake has caused a lot of problems. The farmers start thinking that this is government water so they can misuse it. By reinventing the wheel and bringing the farmers back into the picture, we are actually correcting a situation that is wrong. What happened when we started this experiment is that there was a lot of mistrust between the farmers and the ditch riders and we spent a lot of effort, actually, just to bring them together and also to convince the farmers to start groups themselves, not to come as individuals. This is actually not an easy job. We started this issue in 2002 and we are now in 2006; during this period, we passed through many stages until we reached this business of convincing farmers at first to work collectively and then to take responsibility themselves for opening and closing their gates according to the predefined schedules. What is the result of this? It's very simple. The first result is that there is no misuse of water, because now they think that the water is theirs and if the farmer wants to steal water, he steals from his neighbour, not from the government's water. So this is a very important issue which has greatly reduced the misuse of water, and they are now feeling that it's their water, it's their project and they are defending it. They are also maintaining the structures themselves — the FTAs, the farm turnout assemblies, which means a water meter and a regulator and so on.

Claudia Pahl-Wostl:

Part of the issues have already been addressed by other speakers. I want once more to emphasize this role of water raised by a couple of people — by Mordecai Shechter, by Holger — this role of agriculture. I want to point out that the Jordan Valley in this respect is not different from many, many other basins. I'll just give an example from the Amu Darya and arguments I heard when we had a recent meeting in the Amu Darya, where we have a case study; you can't argue about the role of agriculture. People are simply vulnerable and they are the same; they lift it up to a higher problem. The biggest problem is that Afghanistan will build a dam, so if they wouldn't build a dam, there would be no problem. The other issue is the system boundaries; they have just forgotten that these exist, and there is no dialogue at the level of society groups to talk about alternatives. And I think that since we have here a meeting on global change, apart from the economic considerations, you would generate a system that is incredibly vulnerable, both to political issues and to any climate change. And I wonder if, in these areas at least, at the level of society groups, the issue of alternatives to agriculture and the whole issue of extreme vulnerability has been discussed; I think that if it is discussed at the level of society, there should also be reflective thinking about the need to look for alternatives.

Abdel Fattah Metawie:

When I was listening to the problem we are facing in the Jordan River, I found that it is very difficult. When you link lots of refugees with lots of immigrants, water-quality deterioration per capita, the water level being down, it is a very difficult situation, really, in the Jordan River, and what is happening could be a model or a case study of what could happen in a river basin due to climate change, for example. I mean, assuming the difficulties we are experiencing right now. And I hope that Dr. Alon can use the systems approach, because if we put all those inputs into a model, if we model the region, then we can see what the outcomes will be in 10 years or 20 years, as we did with water quality, such as the quality of life or whatever in the region. So I am feeling very worried about the area and this situation in terms of water resources — even in Egypt, with this flux of population increase, which we have never experienced in all of our history. We don't have any papyrus telling us that when we reach 70 million, this is the way to do business in the Valley, for example, or in the River. And any newborn child in that region gets his food and drink from outside — those are becoming very clear facts — from clean water somewhere else, from other basins.

So I think a first step towards the solution, or towards creating any policy in that area, is that we have to face reality; we have to tell our people that we are going to die in that region because of the deterioration of quality of life and the increase in water shortages. So my reading of what I have said about what is happening right now is that it is like giving tablets to the patient, but the solution is surgery. What type of surgery? It is like heart problems. We have heart problems in many ways in the basin. One of them is that the heart can't pump fluid or love or whatever to the whole body in that region.

Ahmet Oktay Aksoy:

I know the Yarmouk River. I have swum in the waters of the Jordan River below the Golan Heights. I have seen Lake Tiberias from a distance and been to the lower end of the Jordan River. I know the dire situation there, so it was very interesting to listen to what all the participants have contributed. The situation is indeed very extreme, and when Holger Hoff mentioned that extreme situations like that need extreme responses, I remembered some 20 years ago when the Turkish Prime Minister proposed the building of their water pipeline from the rivers running to the Mediterranean to the region so that it would help remove the water issue from the many conflicts in the country and the region. And, in fact, this was not possible, of course, because everybody believes that without general peace and stability in the region, each one of the issues is difficult to handle. And we have also constructed a facility to transfer waters from other rivers running to the Mediterranean. We have an agreement with Israel, but it was never realized because of the cost of transportation, I guess. So there are possibilities, but we probably need stability.

Peter van Niekerk:

Dr. Rimmer showed us the models of runoff from rainfall. We heard yesterday that the temperature will go up in the future. This will cause greater evapotranspiration; it may even change the types of land uses, the types of vegetation, etc. Is that not going outside the parameters of your model, and can you actually use your model for the climate-change situation?

Moneef Zou'bi:

I think governments in all countries have been trying their level best to realize some sort of water security for their populations. Serious efforts have gone into really optimizing the water situation in the various countries. And it's time for the next level of activities and projects and programs to really satisfy water demand in the medium- and long-term future. We need outside help because, at some point, when you're talking to each other in the region, there's often very little that you can say to each other. We need outside help in terms of advice, in terms of monetary help, even in terms of really following the best practices that some of the organizations and some of the individuals in this room have developed and have been party to. Otherwise, I'm afraid to say, very little will happen and, if we've not already done so, we will lose the Jordan River forever. Thank you.

Alon Rimmer:

A general comment. You probably noticed that there is a totally different attitude towards the upper Jordan and the lower Jordan: in the upper Jordan, we are talking so far mostly about hydrological problems; in the lower Jordan, it is not hydrological, it is much more difficult troubles. Regarding the model and the question about climate change — like every model, it's developing, so right now, the surface-runoff equations are maybe the weakest part of the model, because in Israel we know much better how to treat the groundwater component. So the base-flow component is much better treated in the model, whereas the surface-water equations are less accurate and are less pronounced. In the future, we are going to develop it further into much better equations so that it might fit scenarios of climate change also. That's the goal for the next several years, actually. Thank you.

Yousef Hasan Ayadi:

I would like to say that we are doing all we can do to raise the awareness of people about using water, about using the new technologies in agriculture, about using treated waste water. With all that we have done, there is still a chronic problem, and this chronic problem has to be addressed from outside sources. There have been a lot of studies to bring water from Turkey through a pipeline, or through ships to Haifa, and then pump it up to Jordan. There have been a lot of scenarios that were too costly, so that the normal consumer cannot pay for it. So I think, for now, that this Red-Dead issue for us is the most convenient.

Ayman Rabi, Session Chair:

Thank you very much.

SESSION THREE: Case Study Two

Bob Sandford, Session Chair:

At the 2004 Rosenberg Forum in Turkey, Philip Weller gave an outstanding presentation on the Danube River, the most international of all freshwater courses. Mr. Weller told us that the ultimate measure of success of international efforts to improve water quality and the aquatic-ecosystem health of the Danube River was the condition of the wetlands at the river's estuary in the Black Sea. By agreeing on water-quality and ecosystem-vitality objectives, each of the 18 or so states through which the Danube flows could contribute, to the extent they were able, to the improvement of the health of the river.

If a comparably important river exists in Canada, it's the Saskatchewan, which flows from the Rockies across the three huge Prairie provinces to the Atlantic Ocean at Hudson's Bay. If the Saskatchewan is our Danube, then perhaps Lake Winnipeg is our Black Sea, for its health is an indication of the net impacts each of the provinces has on the river. The Saskatchewan is the great river of the Plains, and we are noticing impacts on it. The extent of that impact is the subject of science, but the mechanisms we create to respond to those threats reside in the domain of public policy. One of the greatest challenges in upland water management today is the difficulty of translating scientific-research outputs into effective and timely public policy leading to appropriate action. Our purpose in designing this case study was not just to talk about the link between science and public policy, but to demonstrate that link in action. Our plan was to have a renowned scientist offering evaluation of the state of the river, and then to have the Environment Ministers from each of the three provinces through which the Saskatchewan flows respond from the perspective of public-policy options. And I'm very pleased to announce that we got the scientist and we also have the Environment Ministers of two of the provinces — which, given their schedules, is something of a miracle in its own right — and I'd like to thank everyone for being so committed to this and for attending.

Now to introduce our scientist. Many of you will already know Dr. David Schindler from the excellent presentation he offered at Bow Lake in the pre-Forum field trip. David Schindler is the Killam Memorial Professor of Ecology at the University of Alberta. He founded and directed the landmark Experimental Lakes Project, near Kenora, Ontario, conducting experiments on whole ecosystems to directly test the effects of nutrient inputs, acid rain and climate change — work that is highly regarded, even today, in Canada. His work on purification and acid rain has been used widely in forming ecological management and public policy in Canada, the United States and Europe. Dr. Schindler is the author of over 260 scientific publications. He has received a constellation of national and international awards, including the Gerhard Herzberg Canada Gold Medal for Science and Engineering, which is the highest honour bestowed on a scientist in Canada. Dr. Schindler is also a Fellow of the Royal Society of Canada, the Royal Society of London, the Swedish Academy of Engineering and Sciences, and the National Academy of Sciences in the United States. And, on a personal note, I should point out that Dr. Schindler is one of the most accessible of Canada's high-profile scientists. He gives an uncountable number of public presentations each year and, as a consequence of his credibility, is arguably the most influential scientist in Canada. Please welcome Dr. David Schindler.

A Case Study of the Saskatchewan River System

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Abstract
Despite having relatively low average population density in most of its catchment, the Saskatchewan River has developing problems for management.

Much of the river runs through semi-arid parts of the western prairies which contribute little water to the river. The river's headwaters in the Rocky Mountains provide most of the runoff that has allowed agriculture and large cities to develop along the river. Waters in parts of the South Saskatchewan watershed have already been over-allocated, largely for irrigated agriculture, threatening the instream flow needs of valuable fisheries and the availability of water for downstream users.

The 20th century was wetter than average, and it is likely that prolonged droughts will occur in the future. Climate change is warming the basin rapidly, exacerbating water scarcity by causing glaciers to dwindle, less precipitation to fall as snow, snowpacks to melt earlier, and evaporation to increase. The result will be decreased water supplies, and higher concentrations of nutrients and other contaminants in the rivers.

Modifications to the river's channel and catchment are also significant. Numerous dams and reservoirs have caused modifications to flow patterns and increased evaporation. While the impoundments are highly beneficial to residents near the reservoirs, they allow less water to pass downstream, particularly in the summer months when water is in high demand for human activity, and fishes are stressed by high temperature or low oxygen. The catchments of most mountain headwaters are well protected, but most of the prairie parts of the basin have been converted to agriculture. Over 50% of wetlands have been drained or filled, limiting the capacity of the basin to accommodate drought. Pollutant loads have increased, of both nutrients and pathogens. Again, effects are most severe in the South Saskatchewan basin, particularly in the Oldman and Bow river drainages.

A number of recent water-management initiatives show promise for mitigating some of the river's problems, but they will have to be intensified in order to accommodate both human activity and healthy biota. Coordination between all levels of government will be essential.

Introduction: General Features of the Saskatchewan River System

The Saskatchewan River system drains 334,100 km² of the southern parts of the western Prairie provinces of Canada, and 1800 km² of the adjacent U.S.A. (Figure 1). It is a major part of the Nelson River system, which drains waters of western Canada and the northern U.S.A. to Hudson's Bay (Rosenberg et al. 2005).

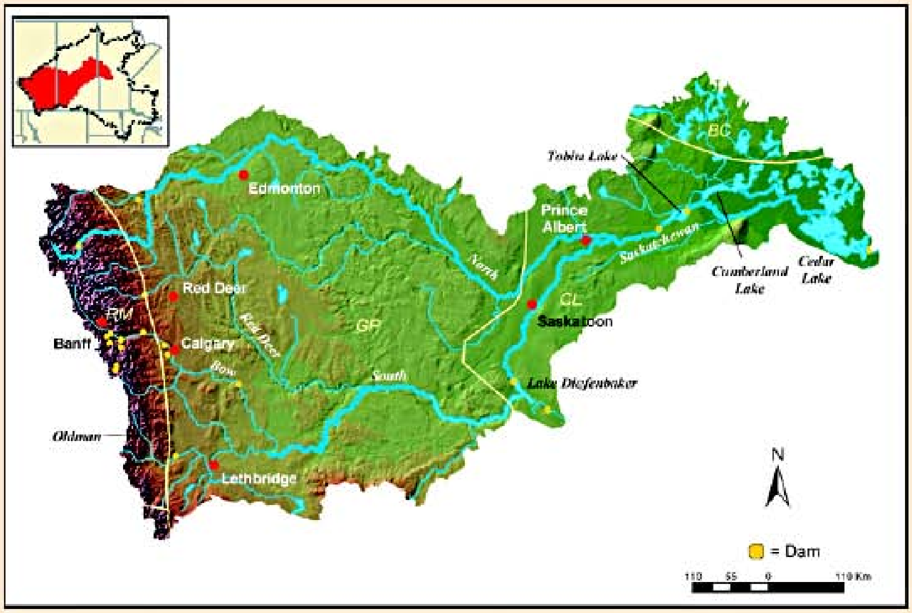

FIGURE 19.11 Map of the Saskatchewan River basin. Physiographic provinces are separated by yellow lines.

SASKATCHEWAN RIVER

Relief: 3307 m
Basin area: 335,900 km^2
Mean discharge: 567 m^3/s (postregulation)
River order: 8
Mean annual precipitation: 45.2 cm
Mean air temperature: −0.3°C
Mean water temperature: 9.7°C
Physiographic provinces: Rocky Mountains in Canada (RM), Great Plains (GP), Central Lowland (CL), Bear–Slave–Churchill Uplands (BC)
Biomes: Temperate Mountain Forest, Temperate Grasslands, Boreal Forest
Freshwater ecoregions: Canadian Rockies, Upper Saskatchewan, Lower Saskatchewan
Terrestrial ecoregions: Alberta Mountain Forests, Alberta/British Columbia Foothills Forests, Canadian Aspen Forest and Parklands, Montana Valley and Foothill Grasslands, Northern Mixed Grasslands, Northwestern Mixed Grasslands, Mid-continental Canadian Forests
24 **Number of fish species:** ≥44
Number of endangered species: none
Major fishes: cutthroat trout, rainbow trout, bull trout, brook trout, brown trout, mountain whitefish, longnose sucker, longnose dace, northern pike, walleye, goldeye, yellow perch, quillback, shorthead redhorse, lake sturgeon
Major other aquatic vertebrates: beaver, mink, white pelican, river otter, muskrat, tundra swan, ring-necked duck
Major benthic invertebrates: mayflies (*Baetisca, Baetis, Ephemera, Ephemerella, Ephoron, Heptagenia, Tricorythodes*), stoneflies (*Isoperla, Choroterpes*), caddisflies (*Brachycercus, Cheumatopsyche, Helicopsyche, Symphitopsyche, Traverella*), true flies (*Chironominae, Tanypodinae, Orthocladiinae*), crustaceans (*Orconectes*)
Nonnative species: brown trout, rainbow trout, brook trout, purple loosestrife, curly pondweed
Major riparian plants: red-osier dogwood, sandbar willows, poplar, water birch
Special features: originates in glaciers and snowfields of Rocky Mountains in Alberta, a World Heritage Site; headwaters of North Saskatchewan River in Banff National Park designated Canadian Heritage Rivers; designated globally important bird areas in portions of prairies and boreal forests
Fragmentation: dams throughout for hydropower and irrigation
Water quality: pH = 8.0, alkalinity = 131 mg/L as $CaCO_3$; relatively free of pollutants in mountains (NO_3-N = 0.075 mg/L, PO_4-P = 0.009 mg/L); higher nutrient concentrations below major cities and in agricultural areas
Land use: 67% cropland, 3% shrub, 7% grassland, 22% forest
Population density: 9.6 people/km^2
Major information sources: Donald and Mutch 1980, Culp and Davies 1982, Charlton et al. 1986, Cross et al. 1986, Hamilton and North 1986, Sosiak 1990, Culp et al. 1992, Chambers and Prepas 1994, Carr and Chambers 1998, Environment Canada 2001, 2002

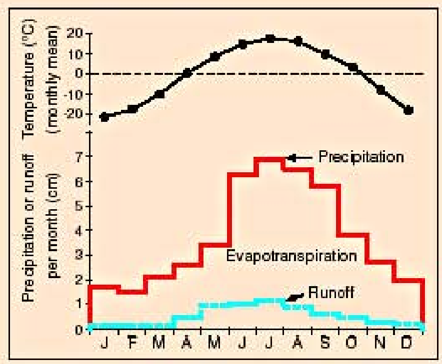

FIGURE 19.12 Mean monthly air temperature, precipitation, and runoff for the Saskatchewan River basin.

Figure 1. A map of the Saskatchewan River basin. Physiographic provinces are separated by yellow lines. The river drains into Lake Winnipeg at the eastern end of the basin. The position of the basin within the Nelson River basin is shown in the inset. Seasonal average temperatures, precipitation patterns, evapotranspiration and runoff, and other information about the basin are shown in the lower panel. From Rosenberg et al. (2005).

The river consists of two main branches, which cross seven terrestrial ecoregions. The North Saskatchewan begins at high elevation in the Rocky Mountains of western Alberta, at the foot of the Saskatchewan Glacier (Figure 1). The South Saskatchewan has three main tributaries: the Red Deer, Bow and Oldman rivers (Figure 1). The Red Deer and Oldman rivers originate in the snows of the Rocky Mountains, and the Bow River originates at the Bow and Peyto glaciers in Banff National Park (Figure 2). The two branches of the Saskatchewan join in east-central Saskatchewan to form the mainstem river (Figure 1). At its mouth, the North Saskatchewan has a mean annual flow of 241 m^3/s (Rosenberg et al. 2005). Where the river enters Lake Winnipeg, its average flow is 567 m^3/s (Rosenberg et al. 2005). During the period 1913–1989, average annual flow at the Pas, upstream of Lake Winnipeg, ranged from 307 m^3/s in 1941 to 1170 m^3/s in 1916 (Cohen 1991).

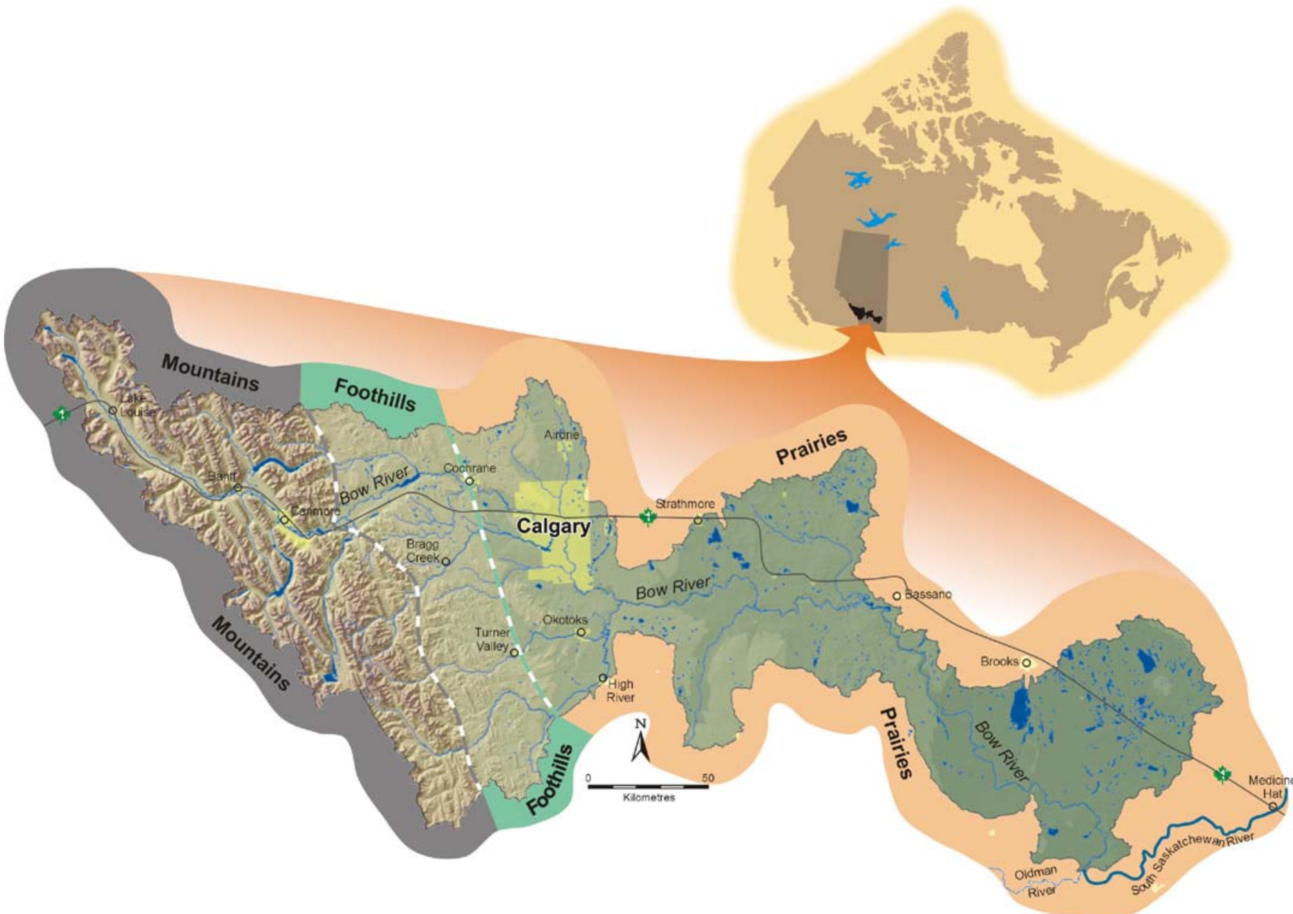

Figure 2. The Bow River basin, showing major features (BRBC 2005)

Seasonality of Flows and Water Yields

The highest flows of the year in the lower reaches of the North Saskatchewan usually occur in July, when the water from melting mountain snowpacks reaches the area. Lowest average flows are in February. In the South Saskatchewan, highest flows occur during spring snowmelt, which typically occurs in late March and April in the lower parts of the basin, and in May-June at the higher altitudes of the Rockies. Once snowmelt has dwindled, glacial melt contributes to summer flow. In a dry year, glacial inputs can be as high as 50% in the Bow and North Saskatchewan rivers, though the annual contribution is <5% (BRBC 2005). Autumn flows can be quite variable, depending on temperature and precipitation. Winter flows are typically low because much of the catchment of the river is below freezing in December through February. Groundwater is an important winter water source in many areas (BRBC 2005). Both branches of the river are ice-covered for about four months.

With the exception of the mountainous regions of western Alberta, the Saskatchewan River drains rather flat areas of prairie. Gradients of various tributaries in the mountains are generally 3–7 m/km, whereas in the rest of the catchment they are only 0.15–0.5 m/km. Much of the prairie part of the catchment is semi-arid, particularly in the south. Most of the flow of the river system is generated by higher precipitation in the Rocky Mountains and foothills. Average water yields are over 500 mm per year in the mountains, but in semi-arid areas of the southern prairies they can be very near to zero. Similarly, runoff/precipitation ratios can vary from over 90% in mountainous areas to near zero for more arid areas of the prairies. For example, the Battle River, which has no mountain headwaters, drains 40% of the North Saskatchewan basin but supplies only 3% of the water reaching the North Saskatchewan from its tributaries (NSWA 2005). There is also a wide range of spatial and interannual variability in runoff (Gan 2000).

Recent studies using proxy indicators of drought indicate that periods of prolonged droughts, some lasting for decades, were very common before the 20th century (Sauchyn, this conference; Case and MacDonald 2003; Cumming et al. 2002; Watson and Luckman 2005). The Canadian Senate's Standing Committee on Energy, the Environment and Natural Resources (2005) expressed concern about the effects of climate warming and water scarcity on human activities and environment in the western prairies.

Until recently, most attention has been focused on annual or natural flows in the rivers. In most cases, the total effect of climate warming and human withdrawals on annual river flow have so far been slight or negligible (Rood et al. 2005), although the South Saskatchewan at Saskatoon has decreased by about 30% in the past century and the average annual flow in the North Saskatchewan at Edmonton has declined by 15% between 1911 and 2003 (NSWA 2005). There have, however, been rather severe disruptions to the seasonality of flow. Summer (May-August) flows in most rivers have declined severely, with the North Saskatchewan at North Battleford now averaging 40% lower than in the early years of record, and the South Saskatchewan at Saskatoon averaging 85% lower (Schindler and Donahue 2006). The summer period is very critical for the Saskatchewan River. The fisheries of the system are generally coldwater species, with preferred temperatures in the teens (°C), and lethal temperatures in the low to mid 20s. They are also very sensitive to low oxygen, with some species intolerant of concentrations less than 6.5 mg/L for prolonged periods.

The summer is also critical for human residents. Irrigation and municipal use are high during the May-August period. Also, reservoirs are usually drawn down in fall and winter, and are refilling during the May-August period.

Biota

Headwater parts of both branches of the Saskatchewan contain coldwater fishes. Downstream parts on the prairies contain a combination of cold- and warm-water species. Overall, the North Saskatchewan has an assemblage of 36 species of fishes. This increases to 44 species in the Cumberland Marshes, on the mainstem Saskatchewan near the Manitoba-Saskatchewan border (Rosenberg et al. 2005).

Introduced Species

In headwater and upstream areas, deliberate introductions of alien species have displaced native species. In particular, non-native eastern brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) have displaced native bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarki*) in the headwaters of the South Saskatchewan. These introductions have combined with overfishing and habitat destruction to make the bull trout a threatened species through much of its range.

Crayfish have also been introduced to the North Saskatchewan River in recent years. They are now commonly found in the river near Edmonton. They are believed to be the result of transport in bait buckets by fishermen. They will undoubtedly slowly work their way downstream. The current extent of their invasion is unknown, but their range will certainly increase. They are resident to the nearby Beaver-Churchill River.

At the lower end of the Saskatchewan, Lake Winnipeg has been invaded by common carp (*Cyprinus carpio*), rainbow smelt (*Osmerus mordax*), and the cladoceran *Bosmina coregoni*. Other invasive species including zebra mussels and the spiny water flea (*Bythotrephes*) are approaching the Nelson River system and have the potential to work their way up the Saskatchewan, where humans will probably assist them in surmounting dams, as has happened in other rivers of the world.

Climate Warming in the Catchment and Its Effects on the Hydrological Cycle

The longest temperature records in the Saskatchewan River catchment generally begin in the 1880s. During the 20th century, most stations that are relatively free of urban "heat islands" in Alberta and Saskatchewan have recorded a warming trend of 1–4°C, mostly after 1970. Regional climate models indicate that average temperatures by 2100 will increase by another 4.8–8.4°C (Schindler and Donahue 2006), well outside the range where human society is prepared to adapt. Winter temperatures in most areas have increased more than summer.

Warming has already affected several aspects of the hydrologic cycle, including increased glacial melt (Demuth et al. 2002), earlier spring melt, smaller snowpacks and a lower proportion of precipitation as snow (Schindler and Donahue 2006). Potential evaporation is expected to increase (Sauchyn, this conference; Schindler and Donahue 2006), although effects on actual evaporation and transpiration are less clear because they depend somewhat on soil moisture, wind and the response of plants to higher concentrations of atmospheric CO_2 (Gan 2000). Glaciers and snowpacks are predicted to continue to decline as climate continues to warm (Demuth et al. 2002; Lapp et al. 2005). The role of snow and ice as "free storage" of water for summer use in the prairies has been underappreciated.

Humans in the Saskatchewan River Catchment

Humans have occupied the catchment of the Saskatchewan since the river was formed by the last glaciation. It is believed that they originally subsisted on large Pleistocene mammals such as mammoths, camels and caribou, switching to bison as these species approached extinction. Bison remained the mainstay for aboriginal people until late in the 19th century, when Europeans began to significantly affect their lifestyles, eradicating bison and introducing alcohol, guns, trade and new diseases. Lac (2004) gives more details.

In mountainous areas, the catchments of the rivers have been modified very little, except by small communities (Banff, Jasper and Lake Louise are the largest at 8300, 5000 and 1500 people respectively, although all three grow by several-fold during the summer tourist season). Highways through the national parks are few; however, they and two railroads through the parks carry much of the traffic between eastern and western Canada. There are also a few reservoirs, as described below. The Saskatchewan's montane headwaters are largely protected as national or provincial parks, World Heritage Sites and other designations that restrict development. Nevertheless, detailed examination shows that some features of the river systems have been compromised in these areas, as discussed later.

With European settlement came the first tillage of the land. It is estimated that 67% of the catchment is now farmed (Rosenberg et al. 2005). With the expansion of agriculture came significant modifications to the catchment and the river, including clearing of forests; construction of dams, canals and diversions for irrigation; draining and filling of wetlands; increasing populations; oil and gas exploration; and other industrial and municipal activities.

While the average human population of the Saskatchewan's catchment is still low (about 3.5 million, or an average of <10 people per km^2), much of the population is concentrated in Alberta, where it is estimated that 80% of the human population live in the Saskatchewan basin, which constitutes only 20% of the province's water supply (AIA 2005). Calgary on the Bow River and Edmonton on the North Saskatchewan have populations of about a million people each. Densities in these urban areas can exceed 1000 people/km^2. Approximately another half-million humans occupy the area between Edmonton and Calgary, and about the same number inhabit the Oldman–South Saskatchewan drainage, near Lethbridge and Medicine Hat. In Saskatchewan, Saskatoon, Swift Current and Prince Albert add about a half-million more humans. Through the rest of the basin, few settlements >10,000 occur, and most are <1000. BRBC (2005) and Lac (2004) give more detailed information on human history and distribution.

Dams and Reservoirs

Gan (2000) estimates that there are 770 dams in the western Prairie provinces. While there is no database showing the locations of all of them, most of these would be in the Saskatchewan River basin. Here we shall describe some of the largest ones.

North Saskatchewan

The North Saskatchewan has two large reservoirs, both constructed mainly for the generation of hydroelectric power. Abraham Lake is where the river leaves the mountains, just below the boundary of Jasper National Park. The Brazeau Reservoir, in the lower foothills, is on a tributary, the Brazeau River.

The South Saskatchewan and Its Tributaries

The South Saskatchewan and its tributaries have a number of large dams, in addition to hundreds of small ones.

The Red Deer River (Figure 1) is still relatively free-flowing. Only Dickson Dam just upstream of Red Deer is a major regulator of river flows. It regulates downstream water supplies, primarily in winter. It also provides some hydroelectric power, recreation, and flood reductions (Alberta Environment 2004).

On the Bow River (Figures 1 and 2), hydroelectric-generation plants rely on several reservoirs, most of them on tributaries in mountainous areas. They generate less than 5% of TransAlta Utilities' power, but are regarded as important because of the rapidity with which they can respond to fluctuating power demand. Further downstream, several reservoirs and weirs impound water for irrigation and municipal supplies. They, and major reservoirs on the Oldman River, will be discussed in more detail later. Overall, reservoirs in the South Saskatchewan basin within Alberta are capable of storing nearly 40% of annual flows (AIA 2005).

Below where the Red Deer, Bow and Oldman rivers join, Gardiner Dam forms Lake Diefenbaker, the largest impoundment on the South Saskatchewan River system. The reservoir is 43,000 ha in area and contains 9.4 billion m^3 of water when full. It supplies drinking water for 40% of Saskatchewan's population, for recreation, for irrigation, for industry (including 10 potash mines) and for flood control (Saskatchewan Watershed Authority www.swa.ca). On the mainstem Saskatchewan River, the Tobin Lake and Codette Lake reservoirs, near Nipawan, Sask., and the Cedar Lake reservoir, formed by the damming of the Grand Rapids near Lake Winnipeg, are for hydroelectric power. Little information is available on the impacts of these dams, although Tobin and Codette lakes have become world-renowned sport fisheries for walleye and pike.

The displacement of two native communities by the formation of Cedar Lake Reservoir caused considerable loss of livelihood for aboriginal people in that area (Loney 1987). Similar fates have met aboriginal communities at other Canadian hydroelectric developments (Rosenberg et al. 1997).

The Effects of Impoundment on Channel Morphology and Other Riparian Features

Reservoirs also have well-known negative effects (reviewed by Hecky et al. 1984 and Rosenberg et al. 1997). It is widely recognized that the form of stream channels is a function of high flows (Hecky et al. 1984; Newbury and Gaboury 1993) and that elimination of high-flow periods by damming or diversion results in gradual changes to stream channels. High sediment loads are also deposited behind dams, causing degradation of downstream riverbeds due to starvation for sediments. Concentration of rivers' energy below dams can adversely affect channels. For example, Galay et al. (1985) found that Gardiner Dam had caused degradation of the riverbed for 8 km downstream from Lake Diefenbaker. The riverbed has eroded by 2 m and has started to "armour" (become coarser). High flood releases are predicted to accelerate the degradation. On the other hand, the broader energy distribution from normal high flows in undammed river reaches scours streambeds of organic matter and vegetation accumulated during previously low-flow periods, helping to minimize the oxygen depletion that occurs during stagnant periods in summer, or under winter ice (Clipperton et al. 2003).

Periodic flooding also helps to rejuvenate and sustain riparian forests, especially species of *Populus*, which are very common in the floodplains of the Saskatchewan River. Often, these forests decline below dams on the river system (Rood and Mahoney 1990; BRBC 2005).

Impoundments that fluctuate widely annually often cause decreased production of stream macroinvertebrates — including *Trichoptera*, *Ephemeroptera*, *Mollusca* and *Plecoptera*, many species of which require a full year to complete their life cycles in cold waters. In many cases, these are replaced by smaller, shorter-lived species of less value for supporting fish stocks, generally *Chironomidae* species (Rawson 1958). Fluctuating water levels also prevent the formation of stable riparian zones.

Downstream of reservoirs, many species of macroinvertebrates become less abundant or are extirpated as a result of disrupted thermal regimes. Typically, discharges from reservoirs are cooler in summer and warmer during winter than natural rivers, hindering hatching of many species. The effect was evident for 110 km below reservoirs on the Saskatchewan River (Lehmkuhl 1972).

Impoundment has been shown to cause increased mercury concentrations in fishes in many areas (Jackson 1998; James Bay Mercury Committee 1995). The increases appear to be the result of increased methylation and mobilization of mercury from flooded vegetation and soils (Kelly et al. 1997). While hydroelectric power has been widely touted by politicians as "good, clean power", reservoirs release both CO_2 and methane to the atmosphere (Kelly et al. 1997; St. Louis et al. 2000). In short, although dams and reservoirs confer many benefits to humans, they negatively affect many features of the ecological integrity of streams and riparian areas.

Human Use and Its Effects on the Rivers

North Saskatchewan

In the North Saskatchewan basin, permanent water withdrawals are small and effluents from communities rather widely spaced. However, much of the area outside the mountains has been converted to agriculture, resulting in a slow degradation of water quality downstream. In applying nine indicators of "health" to the 18 main tributaries of the North Saskatchewan, NSWA (2005) rated four as good, nine as fair, and five as poor.

South Saskatchewan

In the South Saskatchewan basin, where most of Canada's irrigated agriculture and human population is concentrated, water is already scarce and water quality has been compromised. Both human and animal populations are growing rapidly. In order of importance, human withdrawals are for agriculture, power generation and municipal use.

Referring to the entire South Saskatchewan system, Alberta Environment (2003) stated: "We have difficult decisions to make about the use of water, retaining water in the rivers, and maintaining a sustainable aquatic ecosystem. It is not possible to have, in any given river reach, both a high degree of consumptive water use and a near-natural aquatic ecosystem over the long-term." It divides the South Saskatchewan and its tributaries into thirty-three distinct river reaches. Of these, only a single reach is rated as unchanged or recovered. Thirty-one reaches are listed as from moderately to heavily impacted, or degraded (Figure 3).

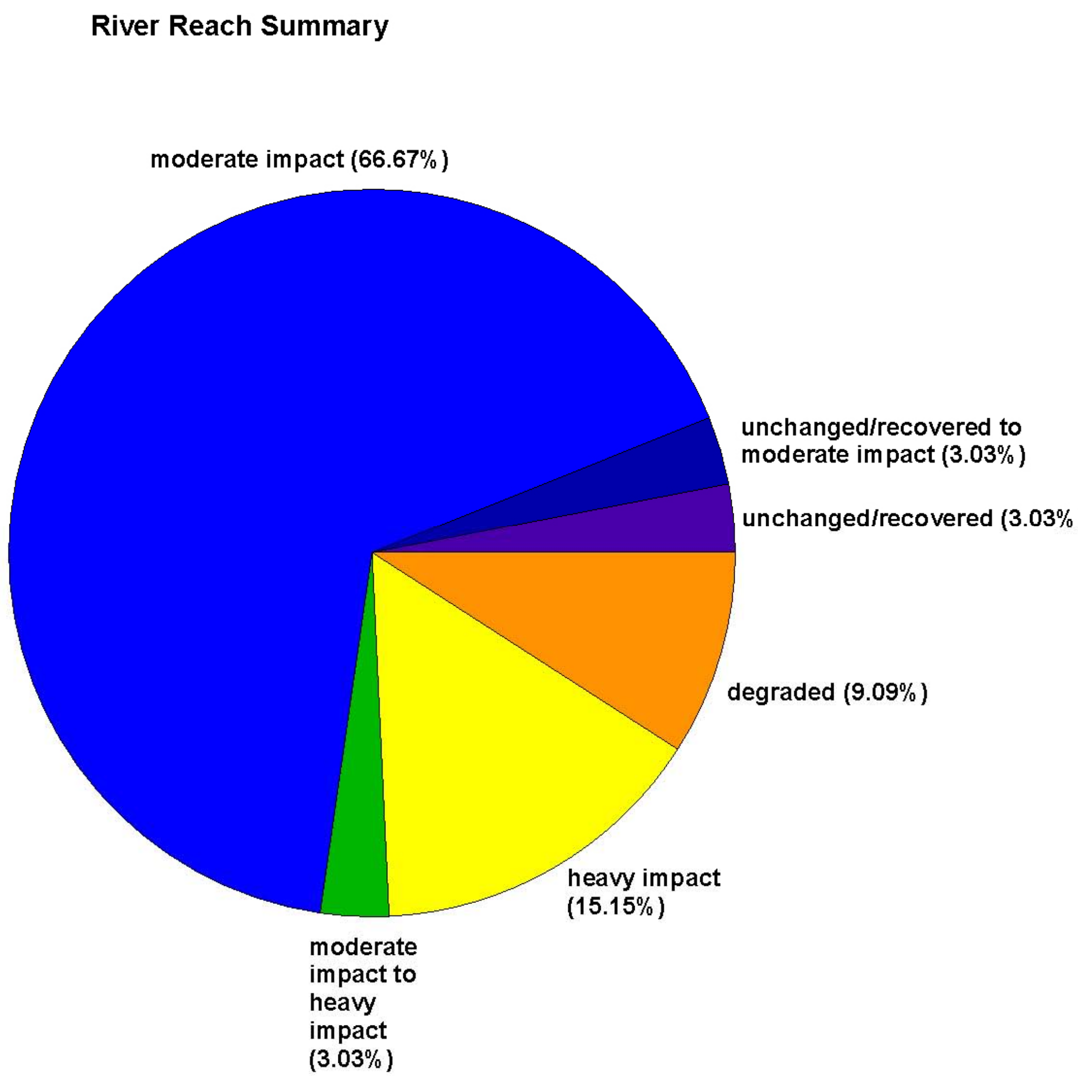

Figure 3. The rating of 33 reaches of the South Saskatchewan and its tributaries.
Data from Alberta Environment (2003).

Prairie Agriculture

Unlike the Great Plains of the U.S.A., which rely heavily on groundwater (chiefly the oversubscribed Ogallala Aquifer), most of the agriculture in the Saskatchewan River basin relies on surface waters. As mentioned above, 67% of the total area of the catchment is used for agriculture. Typically, the Prairie provinces supply about two thirds of Canada's $15 billion in agricultural exports (1994 figures; Gan 2000). The amount can be highly variable, and in drought years, farm relief can be very high. The worst case was the "dirty thirties", when several consecutive years of drought forced 250,000 farmers to leave the Prairies, and 7.3 million hectares of land were affected (Godwin 1986 in Gan 2000). In the 1980s and 1990s, several annual droughts caused export losses of 1 to 4 billion dollars (Gan 2000). Due to extreme spatial and interannual variability of rain and snow, many reservoirs have been constructed for agricultural use. Several of the larger reservoirs and their effects on water resources were described above.

Irrigation is by far the most consumptive use of Prairie water. Almost all of the irrigated land in the Prairies is in the South Saskatchewan basin, particularly in the basins of two of its major tributaries, the Bow and the Oldman rivers of Alberta. Irrigation has a long history, with the Canadian Pacific Railway promoting it as early as the 1890s. The *Northwest Irrigation Act* of 1894 established regulations for the first irrigation districts. Today, 13 irrigation districts and privately irrigated land apply about 2.5 km^3 of water per year to about 1.63 million acres (0.65 million ha) of land. Typically, about 20% of this is returned to the rivers, although it can be quite heavily polluted with pathogens, nutrients, pesticides and herbicides. It is estimated that the 5% of arable lands that are irrigated in Alberta provide 20% of the province's gross agricultural production (AIA 2005).

Livestock culture is also increasing rapidly in the Saskatchewan basin. Alberta is the province most affected, with over 6 million cattle and over 2 million hogs. The province of Alberta has a goal of doubling livestock numbers (Toma and Bouma 1997).

Power Generation

The second-largest user of water in the Saskatchewan basin is power generation. Hydroelectric generation is a relatively small part of the power supply. While it causes problems described earlier, it consumes very little water. Thermal-power generation is more common, as the result of abundant coal deposits, most notably in central Alberta. Much of the thermal generation is in the basin of the North Saskatchewan, where several thermal-power plants near Lake Wabamun use nearby coal to generate 4000 MW of power, roughly 48% of the province's need in 2003 (Schindler et al. 2004). The plants rely on water from the lake or the nearby Saskatchewan River for cooling. It is estimated that 98% of the water used for thermal power is returned to surface waters, with little pollution (AIA 2005).

Municipal Use

Municipal water use is still a relatively small proportion of allocated water. There are some concerns with respect to southern and central Alberta, where rapid population increases in the Calgary area are expected, and also in the Battle River basin, which receives no "subsidy" from glaciers or mountain snowpacks. A number of conservation measures will be necessary to protect water supplies and instream flow needs. A recent study by Watrecon (2005) outlines the problems and discusses likely future water needs in the Battle River basin.

Per capita water use in most urban areas of the Saskatchewan basin is very close to Canadian averages. From 80 to over 90% of water withdrawn for municipal use is eventually returned to the rivers. Sewage treatment at large municipal plants in the basin is excellent, with many cities removing nutrients as well as pathogens. However, storm runoff can still be highly polluted with pathogens, nutrients, pesticides and herbicides. Antibiotics, hormones and personal-care products have also recently emerged as issues. Many of these are not efficiently removed by sewage treatment, and their breakdown in rivers is limited by cold temperatures and ice during part of the year. Most smaller communities have less-effective sewage treatment. In many cases, effluents are simply pumped into lagoons, where they are left for several months before discharging directly to nearby rivers.

Use by the Petrochemical-extraction Industry

Although the petrochemical industry is not a large user of water, several features of its use have been the subject of public outrage. For example, an annual amount roughly equal to municipal use is pumped down wells to facilitate oil and gas extraction. This is permanently removed from the water cycle. Other alleged insults include the pollution or rerouting of aquifers during the drilling of oil and gas wells, and the discharge of polluted or saline water to surface or ground waters. A current plan to extract methane from coal beds promises up to 64 gas wells per square mile. The initial proposal is for development in the area of Pincher Creek, a tributary to the Oldman River. The plan has evoked outrage and opposition among ranchers and farmers, who hold only surface rights to the area and are fearful that their water supplies will be compromised. Alberta Environment has just announced that it will require increased study of the aquifers in an area before drilling, but details are not yet available.

Pathogens in the River Systems

In areas of extensive agriculture and below the sewage outfalls of some cities, pathogens pose a problem with water supplies. For example, significant proportions of >1400 water samples from the Oldman River and its tributaries over two years were found to contain E. coli 0157:H7 (0.9%) and/or *Salmonella* spp. (6.2%) (Johnson et al. 2003). There have also been problems in the North Saskatchewan basin. Outbreaks of gastrointestinal disease caused by the protozoan *Cryptosporidium* have occurred in Edmonton, Alberta (1982), and North Battleford, Sask. (2001) (Hrudey and Hrudey 2004). Both communities draw water from the North Saskatchewan River. The protozoan *Giardia* is also a concern. Livestock (chiefly beef cattle) have been identified as the most important sources of these parasites, especially during periods of high runoff, although wildlife, other livestock and human sewage are other sources of the parasites (Heitman et al. 2002; AFFRD 2006). As the result of the high potential for contamination and the resistance of these protozoa to chlorination, water-treatment plants in Edmonton now treat intake water with UV radiation.

Actinomycetes have also caused taste and odour problems in the North Saskatchewan River, particularly during spring runoff. Some strains are resistant to disinfection at water-treatment plants (Jensen et al. 1994).

Toxic Substances in the River

Mercury in fish is the primary toxin of concern in the Saskatchewan River. It is believed that natural sources to the river are high. Long-range transport in the atmosphere appears to have roughly doubled atmospheric loading. Coal-fired power plants have contributed still more via emissions to the atmosphere in some areas (Donahue et al. 2006).

Mercury was also used in the North Saskatchewan by gold prospectors early in the 20th century. It is still possible to separate elemental mercury from sediments with a simple gold pan in the region around Edmonton.

Alberta Sustainable Resource Development (2006) recommends that women of child-bearing age and children under 15 not eat fish from either the North or South Saskatchewan. Others should not eat more than one meal of fish from these rivers per week. The Bow, Red Deer and Oldman rivers also carry consumption advisories for some species. High mercury has been recorded at many sites in the Saskatchewan River system throughout its length (Wobeser et al. 1970). At least one case of mercury intoxication in a fish-eating mammal (mink) eating fish from the river has been recorded (Wobeser and Swift 1976).

Increased forest fire in the mountains has been shown to increase the supplies of mercury and nutrients to lakes and streams (Kelly et al. in review and unpublished). Forest fire has been shown to cause increased mercury concentrations in fish in downstream waters. Both nutrient inputs, via their effects on food-web relations, and mercury input are responsible. Forest fires are predicted to increase under climate warming (Flannigan et al. 2005). In addition, Parks Canada is undertaking an aggressive policy of controlled burning in order to rejuvenate early-successional stages that are vital for maintaining food supplies for large mammals. A conflict between forest and water management may result.

The Cumulative Effects of Climate Warming, Human Withdrawals and Channel Modifications: Some Worst Cases

The most threatened parts of the Saskatchewan River basin are the Oldman and Bow systems. On average, each supplies roughly 40% of the flow to the South Saskatchewan River, with the Red Deer River supplying the remaining 20%. Most water for irrigation is drawn from the Bow and Oldman rivers, and they are areas of rapidly increasing human and livestock populations. Under the Master Agreement on Water Apportionment, signed in 1969, Alberta must allow 50% of the flow of the South Saskatchewan River to pass into Saskatchewan. In recent dry years, most of the water necessary to meet this commitment has come from the Red Deer River because of high water withdrawal from the Bow and the Oldman. The combination of climate warming — via its effects on glaciers, evaporation and spring melt — higher water temperatures and increasing human populations, agricultural use and industrial development, have put the Bow and Oldman rivers in precarious positions. At present, over-allocation of water in the rivers has not been a problem, because water withdrawal and consumption are much lower than allocated limits. However, the proportion used of allocated water is expected to increase as human activity intensifies (AIA 2005).

The Bow and Oldman rivers have world-renowned fisheries for brown and rainbow trout which generate considerable income. Most of the fishes in these rivers, as well as the Red Deer and the South Saskatchewan, have lethal temperatures of 22–29°C, and seven-day chronic lethality values of 18–24°C (Clipperton et al 2003). Water allocations in much of the South Saskatchewan basin exceed instream flow needs (IFN) for maintaining the morphology of channels and the integrity of biota. A recent analysis recommended that maintaining IFN in the South Saskatchewan system would require 85% of natural flows — which is impossible with allocations already made — in either the Oldman or Bow systems (Alberta Environment 2003). It states: "… the aquatic environment is believed to be in a state of long-term declining health." As a result, a moratorium on further allocations was imposed in 2003 in the St. Mary's, Belly and Waterton rivers, tributaries to the Oldman (AIA 2005).

Below, we discuss in detail the features of the two most heavily impacted tributaries to the South Saskatchewan:

The Bow River

The Bow River (Figure 2) originates in the glaciers above Bow and Hector lakes, in the alpine regions of Banff National Park. At its headwaters, nutrients and coliform counts are very low (Schindler and Pacas 1996), although melting glaciers and contaminated high-elevation snowpacks contribute significant amounts of organochlorine pesticides and PCBs to the river (Blais et al. 1998; Donald et al. 1999).

There is little modification to land use within the national park, although there have been some effects on the river's flow patterns and chemistry. Schindler and Pacas (1996) and Schindler (2000) reviewed the status of the Bow River in Banff National Park. They found that 41.5% of the river's flow within the national park was regulated, all of it towards the park's eastern boundary. The following describes the two largest reservoirs that affect waters of the national park:

Lake Minnewanka in Banff National Park had early low-level dams constructed before 1912. The current structure, built in 1939–1941 with the authorization of an Order-in-Council under the *War Measures Act*, raised the original lake level by 25 m. The reservoir is drawn down in winter and refilled in summer, with an annual operating range of 6–7 m. Water is released via the Cascade Generating Station, and can fluctuate from 0 to 1400 cfs several times a day. The annual drawdown exposes much of the littoral zone, and comparison with pre-dam studies by D.S. Rawson shows that the bottom fauna changed from about 50% macroinvertebrates (molluscs, *Trichoptera*, *Ephemeroptera*, *Plecoptera* and other large species) to over 90% chironomids (Schindler and Pacas 1996).

The Lake Minnewanka reservoir was stocked with several alien species of fishes and invertebrates. It also destroyed most of the Cascade River and surrounding riparian habitat by diverting water around the original river channel. The original Cascade River was about 15% the size of the Bow River at Banff.

The Spray Reservoir, constructed in 1947–1951, lies outside the park boundary, but the Spray River drains the reservoir into the Bow within Banff. The level of the original Spray Lakes was raised by more than 60 m. The raised water level in the lakes and the decreased summer flows destroyed major cutthroat trout (*Onchorhynchus clarki*) fisheries in both the Spray Lakes and the Spray River. The latter was termed by Rawson (1958) "the best stream angling in Banff Park".

The communities of Lake Louise and Banff once discharged sewage into the Bow River within the park, causing eutrophication and contamination with fecal coliforms for some distance below their outfalls. These problems have largely been solved by phosphorus removal and UV treatment of waste water before discharge to the Bow (Schindler and Pacas 1996). The river reaches have now largely recovered, with much reduced growth of attached algae and the return of original benthic communities (Bowman et al. 2005). Salting of the Trans-Canada Highway in winter has caused elevated concentrations of sodium and chloride in the river within the parks (Schindler and Pacas 1996).

Below the Banff National Park boundary, little of the Bow River basin remains in its natural state (BRBC 2005). Logging, agriculture, and oil and gas development are the main activities. Rapid urbanization is occurring between Canmore, at the park boundary, and Calgary. Sixty-eight per cent of the river's flow has been allocated by the time it reaches its confluence with the Oldman River in eastern Alberta. Of the allocated water, 76% is for irrigation (BRBC 2005), although with the exception of irrigation, much of the allocated water is returned to the river. Several dams and weirs impede fish passage. Rapid human population growth in the basin poses additional demands on water supplies, and climate change and glacial retreat are future threats. Water quality declines along the length of the river as the result of coliform bacteria, nutrients, pesticides and salts.

Reservoirs outside Banff National Park include the Interlakes (1955), Pocaterra (1955) and Barrier (1947) dams on the Kananaskis River, a major tributary. The Ghost Reservoir (1929), on the Bow just below the entry of the tributary Ghost River, and Bearspaw Dam (1954), which regulates flow without storage, complete the list of major dams. Overall, 11 hydroelectric facilities rely on the dams. The flows in the reach of the river between the Cascade River and the Bearspaw Dam fluctuate rapidly, sometimes several times a day, in order to facilitate adjustments in electricity supply to changing demands. This makes the reach fairly inhospitable as habitat for riparian animals and fish. The Bearspaw Dam smoothes these flows. The Bow River Basin Council (BRBC 2005) gives more detailed information.

Overall, the reservoirs have had a devastating effect on cutthroat and bull trout populations in the upper reaches of the Bow. With respect to the impact of reservoirs on the fisheries of the mountain parks, Rawson, the most eminent fisheries biologist of his day, remarked (1958): "… we would be inclined to think that reservoirs are fundamentally poor in productivity, the fluctuating water levels are especially unfavourable for our best game trout which tend to feed in shallow water, and that fish plantings are usually ineffective as a management procedure in such bodies of water." Rawson's various publications from the 1930s document the disappearance of many native invertebrates and fishes from lakes and streams after reservoir construction. Stocked lake trout (*Salvelinus namaycush*) have done well in the reservoirs, however, largely replacing native fishes. Altogether, of 20 fish species found in the Bow within the Banff boundary, 10 are non-native. The Banff Bow Valley Task Force (1996) made several recommendations to reduce the impact of impoundments in Banff National Park, but few of these have been implemented to date. In the rivers of the Bow basin, native bull and cutthroat trout have largely been replaced by non-native eastern brook trout, rainbow trout and European brown trout. BRBC (2005) gives more detailed information.

The reach from the Bearspaw Dam to the intake of the Western Irrigation District has the highest population density in the entire Saskatchewan basin because of the city of Calgary and surrounding bedroom communities. Statistics Canada shows that the Census region including the city grew 16% between 1996 and 2001, and this growth rate appears to be continuing or even increasing. The population of the Calgary area is forecast to increase by about 50% by 2030 (BRBC 2005).

Calgary draws roughly half its drinking water directly from the Bow, the other half from Glenmore Reservoir on the tributary Elbow River (Figure 2). Until recently, Calgary has not metered water use in most of its area. In 2002, meters were required on new dwellings. Unmetered homes use 50% more water on average than metered ones (BRBC 2005). The city has also undertaken a program to reduce water leaks in its distribution system, and undertaken a major campaign to reduce water consumption. As a result, peak summer water demand in 2002 was 7% less than in 1987, despite a 39% increase in population (BRBC 2005). The city has also treated its sewage to the highest standard of any waste-treatment plant in Canada, and undertaken a program of constructing and protecting wetlands to reduce the pollutants in storm drainage before they enter the river.

The first major irrigation withdrawals are just downstream of Calgary. Water quality also declines, and there are periodic fish kills as the result of high temperatures and low oxygen (Clipperton et al.

2003). The Bassano Dam, below Calgary, is owned and operated by the Eastern Irrigation District. Its main purpose is to impound and divert the Bow's water for irrigation.

Near its mouth, the summer flows of the Bow River are less than 50% of values in the late 1960s, when record keeping began.

The Oldman River

The Oldman River and its tributaries also have several significant dams. All are primarily to supply water for irrigation, although flood control, municipal supply, erosion control, and recreation are other objectives. The largest are the Waterton–St. Mary Headworks System and the Oldman River Dam, built in 2001 (Alberta Environment 2004).

The Oldman River covers 3 million ha in southern Alberta (Figure 4). The river originates at a small lake in the Rocky Mountains. There are no glacial inflows. The river and its tributaries extend through generally forested catchments in the west at higher elevations, then through savanna-type rangelands of the foothills, to semi-arid grasslands of the western Prairies to the east. Much of the eastern part of the basin receives only 300–450 mm of precipitation per year on average and is classified as semi-arid.

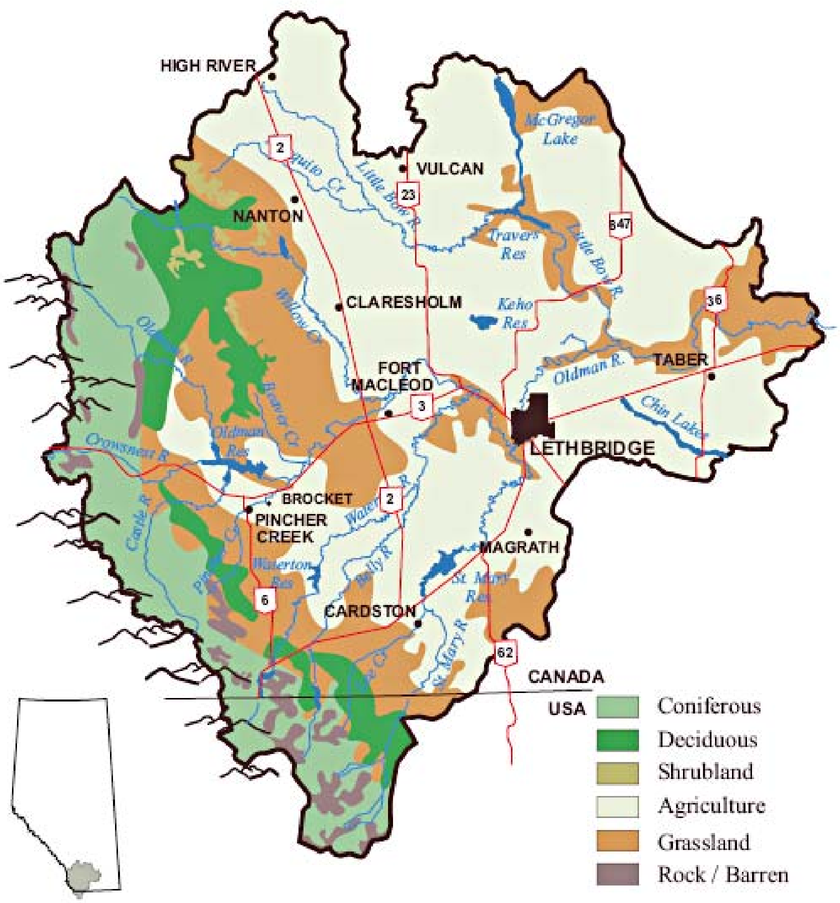

Figure 4. The Oldman River basin, showing vegetation types and other major features. From OWC (2005).

The basin is currently home to about 160,000 people, half in or near the city of Lethbridge. About 266,000 ha of land is irrigated, 40% of the total in Alberta. It also has the greatest density of intensive livestock operations in the province (Figure 5), making it one of the most intensively managed agricultural regions in western Canada (OWC 2005). In addition, the catchment is the site of high densities of oil and gas extraction. This is expected to intensify even more as coal-bed methane is extracted in the coming decade.

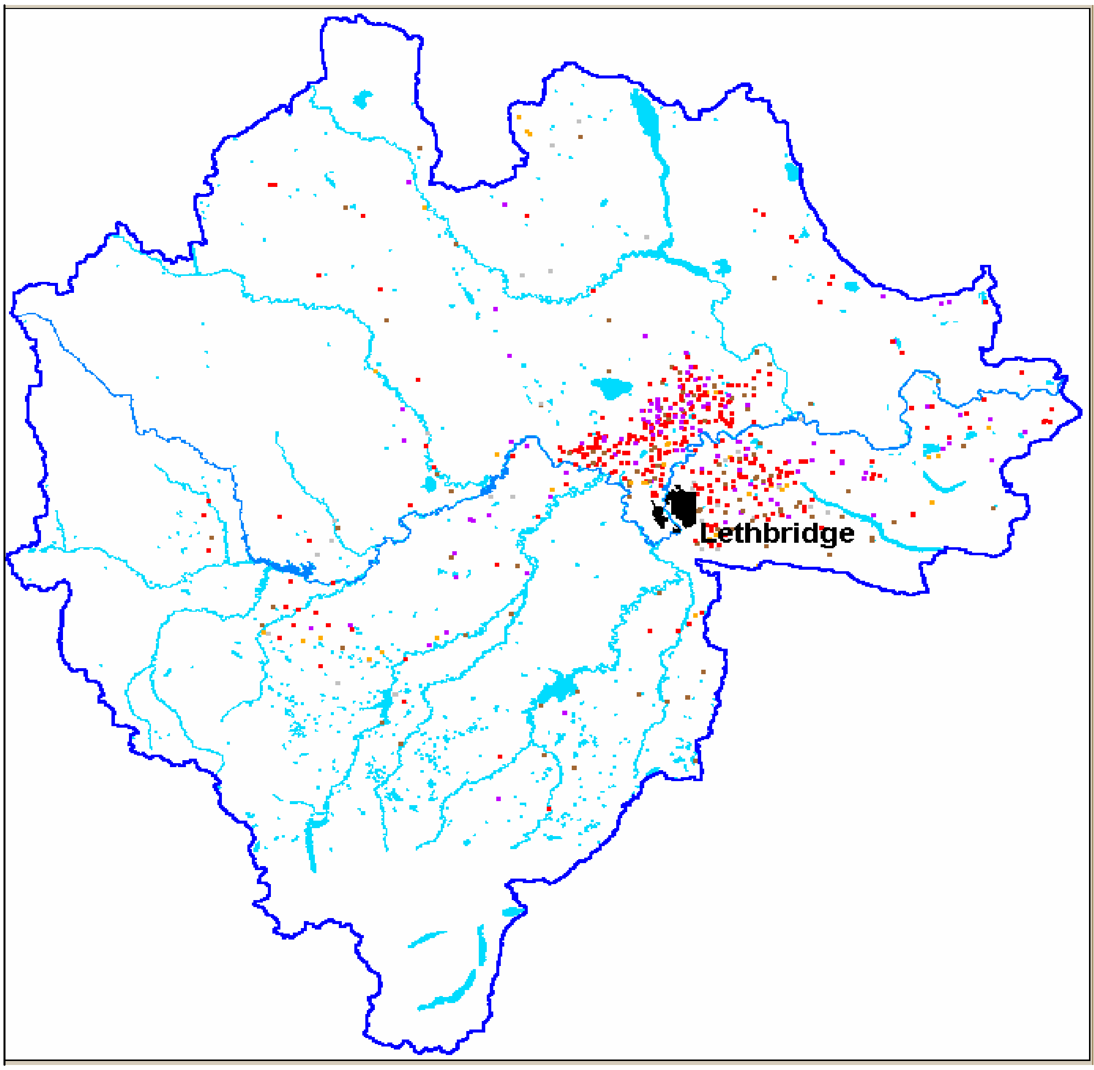

Figure 5. Livestock density in the Oldman River basin. Figure supplied by Brad Stelfox.

In the late 1990s, many of the sub-basins of the Oldman had poor water quality, with waters nearly always exceeding fecal-coliform guidelines for drinking, and often exceeding coliform guidelines for irrigation and recreation. The protozoa *Cryptosporidium* and *Giardia* were also common (CAESA 1998). Many waters contained high concentrations of herbicides and pesticides. In response to the concerns of residents, the Oldman River Watershed Council was formed to investigate poor water quality and remediate its causes.

A large step in cleaning up the Oldman was the improvement of sewage treatment at Lethbridge, which had been responsible for 59% of the point-source inputs of nitrogen, 87% of the phosphorus and 82% of bacterial inputs to the river. Overall, the city's effluent was reduced to

11% of the nitrogen, 24% of the phosphorus and 0.1% of the fecal-coliform input from point sources (OWC 2005). Other measures were taken to curb inputs from agriculture, including off-stream water sources for cattle; restoration of riparian areas; construction of confined, low-impact cattle crossings on streams; and improved incorporation of manure in soil immediately after application. Measures were also taken to reduce street runoff of pollutants, including effective lawn-watering practices, use of lawn fertilizers and pesticides, and "poop and scoop" pet management. Much of the rapid success of the OWC program was the result of public education in rural and urban areas, earning its Water Quality Initiative an Emerald Award for Environmental Excellence in 2001.

Summer flows at the mouth of the Oldman River are currently about 40% of values in the early 20th century (Schindler and Donahue 2006).

Lake Winnipeg

As mentioned in the introduction, the Saskatchewan River drains into Lake Winnipeg. At the turn of the 20th century, it was the major source of water to the north basin of that lake. Due to flow reductions, the importance of the Saskatchewan River in renewing the waters of the lake is greatly decreased. Nutrient inputs to the lake have increased, largely as the result of increased livestock production, fertilizer use and human populations in the southern part of the lake's catchment. The result has been rapid increase in the eutrophication of the lake (A. Salki, Freshwater Institute, pers. comm.).

Summary

Extensive and increasing human population and land use are causing increasing demand for water. At the same time, climate warming is providing further strain on the meagre water supplies of the Saskatchewan basin. There is increasing evidence that the 20th century, regarded by most people as "normal", was unusually wet in the western Prairies.

The cumulative effects of climate warming, drought and human activity have seldom, if ever, been considered by land managers and policy-makers. There is little integrated catchment planning in the western Prairie provinces (WPP), and science is poorly represented in the planning process. Decisions to expand cities, clear forested land, fill in wetlands, place and construct feedlots, approve major industrial projects and expansions, apply fertilizer, apportion water supplies and expand cottage developments are made on a project-specific basis by different government departments, communities or committees, or even by individuals. Ecological instream flow needs and lake levels have been ignored until recently. This has resulted in the allocation of more than 100% of at least one river's water, leading to potential conflict between licensed users. When communities resist development because of concerns over environmental impacts, decision-making powers are often removed to provincial political levels. In addition, governmental agencies charged with environmental monitoring and with applying and enforcing laws protecting freshwater resources have suffered extreme funding cuts, primarily for short-sighted budgetary reasons. As a consequence, historical weather, snowpack and water-quality and -quantity data are often incomplete or non-existent. As problems arise, reactionary solutions are derived piecemeal — usually by different departments and levels of government, and too late for easy, inexpensive or timely remediation. Catchment-scale planning for management and conservation of freshwaters in the WPP and other rapidly developing dryland areas is urgently needed in order to maximize efficient use of increasingly scarce freshwaters in a time of warming climate and rapidly increasing human activity.

In response to increasing evidence of water shortages and of the need for integrated watershed management, several new programs are attempting to provide direction. The Alberta Water for Life program (www.waterforlife.gov.ab.ca) has formed committees to study sustainable water strategies for the major river watersheds of Alberta, to summarize problems and to provide public information. This process is in its early stages, and reports have just begun to appear in the past year. So far, there is no sign of comprehensive policies to manage water problems.

While little can be done to halt the disappearance of snowpacks and icefields, much can be done to protect the integrity of the watersheds of the WPP by retaining or restoring wetlands and riparian zones. Agricultural developments and industries can be chosen that do not require extensive water supplies, at least during the water-scarce summer months. Controlling greenhouse gas emissions soon can reduce the amount of warming, and hence evaporation and glacial wastage, expected in the latter years of this century. Finally, it may prove wise to keep human populations in the drier parts of the Saskatchewan basin relatively low, in order to avoid the water scarcity that has already become a major problem in the southwestern U.S.A. and many other populous dryland areas of the world, as described in the recent Millennium Assessment (www.MAweb.org).

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Bob Sandford, Session Chair:

Scientists have the luxury and the duty of being highly focused on their work, and focus can be quite specialized. They also belong to an expanded network that reviews, analyzes and tests their findings. Politicians work in a slightly different domain. They do not enjoy the luxury of being focused so specifically on singular subjects or issues. Their constituencies demand that they respond to the widest range of interests and give consideration to all of these interests simultaneously. Politicians often live within a cacophony of complaint and criticism, in the midst of which they're expected to craft and implement durable public policy that balances individual interests with long-term common good. In the process of developing such policy, politicians are also legally bound to respect and establish precedents in which investments have been made. Because you are seldom, if ever, developing public policy with a clean slate, the implementation of innovative new policy is often a tightrope act. We have with us two very experienced and highly competent public-policy practitioners who will speak to the challenges of integrated watershed management in Canada.

Our first speaker is Minister of Environment for the Province of Alberta, the Honourable Guy Boutilier. Minister Boutilier, in my opinion, has one of the most difficult jobs in the province — that of balancing rapid economic growth with long-term environmental sustainability. It seems sometimes, too, that Minister Boutilier is in the eye of every hurricane. He is the Member of the Legislative Assembly representing Fort McMurray−Wood Buffalo — the home of the oil-sands development, one of the biggest resource projects in the world. He is also charged with dealing with issues such as coal-bed methane impacts on water; allocation challenges on southern rivers; and also climate change. Fortunately, this public-policy expert is up for these challenges. Before being appointed Minister, he chaired the Standing Policy Committee on Sustainable Development and Environmental Protection, the Cabinet Committee on Climate Change, and the Northern Alberta Development Council. He is also a well-regarded academic. He lectured at the University of Alberta School of Business. He holds a Master's Degree in Public Administration from Harvard, a Bachelor's Degree in Business Administration, and an Education Degree with Honours from St. Mary's University in Halifax. He is also, as you will discover, very passionate about water issues in Alberta. Please welcome the Honourable Guy Boutilier.

The Honourable Guy Boutilier, Alberta Minister of Environment:

Thank you very much. What a pleasure it is to bring greetings and to be among such a distinguished group of people from around the world. Dr. Schindler — as with Dr. Taylor [former Alberta Minister of Environment] — you and I will not always agree, and as Winston Churchill said, if everyone were thinking the same, nobody would be thinking. I can say to you as a scientist, we're honoured that Alberta is your home, and I thank you for providing us with so much important information, which we try to, as interpreters, be able to put into public policy. I know Dr. Taylor is here today, and I want to say to Dr. Taylor, as the former Minister of Environment, I'm so very proud of the approach you've taken. Lorne [Taylor] has taken the approach of: be bold, be determined, be persistent, in whatever we do in public policy. In some of my comments today, we'll talk about some of that determination, which I believe is paying off, specifically with the SSRB (South Saskatchewan River Basin) as a good first step in terms of where we have to go in the challenges we face.

I want to say today that, as indicated in our most recent announcement, we as the Ministry of Environment are certainly stressing that scientific research and technology is ultimately the foundation for this province's water-management efforts. And we do believe that we are on the right track. I know that later on in the panel, my distinguished colleague Minister Nilson is going to talk about the important points we have as neighbouring provinces, and I look forward to them; we've been able to collaborate so that we're not talking about the same thing, and I'm going to leave that to him. But today's meeting of minds is an opportune time to really discuss the challenges of the SSRB, and in particular what our government and our province is doing to address them. In fact, the timing of this forum couldn't really have been better, because the Government of Alberta officially announced just a couple of months ago the actual water-management plan, or senior water-management plan. The seed was planted by my former colleague; I appreciate, Lorne, your work and effort to get to this point today. So I can stand here and take credit, but the reality of it is that it truly is a team of people who formulated this public policy.

Dr. Schindler's case study presents a very clear picture of the multitude of factors impacting the SSR system, which includes both the North and South river basins. Water shortages and the conflict between water in rivers for aquatic ecosystems and water withdrawals for agriculture are the greatest water-management challenges facing us in the Saskatchewan basin. Of course, our increasing population, combined with climate change, is severely increasing our demand for this important resource, which I refer to as "blue gold". And in this respect, I'd like to take some time to discuss some of the actions that my Ministry and our government has taken in terms of hoping to sustain and protect the South Saskatchewan River Basin. Ultimately, I'm an eternal optimist, and whatever problems are identified, it's so important for us to be armed with the knowledge of a Dr. Schindler, and armed with public-policy makers on how we connect back to our bosses. And for me, our bosses, ultimately, are the people who give us our jobs as elected politicians.

So the question is: How do we do the full cycle in terms of taking important information and translating it into public policy so that we can move forward? And I believe that our most recent announcement about the South Saskatchewan River Basin, where we are essentially saying that we are not accepting any new water applications on the SSRB, is quite monumental. I might add that I've never had any bodyguards as Minister of Environment, and now I have five. I'm just kidding; I don't have any. We still live in Canada — that's a good thing. And the dodging of bullets you speak of; sometimes we have much in common in terms of dodging bullets. But, ultimately, the question is the values of our province and the values of our citizens, who are our bosses.

I'm very proud that this forum is being hosted in our province of Alberta, Mr. Rosenberg. We were the first province in Canada to have a Ministry of Environment, dating back to the early '70s. And I think it's a very positive signal to demonstrate that, traditionally, politicians do what their citizens are concerned about. So I'm very proud to say that our province was the first to have an environment Ministry in Canada. I know that many people across Canada are surprised when they learn that, because they view Alberta, based on how some media report about our province, as an energy capital of Canada. And I believe, in this 21st century, that we, ultimately, with the good work of Dr. Schindler and others, and industry as well, can become the environmental capital of North America when it comes to water management, when it comes to bringing together a forum such as this. We're so pleased that you've chosen Alberta as your location.

As we go forward, we're all in this together, and I think I can interpret from what Dr. Schindler has said, that our strategy for the Saskatchewan River Basin is an important first step. So our Water for Life strategy — really, I'd like to refer to it as our vision — is recognized as a good first step of public policy and a strong commitment to environmental protection. Our Provincial Water Council is preparing a wetland policy framework, which I'm looking forward to seeing this coming fall, and I do know that you, Dr. Schindler, have played an important role. Obviously, it is not happening quickly enough, but I do believe that we are on the right track. The goal of part of our Water for Life strategy is to have a 30% improvement in water conservation and efficiency over the next few years; that is an important pillar of the strategy. Ultimately, our vision has three desired outcomes: safe, secure drinking water; healthy aquatic ecosystems (protecting our wetlands); and reliable, quality water supplies for a sustainable economy. As was mentioned earlier, we are growing by incredible leaps and bounds, and what we can learn from the Jordan River in terms of the knowledge you bring to this forum is so important as we go forward.

As Don Lowry, the CEO of EPCOR, mentioned yesterday, and other presenters have suggested, this 21st century really is about a new way of thinking — and not only that, it really is about unlearning old habits. This includes a message as simple as not keeping the water running while we brush our teeth. Water is good to the last drop, and governments have a role to play in that education of our citizens.

The Government of Alberta SSRB is a powerful first step, but we recognize — and I want to reassure Dr. Schindler — that it is only a first step in terms of the challenges we face. I want to say that this long-term and indeed monumental first step, and the plan, are going to impact about half the population of this province; about 1.5 million Albertans are going to be impacted by what we have just announced. So we do believe it's substantial, and we do believe that when we talk about Alberta's booming economy and whether it's possible to restrict water, the answer is loud and clear: yes, it is. We need to rethink, in this 21st century, what we are doing.

We have over 20 Cabinet positions within our government, and my colleague, the Minister of Energy, and the Ministry of Environment traditionally don't really get along. It was quite interesting when the Minister of Energy, the Minister of Environment and the Minister of Sustainable Development came together and we spoke to the Alberta Chamber of Resources; that was the first time in the history of the province that the three Ministers were there together. These are important steps of an integrated management approach, where we take down the silos of a variety of government Ministries, where we pull our resources together — because, ultimately, citizens in this province have a higher expectation that our Ministries will work together and reflect their values. What we do know is that they value water, they value how it is used, and they're looking for leadership.

I was very pleasantly surprised with the public reaction based on the water restriction and allotment we are talking about regarding the South Saskatchewan River Basin. It gives confidence to politicians, though I am not afraid to make a decision that isn't popular — public officials need to be able to do that. Dr. Schindler, we have a mutual respect; we may not always agree, but we understand the values we do agree upon. And I know they are values that Albertans share.

So the key for all of us is: How do we take that and inject it into public policy? We need to be champions; elected officials, Cabinet Ministers, they need to champion, they need to be — as I described Lorne — bold, persistent, determined. Don't be afraid to take negative criticism, because at the end of the day, when you're shaving and looking in the mirror, you can say, "I'm doing the right thing." And maybe fifty years from now, my grandchildren or great-grandchildren will say, "Thank you for what you did." Any less than that will not be acceptable.

My home is the oil-sands capital of the world — Fort McMurray. Our slogan is: "Nous avons l'énergie; we have the energy." But it has to be about more than the natural resource we've been blessed with as a fossil fuel. It has to be about the energy of people, of bringing minds together in terms of how we develop our public policy as we go forward in this 21st century. This past year, we've had two of President Bush's cabinet ministers visit our small city of under 100,000 people. They were the Secretary of the Treasury, John Snow, and the Secretary of Energy. I haven't met yet the Secretary of the Environmental Protection Agency, but I certainly have invited him. We have a valuable resource, we have a world with an insatiable appetite for energy, no matter where it is, and the question is today: What do we do with policy to be able to ensure that fifty years from now, I'm going to be able to fly-fish with the CEOs of those companies, with their grandchildren and that we will know we have done the right thing?

The role that technology continues to play is so critical. In Buenos Aires, Argentina, and in Montreal, at COPs 10 and 11, we talked about the fact that technology will play an important role. One small example of that, in defence of the oil sands, is simply this: at one point, it took 10 barrels of water to produce a barrel of oil; today, through technologies, that has gone down to about two barrels. Am I happy with the fact that two barrels are being used? No; I believe that we share an attitude that we can do better than that, and I'm convinced that with the right energy, we can.

So as we go forward, an important step such as the South Saskatchewan River Basin strategy is just one first step in signalling that we're in the 21st century, and our public policy, I believe, will mirror what citizens are telling us. Please realize that politicians are people; remember, we don't have to be smart, we just have to be popular every four years. But, believe or not, there are a few politicians who are even smart too. So embrace those, work with them, and I believe that at the end of the day, we'll have public policy that will reflect what the world is looking for. Thank you very, very much.

Bob Sandford, Session Chair:

Our final speaker is also a well-established public-policy expert. The Honourable John Nilson was born in Saskatoon and raised in western Canada. John was educated at Pacific Lutheran University in Tacoma, Washington; the University of Oslo, Norway; St. Olaf College in Minnesota; and the University of British Columbia Law School. He was admitted to the Bar in British Columbia in 1978 and to the Bar in Saskatchewan in 1979. Minister Nilson's distinguished academic career established a foundation for what has been a brilliant political career. John practised law and mediation from 1978 until he was elected as MLA for the Regina-Lakeview constituency in June of 1995. John was appointed to the Saskatchewan Cabinet as Minister of Justice and Attorney General in November of 1995. He was named as Minister of Crown Investments Corporation in 1999 and then Minister of Health in 2001. In 2002, he took on additional duties as Minister Responsible for Seniors. In 2006, John was appointed Minister of Environment and Minister Responsible for SaskPower and the Office of Energy Conservation. John is Chairperson of the Cabinet Committee for Legislative Instruments and is a member of the Treasury Board. He is responsible for the Saskatchewan Watershed Authority, the Water Appeal Board and also the Saskatchewan Centre of the Arts. This man clearly has a great deal of influence on evolving water policy relating to the flow of the Saskatchewan River through his province. Please welcome The Honourable John Nilson.

The Honourable John Nilson, Saskatchewan Minister of Environment:

Thank you, Bob. And thank you to the organizers of this event and to you, Mr. Rosenberg, for being part of what this event does. As many of you know, I've been here all these days because I'm very interested in this. What I'm going to do, very quickly, is talk about some of the things we do jointly across the Prairies, give a perspective on what we're doing in Saskatchewan, and then talk a little bit about my own personal involvement. I have a few slides and I want to really thank Dale Hjertaas, who is here with me from the Saskatchewan Watershed Authority, as well as Dave Phillips, who is in our department in regard to environment in Regina.

Dr. Schindler, your paper and your continued work is thought-provoking. Even though Canada is perceived to have an abundance of fresh water, it's clear that here in the Saskatchewan River Basin, and especially the South Saskatchewan River Basin, we do have challenges in water management. Our government's last election campaign included a pledge to develop a green and prosperous economy. In developing a provincial green strategy to fulfill this campaign promise, water has emerged as a very important theme. The Saskatchewan, as the only mountain-fed river system in our province, provides the largest and most dependable water supply in the southern area, where most of our population lives.

During this case study, we are endeavouring to examine the whole watershed. My colleagues and I; our Manitoba colleague, who is not here; and all the officials work within mandates that split the watershed into three provincial jurisdictions. One of our major integrating tools is called the Prairie Provinces Water Board. The Board comprises senior officials from Saskatchewan, Alberta and Manitoba, as well as Environment Canada and Agriculture and Agri-Food Canada. The Board has established five goals. The Master Agreement on Apportionment, which the Board administers, specifies both minimum flows and the sharing formula, based on each province having the right to use up to 50% of the flow. As increases in water demand; changes to the climate; and potential long-term climate fluctuations impact the water supply in the rivers, the Board ensures equitable sharing of the available supplies. The federal and provincial governments showed significant foresight in signing the Master Agreement on Apportionment back in 1969, when shortages still appeared distant.

Many of Saskatchewan's current initiatives in water started around an unfortunate event, which was referred to yesterday: the *Cryptosporidium* outbreak in North Battleford in March and April of 2001. There was contamination of the city water supply, and it affected between 5800 and 7100 people from the Battlefords area — and actually many other areas, because people were visiting for music festivals, dance festivals and various athletic events. Following an inquiry into the causes of the outbreak, Saskatchewan released its Safe Drinking Water Strategy in April of 2002. The goals of the strategy include source-water protection.

Our province has made very significant progress in implementing the strategy and addressing the safety of drinking water; reasons for this success include clear and focused direction, effective interdepartmental co-operation, annual publication of an interdepartmental performance plan, and reporting of progress based on the performance plan as well as indicators of progress. A coordination committee of Deputy Ministers, and then a Directors Committee, meet regularly to review issues and to ensure that emerging issues are addressed, which allows the plan to be kept current and responsive. An early action in the strategy was the creation of the Saskatchewan Watershed Authority in October of 2002 to integrate the management of water resources with ecosystem protection. Watershed planning has been initiated in seven watershed and aquifer planning areas, including the North and South Saskatchewan watersheds. This planning process is facilitated by the Watershed Authority but is controlled by the citizens of the watersheds. The plans eventually come to me as the Minister responsible, and I am obligated to respond to the plan recommendations on behalf of the government. Four plans are currently complete, and I expect the plans for the North and South Saskatchewan to be completed next year.

Even as planning proceeds, we are initiating new source-water protection activities. We emphasize the stewardship model, in which we seek an improvement that has benefits for the agri-producers or -business as well as for the river. This makes benefits more acceptable and sustainable without ongoing subsidies, much as we heard from our friend from Tunisia — it's something that has been successful there as well. Agriculture is the major land use in the watershed; therefore, much of the focus is on agricultural impacts. We find that initiating stewardship programs while the planning process is underway not only yields environmental benefits, it greatly helps the planning process. Citizens in the watershed see government commitment to some action and so become more committed to the planning. They also see neighbours taking beneficial actions that work, and therefore find it much easier to write similar proposals into the plans.

Environmental Farm Plans are a component of the federal-provincial Agricultural Policy Framework and allow farmers to receive financial assistance to implement environmentally beneficial practices. Group plans are proving to be a cost-effective alternative to individual farm plans. The Lower Souris plan, which was initiated through our watershed-planning process and was the first in Canada, has resulted in a $1.5 million investment in beneficial management practices to protect water. Based on this success, Canada and Saskatchewan have initiated additional group Environmental Farm Plans, including ones covering parts of the Saskatchewan River watershed.

The Saskatchewan Watershed Authority will shortly be releasing our first State of the Watershed Report. The indicators will provide a broad assessment of watershed health and will be presented in an easily understood visual format. The report is founded on the premise that assisting citizens to understand issues is an essential part of protecting a river.

Now, Dr. Schindler has pointed out the risks to our future water supply. One response to possible water shortages is to reduce consumption. Saskatchewan has developed a Water Conservation Plan that is being considered by Cabinet this month. Metering water was mentioned yesterday; more than 90% of municipal users in Saskatchewan are metered, and we're hoping to get that up to as close to 100% as soon as possible. Our municipal water use is about 21% of total withdrawals, and we know that significant reductions in this use can be achieved. Saskatchewan's largest water withdrawals are estimated for agriculture at 67%, which primarily goes to irrigation. The Water Conservation Plan identifies steps that can make the irrigation industry more efficient and increase production per unit of water. We are reviewing allocation policies as part of the water-conservation initiative, and we're targeting legislative change to implement the new policy for the spring of 2008.

As Dr. Schindler has pointed out, the dams and reservoirs provide benefits but they also create environmental change. The Gardiner Dam became operational in 1967, and it creates Lake Diefenbaker, with total storage of 9.4 billion cubic metres and a surface area of 43,000 hectares. The reservoir ensures a water supply for Regina, Saskatoon, Moose Jaw and other centres, as well as for industry and irrigation, and flood protection. Lake Diefenbaker is a very popular destination, and the No. 1 fishing lake in Saskatchewan. It generates hydro power, and its water storage enhances the operation of two downstream hydro-power stations. We're also much more aware of the stream ecology today than we were in the '50s, when the dam was being designed. The dam has had many ecological effects, including changing 225 km of river into a lake and creating a barrier to fish movement. Changes in the water temperature and the flow regime, as well as a reduction in sediment loads, have changed the ecology of the river downstream of the dam. While management changes can mitigate some of these impacts, others are not reversible.

Four weeks ago, my family and I put in just below the dam on the Saskatchewan River for a two-day canoe trip. Basically, we were able to experience the working of the river. When we camped at night, the water was right up there — maybe 5 metres from where the tents were. In the morning, when we got up, it was 150 metres to the water. This related to the fact that in the evening, the power company, which I'm the Minister for, was responsible for using extra water to get power for evening domestic use. By the morning time, they didn't need that power, so they shut down the flow. This is one of the impacts of dams which severely affects fish and other wildlife, but it also affects campers. That was pretty interesting.

What we need to remember is that our own connections and our own personal observations are supported clearly by scientific evidence that brings the point to us. Things are changing, and we need to help make the right decisions.

When we look ahead, our Safe Drinking Water Strategy has guided our progress in protecting Saskatchewan's water and it has allowed us to broaden our focus. We've initiated a joint federal-provincial undertaking to develop an Integrated Water Management Framework for the whole province. I think this will become a senior policy that will bring all jurisdictions together; using that, we'll be able to work with our neighbouring jurisdictions as well to make sure that we have an integrated approach.

The last point I want to make is to explain why all Canadians are treaty people. Our relationship with First Nations is based on a series of treaties negotiated between Canada and the First Nations in the latter part of the 19th century. Settlers came to western Canada because they could access land and resources under the treaties. Those treaties gave our families certain rights. At the same time, the treaties guarantee the First Nations a number of rights, including the right to hunt and fish for food. The modern interpretation of the treaties requires governments not only to maintain the right to hunt or fish, but also to avoid actions that would deplete wildlife or fish populations that First Nations use — as the right to fish, when there are no fish, is meaningless. If an infringement on the rights is unavoidable, governments have a duty to consult with the First Nations. The duty to consult will be a major part of any new project on any river — in western Canada, for sure — especially on one that is going to affect the fishery or other treaty rights. So consultations with First Nations are also an important part of how we manage the environmental issues. I think that when we understand what the treaty obligations are, they also assist us in our future decision making.

I want to close with a note that you can get information about a lot of the things we do in Saskatchewan by that very short Web site — www.swa.ca. There's a lot of information there. A final point: as a parent, but also as a great-grandchild of my great-grandfather, who came to the Saskatchewan River, you do things for future generations. I just want to close with a poem by the first Poet Laureate of Saskatchewan. This poem was written, I think, just a couple of years ago. It's called "Rivers" and it's written about the North Saskatchewan River, but I think all of you could use it worldwide:

The river flows one way,
and in its passing, swift or slow,
you feel the weight of time, the lunar pull,
the turn of seasons.
Go with the current, and it takes you
where all things come at last together.
But there is another way;
turn against the flow, and brunt the mystery,
leading you where things begin,
where river is just a notion
wrought from sun and ice and stone.
The river flows one way,
but in the wonder of its passing, we choose.

As politicians, we make choices based on the best advice we can get — from scientists, but also from the public. That's what this conference is about, and I think that's what Guy and I would like to say we as politicians are about. Thank you.

Bob Sandford, Session Chair:

I will now take questions, and just before we begin, I would like to offer David Schindler a moment to make any observations on the presentations of the two Ministers.

David Schindler:

I heard a lot of things I agree with and, for a change, not much I disagreed with. A few suggestions that I think could help the position of Environment: In most provincial and federal Ministries, Environment is regarded as a very junior portfolio. Finance and Energy and Ministries like that have all the power. I'd reverse that. The second thing I would do concerns the Canadian tradition, both federally and provincially, of putting Fisheries in one Ministry and Environment in the other, so there are always weird things that happen when you try and merge those two. They belong in the same Ministry. The third thing that I think is really underestimated is the value of tourism. In Alberta, we've heard a lot about agriculture. At a lot of other conferences, you hear a lot about forestry. If you look at the numbers, the area we're in right now generates as much revenue as agriculture or forestry on average, and you can do it without cutting trees or ploughing land and so on. It tends to be forgotten by Alberta politicians, and I think Ministers of Environment should ensure that it's on the table when economic factors are developed. And finally, I think we're in an era where we need to look at the downside as well as the upside. Economically, we still hear about all the benefits of power and all these things that happen. We never look at the costs, usually because we're a couple of generations of politicians down the road of clawing back the environment and rehabilitating the systems afterward. We should start looking at that in advance. Some things look like great bargains if you shorten the time scales. It's like looking at your paycheque without looking at your expenditures.

Lorne Taylor, former Alberta Minister of Environment:

I've really enjoyed the presentations. On the trip these last two days, one of the eminent scientists said to me, "Lorne, there's lots of good science sitting in the reports on shelves." And I think that's a sad commentary, quite frankly, on the science. My experience has been — I was in politics for 12 years — that science has had little input or little impact on public policy. I think that is largely due to the inability of the scientist to structure a framework that politicians could understand, that politicians can sell to their constituents. So I'd like to hear David's response to this, because scientists have to do better. Further, I'd like to say that I'm not sure scientists have done a good job in knowledge transfer and knowledge translation to the general public. We had a whole bunch of irrigators here last night. One of them asked me, "What did you learn, Lorne, that could help us as irrigators?" Well, I'm not sure. So science has to do a better job.

The other thing I would say is that science has done a good job of convincing people about the problems we've got. Everybody knows there are lots of problems. People are tired of hearing the problems. People want solutions. I would like to conclude with an anecdote that happened to me yesterday. I got back to my room and got a phone call, and apparently in the *Medicine Hat News* — Medicine Hat is a city of about 60,000 people on the banks of the South Saskatchewan — there was an article in the newspaper which came out of this conference, and it was: "Water Crisis Imminent". I know reporters, and oftentimes they don't interpret what scientists are saying well; but once again, it's the scientists' job to do a better job of communicating. The article was saying that the South Saskatchewan's going dry and we're up the creek without a paddle, and that, in fact, there's not even any water in the creek if we did have a paddle. This person was quite angry and said to me, "Are you at a conference with a bunch of Chicken Littles?" and, "We know there's problems; we want to hear solutions, we want to hear how we can change our behaviour to make a difference and we want to be able to understand how to do that." I'd like to hear a response from David.

David Schindler:

I agree with you on the inaccessibility of science. I think that the day when scientists could put papers in obscure journals for the amusement of a hundred of their colleagues, written in things that only a hundred colleagues could understand, should be gone, and I certainly try hard to avoid that. I can't claim I'm a hundred-per-cent successful. I think, though, that I'd throw back politically. A lot of scientists are afraid to try to do a better job, and I remember some of your predecessors who would announce to the press, "We shouldn't believe a word that guy says. He was against Project X from the start," which wasn't true. Most scientists say, "Holy mackerel, how do you keep going? I'd never be able to put up with that kind of thing." So I think scientists could use some encouragement. Often you have something you want to say to a Minister which you think is important and you don't get an opportunity; Ministers are too busy. I think that in the last few years, fortunately, that relationship is beginning to thaw.

Solutions with this guy in Saskatchewan: I'm not sure what he's talking about. I usually don't read what's out of my interview, but if you look at my paper here, the back half of it is about solutions, and today — simple solutions. Leave the wetlands alone; leave some riparian areas. There are some very practical things that can be done. Maybe we need some trade-offs, like giving those poor farmers trying to eke out a living a bit of money so they don't have to plant every wetland to get ten cents' worth of wheat off it and destroy every riparian area in lieu of being able to buy a pump to pump water up to their cows. But I think the solutions are there; I talk about them all the time. There's not only a saying problem, there's a hearing problem.

Richard Adams:

Dr. Schindler makes a compelling case for one of my favourite landscape features, which are wetlands; in the United States, we have a checkered past with respect to how we've treated wetlands. For approximately 50 years, under the auspices of what we call the *Farm Bill*, we paid farmers to drain wetland; it was a nuisance, something you'd have to plough around, something you had to get out of the way as quickly as possible. Well, about 20 years ago, we began to realize that there are obviously valuable ecological services provided by wetlands, and in the last two or three versions of the *Farm Bill*, we have now put in place incentives to save wetlands. No longer do we pay farmers to drain wetlands. In fact, if you drain wetlands, you will be cut off from your commodity supports. But more importantly, we provide incentives for them to create wetlands, to restore wetlands, under something called the Wetland Reserve Program, and this seems to be having some success. It's not perfect, but it does provide an incentive to farmers. To get their payments, they need to be somewhat better stewards in terms of these services that wetlands and other parts of the landscape provide.

My question is: There was some mention that you may have some programs of this type underway in Canada; if so, what is the status of them, and what will be the reception from the farm community? That may be something you cannot answer unless you are farmers, but I'm curious as to whether you have a program comparable to the Wetland Reserve Program in the United States?

David Schindler:

Nationally, we don't. I don't know anything about the program in development here in Alberta that Guy referred to. He's probably better qualified. We desperately need a national program. If you look at the mapping of wetlands in the Great Lakes, there is this big black-hole area known as Canada where there are no wetland maps because they haven't been inventoried. The U.S., though it might have destroyed some of them, at least has done a good job of locating the ones in the Great Lakes Basin and determining their current status.

The Honourable John Nilson, Saskatchewan Minister of Environment:

I appreciate that question. In Saskatchewan, in many ways, we have some of the most altered terrain on Earth because of the way that farming has been practised for the last hundred years. But in the spring, we brought forward a Southern Conservation Lands Policy, and that means southern Saskatchewan, not the boreal forest. It was developed by agriculture, by environment, by industry and by Ducks Unlimited, The Nature Conservancy, other groups like that, to basically say that preservation of wetlands is crucial, that in every township — which is thirty-six square miles — up to three square miles can be purchased or used for that without any public hearings. If it goes above that — because it's often the conflict with the agri-producers, that you're going to take away all our production land — there would be the ability to do that. This has received a good positive commentary. I think the watershed work that we're doing shows that most of the farmers, when they understand the science behind the wetlands and what they need to do to protect the rivers and the streams and the lakes, are very willing to change their practices but often they haven't had all of the information. And that's why I said that getting the citizens the information is crucial.

Richard Adams:

If I might interject something: My experience with the Wetland Reserve Program in the United States is that, as you've just noted, farmers generally try to be good stewards of the land and that once they realize the value of these wetlands, they're more than happy to participate in the program. I would also just conclude by saying that I've heard throughout today and yesterday how wealthy Alberta has become, and you talk of seven or eight billion dollars in surplus, and billions on the way from energy; perhaps this is the time for some of these environmental investments to be made while you have the money. It's much easier to deal with these issues when you can pay for them than in times of a bust, so start spending your money, please.

The Honourable Guy Boutilier, Alberta Minister of Environment:

Well, you, along with many others, are telling us how to spend our money, but I don't want to lose the point of what you're saying, which is, I believe, an important one in terms of our Water for Life strategy. In terms of wetland policy, we've taken a two-pillar approach. Number One is the issue of industry work and the cost of doing business going into what is soon to be our wetland policy. This is what our Watershed Council is doing. The Watershed Council will be coming back this fall; it has really built capacity in every corner of our province, which is very important. But even further to that, we've decided to go to adults' kids. In Grade 5, we have wetland policy so that children, students, are going back to their mothers and dads and grandfathers and farmers and others, indicating the importance of wetland. The next point is how do we implement it, which comes back to your original point of: What resource can we use from the activity to be going into that wetland policy? Certainly, that is our vision, and I'm very optimistic that it's going to become a reality sooner rather than later.

Sekou Toure:

I wanted to touch on three key issues that are very critical from my own perspective. Before doing that, I just wanted to appreciate the presentations made by the two Ministers, because transforming scientific information into policy is very key in everything we are doing; unless you have in place policies that are informed by good science, I really don't think we can make a dent. And what is really striking, listening to the Honourable Minister, is that you feel that you have heard his speech elsewhere. What is interesting and striking is that wherever you are — whether it is in Canada, in a developing country, in a developed country — policy framework seems to be highlighting that these issues are very critical.

What also strikes me are the wetland issues, and David's presentation, which shows that from 1995 onward, the quality of this river is really degrading. So somehow there is a major gap, and what do you do as policy-makers to ensure that those gaps do not go on widening and that you bridge them?

Second is the issue of integration, and I would love to hear and learn from you. We are talking about water resources here and, as scientists, we have been struggling and we tried to convey the message that it has to be approached in an integrated manner. But unfortunately, government structures and institutional structures are set up in such a way that they are split. How do you try to reconcile this splitting of institutional structures with the need for integration as you approach integrated water-resource management, which is really crucial in what we are doing?

Third, what are the two or three key lessons that you as policy-makers would like us to go back with, walking away from here? Thank you.

David Schindler:

I think those were excellent questions. I've got a suggestion for the Ministers about one that goes back to Dr. Adams' comment as well. We have all this wealth in Alberta, but it's generated in an area where we can't protect the wetlands; we don't know how to restore them. These oil sands are overlain by what are known as wooded fens that are thousands of years old. Perhaps we ought to take their money for restoration and invest it in wetlands in the South Saskatchewan basin. We know how to reconstruct and restore prairie wetlands. The oil sands are responsible for many of the problems we see. Calgary is exploding because of all the things going on in the oil sands, so a lot of the trouble here is because of what's going on up there. Perhaps we should take their money and invest it here. This is the basin that's going to hit the wall first.

The Honourable Guy Boutilier, Alberta Minister of Environment:

Yes, thank you and for the important points you make. I thank Dr. Schindler for suggesting that what is taking place up North can still be applied with the resource in southern Alberta; I think it is an important part of our framework which we're working on. From an integrated energy perspective, traditionally, the goal of one Ministry may be very different from that of another. In fact, the Deputy of all the Deputies of our government is here, Ron Hicks. We refer to it as a cross-Ministry initiative, and it has become more and more part of our government. So, from an environmental standard, before coal-bed methane, for instance, takes place, as we map and study our aquifer, we need to have a database, and one of the objectives that both Energy and Environment have set up is that we have baseline testing. That was not there before, and so people were jumping to conclusions that might be right or wrong. But we need science to assist, and so even though Energy might be resistant to certain policies, I believe that all of us as Ministers need to connect with what Albertans are saying, and that is values. I am uncertain of how many cross-Ministry initiatives we have, but I can say that it will pass through the environmental lens on every Ministry course because of what we believe is a value that Albertans have. So we want to be able to do it. Is it easy? No, it's not easy. Is it protective? Yes — it's very difficult, but I do believe that with the right mix, it can happen, and I believe we have some small successes and we want to build on those successes.

The Honourable John Nilson, Saskatchewan Minister of Environment:

I'll just comment on the integration issue, which Guy just talked about. As you can tell, I'm a senior Minister. I have felt no sense of going from Justice to Health — Health spends 45% of the budget — to Environment as being any kind of a downgrading. My own personal perspective is that in government in Canada, in probably 10 to 15 years, you'll have a Ministry of Finance, which manages the money; a Ministry of Health; a Minister of Education; and a Ministry of Environment — that's it. And all the other present Ministries will be junior Ministries or Assistants. The reason for that goes right to your point, Sekou, about the integration of the understanding of people of how crucial where we live is to what we do. And that's true in this meeting as we come from a water focus, but it's very true no matter what our focus; we can talk about air, we can talk about the soil and the land and how that works.

You asked what key point do I want you to take from this meeting, from our session — the one key point or key suggestion I would give to scientists who are here. When you have a scientific conference, invite one or two or three or four politicians or policy people just to be there to listen, because they'll tell you, "We don't have a clue what you're talking about," or "Here's something the public should know," or "Tell us more about this because this will help us in our work." And I don't think that happens at scientific conferences very often right now. Another key point is that as policy-makers, or people trying to make choices on behalf of the public, we like to have the detailed report, the summary — but also, if you can't tell it to me in one page, then it's probably not worth telling me. And scientists don't get that.

The other thing: "On one hand or the other hand" — and I have to steal Alon Rimmer's story that he told me: that, I think, the first prime minister of Israel wanted a science advisor but he wanted to make sure he only had one hand because he wanted advice, not options. And I think that's one of the problems, and this is coming from a lawyer; lawyers are often that way as well, except good lawyers are solution bringers, they're not option bringers. So scientists, don't be an option bringer, be a solution bringer. Thank you.

Bob Sandford, Session Chair

I apologize that we don't have more time for questions, and I hope that those people who have cards up — and I know that there are many engaging questions to be pursued here — will take it up with the Ministers and with Dr. Schindler.

Compared to the Jordan, we have room to move on the Saskatchewan. We can make public-policy choices now that will save us a great deal of difficulty in the future. Will you please join me in thanking our distinguished panel.

SESSION THREE: Case Study Three

Alberto Garrido, Session Chair:

Good afternoon. It's a real pleasure to chair this session on the Rhône, which is the Swiss and French magnificent Mediterranean river. It was formerly named the King River. Across the Mediterranean, the Rhône inspires great wonder; total discharges are three times larger than those of the Ebro River basin and about three-fourths of those of the Nile. Jet-irrigated agriculture is not very important, and only 2.5 million people live in the area. The Rhône drains an area equivalent to one-sixth of the French territory but only has 4% of the population. But perhaps the most interesting feature of the Rhône is that it is undergoing a process of renaturalization, a word we will hear about in this session. To understand why the Rhône is to undergo this process, we could not have better speakers to help us go through the Rhône's problems and complexities and difficult decision-making processes. So our first speaker in the afternoon is Professor Jean-Paul Bravard. He is a professor at the University of Lyon-Lumière, and head of the Rhône Watershed Workshop Zone. He has been an extremely productive scholar and has focused on many different issues. He is unanimously recognized as a true interdisciplinary researcher, so in addition to being a leading scholar in geophysics and geography, his work has been nurtured by archaeological and historical studies. He was the recipient of the Bronze Medal of the French National Centre for Scientific Research in 2004. So please welcome Professor Bravard.

Impacts of Climate Change on the Management of Upland Waters: The Rhône River Case

Jean-Paul Bravard, Head of the Rhône Watershed Workshop Zone, Department of Geography, GHHAT Faculty, Université Lyon-Lumière 2, Bron, France

Abstract

The Rhône River watershed covers an area of 98,000,000 square kilometres, including 10,000 square kilometres in Switzerland. Most of the discharge originates in the Alps, but a significant contribution is provided by the Jura Mountains and the western Massif Central. The main rivers are the Rhône, the Saône, the Isère and the Durance. The watershed's total discharge into the sea is 1700 m^3/s^{-1}.

Over the last 10 years, several models have detailed the General Circulation Model proposed by the IPCC (1996 and 2002) and predicted changes in the natural components of the hydrological cycle — from temperature and precipitation, to ice and snow cover and river discharge. They anticipate a decrease in total discharge, a marked decrease in summer discharge, an increase in winter discharges and winter storms and a decrease in ice and snow cover, inducing a change in the river regime.

However, one of the main characteristics of the Rhône is its high level of economic development, which has triggered complex impacts on river and lake hydro systems. High-altitude reservoirs have been affecting the river regimes for at least 50 years, to the detriment of summer discharge, altering pristine mountain discharges. While the temperature of Lake Geneva has increased over the last 20 years for climatic reasons, the temperature of the French river course of the Rhône has been affected by the impact of nuclear power plants. These documented changes anticipate the changes predicted in the 21st century and provide very interesting insights into the future of aquatic ecosystems.

Finally, an attempt has been made to summarize the possible impacts of climate and river changes on future water use and on humans. Hydro and thermal power will be affected, as well as tourism and agriculture through an increase in pressure on consumer uses of water. Human health may be affected, in addition to the risk level in valley bottoms.

1. Introduction

Over the last 10 years, many detailed studies and general reports (IPCC 2002; Deneux 2002; Renaud et al. 2002; Pont 2003; Husting 2005; OcCC, 2003) have been devoted to the impacts of predicted climate change in Europe, and notably in the Alps and on the Rhône River. These reports deal mostly with probable changes in the hydrological regime of the upper Rhône River in Switzerland and with the hydrological and ecological changes of the Rhône River downstream from Geneva. This report will present a summary of the main results obtained by specialists in the field, which combine past, present and future changes of natural components of hydro systems, as well as the complex interactions between natural and human-induced changes. The approach will take the complete hydro system into account — from upland ecosystems down to the delta of the Rhône, with some insight into the tributaries. We have decided to follow the proposal made by Leblois et al. (2005), i.e. making a distinction between "effects" and "impacts". "Effects" are changes to hydro systems which are direct consequences of climate change, while "impacts" are consequences of hydro-system changes on human or in-stream uses of water (ecological requirements).

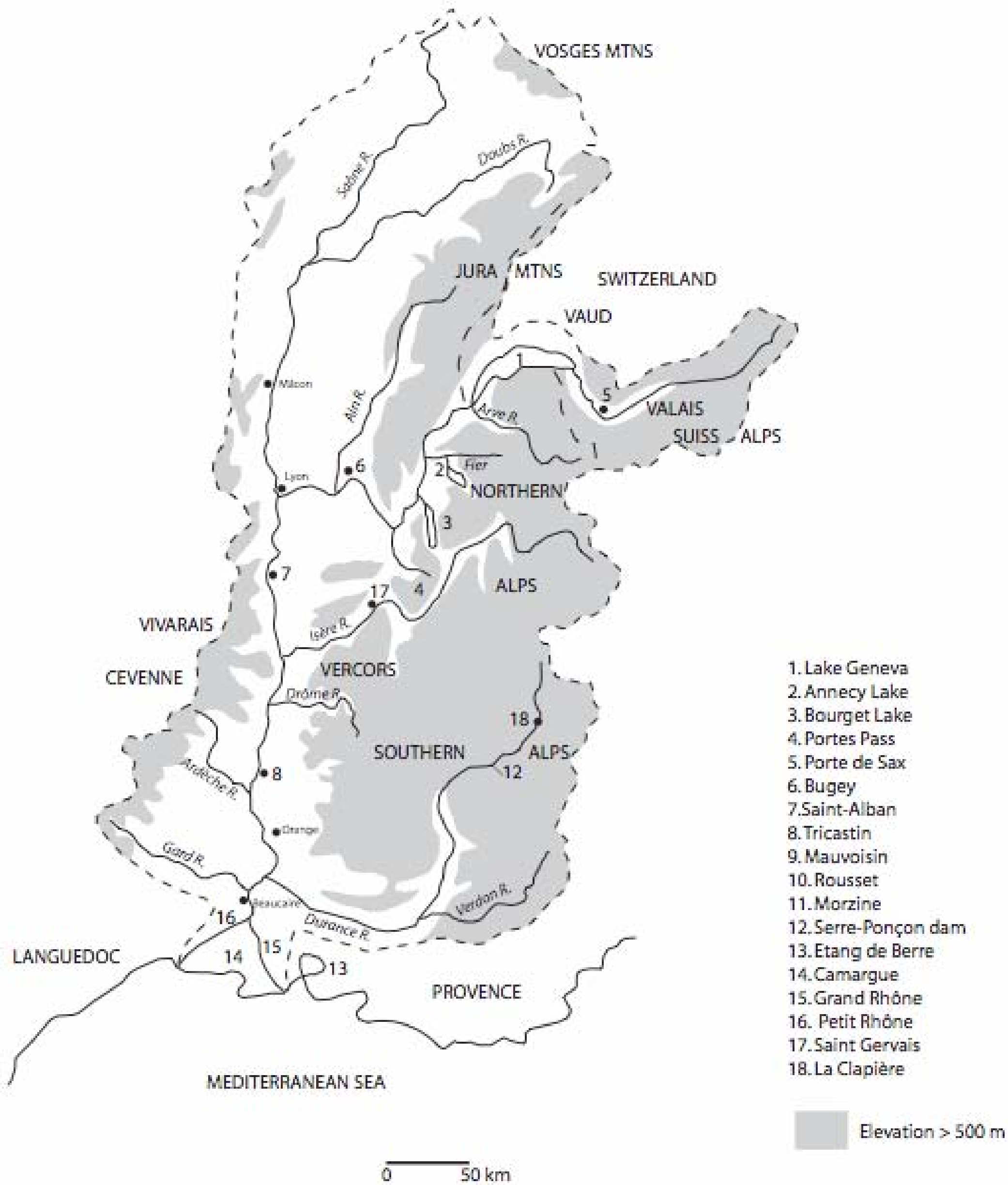
Although much research has been done on river discharge, few studies have dealt with water as a resource prone to locally intensive uses and sensitive to climate change. At a broader scale than that of rivers, and considering combined criteria, an interdisciplinary study has reviewed past situations in order to determine the causes and effects of "degradation", "desertification" and human "desertion" in selected areas of the Mediterranean, notably the southern Rhône valley, during the Holocene and in the 19th century (Van der Leeuw 1998). We will not address this broader perspective below.

2. Study Area and Methods

2.1. The Rhône River Basin

The Rhône River watershed covers an area of 98,000 square kilometres, including 10,000 square kilometres in Switzerland (Figure 1). The Swiss Rhône in Valais is influenced by mountain climate. Its natural regime is characterized by low winter discharge due to snow retention and by high spring and summer discharge due to the melting of snow and ice. Like other subalpine lakes, Lake Geneva smoothes out flood peaks downstream, as do Lac d'Annecy for the Fier River and Lac du Bourget for the Rhône. The tributaries of the Rhône between Geneva and Lyon (notably the Arve, Fier, Guiers and Ain rivers) drain lower ranges but preserve the snowmelt regime, while the glacial influence is strongly attenuated. Due to the influence of the ocean on the Jura Mountains, the 200-kilometre-long Ain River may peak at 2400 m^3/s, which is as high as the peak of the upper Rhône. The Saône River, which joins the Rhône in Lyon, has a typically oceanic regime, with high discharge during the cold season, and low discharge during the warm season due to evapotranspiration. As a consequence, the "compensated" type of regime is more regular downstream from Lyon (Pardé 1925). Flowing from the Alps, the Rhône's left-bank tributaries regenerate the influence of snowmelt; its right-bank tributaries and the Durance, on the other hand, deliver high discharges during fall and spring, under the influence of the Mediterranean. At Beaucaire, the regime is characterized by low flow from September to November, along with the risk of extreme low flow.

Fig.1 The watershed of the Rhône River



2.2. Observed Climatic and Hydrological Changes since the 19th Century

Climate is widely considered to have changed since the late 19th century and during the last decades. Climate change may have affected both temperature and precipitation. A change in temperature has not been documented since the late 19th century in the hydro system of the Rhône. The temperature of large subalpine lakes such as Lake Geneva has been proven to have increased by 1°C since the 1960s. Concerning river discharge, statistical tests applied to eight gauging stations on the Rhône River downstream from Geneva have demonstrated that the river's hydrology has been stationary. However, two ruptures are apparent: one locally in 1891, due to human-caused development at the outlet of Lake Geneva; and the second starting in the late 1970s, with the occurrence of wet decades throughout the basin, following a period (1940–1975) of lull. A new cycle of strong flooding has occurred in recent years, similar to that in the late 19th century, but no effect from global change has yet been detected (Sauquet and Haond 2003).

This study introduces an important point. This report deals with the impact of climate change on the Rhône River hydro system. Traditionally, this question has been dealt with using predicted climate data and expected induced changes in the different compartments of natural systems, as well as predicted impacts on human uses. In this report, the registered changes since *ca*. 20 years ago will be presented because their occurrence is documented and because they provide tested useful insights of expectable changes in the future.

Moreover, changes in hydrological systems incorporate human-induced changes, particularly in highly developed watersheds. Indeed, the control of upland hydrology has been a long-term process in the Alps, changing the hydrology of rivers. Also, thermal plants have been located along the Rhône River to benefit from cooling by its waters, thereby inducing an increase in water temperatures and subsequent consequences on aquatic ecosystems.

2.3. Modelling the Changes

The assessment of climatic change has traditionally been based on general circulation models (GCMs) that typically have a resolution of 2.5° latitude and 3.75° longitude. At the basin scale, the GCM (IPCC 1996, 2002) projects that the expected climate warming will enhance the hydrological cycle, with higher precipitations in winter, higher rates of evaporation and decreased precipitations in summer and fall, and a proportion of liquid to solid relatively greater at high altitude. Two scenarios have been tested:

- B2: Average temperature would increase by 2–2.5°C in one century.
- A2: Average temperature would increase by 3–3.5°C.

This model having been determined to be unable to reproduce the characteristics of variables at regional and short-time scales, different projects have been launched in order to address this issue. Computations were made in the Swiss Alps, using a high-resolution model (20 km x 20 km) under a hypothesis of a doubling of CO_2 concentration. The MEDALUS Project (1996–1999) was funded by the EEC to explore future changes, such as desertification, to the Mediterranean region. In this program, Palutikov and Goodess (2000) applied downscaling procedures in order to develop scenarios in Spanish and Italian regions. The ECLAT-2 project (1998–2001) was funded through the climate and environmental program of the DGXII of the EEC to complement the IPCC, IGBP and HDP programs. Downscaling techniques were applied to the Rhône basin (Noilhan et al. 2000), using selected GCM outputs in the basin for conditions of doubled CO_2 concentration. These studies explored the sensitivity of the production functions of the hydrological model to anomalies in precipitations and temperatures for selected sub-basins during the period 1981–1985. The ECLAT-2 program provided the first evaluation of predictable climate-change impacts in the basin in different components of the water budget — such as runoff, and snow and soil-moisture availability for the interface between soil and atmosphere. It was based on the GEWEX-Rhône program, which used the macro-scale Coupled ISBA MODCOU (CIM) model for the 1981–1998 time series. This model was calibrated with present-day conditions using atmospheric forcing, land surface types, soil freezing, surface runoff, evapotranspiration, river flow series and snow depth in the Alps. This model was run over 15 years for spatial resolutions ranging from 1 to 8 km. Indeed, it was recognized that the model could be used for testing GCM anomalies (Habets et al. 1999; Etchevers 2000). Research was continued through the GICC-Rhône program (1999–2004) with the hypothesis of a doubling of CO_2 concentrations by 2050 (Leblois and Grésillon 2005).

3. Predicted Changes of the Natural Components of the Hydrological Cycle

3.1. Climatic Change

3.1.2. Present and predicted changes in air temperature

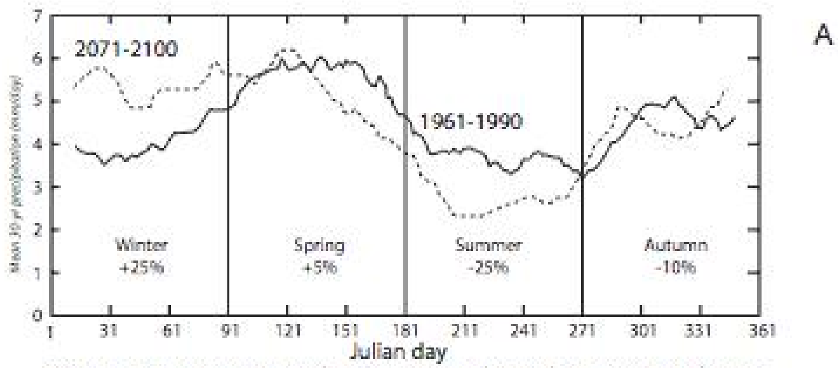
During the 20th century, the average temperature of the globe increased by 0.6 +/–.2°C (IPCC 2002). The Alps experienced a temperature warming of between 1° and 2°C. However, over 1°C of the strong recent increase, which occurred after 1990 (along with a decrease in precipitations), can be related to positive values of the NAO (North Atlantic Oscillation, a measure of the intensity of westerly flow and associated storms tracks), according to Beniston and Jungo (2002). These authors propose that the warming would have been weaker without the NAO effect and suggest that we should "improve the performance of models in simulating NAO decadal-scale variability".

During the 21st century, global temperature should increase by 1.4 to 5.8°C (IPCC 2002). In the Swiss Alps, the worst scenario is that winter temperatures could increase by up to 4°C and summer temperatures (July) by 6°C (Beniston et al. 1995). Horton et al. (2005) proposed a scenario of +1°C (expected for 2020–2049), and two scenarios considering two increased greenhouse gas emissions (period 2070–2099: +2.4 to 2.8°C and +3.0 to 3.6°C, with rates higher in summer than for annual averages). In France, the ECLAT-2 program models predicted warming for all months, but temperature increases were greater from July to September, ranging from 2.5°C to 7.5°C according to the different models tested. The GICC-Rhône study, using the ARPEGE-CLIMAT model, predicts an average yearly increase of 2.5°C and an increase in July of 4°C due to the doubling of CO_2 concentration.

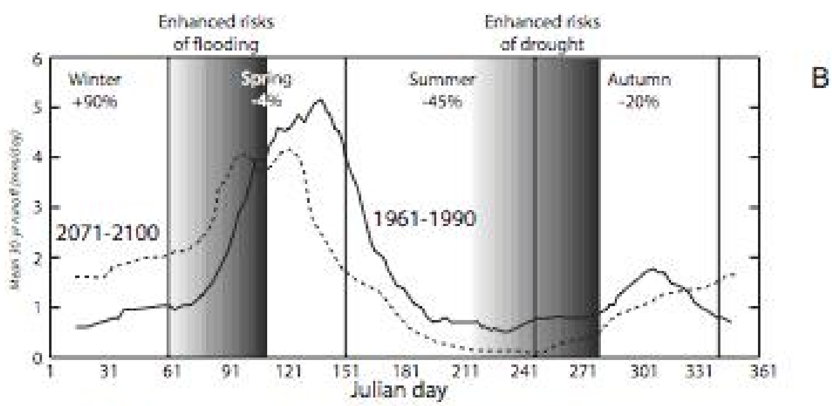
3.1.3. Changes in precipitations

According to GIEC models applied to France, with the B2 scenario, precipitations would increase in the winter, whereas they would be reduced by 5–25% in the summer. According to the A2 scenario, summer droughts would be more severe, with a decrease of 20–35% in summer rainfall, associated with severe episodes. In the Swiss Alps, Beniston et al. (2003) have shown that "milder winters are associated with higher precipitation levels than cold winters, but with more solid precipitations at elevations exceeding 1700–2000 m above sea-level, and more liquid precipitations below." With anticipated climate warming, the average predicted precipitations would not change, but summer precipitations would decrease whereas winter precipitations would increase (Figure

2-A). Modelling of winter storms suggests a higher frequency of southern flows from the Mediterranean and of heavy storms such as the 1999 Lothar storm (Beniston 2004). Also, periods of drought could be more frequent, as well as periods of heavy rainfalls. Higher snowfalls at high altitudes would not compensate for increased ice melt. According to Beniston et al. (1995), winter precipitations would increase by 15% in the western Alps. In France, the ECLAT-2 program predicted low precipitations in the summer months (from –45% to +8%), and increased precipitations in winter, up 5–30% according to the models.



Changes in precipitation in the Alps, averaged over the1961-1990 reference period (solid line) and the 2071-2100 future simulated period (dotted line). Figures refer to the schifts in precipitation amounts by season, in %.



Changes in surface runoff in a typical alpine catchment area, such as the Rhône and the Rhin, averaged over the1961-1990 reference period (solid line) and the 2071-2100 future simulated period (dotted line). Figures refer to the schifts in runoff by season, in %.

Fig.2 Predicted precipitations (A) and surface runoff (B) changes in the Swiss Alps. (after Beniston, 2005, modified)

The changes associated with an increase in global temperature are rendered more complex by interactions with NAO shifts. Indeed, precipitation amounts are influenced by the Northern Atlantic Oscillation. Beniston (1997) has correlated thick snow cover and long duration in the Swiss Alps with a high NAO index, because during these episodes, winter temperatures shift towards higher values ("The frequency of temperatures exceeding the freezing point is more than doubled above 1000 m, thus enhancing the potential for early snowmelt.").

3.1.4. Changes in the depth and duration of snow cover

The depth of snow cover is influenced by temperature. At Portes pass (northern French Alps, alt. 1320 m), snow depth from February 11 to 20 has decreased during the last 40 years (Figure 3). The significant decrease over the last ten years is "probably related to climate warming" (Etchevers and Martin 2002; Martin and Etchevers 2002). This reduction in the duration of *snow cover* was hypothesized by Föhn (1991) and documented in low-altitude zones of the Swiss Alps. Using satellite imagery, Baumgartner and Apfl (1994) observed a reduction in snow cover by three to four weeks during the late '80s and the early '90s. An average increase of 4°C in temperatures, forecast by several regional models for this area of Europe, would reduce the volume of snow by *ca.* 50% in the Swiss Alps. For every °C increase in temperature, snow line will rise by about 150 m, so that "regions where snowfall is the current norm will increasingly experience precipitation in the form of rain." (Beniston 1997). According to the scenario of Météo-France (Martin and Durand 1998), assuming an increase in temperature of +1.8C° at an elevation of 1500 m, the average length of snow cover, presently ranging from 160 to 180 days in the northern French Alps, could decrease to 125–135 days. In the southern Alps, it could decrease from 130–100 to 80–55 days/yr. (Figure 3). This would mean one month less of snow cover than today (SAFRAN-CROCUS snow model, in French ARPEGE GCM – Equipe Climate Modelling and Global Change). According to the GICC-Rhône study, depth may be reduced by 50% at low altitudes but is less affected at higher altitudes (1800–2000 m). In the different scenarios, the area covered by snow decreases by 25–40% (Etchevers and Martin 2002; Lebois and Grésillon 2005).

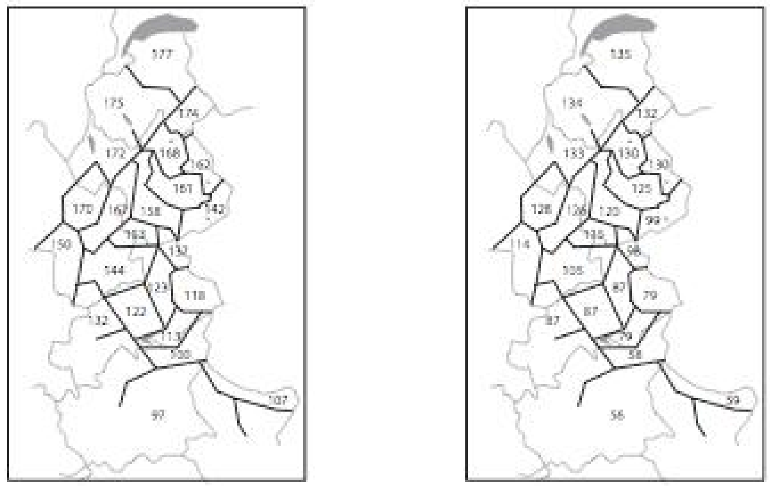


Fig. 3 Simulated number of average snow cover at the elevation of 1500 m in the French Alps in day / year
Left : present situation. Right : prediction using SAFRAN & CROWS models. (After Etchevers and Martin, 2002, modified)

As a result of climate change, *glaciers* have already retreated because they stand close to the freezing point. Haeberli (1994) considers that past and present fluctuations of glaciers and permafrost are proof of past and present climate changes through the changes in energy balance. Due to the greenhouse effect, the velocity of observed changes exceeds that of changes monitored during the Holocene. Haeberli (1995) and Haeberli and Beniston (1998) have shown that "the glaciers of the European Alps have lost about 30 to 50% of their surface and about half of their volume. 30–50% of existing mountain glacier mass could disappear by 2100 if global warming scenarios in the range of 2–4°C indeed occur." With an upward shift of 200–300 m in the altitude of the line of equilibrium, the reduction in ice thickness could reach 1–2 m per year (Maisch 1992). The sensitivity of the line of equilibrium to temperature is between 60 and 120 m/°C according to different authors (Green et al. 1999; Maish 2000; Vincent 2002). According to Vincent (2002), the glaciers of the French Alps retreated during two periods:

- from 1942 to 1953, due to low winter snowfalls and to a high rate of retreat in summer
- from 1982 to 1999, due to a high level of summer ablation (from 1.9 m to 2.8 m at 2800 m). This is due to a strong increase in the energy balance.

The difference in mass balance between the 1800–1850 and 1970–1980 periods ranges between 0.50 and 1.00 m in water equivalent for the glaciers of the French Alps (Vincent 2002). Six et al. (2002) proposed that the mass balance of alpine glaciers could be negatively correlated to the oscillations of the NAO index, as Beniston et al. (1995) proposed for periods of warm temperature and low precipitations.

3.2. Present and Predicted Changes of Discharge

3.2.1. Vegetation, soils and water balance in mountain ecosystems

Changes in direct water consumption by existing vegetation will occur. They will be due to changes in forest cover and to changes in the amount of evapotranspiration. If an increase in water consumption can be predicted, then a decrease in river flow is logical. At the basin scale, the GICC study predicts that the pattern and spatial extension of natural vegetation would not change significantly, so hydrology would not be affected by this parameter. However, in the long term, vegetation will colonize the upper slopes of the Alps. In the southern regions, the decrease in water content of soils and vegetation will increase the stress on vegetation and may induce a higher sensitivity to fires during the driest periods of the year and increase exposure to soil erosion (IPCC 2001). For instance, the 2003 summer drought provoked several forest fires in the Vercors, a wet massif of the northern Pre-Alps which had not experienced any fires during the previous decades.

3.2.2. River discharges

A statistical study of river discharges in France did not detect any significant changes in the number and intensity of floods since the mid 20th century. Also, it is impossible to confirm any change in low discharges, mostly because of heavy human impacts on rivers (Lubès-Niel and Giraud 2003; Lang et al. 2005). However, the situation may be different in regard to the regimes of mountain rivers. Indeed, the specific annual discharge of mountain rivers is higher than the specific discharge of extended watersheds including lowland areas. This results from higher precipitations, low evaporation rates, and conditions favouring runoff. "The hydrological regime is strongly influenced by water accumulation in the form of snow and ice and the corresponding melting processes resulting in a pronounced annual cycle of the discharge. A modification of the prevalent climate and especially of the temperature can therefore considerably affect the hydrological regime and induce important impacts on the water management." (Horton et al. 2005). The recent increase in temperatures has probably already had consequences on river regimes.

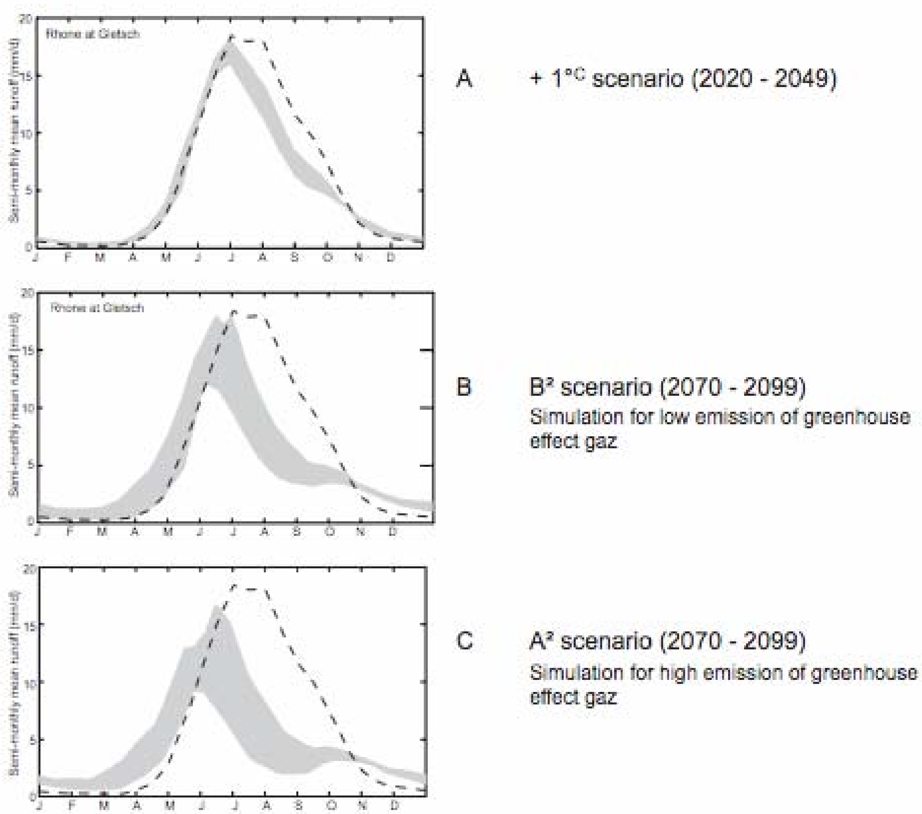
In Switzerland, "shifts in snow-pack duration and amount will be crucial factors in water availability" for runoff, according to Beniston et al. (2003). The increase in winter temperatures will have clear consequences on the beginning of snowmelt and on the reduction of flow in spring at low altitudes and on summer flow at the highest altitudes. The increased scarcity of snow cover below 1000 m will reduce runoff. These shifts will affect river regimes with higher winter discharges (Figure 2-B). However, increased evaporation in winter may partly reduce runoff and river discharge. Climate warming will initially increase the average discharge of rivers flowing from glaciers during the period of retreat, but then will decrease summer discharge as rivers progressively lose their glacial-type hydrological regime. A detailed study has been performed on the potential impacts of climate change on the runoff regimes of 11 small catchments having glacier surfaces ranging between 0 and 50%, at altitudes of between 1340 and 2940 m, under different hydrological regimes (Horton et al. 2005; Schaeffli 2005). Predictions were developed for a scenario of +1°C (expected for 2020–2049) and for two scenarios considering two increased greenhouse gas emissions (period 2070–2099: +2.4 to 2.8°C and +3.0 to 3.6°C, with rates higher than average in summer). Conclusions are the following for the +1°C scenario:

- a decrease in annual precipitations
- an increase in winter precipitations, with the risk of higher flood peaks
- a decrease in summer precipitations

- a strong decrease in ice-covered area, due to the strong increase in summer temperatures. The regimes will be mainly driven by snowmelt during the late 21st century.
- a decrease in the amplitudes of discharge
- significant decrease in annual discharge (5–15% for the +1°C scenario) due to the reduction in precipitation, the increase in evapotranspiration and the long-term decrease in glacier surface and in discharge

Horton et al. (2005) predicted "a significant decrease of the total annual discharge and a shift in the monthly maximum discharge to earlier periods of the year due to the temperature increase and the resulting impacts on the snow melt processes". At lower altitudes, "the influence of precipitations is more pronounced and the variability of the predicted climate change impact is mainly due to the large range of predicted regional precipitation change." (Figure 4).

Fig. 4 Predicted changes of the hydrological regime of the upper Rhône at Gletsch, Switzerland (glacial discharge regime). (After Horton et al., 2005, modified)



- in grey : zone of tested models
- bold dashed line : regime of the controled period (1961 - 1990)

In France, a statistical analysis of discharges at 140 gauging stations from 1975 to 1990 shows a reduction in snowmelt regimes in favour of "transitional" regimes and to a marked irregularity in the seasonality of regimes. With climate warming, "minimal and maximal discharges will be observed more frequently than in present times during other periods of the year than it is presently expected." In others words, prediction will be more difficult and the authors recommend the adoption of a probabilistic approach (Krasovskaia et al. 2002). However, specialists consider that discharge regimes have not changed enough to justify any change in the policy of dam management (D. Duband, verbal comm.). The coupled ISBA-MODCOU model was used in three sub-watersheds and on the entire Rhône basin for a selected warm year, then tested for the prediction of change (Noilhan et al. 2000; Etchevers et al. 2001; Etchevers and Martin 2002; Leblois 2002; Leblois and Grésillon 2005) (Figures 5, 6, 7).

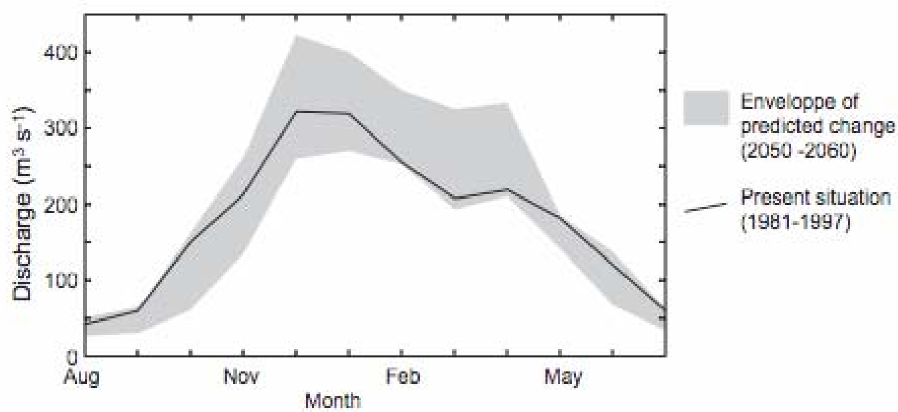


Fig. 5 Predicted change of the discharge of the Saône River at Mâcon
(source : Leblois et coll., 2002, modified)

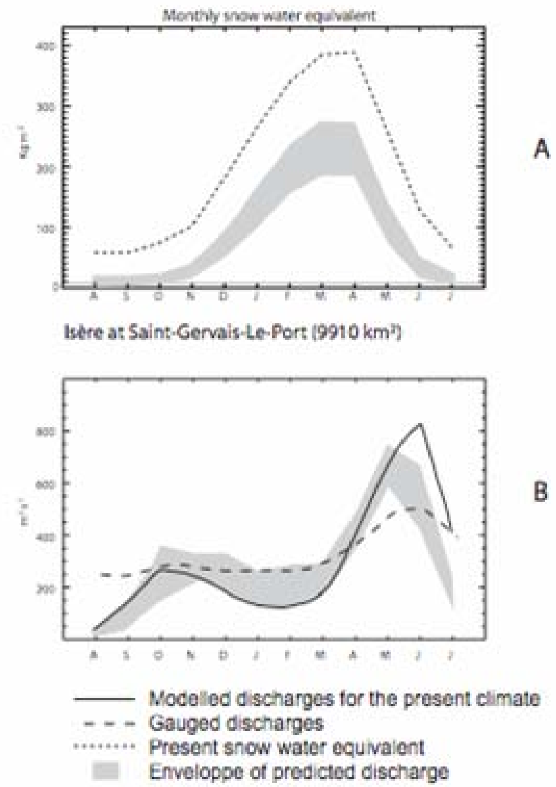


Fig. 6 The watershed of Isère River. A - Monthly snow water equivalent. B - Monthly discharge at Saint-Gervais-Le-Port (9910 km²). (After Etchevers & Martin, 2002, modified)

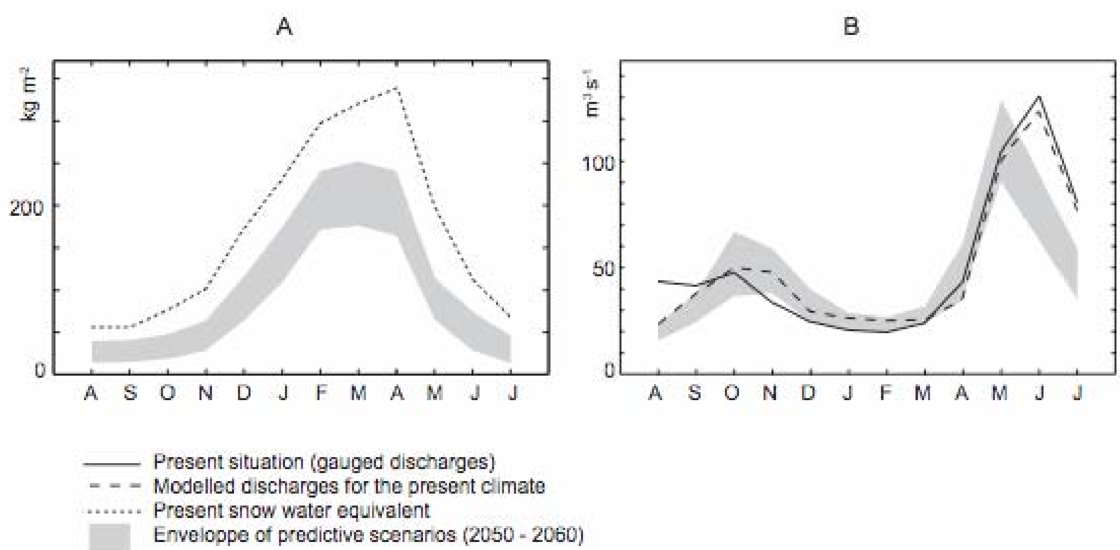


Fig. 7 The upper watershed of the Durance River. A - Monthly snow water equivalent. B - Present and predicted monthly discharge of the Durance at La Clapière (2710 km²) (after Etchevers & Martin, 2002, modified)

- In the Doubs basin, the snow-rain regime shifts to a rain regime, with an increase in discharge in December and January and a decrease in spring, without a significant change in the total yearly discharge.
- In the Saône basin (Mâcon), the rain regime remains the same, but discharges decrease in summer (Figure 5).
- In the Isère basin (northern Alps), the maximum shifts from April to March, the winter maximum increases, and the summer minimum decreases by 50% (Figure 6).
- In the southern Alps, during current dry years, the Durance basin experiences a "precocious and excessively rapid snowmelt… resulting in an early peak and correspondingly very weak summertime flows". The simulated change forecasts "an annual reduction in river discharge and in soil moisture, decreasing by as much as 30% below the present values" (Figure 7).
- However, if "the reduction of snowfall and earlier snow melting (increased air temperature) induced a decrease of the average snow depth by 50% and of the snow duration by more than one month", snowpack at high altitude is less affected, because even with the air warming, the average air temperature would remain below 0°C.
- The Ardèche river basin experiences a "significant reduction in summer flow" and a strong reduction in soil water content "reflecting the heavy reduction in precipitation in that area".

The GICC-Rhône program extended these conclusions drawn from sub-watersheds to the larger area of the French part of the Rhône basin (Leblois et al. 2005):

- Average yearly discharge and low flows decrease (from May to November), but high discharges increase. Low flows may be reduced by 40–50% close to the outlet of the Rhône.
- Spring flow related to snowmelt decreases, since climate warming reduces snow depth and the duration of snow cover, and snowmelt occurs one month earlier.
- The behaviour of rivers in winter depends on the different scenarios, but the increase in winter rainfall generally induces an increase in winter discharges.

3.2.3. Interactions between sediment supply and floods

With regard to winter peak flows, they should interact with changes in sediment fluxes and, locally, with the hydraulic geometry of rivers, increasing water-borne risks. The increased elevation of the permafrost line due to increased temperatures will decrease the cohesiveness of soils and trigger mass movements (Haeberli et al. 1990). Extreme rainfalls, increased average winter temperatures and increased alternation between freezing and warming in weak rocks will increase landslides and rockfall hazards. However, recent catastrophic events in the Mattertal (Valais region) in 1987, 1993 and 2000 and an above-average concentration of events have been proved to be caused by insufficient and short-term archival data (Stoffel et al. 2005).

These changes in slope processes will increase sediment inputs into rivers, induce deposition and raise the level of floods, interacting with land-occupation issues along valley floors. This trend could affect northern regions of the basin, as predicted by Beniston et al. (1995).

4. Observed Current Human Impacts on Hydrological Variables

4.1. Hydrological Impacts of High-altitude Reservoirs on River Regimes

The effects of ongoing natural climate warming on river regimes are rendered more complex by the impacts of the management of Lake Geneva and of upland reservoirs. The economic use of Lake Geneva has slowly evolved since the late 19th century towards tourist activities predominantly, which require a constantly high water level during the warm season. The development of the tourist industry has imposed a reduction in the amplitude of vertical variations in Geneva Lake, inducing a reduction in flood control, and difficulties for the optimal use of water at the outlet (Coulouvrenière dam). The Rhône at the outlet of Geneva Lake was initially developed to maximize the efficiency of energy production, through strong variations in the level of the lake, and then unpredictable variations downstream. However, these variations have decreased with time ever since the conservation volume of the lake, which peaked in the 1850s (810 hm^3), was reduced to meet the tourism needs (i.e. stability) of the Vaud and Valais cantons (330–340 hm^3 after 1892). The artificial regime of the lake decreased the discharge of the Rhône from July to October (to preserve storage capacity in case of a summer flood) and increased it in the winter for the production of energy (Bravard 1986).

These changes interfered with the impacts of the development of energy production in the Alps. Indeed, the rapid development of water storage in high-altitude reservoirs of the upper Valais since the 1950s has impacted the filling up of Lake Geneva, because more and more water has been used in the inner Alps during the spring. This delays the filling up of Lake Geneva and affects the hydrology of the Rhône downstream from Geneva, high summer discharges being reduced when compared to natural discharges. At the end of the 1960s, the accumulated conservation storage was up to 1400 hm^3, i.e. three times the conservation storage of Lake Geneva (Bravard 1986). Vivian (1983, 1989) insisted on the impacts of Valais dams on the regime of the Rhône River. During the winter season, the production of high-priced energy in the Valais increases river discharge (the deep waters of the reservoirs do not freeze and may be turbined). These impacts trigger a change in the regime of the Rhône River at Porte de Scex, where it loses some of its mountain characteristics (changing from an ice- and snow-fed regime towards a regime artificially similar to one that is rain-fed). This change, which is still visible at Valence, allowed Vivian (p. 66) to state: "the hydrological regime has become an oceanic type." Upstream of Lyon, low flow no longer occurs in winter but rather in the fall, whereas the winter high flow downstream from the confluences with the Ain and the Saône increases ("exaggeration of the natural regime"). Similar changes have been noticed in the Isère watershed, since modelled discharges differ significantly from gauged discharges. It is worth noting that reservoir construction upstream of Saint-Gervais strongly decreased spring discharges in favour of all the winter months. Thus, the predicted increase in winter flow is already anticipated by an artificial increase linked to the production of hydro energy.

In conclusion, Lake Geneva and the mountain reservoirs have cumulative impacts, since they store water in spring and summer and decrease the Rhône's discharge during these seasons and increase its discharge during the cold season. These artificial changes have anticipated the ongoing and expected impacts of climate warming, even if a higher degree of complexity in engineered flow could be taken into account. This complexity deserves more attention and international collaborative research, considering the economic consequences along the French course of the river (operation of nuclear power plants).

4.2. Human Impacts on Water Temperature

The temperature of Lake Geneva has increased by 1°C since the 1960s, whereas the temperature of Lac d'Annecy has increased by 1°C since the late 19th century. Between 1977–1987 and 1988–1999, the temperature of the Rhône River increased by 1.3 to 3°C at the various stations. It increased notably in spring and summer. The former temperature at Orange is now the present temperature at Lyon (Poirel 2004). The reasons for this warming are distributed between natural and human-induced causes.

The CNR estimated the yearly average warming impact of the chain of hydroelectric schemes to be 0.14°C due to the slower velocity of flow in the 16 reservoirs (Cottereau 1989). A far more important contribution to the warming must be attributed to the impacts of nuclear power plants. Indeed, the influence of these plants on the thermal regime has been demonstrated by Electricité de France (Desaint 2004): 90% of time, the theoretical impact is less than 3°C just below the plants, whereas the average warming is 1.72°C (Bugey plant), 1.03°C (Saint-Alban plant) and 1.34°C (Tricastin plant). Temperatures exhibit a strong seasonal behaviour, depending on the weather, on the discharge of the Rhône, on the input of cool water from tributaries (the Isère River) and on the energy production of the plants. Artificial warming decreases downstream from the plants, but the warming due to the Bugey plant, which is the most upstream, is still noticeable on the lower Rhône, except that it is delayed in time. The residual artificial warming ranges between 1° and 1.5°C on the downstream course.

5. Complex Changes in Water Ecosystems

5.1. Changes in River Ecosystems: Upland Rivers and Foreland Rivers

Given a reduction in discharges of 30–40% and an increase in temperature during the dry months throughout the basin, biologists (Pont et al. 2003) working in the GICC program propose the following preliminary results:

- A potential reduction in cryophilous and rheophilous fish species, such as the trout, the bullhead, the loach, Planer's lamprey and the introduced sun perch. The main threshold will be a 2°C increase in temperature. This trend would increase the already-noticed reduction in these species in Europe, which has been caused by river training. Considering the impact of decreased discharges on river hydraulics and river habitat for fish, models predict a negative impact from lower summer discharges on rheophilous species such as grayling, dace and barbel. Their abundance could decrease by 20% due to this factor.
- Some cyprinids will be positively affected, such as chub, bleak and perch. The most rheophilous cyprinids will colonize the upstream reaches of the river.
- Some families of macroinvertebrates are negatively influenced by increased temperature (*Perlidae*, *Odontoceridae*, etc.). In fact, several physical and chemical factors interact in a complex manner with an increase in temperature.
- These tendencies reinforce the negative impacts of river training, monitored since the 19th century along rivers in Europe.

The response of exotic plant species has been studied in southwestern France; those conclusions may be extrapolated with caution. The competitiveness of the most thermophilous species will be positively affected by an increase in temperature of 1°C (Tabacchi and Planty-Tabacchi).

Finally, the effects of recent river warming are of major concern. Two types of studies have documented these changes:

- The average yearly temperature of the Saône River increased by 1.5°C between 1987 and 2003. The 2003 summer heat wave could exemplify future years, as temperatures reached their highest since 1500 at the latest. Mouthon and Daufresne (2006) studied the response of mollusc communities between 1996 and 2004. The resilience of these communities to high temperatures is low, particularly for *Pisidium*. As much as "more than half the mollusc species currently inhabiting the potamic area of the Saône and Doubs rivers, and probably other large rivers, are probably directly threatened with extinction."
- The effects of a 1°C increase since 1985 have been studied on macroinvertebrates of the Rhône. While improvement in water quality did not introduce significant changes in community structure, temperature was proved to be a major factor all along the river, whatever the constraints linked to local development schemes may have been (hydro-power schemes, nuclear power plants). The period was characterized by the progressive increase in invasive species and by progressive changes in native community structure due to gradual environmental changes (Daufresne et al. 2004). Moreover, large recent floods (pulse disturbance) and the 2003 heat wave have triggered rapid shifts. These have been beneficial to eury-tolerant and invasive taxa in the downstream and middle reaches of the river. No sign of recovery has been observed after the disturbances, and the sensitivity of community structures seems to increase with time, due to catastrophic bifurcations (J.F. Fruget, oral comm.).

5.2. Changes in Lake Ecosystems

The impacts of the temperature increase in large, subalpine Lake Geneva have been studied for the current conditions, which provide some insights into predictable changes linked to global warming. Temperatures have increased by 1°C along the vertical profile since 30 years ago (Figure 8). Thermal stratification sets up one month earlier in the epilimnion, along with the primary production and the growth of herbivorous zooplankton. Complementing the human-controlled decrease in the concentration of phosphorus, the spring mixing of water, then the availability of nutrients, and the structure of phytoplankton and grazers, were influenced by the winter warming of the lakes, which in turn is linked to the NAO (Anneville et al. 2005). The different fish species were also affected by the warming of the water (Gerdeaux, in press; Gerdeaux 2005):

- The arctic chars (*Salvelinus alpinus* and *Coregonus lavaretus*) are endemic species adapted to the cold, deep waters of the hypolimnion since the Late-glacial Period, as in Arctic areas. They are very important in the fishing economy of the lake. These species spawn in winter when the photoperiod and the temperatures both decrease. The warming of the lake delays spawning in December, reducing the development of the embryos so that the larvae hatch a few days earlier than before and benefit from warmer waters and plenty of food from plankton. Then moderate warming benefits the artic chars, whose catches have increased from 50 tons in the 1970s to 300 tons since the late 1990s. The bottom temperature has increased from 4.5°C to 5.5°C over the last 30 years. When the temperature reaches 7°C, ovogenesis of females will be halted and these species will not be able to adapt.

- The roach, a cyprinid living in the warmer epilimnion, is spawning in May, one month earlier than before. Generally speaking, white fish have benefited from the recent warming of the lake through better survival of larvae due to increased plankton food supply.
- The perch, which lives deeper (below the epilimnion), does not benefit from the earlier warming of the water. Since the reproduction of perch does not occur earlier, the alevins no longer benefit from the presence of roach larvae and experience slower growth.

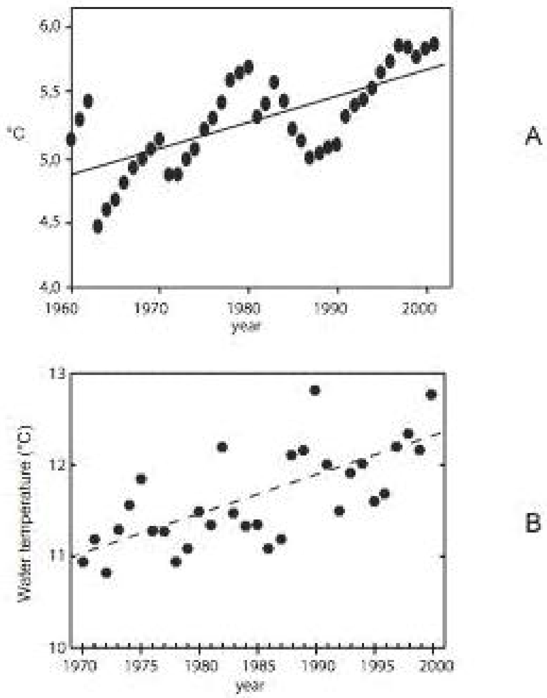


Fig. 8 Mesured changes in water temperature of Lake Geneva. Bottom from 1960 (A). 5 m depth from 1970 (B).
(after Gerdeaux, 2003 & 2004, modified)

In the future, the lakes will experience warming due to warmer air temperature and tributary waters. Earlier snowmelt and earlier peak flows from the Alps will increase spring warming of the lakes. Also, the reduction of glacier mass will reduce the cooling by tributaries in late spring and summer. The impact of warmer waters on the vertical profile will depend on the future conditions of mixing influenced by changed conditions of stratification and by tributary inputs. Danis et al. (2004) have particularly studied the future conditions of water-mixing behaviour, using a thermal model. Lac d'Annecy is a monomictic lake experiencing one full mixing when air temperature cools surface waters down to the maximum density of 4°C. The mixing of Lac d'Annecy will be preserved. The epilimnion temperature would increase by *ca.* 2.2°C in one century. The hypolimnion temperature will experience the same change, thanks to the high transparency of water, which allows the absorption of solar radiation. The regular overturning will then be preserved. However, as in Lake Geneva, the arctic char will disappear due to the increase in temperature to above 7°C.

6. Predictable Impacts on the Uses of Water and on Humans

6.1. Energy

6.1.1. Hydro power

The general reduction in runoff will affect the production of hydraulic energy throughout the Alps, particularly in the southern Alps, which will experience the strongest reduction. In Switzerland, change scenarios predict a reduction in the mean annual hydroelectricity potential due to a significant decrease in mean annual discharges. After 2050, the reduction in summer discharge will reduce the differences in seasonal discharges, resulting in easier management of energy production. Winter discharges will increase in response to earlier snowmelt and increased precipitations. Spring discharges will increase, but the change will be more limited. Modelling production at the Mauvoisin hydro-power plant allowed B. Schäfli (2005) to predict a 36% decrease between 1961–1990 and 2070–2099. The same pattern is predictable in the northern French Alps (cf. the regime of the Isère River, Figure 6).

Since future hydrological regimes will be driven more by precipitations than by snowmelt and glacier-melt processes, the "inter-annual variability of mean annual discharge is expected to increase," and possibly "the year-to-year hydroelectricity potential" (Horton et al. 2005). The filling of high-elevation reservoirs will occur earlier in the season due to earlier snowmelt and increased winter temperatures.

Economically, this change may fit with the highest values of energy during winter peaks of demand. However, the recent increase in summer energy consumption observed during the hot months of 2003 due to the use of air conditioners, has triggered price peaks on the European market. This unexpected peak in demand will enhance the value of summer production and may change the conditions of water storage in the western Alps to the detriment of summer storage, given that increased precipitations in winter decrease the importance of summer storage for winter production.

6.1.2. Thermal power cooled by rivers

The increased temperature of the Rhône will reduce the production of thermal energy, following Carnot's rule. The cooling of nuclear power plants on the Rhône in France requires differences in temperature between the river and the cooling system. Any warming of the river decreases the potential of energy production, since the maximum temperatures of the releases are controlled by strict rules. However, it is probable that these regulations will be softened, to the detriment of aquatic ecosystems, as occurred in August 2003. This policy is all the more probable given that energy prices will increase during the hot season.

6.2. Tourism

Climate change will have impacts on tourism through the status of water. Beniston (2003) proposes to make the distinction between direct impacts (through conditions for specific activities) and indirect impacts (through changes in landscapes and the modified pattern of economic demand). We will consider below the direct impacts on tourism that is based on snow and lakes.

6.2.1. The challenge of snow-cover reduction

According to Abegg and Froesch (1994), an increase in temperature of 2–3°C by the year 2050 would adversely affect ski resorts located at low altitudes (below 1200–1500 m). Warmer winters will bring less snow at these altitudes, and snow will melt faster, reducing the possibility of skiing, a sport requiring a snow cover of 30 cm for at least 100 days. A warming of 2°C would reduce the reliability of resorts in Switzerland from 85% in the late 20th century to 63%, affecting in particular the low-altitude resorts (Koenig and Abegg 1997). In France's Isère department, the Conseil Général ordered a study of the last 29 winters. Its results point to the vulnerability of those resorts whose ski runs are lower than 1500 m in elevation, the snow cover being more and more uncertain. In the Drôme department, the Conseil Général finances the yearly deficit of four small ski resorts. In 2003, it allowed the construction of an upper ski lift at the Rousset resort, above 1400 m and within the perimeter of a protected natural area.

The Conseil Général of the Isère department has proposed a new type of contract to the lower-elevation resorts in order to avoid being financially solicited in case of a series of snow-less winters. Indeed, these changes in snow cover and in the duration and quality of the winter season will have economic consequences, such as at the Morzine-Avoriaz resort complex (Frangialli and Passaquin 2003). The lack of snow is being compensated for by costly investments in snow-making equipment, better vegetation cover on the runs, the development of resorts at higher elevations, and investments in other types of activities. Whereas overuse may be predicted at high-elevation resorts, the Christmas and Easter periods will generate less revenue and property value will decrease at the lowest elevations. Past heavy investments may not pay off, which will affect the finances of towns or private investors. Thousands of seasonal workers will have shorter seasons and reduced incomes.

The development of artificial snow production in the French Alps has been precisely documented (Dugleux 2002). In 2002, 85% of the 162 ski resorts in the French basin of the Rhône were able to produce artificial snow, on 15% of surfaces, mostly between 1500 and 2000 m, but at higher and higher altitudes. This is detrimental to local water resources, since making 2 m^3 of snow requires 1 m^3 of unfrozen water when rivers are at low flow. In 1999–2000, 10 hm^3 of water were used in 119 resorts in the Savoy, i.e. the same amount that a city of 170,000 inhabitants uses, or 20% of the volumes used in the Savoy for domestic uses. In terms of specific consumption, artificial snow requires 4000 m^3/ha, as compared to 1700 m^3/ha for the irrigation of corn in the Alps.

Water for artificial snow has three origins:

- More than one third of resorts experience shortages in water supply for domestic uses because in 25% of resorts, snow production competes with human uses (total volume: 2 hm^3 per year).
- 50% of ski resorts have built artificial tanks storing 20,000 to 150,000 m^3 (total volume: 5 hm^3 per year).
- 25% of resorts withdraw water from rivers during the cold season.

Making artificial snow has impacts on the aquatic environment:

- Storage tanks are harmful to wetlands, have no hydrological impacts on rivers during the cold season, but are filled in during the summer season and may be prone to destruction by floods.

- Direct winter withdrawals impact rivers at low flow, from November to February (January represents 30% of total consumption).

Dugleux (2002) proposed an indicator of pressure on low-flow discharges. For 60% of resorts, withdrawal represents less than 10% of low-flow discharge. For eleven resorts, it represents from 30 to 49% of this discharge; for two of them, more than 50% (Figure 9). It has been underlined that if the present impacts are not too harmful, they will increase in the future. Since artificial snow meets major economic objectives (in some cases, the survival of the resort; in others, maximum snow depth on all ski runs over the whole season), the phenomenon must be strictly monitored and controlled.

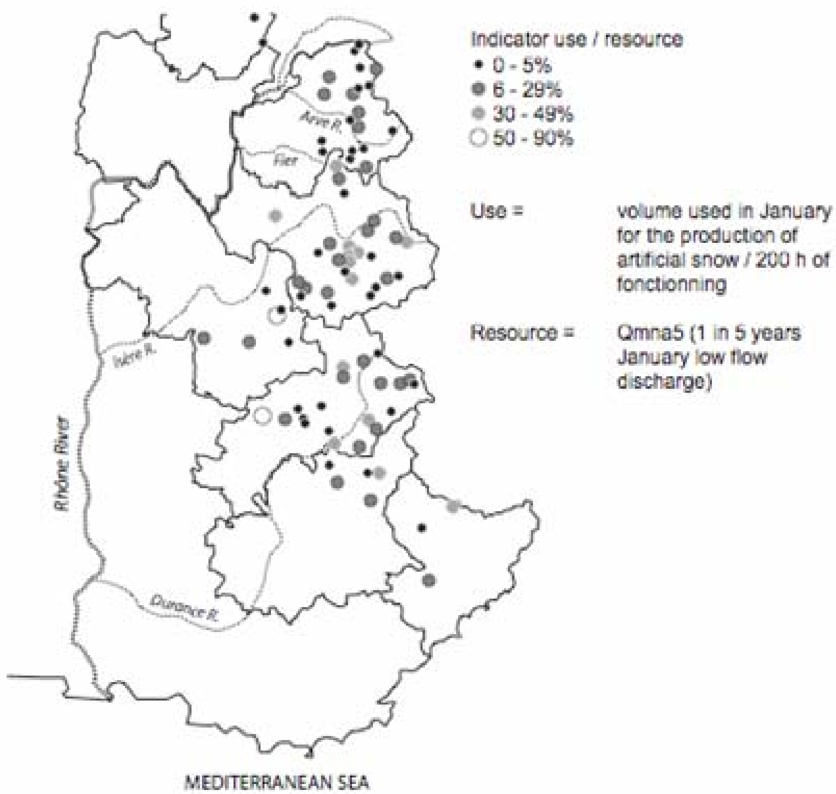


Fig.9 Pressure of the production of artificial snow on the upland water resources (after Dugleux, 2002, modified)

6.2.2. Water supply to southern resorts

Water supply to resorts (swimming pools, lawns) and for leisure (golf courses) will be reduced if summer precipitations decrease and if evaporation increases, notably in the southern part of the watershed (Ceron and Dubois 2003). Demands will be made on mountain reservoirs, as it is presently the case in the Ardèche basin, where a minimum discharge guarantees the possibility of canoeing in the downstream gorges in July and August.

6.2.3. Maintaining the levels of large subalpine lakes

Tourism on large lakes will be impacted by climate change in a complex way. Coupled with the early reduction of discharge, it will probably impact the conditions of the seasonal filling of Lake Geneva. Lac d'Annecy and Lac du Bourget have small tributaries that will be affected by earlier snowmelt and decreased summer discharge in a context of increased evaporation, as in 2003. Due to water withdrawal for domestic uses from Lac d'Annecy and withdrawal of used water collected around both Lac d'Annecy and Lac du Bourget, the natural inputs into the lakes have been artificially reduced. Maintaining high water levels in summer for the sake of aesthetics and tourism is a challenge, which precludes any variation for the sake of the sustainable ecology of the banks of Lac d'Annecy. In the case of Lac du Bourget, maintaining a high and constant level would require supplying water from the Rhône to the lake, as in July 2003.

6.3. Pressures on Consumer Uses of Water

6.3.1. Present consumption in the Rhône watershed (France) and along the Rhône River

Total withdrawals at the watershed scale amount to 15,800 hm^3/yr. (Table 1), but do not exceed 4600 hm^3 if one excludes withdrawals from the Rhône River (most of this withdrawal is just a diversion to the cooling systems, since a small proportion is lost in cooling towers, most of the cooling systems being "closed" systems). This yearly volume must be compared with the yearly discharge of the Rhône River at its outlet, i.e. 54,000 hm^3 (95,000 hm^3 are stored in lakes and 15.5 hm^3 stored in the receding Alpine glaciers).

Domestic uses	**Industry**	**Thermal energy**	**Irrigation**	**Total**
1900	950	11,200	1750	15,800

Table 1. Withdrawals in the Rhône watershed for the different water uses, France only (hm^3/yr.)

Excluding energy uses,

- withdrawal from the Rhône River alone is below 850 hm^3/yr. (Table 2), i.e. represents less than 1.6% of the total discharge into the Mediterranean;
- withdrawal at the watershed scale (4600 hm^3/yr.) represents 8.5% of the total discharge into the Mediterranean.

Portions of these withdrawals devoted to domestic uses, agriculture and industrial processes are not consumed and go back to the groundwaters and the river.

	Domestic uses	**Industry**	**Thermal energy**	**Irrigation by gravity**	**Pressure irrigation**	**Others**
Surface water	10.4	112.1	11,200	45.6	134.8	0
Groundwater	212.6	277	0.1	4.3	13.7	15.4
Total	223	390	11,200	49.9	150	15.4

Table 2. Withdrawals from the Rhône River only (hm^3/yr.)

6.3.2. Irrigation from the perspective of climate change

The GICC-Rhône study (Leblois et al. 2005), using the STICS model, predicts that the doubling of CO_2 concentration will induce a shorter seasonal cycle for corn cultivation (reduction by 21%) and a 15% loss of yield. The shorter cycle induces an increase in irrigation rates, which combines with increased plant requirements due to climate warming. However, the earlier growth reduces the intakes in August, the most difficult period for river hydrology. The Drôme River case study provided interesting insights into future climate change, since the average yearly temperature increased by 0.9°C and the temperature in July by 2°C, with marked consequences on hydrological resources. The GICC study predicts that agriculture will probably adapt through a reduction in irrigation practices in favour of crops less dependent on water resources.

The pressure on water resources (surface water and groundwater) will change in a complex way. Industrial consumption is decreasing, while domestic uses are stagnant, partly due to an increase in prices. Global water consumption by agriculture will be influenced by EEC policy and the global market, in ways that are difficult to predict today. It is clear that different eco-regions have different potentialities and that a unique set of rules is not advisable in order to overcome periods of water shortage. Beyond the modelling of river discharges, the GICC-Rhône study recommends investigating the different components of water balance at the scale of the geographical unit. Variations in precipitations from year to year and in water volume should be computed in order to allow for a better management of resources in situations of potential conflicts.

It is worth considering the present responses of farmers to drought such as they occurred in 1989 and in 2003 and 2004, because they may foretell future massive forms of adaptation to crisis situations:

- In those eco-regions whose rivers are prone to drying up and which lack subterraneous resources, i.e. mainly in the crystalline regions of the basin, farmers were allowed to build tanks in order to intercept the headwaters and the subsurface flow. Hundreds of tanks have been built along the eastern rim of the Massif Central in the last 30 years (Lyon Mounts, Vivarais). They are inducing a severe reduction in summer flow and a decrease in winter floods during the infill period. Thus, they have been proved to induce such severe impacts on river hydrology and ecology that they are no longer a priority of public authorities, even if they are economically efficient.
- One kind of adaptation is the development of wells into the alluvial aquifer bordering the river. This practice is detrimental to small rivers, which are fed by the aquifer and are prone to severe and long-lasting desiccation. Authorities are reacting by delineating the riparian aquifers and by limiting permits to pump from wells (Bonhomme and Nicolas 2005).
- Most recent developments concern the aquifer included within the deep and rich mollassic sandstones of the Alps and Jura foreland. Water extraction is so intense that groundwater levels are declining due to a negative balance between refilling by precipitation and extraction during the warm season. The public authorities have recently decided to develop a network of piezometers in threatened areas, because these are sensitive to the overexploitation of water resources (in a few rare cases, water for domestic use was no longer available due to the lowering of groundwater levels). Undoubtedly, controlling the volumes that are actually extracted from aquifers will be a challenge.

As indicated in the above cases of development, human interference with the effects of climate change is increasing with regard to agricultural use. The more river discharges are affected by water withdrawal from aquifers, the more it will be difficult to distinguish between anthropogenic impacts and changes induced by climate change, even along large rivers such as the Rhône.

While admitting that French agriculture will need more safeguarding, Redaud et al. (2002) recommended reinforcing regulations aimed at controlling irrigation in order to better respect the low-flow objectives of the watershed directory schemes (SDAGE) in heavily impacted basins.

6.3.3. Massive withdrawals from large rivers

The intake of water from large rivers in southern France has quite a history. In the mid-'50s, the Durance and the Rhône rivers were affected by large withdrawals for various purposes. The average yearly discharge of the Durance River was 210 m^3/s at its confluence with the Rhône River. On the upstream course of the river, the Serre-Ponçon dam (1955–59), along with a complex hydraulic system on the Verdon (a left-bank tributary), allowed the diversion of 0.7 km^3 for energy production and 0.2 km^3 for agriculture into a lateral canal designed for carrying up to 300 m^3/s. Also, part of the discharge was diverted to the cities of the Mediterranean coast in order to secure water supply during a period of tourism growth. The lower reach of the canal pours into the Etang de Berre, to the detriment of the Rhône's discharge. Below Serre-Ponçon, the minimum discharge of the river is no more than 2 m^3/s for most of the year (when the canal discharge is not exceeded), whereas the absolute minimum was 25 m^3/s before 1960. R. Warner (2000, 2001) has described the artificial river corridor as a case of "desertification". The vast array of upstream development has ensured "exotic" areas (the irrigated and coastal regions): "with further effective reductions in precipitations and increase in temperature, sustaining these enterprises will be very difficult. The opportunity for further exploitation is virtually nonexistent. So the trends for desertification [which are] already apparent will continue and promote greater concern." (Warner 2000).

The Languedoc canal (1957–60) was dug to divert up to 75 m^3/s from the Petit Rhône — the eastern branch of the Rhône in the Camargue delta — for the sake of irrigated agriculture. However, withdrawals have never exceeded 15–20 m^3/s, due to lack of consumption in the low coastal plains, which remained widely devoted to non-irrigated vineyards. In 1995, the company running the canal and a company delivering drinkable water to the city of Barcelona proposed to divert 10–15 m^3/s from the Rhône to Barcelona, using the same intake. The purpose was to secure water delivery to Barcelona and provide better quality. The development of tourism, and an increase in the summer discharge of coastal rivers in Languedoc were other objectives. This project failed for complex political reasons, but it reveals the renewal of pressure on the Rhône River.

6.4. Risks

6.4.1. Floods

The major apparent risk is linked to increased flood hazards. If winter floods occurring on rivers in Switzerland have negative influences on discharges in downstream countries, then these countries may ask for improved retention in the Swiss lakes and reservoirs, resulting in political consequences (Schädler 2003). In the last 15 years, severe floods have occurred on the upper Rhône downstream from Geneva (1990 was the 1-in-100-years flood) and on the lower Rhône (e.g. 1993, 1994, 2003). As stated above (Sauquet and Haon 2003), they may simply constitute a cycle of high discharges, as has occurred in the past. They may also be the first signs of higher peak floods being caused by climate change. In any case, they have revealed the significant vulnerability of the Rhône valley to flooding. In 1995, the French government launched a large study called the "global Rhône study", combining hydraulics, sediment transport and land use, as these different topics have been recognized as complementing each other. The 2003 flood, the approximately 1-in-100-years flood for the downstream gauging stations, motivated the French government to launch the so-called "Rhône master plan" (2005), which includes a series of measures to mitigate the human consequences of flooding, the reduction of hydrological hazards being recognized as quite impracticable. The expected risk explicitly refers to the largest previous floods (e.g. 1856), to extreme scenarios involving several meteorological origins (the so-called "general flood" in the sense of Pardé 1925) and to the negative impacts of the occupation of the floodplain. It is thus worth noting that the possible effects of climate change on the intensity of large floods is not being taken into account, despite the possible increase in extreme winter events. Also, to deal with the expected changes, the French Ministry of Environment and Sustainable Development has recommended increasing the number of Plans de Prévention des Risques and improving forecasting procedures (Redaud et al. 2002).

6.4.2. The Camargue delta and the mouth of the Rhône River

From the perspective of a rise in sea level, the coastal dunes protecting the Camargue delta will be threatened and brackish water may extend upstream, changing the ecological conditions of the lower river. According to Provansal and Sabatier (2000), the main cause of present coastal retreat is not a rise in sea level but a decrease in sediment supply from the Rhône River, which has complex causes (sediment retention in reservoirs, the impacts of the Rhône's embankments, reforestation of the watershed, etc.). The velocity of coastal retreat should increase, in particular if sea storms and surges become more intense.

In addition, the intrusion of brackish water will affect the Grand Rhône itself. In the 1990s, an outcrop of bedrock was removed for the sake of navigation downstream from the city of Arles, making the intrusion of marine water easier at low flow. It is probable that the expected reduction in low flow and rise in sea level will induce longer periods of brackish conditions between flood pulses upstream of the present limit, to the detriment of human uses (domestic uses and irrigation of paddy fields inside the delta).

6.4.3. Increased temperatures and pathologies

The rise in water temperature should increase sanitary hazards through more favourable conditions for the hosts of viruses (West Nile virus, bird influenza, etc.), such as horses, mosquitoes and birds. The Workshop Zone "Rhône Watershed" (P. Sabatier) has launched a research program on the environmental parameters controlling sanitary conditions in marshland areas.

Conclusion

Changes have begun taking place in the hydro system of the Rhône River due to the direct impacts of recent climate warming. These documented changes interfere with human-induced changes in a highly developed watershed. Predicted changes linked to modelled climate change may have significant hydrological, ecological and economic impacts in the next decades.

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Alberto Garrido, Session Chair:

Thank you. Our next speaker is Professor Claudia Pahl-Wostl. She is Professor of Resource Flow Management, an Endowed Chair of the German Environmental Foundation at the Institute of Environmental Systems Research, University of Osnabrück, Germany — a position she took five years ago after several decades of experience in Switzerland. Professor Pahl-Wostl is also an extremely productive scholar and can be considered one of the most prominent supporters in Europe of the new concept called adaptive management. She has been the coordinator of a large European Union research project and is now coordinating the largest European Union research project focusing on adaptive management, which is called NeWater. Taking into account the interdisciplinary and diverse geographical setting of NeWater, I believe we could not have a better opportunity to learn about what adaptive management means, so please let's welcome Professor Pahl-Wostl.

Adaptive Management of Upland Rivers Facing Global Change: General Insights and Specific Considerations for the Rhône Basin

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Abstract
The growing awareness of complexities, the unexpected consequences of management strategies and an increase in uncertainties have triggered critical reflection about prevailing water-management paradigms. This paper provides arguments for the need to change towards more-integrated and -adaptive water-management regimes. The example of the Rhône basin is used to illustrate the challenges upland watersheds face in times of increasing uncertainties due to global and climate change. The analysis of a large water-management project, the Third Rhône Correction, provides evidence that changes in water-management practice are slow and limited; however, there is expressed political will and initial tentative steps. Reasons for the barriers to change are analyzed, and it is concluded that processes of social learning are of paramount importance to initiate and sustain change. A number of recommendations for policy-making are given. Developing adaptive capacity with a long-term vision would be a wise strategy rather than responding to disaster and escalating conflicts.

1. Challenges for Water Management

Water management has been successful in the past in securing the availability of water-related services and protecting society from water-related hazards through technical means. Rather than adapting to periodic variability in water levels (i.e. flooding), the approach has been to control rivers in order to provide for hydro-power production or shipping. The control approach can reach its limits in upland rivers that experience extreme weather events. For example, channelled rivers with high rainfall can have severe floods and there has been an observed increase in damage since people began settling in vulnerable areas such as floodplains. However, once high-risk areas are settled, economic investments and assets need to be protected from natural disasters, despite the fact that land use should have been originally restricted. Reliance on engineered infrastructure for protection against water-related hazards means that societies have become more vulnerable when this infrastructure fails.

Water quality has been the preliminary focus of improving the ecological integrity of riverine ecosystems. Consequently, there has been a lack of attention to the structural changes in riverbeds and changes in the spatio-temporal variability of water flows which have a strong influence on habitat diversity and ecological function. The building of reservoirs and the use of hydro power have altered the flow regimes of many rivers, resulting in detrimental effects on stream ecology (Ward 1998; Pahl-Wostl 1998; Bergkamp et al. 2000). Increasingly, efforts are being undertaken to restore the ecological integrity and functions of river-basin ecosystems by focusing on the structural properties of river and ecosystem flow requirements (Tockner and Stanford 2002). Prospects of climate and global change leading to possible increases in extreme weather events, and fast-changing socio-economic boundary conditions mean that more attention needs to be focused on water flows and river structure. The growing awareness of complexities, unexpected consequences of management strategies, and an increase in uncertainties have triggered critical reflection about prevailing water-management paradigms (Pahl-Wostl 2006*b*). There are now calls for more-robust, -flexible and -adaptive strategies (Gleick 2003; Mönch et al. 2003; Kabat and van Scheick 2003; Pahl-Wostl, in press).

2. Adaptive Management

Adaptive management in relation to ecosystem management has been discussed for several years (Holling 1978; Walters 1986; Pahl-Wostl 1995; Lee 1999). It is based on the insight that the ability to predict future key drivers influencing an ecosystem, as well as system behaviour and responses, is inherently limited. Therefore, management must be adaptive and have the ability to change depending on environmental events.

Adaptive management can more generally be defined as a systematic process for improving management policies and practices by learning from the outcomes of implemented management strategies. One form of adaptive management employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed (e.g. Gunderson 1999; Kiker et al. 2003; Richter et al. 2003). This implies that hypotheses can be generated and that the outcomes of experiments can distinguish the comparative advantages of different hypotheses. An experimental approach may also structure dialogue and, in the spirit of reflexive governance, support processes of social learning and develop the capacity of actors to deal with uncertainties and to learn from experience.

Capacity in adaptive management is needed to deal with different kinds of uncertainties:

- There are ambiguities and conflict of interest in defining operational targets for different management goals; thus, participatory goal setting based on different kinds of knowledge is needed.
- Outcomes of management measures are uncertain due to the complexity of the managed system; furthermore, there are uncertainties in environmental and socio-economic developments which influence the performance of implemented management strategies.
- New knowledge about system behaviour may suggest options for change in management strategies.
- Changes in environmental and/or in socio-economic boundary conditions may demand change in management strategies.

Overall, a clear need for a more coherent and comprehensive approach can be identified, based on sound conceptual foundations that deal with uncertainties in integrated water-resource management (IWRM). Uncertainty has often been perceived as an impediment for effective and efficient resource management, and the main goal has always been to reduce and control uncertainties. However, such a strategy may be counterproductive when uncertainties cannot be reduced. The acknowledgement of uncertainties, along with open negotiation processes, may help move entrenched positions and start constructive dialogue, as different actors may perceive opportunities in collaborative efforts rather than continuing to defend their rigid positions.

The requirements for implementing adaptive management in river basins include:

1. New information that is available and/or consciously collected (e.g. indicators of performance of management regimes, indicators for change that may lead to desirable or undesirable effects) and monitored over appropriate time scales (longer than those mandated by short-term political objectives);
2. Actors in the management system must be able to process new information and draw meaningful conclusions. This can be best achieved if the learning process is open and transparent by uniting actors in all phases of assessment, policy implementation and monitoring; and
3. Management must have the ability to implement change based on the availability of new information. Implementation of changes in adaptive river-basin management is part of a learning process where it must be made clear who decides how and when to change management practices based on available evidence.

It can be argued that current water-management regimes are not adaptive (Pahl-Wostl 2002; Tillman et al. 2005). Large infrastructure and investment costs prevent change. Rigid legal regulation prescribes technical standards and practices and leaves little room for innovation. Infrastructure (flood protection, water supply, waste-water treatment) is designed to cope with extremes, which is a strategy very sensitive to errors in the prediction of extremes. Water supply and waste-water infrastructure have, for example, been designed to meet peak loads, rather than trying to break demand peaks by introducing flexible pricing schemes (Tillman et al. 2005). In addition, the professional culture in the water sector tends to be risk-averse and does not reward innovative thinking. Such attitudes are partly understandable, given that the task of the water sector is to protect the public from water-related hazards and to guarantee water-related services. Processes of social learning are needed to develop structural conditions, and to implement and sustain adaptive and integrated water-management regimes. The following section critically explores the situation in the Swiss Rhône basin, using the background and arguments already presented.

3. The Rhône — Analysis of Current Management Regime and Suggestions for Improvement

The implications of climate change for Switzerland in general and the Rhône basin in particular are summarized in Box 1.

Box 1. Expected Impacts of Climate Change in Switzerland

- Temperature: increase of 3–5 degrees by 2100
- Temperature extremes: increasing by a maximum of 5 degrees, increasing by a minimum of 1–4 degrees
- Precipitation: Heavy rains and higher precipitation during winter seasons will become more frequent.
- Snow: rise of the snow line to approximately 200–300 m
- Floods: more-frequent winter floods
- Drought: southern part drier; low-flow conditions more frequent
- Glaciers will largely disappear.
- Permafrost: rise of the altitude of permafrost
- Landslides: increased likelihood due to melting of permafrost soil

Sources: Frei and Schär 2001; OcCC 2002; Schmidt et al. 2002

Climate change will have pronounced impacts on the hydrological regime of many Alpine watersheds. The increase in temperature will result in a decrease in the amount of precipitation in the form of snow in winter. Glaciers will disappear, resulting in reduced natural water-storage capacity. Changes in the seasonal distribution of precipitation — with more rain in winter and less rain in summer, and an increased probability of extreme precipitation events — will result in a greater likelihood of extreme floods in winter and spring and a higher chance of drought and low-flow conditions in summer. Due to temperature increases, the altitude of the permafrost zone will be higher, which, in combination with increased extreme precipitation events, will likely lead to more-frequent landslides. Overall, the Alpine region will be more vulnerable to extreme weather events.

Consequently, the water sector has serious challenges ahead, in particular the management of extreme climate conditions (Schädler 2002). In summer, water shortages are expected due to decreasing precipitation, the increased likelihood of drought periods, an increase in the probability of low-flow conditions (decline of natural buffering capacity due to retreat of glaciers and snowfields) and an intensification of water demand for irrigation. This will have undesirable consequences for water temperature and quality. Due to the increased likelihood of winter and spring floods, there will be increasing demand to use reservoir storage for flood prevention. Overall, a request from downstream areas for balancing water flows to buffer extremes (floods and droughts) is expected. Such requests will require negotiations about changing use priorities and potential trade-offs in reservoir and flood management. Given the considerable uncertainties in climate-change predictions, it will be important to develop appropriate adaptation strategies. This has been clearly acknowledged at the ministerial level in Switzerland, and pleas for new, integrated and flexible strategies have been made (Willi 2006).

To investigate whether management practice can respond to these challenges, a major construction effort to improve flood protection in the Rhône basin is investigated more closely. The first coordinated attempt to protect the Swiss part of the Rhône valley against floods was undertaken in the 19th century after a series of heavy flooding events. Following the catastrophic floods that took place in 1860, federal funds were attributed in 1863 to the cantonal administration to undertake a first major correction of the Rhône River. After being completed in 1894, the first construction phase provided the conditions for the drainage and reclamation of the plains area (Colenco Power Engineering Ltd. 2005).

The second major correction was started in 1937 after a dike broke during a flood event in 1935. The purpose of the second correction project was to complete the works started during the first phase and to improve the solid- and bed-load transport capacity of the river (Département Fédéral des Affaires Intérieurs 1964). Another dike broke in 1948, so work continued until 1960 and improved the surface drainage of regularly flooded land.

A change in the control paradigm began in the 1990s due to extreme floods occurring in 1987 and 1993, where observed changes indicated an imminent rupture of the protection dikes. In addition, accretion of the riverbed was still occurring in places and could not be fully controlled. Thus, doubts emerged as to whether dikes constituted a safe control against floods. In addition, it become progressively evident that the systematic embankment of the river initiated at the end of the 19th century had modified the river's morphology by reducing the area of the natural channel, thus diminishing most of the river's natural ecological functions. Furthermore, retention reservoirs for hydro-power production constructed in the 20th century have changed the flow of alpine tributaries and the embankments of the Rhône, resulting in reduced surface areas of pristine floodplains. Today, floodplains are a remnant of the original biodiversity in the 19th century, occupying 6% of the original floodplain area. As a consequence, more than 170 flora and fauna species are endangered. In spite of intensive aquaculture, the fish population of the river remains low. The geometric straightness of the river embankment is also a factor limiting both biodiversity and alluvial dynamics.

In recognition of the detrimental effects outlined above on ecosystem functions, the third Rhône River Correction (R3 Project) has three main objectives:

1. safety, to ensure protection against floods;
2. environmental, to re-establish and even strengthen the biological functions of the river; and
3. socio-economic, to re-establish the social and economic legacies that normally take place along the river.

The R3 Project aims to control potential flood damages within the plains area of the upper catchment of the Rhône River, particularly between Brig and the mouth of the river in Lake Geneva in the canton of Vallis. The project will be implemented over a period of approximately 30 years, with construction work anticipated to start in 2008.

Analysis of the Participatory Process

Among the leading stakeholders (the Implementing Entities) there is a tendency to identify participation with consultation (Colenco 2005). As a result, the public, invited to express an opinion on an already-planned concept, might use its right to opposition. This might not occur in a scenario with public representatives participating in the early stages of the planning. Further, consultation processes are insufficient when profound changes in management strategies and thus in the role of different actors are envisaged (Pahl-Wostl 2002; Pahl-Wostl et al., in press). Construction plans for the Third Rhône Correction have been published for consultation by all affected stakeholder groups (Rhôneprojekt 2005). The implementation plans reveal that economic considerations, technical considerations and the avoidance of any use conflicts dominate the overall planning process. A widening of the riverbed of up to twice the current size is foreseen, whereas a three- to fourfold widening would be desirable from an ecological point of view. An accompanying research project (EAWAG News 2006, www.rhone-thur.eawag.ch) has provided empirical evidence that the planned construction measures and the flow regime will not lead to a significant improvement of the ecological situation, despite the rhetoric in official documents conveying the impression that a balance between the competing interests of flood protection, hydro-power generation and ecosystem restoration has been found.

Given the dual objective of the project — flood protection and ecosystem restoration — the trade-off between flood protection and floodplain restoration could be reduced by explicitly taking into account the function of ecosystem services in floodplains. To realize such an approach would, however, require major changes in current and future land use in the floodplain. The consultation report mentions uncertainties and climate change only once — in parentheses. If they have been taken into account, it seems information on climate change and associated uncertainties are not a high priority to communicate to the public. Dimensions of flood-protection measures are still derived from the expected magnitude of a century flood. Uncertainties are only taken into account by an increase in the safety margins. However, as shown by Aerts et al. (in review), a strategy combining a portfolio of measures with different damage-to-discharge characteristics may be a more robust strategy than relying on measures that provide complete safety but lead to disaster in the case of failure.

Despite the stated policy goals by government to foster innovation in flood management, the suggested strategies are conservative. The situation observed in the Rhône basin is quite characteristic of many river basins, as has been shown by first results from the European project NeWater exploring the need for a transition towards adaptive water management in a number of river basins in Europe, Central Asia and Africa (New Approaches to Adaptive Water Management under Uncertainty, www.newater.info). A lack of change at the operational level similar to that in the Rhône basin can, for example, be observed in the Netherlands: on the one hand, the government asks for a radical rethinking of water management — more space for rivers, and living with water rather than control — on the other hand, management practice is very slow in adopting new strategies. Such inertia can be explained by the radical changes in the management regime which would be needed for more-integrative flood-management practices.

4. Radical Change in Management Regimes and the Importance of Processes of Social Learning

The implementation of integrated and adaptive management strategies and the reduction of the trade-off between flood protection and floodplain restoration can be achieved by taking into account ecosystem services of floodplains and moving towards multi-functional, dynamic landscapes. As highlighted by Pahl-Wostl (2005), efficient integration requires processes of social learning, since fundamental changes are needed in the governance structure, as summarized in Table 1. This table also incorporates classifications according to the water-management hierarchies for adaptive management as described in Section 5. This classification outlines how decisions and management of water resources are interrelated between different political levels (context, network and game levels).

Table 1. The current management regimes in regulated and controlled rivers, compared with a future state that has multi-functional and dynamic landscapes

	Current state, with regulated and controlled rivers	**Potential future state, with a multi-functional, dynamic landscape**
Stakeholder groups and their roles (roles of actors at the game level — switching)	• authorities as regulators in a highly regulated environment • engineers who construct and operate dams, reservoirs and levees • environmental-protection groups fighting for floodplain restoration • insurance companies selling insurances against flood damage • house owners living in floodplains • agriculture using land in the vicinity of rivers • shipping industry interested in well-functioning waterways	• Authorities act as contributors to an adaptive management process with shared responsibilities. • Neutral third parties act as facilitators of the decision-making process. • landscape architects • engineers who have skills in systems design and co-operate with ecologists • environmental-protection groups • insurance companies • house owners with property in a floodplain at a higher risk of being flooded • tourism industry and tourists using the floodplains for recreation

Stakeholder participation (roles of actors at the network level — activating)	Little stakeholder participation — occasional consultation where different stakeholder groups and the public at large are asked to give their opinion on a management plan or scenario that has already been prepared by experts	Stakeholders and the public are actively involved in river-basin management. This can be described as co-production of knowledge and co-decision-making. Involvement can range from discussions with the authorities and experts, to actively contributing to policy development (co-designing), influencing decisions (co-decision-making), or even full responsibility for (parts of) river-basin management.
Paradigm of water management (perceptions at the network level — reframing)	• Management as control. Technology-driven. Risk can be quantified and optimal strategies can be chosen. Zero-sum games in closed decision space. • Implementation of controllable and predictable technical infrastructure (reservoirs, dams) based on fixed regulations for acceptable risk-thresholds	• Adaptive and integrated water management. "Living with water". Acceptable decisions are negotiated. • Implementation of a multi-functional landscape and increased adaptive capacity of the system. Designed risk dialogue and cascade of adaptation measures to live with extremes. Increased importance of real-time forecasting systems.
Institutional setting and governance (institutions at the network and game level — reforming and arranging)	• Institutional fragmentation • Flood protection, nature conservation, regional planning and water management are often located in different authorities. Even the European Water Framework Directive does not address flood management. But it asks to preserve and/or restore the good ecological state of freshwater ecosystems. This includes the restoration of floodplains and will thus directly interfere with flood protection.	Polycentric governance and better institutional interplay • Better horizontal and vertical integration of formal institutional settings to overcome fragmentation, which might imply new institutions such as river-basin management panels with defined responsibilities and decision-making capabilities • Stronger role of informal institutions and participatory approaches
Adaptive capacity (tools at the network and game levels — selecting and using)	"Hard" approach to systems design which aims to implement long-lasting, optimal solutions. Adaptive capacity is in general quite low due to high investment in infrastructure and often inflexible legal regulations (e.g. water-use rights allocated for decades; technological norms that prescribe good practice and prevent innovation and change to new management practices)	"Soft" approach to systems design allows new insights to be taken into account, including responses to changing environmental and socio-economic boundary conditions. This is more in line with the new paradigm of adaptive water management.

4.1. What is social learning?

Social learning in river-basin management refers to developing and sustaining the capacity of different authorities, experts, interest groups and the public to manage river basins effectively. Collective action and the resolution of conflicts require that people recognize their interdependence and their differences and learn to deal with them constructively. The different groups need to learn and increase their awareness about their biophysical environment and about the complexity of social interactions.

4.2. Why is social learning needed to move towards and to sustain integrated, adaptive water management?

As previously mentioned, technical infrastructure (e.g. large technical infrastructure for flood protection), citizen behaviour (expectations regarding safety in floodplains, risk perception) and engineering rules of good practice are often mutually dependent and stabilize each other, resulting in the blockage of new and improved resource-management schemes (Pahl-Wostl 2002). Social learning is assumed to be crucial to break through such "locked-in" situations. It is also required to implement change in order to sustain adaptive-management practices.

A new concept for social learning in river-basin management has been developed in the context of the European project HarmoniCOP. Figure 1 shows the framework for social learning developed to account for learning processes in water-resource management (Craps et al. 2003; Pahl-Wostl 2002). The framework is structured into context, process and outcomes and has a feedback loop to account for change in cyclic and iterative processes. The context refers to the governance structure and the natural environment in a river basin. To improve the state of the environment in practice most often implies a change in governance structure.

The concept referring to multi-party interactions in actor networks has two pillars (Figure 1). The pillars relate to the processing of factual information on a problem (content management) and engaging in processes of social exchange (social involvement). Social involvement refers to essential elements of social processes such as the framing of the problem, the management of the boundaries between different stakeholder groups, the type of ground rules and negotiation strategies chosen, or the role of leadership in the process.

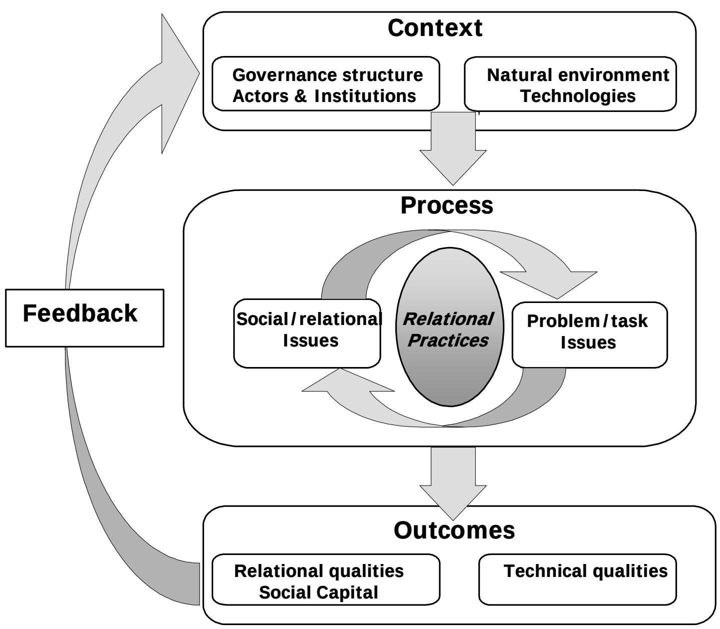

Figure 1. Conceptual framework for social learning in resource management. In the centre are multi-party processes that are influenced by the context in which they are embedded and that produce outcomes that may lead to changes in the context and thus to a cyclic and iterative long-term process of change.

As one example, the role of framing is explained in more detail. During the initial stages of dealing with a problem, **framing and reframing of a problem domain** determines the direction of the overall process. Frames may be derived from culture, social roles, scientific disciplines, etc. Actors have frames that determine how they make sense and meaning of information and their physical and social environment. Differences in the framing of an issue are among the key reasons for problems in communication and for entrenched conflicts among actors. The framing of an issue includes, for example, what is at stake, who should be included and in which role. Processes of framing and reframing are essential elements of social dynamics in a group during the negotiation of meaning of key issues such as goals to be achieved or how to measure success of management. It is important to be aware that powerful actors often impose their frames or interpretation of an issue onto a process. A relational practice may be a moderated role-playing game or policy exercise where actors are willing to reflect and discuss their own perspectives as well as listen to others. This type of social learning does not necessarily lead to consensus, but it develops the ability to deal with differences constructively.

The overall social-learning process in a group leads to input on how to move the state of the environment towards desired properties (technical qualities), and to social capital such as an increase in the capacity of a stakeholder group to manage a problem.

Table 2 summarizes results from the case studies in HarmoniCOP regarding factors that constrain and support social learning (Tippett et al. 2005; Mostert et al., in press).

Table 2. Factors That Constrain and Support Social Learning

Factors Constraining Social Learning	Factors Supporting Social Learning
STRUCTURE — CONTEXT	**STRUCTURE — CONTEXT**
• Centralized political and economic systems • Privatization and commercialization of the environment • Bureaucratic systems • Political secrecy and poor public access to information	• Increased decentralization of power • Move away from overregulated bureaucracy • Political recognition of the positive value of the public voice • Greater environmental awareness by members of the public • Developing a more consensus-based culture
PROCESS	**PROCESS**
• Lack of clear objectives and process for involvement • Lack of time and effort taken to build trust • Lack of process to explore common ground rules and manage conflicts constructively • Lack of process to link planning at different levels of scale • Ineffective communication of technical issues • Non-communication of supposedly shared or common knowledge or premises	• Provision of sufficient time and resources • Opportunities for participation early enough in process • Use of facilitators and process management • Definition of commonly accepted ground rules • Explicit recognition of different perspectives • Clear formulation of interests / illustrate the framing of the respective issue

There is a recognized need for social-learning processes in the transition towards integrated- and adaptive-management approaches, and a requirement for insights on the nature of such processes and factors that constrain and support social learning. This gives rise to the question: What are the appropriate approaches to facilitate change?

5. How to Promote Change?

Decisions and management of water resources do not take place in isolation but rather are complex political processes that take shape at different political levels (cf. also Figure 1):

- The **Context** level, which incorporates the wider political and institutional environment that determines the governance structure.
- **Networks** (policy arenas), which determine actors and institutions, who is in and who is out of the process, and thus also the boundaries and framing of the problems and solutions taken into account.
- **Games:** the level of rules, institutions that shape individual behaviour and collective negotiation, learning and decision-making processes.

Understanding how — at the level of context, networks and games — actors and institutions create perceptions and make use of tools, is critical for an adaptive management of water resources. The coupling between the various levels shapes the outcome of water decisions and investments and hence determines the adaptive capacity of the water sector or of a specific river basin. Table 3 showed how perceptions, tools, actors and institutions can be used and applied at the network and game level in relation to managing rivers in the current state, which focuses on regulated and controlled rivers. This was then compared to a potential future state with more multi-functional and dynamic management of rivers which incorporates adaptation to change.

These ideas are worked into a coherent framework for analyzing the political context within which an adaptive capacity needs to be developed for river-basin management. To do so, 12 political actions (PAs) are described which actors need to consider if they wish to develop adaptive capacity for the management of a river basin. The case of the upper Rhône River is used to provide tangible examples for each of the 12 PAs. Examining the R3 Project through the lens of the water-management hierarchies framework demonstrates that elements of adaptive management are being used but that there is considerable potential to do more through reframing and social learning. The challenge is to build further on each of the described political actions. Efficient application of adaptive management can ensure that a river basin such as the Rhône can respond to pressures such as climate change. If a river is widened sufficiently to take into account changes in flow due to climate change, then the significant investment into watersheds will be worthwhile and will have an effective impact.

Table 3. Water-management Hierarchies for Adaptive Management

Hierarachical Levels	Perceptions	Tools	Actors	Institutions
Level 1: Context level	***Shaping***	***Developing***	***Grouping***	***Creating***
Description • Applies to the national policy level • On a slow time scale of decades	→changing society wide views and ideas that shape the context within which networks are created and are functioning	→emergence of new tools relevant for policy networks and games can shift the tool options networks have at their disposal	→new groups of actors are created from which actors for the network can be selected	→setting up new (groups of) institutions that that can be a driver of reforms
Leading Example	*e.g. changing societies perception of full protection from floods (flood control) to an acceptable risk (flood risk management) changes the context and solutions space*	*e.g. advanced modelling of unguaged basins can form the basis of a series of new tools actors can choose from*	*e.g. strengthening civil society can create a group of new actors relevant for water policy and management networks*	*e.g. creating a ministry of water resources that pulls together all different strands of water resources into a single ministry*
Level 2: Network level	***Reframing***	***Selecting***	***Activating***	***Reforming***
Description	→changing actor's perceptions of the network, its role, goal, structure and functions	→choosing the tools or changing the tools with which the network can alter the functioning of the network	→bringing new actors or changing (network) positions of existing actors	→changing rules and resources in networks that change fundamentally the network's structure and functioning
Leading Example	*e.g. changing the perception that a flooding problem can only be solved in the floodplain to a basin wide approach can change the flood network membership and ways of working*	*e.g. the use of facilitation tools during water meetings can alter the way that actors interact, their level participation and the quality of the discussion*	*e.g. involving a wider group of actors such as business representatives or downstream riparians can alter the functioning of the network*	*e.g. setting-up a small grant scheme that assists civil society groups to prepare for and participate in monthly water meetings*
Level 3: Game level	***Convenanting***	***Using***	***Switching***	***Arranging***
Description • Individuals and organizations • Decisions are made over months	→exploring similarities and differences in actor's perceptions and the opportunities that exist for goal convergence using the 'rules of the game'	→changing the access to and ability of actors to use tools	→(de) mobilising actors possessing resources to (un)block the game	→creating, sustaining and changing ad hoc provisions which suit groups of institutions
Leading Example	*e.g. using interest based negotiations to define what water users wish to achieve rather then position based negotiations that only defends a status quo*	*e.g. building the capacity of actors to use decision support systems in water management can shift the balance the game*	*e.g. temporarily working with only a sub-set of network actors that are powerful can help find a partial solution for a water allocation*	*e.g. the chairmanship of a meeting can be given to one particular actor at a particular point in time to forge a breakthrough*

5.1. The Context Level

The Context Level refers to the wider context within which river-basin management takes shape. It refers to societal views, cultural norms, (national) constitutions and laws, the approaches and tools used for management, and the existing landscape of actors and organizations. The Context Level has been formed over longer periods of time: decades or even centuries. It typically affects the management of several river basins, as it constrains and determines practices at larger spatial scales — countries or (economic) regions.

Shaping and developing

Actors at the Context Level sometimes have the possibility or can create the opportunity to change societal views that determine how a problem can be framed. They also might have the opportunity to change existing water policies at a national or regional level in such a way that water problems can be framed differently. As such, actors and organizations can ***shape*** the context and discourse within which networks are managed and games are conducted.

For the management of the upper Rhône basin, the context is, among others, defined by the Swiss and French constitutions and the water-management organizations in both countries. Increasingly, however, this context is changing through the implementation of the EU Water Framework Directive, the Nature 2000 Directive and other EU directives. In France, for example, the established water organizations are challenged by the obligation to allow for much wider public participation in decision making (Pflieger 2006). Furthermore, societal perceptions are (slowly) changing in both Switzerland and France. In Switzerland, rivers are increasingly viewed as important recreational and nature areas and not only as conduits of irrigation water or drains of storm water (ProNatura 2006). At the same time, however, the opening of the European energy markets has generated interest from Swiss electricity companies to generate hydro power in order to service peak power demands (e.g. on Monday mornings). The generation of this power results in significant fluctuations in river levels throughout the upper Rhône River system at short time intervals, impacting negatively on the Rhône River's ecology (Meile et al. 2005).

New tools or mechanism can be ***developed*** that can change the way networks and policy actors find solutions for water-allocation problems. For example, the "green power tool" allows Swiss electricity companies to generate "green hydro power" that can be sold at a premium price. In the upper Rhône valley, the Pont-de-la-Tine hydro-power plant is currently operating using the NatureMade certification label (Romande Energie 2005). The plant generates electricity but also leaves residual water in the river in order to maintain downstream river ecology. Though the capacity of the plant is small, this is nevertheless significant, as it demonstrates that hydro-power generation can be combined with ecological objectives. It also shows that a new tool can change the way water is managed and even create a win-win situation — in this case, at the local level.

Grouping and creating

Stakeholders in river basins and at national levels often cluster in different ***groups*** that hold similar views or interests. Creating or (re-)grouping actors, either at national levels or within a river basin, can help to change the way a policy network is managed or functions. This type of grouping has been done to an extent in the Rhône River basin with stakeholders at the internal and external levels. At the internal level, the heads of government departments are grouped into the Steering Council (described further below) and are in charge of strategy and project implementation. At the external level, there are thematic and local/regional groups. The thematic group consists of various subgroups of actors which represent different sectors of interest (tourism and leisure, the environment, the economy, agriculture, land and safety). The local/regional groups represent local/regional interests of communities or municipalities which are represented by regional Steering Committees (HarmoniCOP, 2005).

While different actors can cluster in different ways, another option is to ***create*** new (groups of) institutions. This often happens at the national level when a new water policy is developed and the existing institutional set-up needs to be brought in line with the policy. A typical mechanism in water management is the creation of a national-level coordinating body. This body then includes representatives from different ministries that each have responsibilities for some aspects of water management, such as water-quality monitoring; operation and maintenance of river infrastructure; hydro-power generation; irrigation and drainage development and maintenance; etc. The State Council of the canton of Valais created a number of institutional bodies to direct the implementation of R3. The Conseil de Pilotage (COPIL), or the Steering Council, consists of representatives from various federal offices, including the Office of Water and Geology and the Department of Transport, Infrastructure and the Environment, as well as external stakeholders in the form of associations of municipalities and organizations (Canton du Valais 2005; HarmoniCOP 2005). Although this group was specifically created for the R3 Project, it could be useful to create more-dynamic groups that fully incorporates external stakeholders from the very beginning of the planning process.

5.2. The Network Level

The Network Level refers to the provincial context of river-basin management. It includes interactions between actors across organizations at the basin level and is influenced by the Context Level. The Network Level refers to the relationships established between interdependent organizations, and how they co-operate (or don't co-operate). The Context Level determines how the Network Level will be formed and how it will function, and in turn the Network Level will determine how organizations will play the game (i.e. their approach to decision making, their attitudes to new tools for river-basin management). The Network Level is formed over years and usually applies to the management of a regional river basin.

Reframing and selecting

As previously mentioned, social learning includes reframing of problems to make sense of available information and how it can be used in adaptive river-basin management. ***Reframing*** changes the perception of the network's role, goal, structure and functions. Problems can be redefined and possibly solved using different approaches derived from reframing. However, reframing can be a long process, as perceptions are rooted in mental constructs derived from past experiences (Kickert et al. 1999). Often actors within a network will need to go through a learning process in order to understand how reframing occurred and why. In addition, the network can also be used as a tool to bring forward ideas and redefine river-management problems into a more manageable form. In the case of the R3 Project, reframing should occur around the main project goals (ensuring safety from floods), changes in the river landscape, and its use to change the view from flood management to watershed management. The impacts of climate changes and uncertainties need to be incorporated so that the management plan is adaptive and flexible to changing events.

Traditional instruments such as existing regulations used for river-basin management may not be very effective within a network; instead, instruments must be ***selected*** and altered to fit the frame of reference of the network. Legal, economic and communicative tools within a network must be able to be deployed at a horizontal level across the network as opposed to the vertical, top-down approach. Although tools are what enable networks to function, they need to fit into the network structure within which they are used. The tools selected and adapted for the network depend on the actors that make up the network and the relationships that exist between the actors (Kickert et al. 1999). Tools introduced to the R3 Project, such as the www.rhone.vs site, were implemented to facilitate social learning in the general public but had limited outreach to stakeholders (HarmoniCOP 2005; Canton du Valais 2005). The use of geographical information systems and other computer graphic displays such as AutoCad and PowerPoint were found to have some success in facilitating dialogue and understanding of the R3 Project (Luyet 2005). The canton of Valais has produced a report on the structural plan for the third correction, as well as maps for each commune, displaying land use and flood-prone areas along the Rhône (Canton du Valais 2005). These types of visual tools can aid in understanding the problems and help stakeholders in the network with reframing their understanding of the extent of the ecological and social issues to be tackled in the Rhône floodplain.

Activating and reforming

Sometimes new actors are ***activated***, created or brought into a network to carry out functions needed to manage the network. The introduction of new actors can occur by setting up or reorganizing a commission; recruitment; or bringing in an advisor (Kickert et al. 1999). For example, an association of business owners could be created to take part in public-participation discussions on floodplain management in order to ensure that the interests of the business community are represented. Introducing a new party into a network does not automatically solve problems and create new ideas; rather, the latter develop through the course of interaction. Including organizations in public discussions is only useful and representative if they are actively involved in the network and their input is considered important to the decision-making process. In the Rhône example, new actors were brought into thematic working groups within the R3 Project by the State Council of the canton of Valais to ensure representation of interests outside government. The stakeholders include five municipalities, the Sierre region association, and six different regional associations representing agriculture, ecology, environment and nature protection (HarmoniCOP 2005). It would be useful to also bring in new actors with specific knowledge on climate change and ideas on adaptation within the river basin.

Reframing problems in discussions will lead to actual reformation through action. For example, institutions that are created or activated can be part of the ***reforming*** process in a network. Policy processes in networks can be unpredictable and complex. There are often a variety of actors whose preferences can change during the course of interactions. Consequently, rules and resources within networks can change, leading to structural and functional shifts. However, networks do not function without management, which can be seen as promoting the mutual adjustment of the diverse objectives of actors, and ensuring a co-operative strategy with regard to tackling problems (Kickert et al. 1999). Network management steers the process of reforming as perceptions shift and actors enter and leave the network. In the R3 Project, new actors brought into the river-basin network in the canton of Valais can be a mechanism to reform project organization and ensure the participation and perspective of external stakeholders.

5.3. The Game Level

Networks, which are the relation patterns between actors, are the context in which games take place. At the same time, the games change and influence the shape of networks. Actors within networks choose game strategies (i.e. policy-making processes) that seem rational according to the network they interact with, their individual goals, and the overall context of the policy-making process. Furthermore, actors driving river-basin management at the game level are influenced by other forms of management (i.e. agricultural management) and the relationships developed in the network through present and past interactions. A characteristic feature of a game is that the result derives from the interaction between the strategies of all actors involved (Kickert et al. 1999). The rules of the game put constraints on actors but are at the same time the product of their interactions (Kickert et al. 1999).

The Game Level includes individuals and organizations that are making decisions over periods of several months. These decisions are steered by context and network structure but also have an upward impact that can shape interactions within the Network Level, leading to shifts in the Context Level. Actors' perceptions undergo incremental change during games due to interaction or confrontation with other actors' perceptions (Kickert et al. 1999).

Convenanting and using

Convenanting refers to a management strategy aimed at improving the consistency of decisions made in the game by exploring and consolidating the perceptions of actors (Klijn and Teisman 1997). Consistency is improved through social knowledge and learning, which involves changes in norms, practices and behaviour, as well as changes in perception and understanding among stakeholders. This management strategy uses the informal rules that exist in a meeting, committee or organization to manage the participants. The convenanting concept is used to emphasize that specialized actors (i.e. network managers) have potential for enriching new initiatives. An effective network manager will interlink specialized initiatives in order to improve the policy initiative around which a game is constructed (Klijn and Teisman 1997). Convenanting in the R3 Project occurred to an extent, as the Regional Steering Committee was involved in workshops where actors representing various interests learned and discussed the advantages, disadvantages and consequences of implementing the plans of the Third Correction, as well as ensured that participants understood the rules of the game (i.e. the boundaries in which they have to make decisions). Workshops and discussions promote social learning and allow actors to make informed decisions and to work towards goal convergence using the rules of the game.

For a management strategy to achieve its goals, a process of social knowledge and learning progression is undertaken by actors involved in a game. Actors may need to be trained to *use* the tools they need in order to be effective in playing a game. For example, a tool kit for environmental flows can be developed to guide river-basin management, but it may be of little use unless the actors are trained in how to apply the knowledge from the tool kit. This learning can evolve over time through interactions with other actors or through active training courses. The result is that the actors can shift the balance of the game as their perceptions change. As previously mentioned, a few visual tools were selected to help stakeholders in facilitating constructive dialogue. Taking photographs was a tool employed to help stakeholders identify their objectives in the participatory process in the R3 Project. Participants were asked to take pictures of what they thought was beautiful, ugly, unsustainable and attractive to tourists in the river basin, then elaborate why they took each picture. This approach was used to get stakeholders to think about how to transform their theoretical knowledge into concrete pictures (Luyet et al. 2004). This approach is a good start, but application of tools and training should be taken further and incorporate adaptive management to climate change and uncertainties.

Switching and arranging

Policy-making processes can be improved by ***switching*** on specific participants. Selective activation demands that managers assess which actors are essential at given moments in a policy process, and whether and how to involve them. Success in activating and deactivating depends on choosing the appropriate actors, as well as on the willingness of actors to invest time and resources in a policy process. The R3 Project involves internal and externals actors at the federal, canton and municipal levels, as well as independent organizations concerned with ecology, agriculture, business and land ownership. R3 depends on activating or deactivating the different stakeholders at the appropriate levels in order to determine solutions to problems such as water allocation. There is no point in engaging actors in a game if they do not possess the necessary resources to actively participate. If the input of a set of actors is considered essential to the policy process, then tools must be used to ensure that they have the needed capacity to participate.

Arranging refers to the capacity of the participants involved to develop platforms on which games can be played, and to the capability of the participants to develop or use rules for interaction (Kickert 1999). Arranging includes creating, sustaining and changing ad hoc provisions to suit various situations or games (Klijn and Teisman 1997). Arrangement as a management activity is the art of linking interdependent actors in such a way that the arrangement costs are low and do not result in high transaction costs (Kickert 1999). Arrangement in the R3 Project can refer to the evolution of the structure of the project and relationships between stakeholders. Different actors may be brought in or new relationships forged in order to change the status quo and move forward on an issue.

6. Requirements and Challenges for the Implementation of Adaptive Management in Upland Riversheds

The analysis in the previous section provides evidence that there have been opportunities to engage in a dialogue that could influence a change in management practices in the Rhône case but that further development in all political actions is needed to implement effective adaptive-management practices. Undergoing reframing and the process of social learning can open up discussions to alternative perspectives, solutions and other stakeholders. Social learning leading to change requires leadership and clear commitment from those designing and coordinating the process. Developing adaptive capacity with a long-term vision would be a wise strategy, rather than responding to disaster and escalating conflicts.

Currently, adaptive management in relation to climate change is limited in prevailing designs, practices and ideas surrounding river-basin management. Therefore, reframing issues of river-basin management to include climate-change scenarios may aid in shifting the focus from flood management to a wider basin-management view that includes storage and buffering of flow and capacity upstream (Dyson et al. 2003). Another example of the importance of adaptive management pertains to ecological restoration. If ecological restoration of a watershed is narrowly defined (i.e. one section of a river), then the results are unlikely to be sufficient to significantly justify investment, as other sections of the river will not be restored and benefits will be minimal.

Drawing on the conceptual and empirical analyses, it is possible to make a number of recommendations for policy-making to develop, implement and sustain adaptive-management practices in upland riversheds facing increased uncertainty due to global and climate change:

- The complex socio-ecological nature of river-basin environments and the inherent uncertainties associated with their management have to be taken into account in policy development and implementation.
- Selected management strategies should be robust and perform well under a range of possible, but initially uncertain, future developments.
- The design of transparent and open social-learning processes is a key requirement of sustainable water-management regimes.
- Effort has to be devoted to building trust and social capital for problem solving and collaborative governance.
- An increase in, and maintenance of, the flexibility and adaptive capacity of water-management regimes should be a primary management goal.
- Trust in a collaborative process is a more robust strategy in conditions of uncertainty then any belief in prediction and control.
- Entrenched perceptions and beliefs block innovation and change. Space has to be provided for creative and out-of-the-box thinking.
- There is a significant need to train a new generation of water-management practitioners skilled in participatory system design and implementation.

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Alberto Garrido, Session Discussant:

Thank you, Claudia. As Henry Vaux said, I'll be the discussant for this session. The Rhône is one of the most important river basins in the Mediterranean. Three basic facts: First, the Rhône is undergoing changes that may or may not be irreversible within a relevant time frame. Many of these changes are due to climate change. The second point is that the Rhône has gone through a long process of alteration over the last 400 years. Jean-Paul mentioned that there are 19 bypass sections on the whole river on the French side. There have been major improvements in water treatment and in the reduction of nutrients and contaminant discharges. And yet, the river dynamics, the significant hydromorphological impacts and the remarkable channelization of the river are now perceived in France and Switzerland as a negative outcome of development.

So, renaturalizing the Rhône — I didn't invent the word; I saw it when I was reading about the Rhône — is a significant challenge. It means opening more space for the river, it means restoring hydromorphological features, it means ecological rehabilitation. And it seems that it goes much beyond the objectives of the European Union Water Framework Directive, which is remarkable, and something we should think about.

Claudia made an analysis of the R3 Project in Switzerland, which is meant to increase flood prevention and reduce flooding. Eventually, they decided to double the width of the riverbed, whereas she believes that tripling or quadrupling its width would be much more desirable. So, as she said, there was too much rhetoric and not many substantive results. And there was a failure to recognize the ecosystem services of the floodplain, and this failure prevented the decision making from relaxing the trade-off between flood prevention and ecosystem restoration. So, in the end, the preventative studies were, in her view, too timid.

So what are the major obstacles for effective implementation? First, flow increases in bypass reaches — that's a French problem — are seen as economic losses. Secondly, the complexity of hydro systems represents cognitive problems, framing issues. Third, there are very few demonstrative and positive case studies. And fourth — and this was also mentioned by Claudia — there are entrenched positions of major stakeholders.

So, adaptive management: The main motivation, in a nutshell, is that the uncertainties cannot be reduced or controlled, so management must be adaptive. And in my view of reading Claudia's paper, I believe that adaptive management is primarily based on social learning. Social learning requires that arguments be posed scientifically, with a rigorous setting, but they must be understood. They must be understood by the managers and stakeholders, who have to have a grasp of the complexities of the system they're working with. Social learning and radical adaptive management: the expected outcome of social learning is to make breakthroughs when positions are entrenched on more-radical strategies, and to increase the awareness of renaturalization benefits.

What are the strengths, in my view, of this approach? First, it makes realistic assumptions about collective deliberative processes. It's realistic on the difficulties, on the need to structure the decision making and the deliberation process in a very thoughtful way. It's also science-based, which means that it requires a lot of development of models and pedagogical representations of the reality of the complexity, so that stakeholders understand what they're dealing with and the importance of social learning as a way of creating a capital of knowledge that is available for all the relevant stakeholders.

However, I find that there are other important elements that may be missing. The first one is economic incentives, both at the private level and at the political level. Secondly, there is a clear distinction between cost-effectiveness and cost-benefit analysis, and that's one of the most important innovations of the Water Framework Directive in Europe, because all the probable measures must pass the test of cost-effectiveness; however, when a member state wants to have a derogation of the objectives, then cost-benefit analysis must be brought into the picture to show that it's too expensive, too costly, to pursue strong restoration or to bridge the gaps of ecological quality. The third problem is that gains may be very difficult to measure. There are symmetries between the stakeholders, there may be strategic thinking, and outcomes at the end may not be socio-efficient. The fourth element is leadership; I think leadership is necessary to bring about radical changes, and that's probably not given a full emphasis in the approach. So there are potential problems and difficulties. Measuring the effects of adaptive management was mentioned yesterday.

I will finish with a photo from the city of Arles — you can see how integrated the architecture in southern France is with the river — and also with a painting by Van Gogh, which is "Starry Night over the Rhône". Thank you very much.

Alberto Garrido, Session Chair:

And now we'll have time for discussion; we will follow the same procedures we've been following, and I'll give the chance to Claudia or Jean-Paul to say something now if they want to, before we take questions from the audience.

Claudia Pahl-Wostl:

I can just briefly comment on two of the points. I agree entirely that social learning is a necessity but is not sufficient for this type of adaptive management. I agree that economic considerations are very important, but sometimes the types of costs may very much depend on who is involved and the system; that is why I think the things should be linked. So that's very important. And the other issue — leadership: Yes, in the Harmoni-CA project, which I mentioned, leadership is the key element. So I agree on this.

Jay Lund:

I really enjoyed these presentations, particularly the discussion on adaptive management. I like this concept very much. It's been almost 30 years since Hollings worked on adaptive management, and I've been impressed over the thirty years by how many implementation definitions this concept takes on, but I like the original one best of all. We've had some curious problems with adaptive management in California, and I'd like to talk about one where farmers were paid additional money to allow additional flows in the river for moving salmon downstream. And this was a classic adaptive-management experiment where they were going to take measurements to see how well this worked. The farmers found that they really liked this money that they were being paid. Now there's a need for more data, and I think this is a common kind of problem with adaptive-management experiments where every experiment implies a reallocation of benefits; when you conduct an experiment that reallocates benefits, the people who are receiving those benefits now have a stakeholder interest in seeing that experiment continue. So that's an interesting wrinkle of actually applying adaptive management.

Helen Ingram:

Just to follow up on Jay's comment; it's just a lesson in policies. Policies create constituencies and we usually look at it the other way around, of constituencies creating policies. But that's not what I wanted to ask Claudia about. I really, really enjoyed her presentation, and it seems to me that it raises some issues that we talked about in the last panel about the role of science in policy, and there was a good deal of back and forth about how scientists should speak to politicians. If I interpret Claudia's paper correctly, there is also a very important role of science in speaking to the public in the process of social learning, and she also suggested that we may have to educate both managers and scientists differently in the future so that they can participate more productively and provide better inputs to this social-learning process. I wonder if she might comment about that.

Claudia Pahl-Wostl:

Yes, I think in terms of the water-management community, simply that these people have been most often only trained as technicians; for example, in Europe, what we face is that the need to have stakeholder involvement is something that is at least perceived as being important — I think mainly also for pragmatic reasons, of course. Definitely, I agree. We have to; otherwise, we wouldn't be able to implement certain strategies. We need to involve stakeholders, but most of these people have never been trained to work with participation. For example, we face now in Europe that the [European Union Water Framework] Directive is asking all the water boards to suddenly design participatory processes. But they have no money, so some people who have spent their whole lives working on technology and stuff, suddenly have to work on participation. And I don't think that you would allow a communications expert or someone else to build you a dam or run a waste-water treatment plant. But suddenly these people are supposed to, and I think people who work in business management, they understand what I'm talking about, because it's about human beings, and these processes are very fragile.

We have a big demand also for education. I think we need to train a new generation of engineers — and many engineers are interested in this — who have this capacity, who are capable of dealing with these issues. In terms of science, I think many of my colleagues are reluctant. They find policy to be a bit dirty; science is objective facts, and they don't want to get too close to policy — though perhaps not the community that is here. But I think that science has to take a more active role in shaping the science-policy interface. And that's where working with social science is easier, because we're party to action research — which means that we design processes where we solve a problem, but by designing the process, such as a water-management process involving stakeholders, we also use the process to analyze what's going on. I think that having an active role and not just being a passive provider of facts but also making assessments and judgements and giving advice that sometimes needs subjective assessment — in particular, our ecologists are very reluctant to give advice, because that means they have to make subjective assessments — is important.

Sylvia Rafaelli:

I thank you for the presentations; they have been very good. But I would like it if we could talk a little about one subject that concerns a lot of South America: the performance of global models in relation to precipitation. I will just mention the La Plata Basin; we don't have glaciers, and so we depend 100-per-cent on precipitation. We are experiencing climate-change effects in a good way, because we have more water than in the '70s, we have more energy, and also the frontier of agriculture has moved. But when the climate-change experts try to induce what will happen in the future, there we have a very big problem: they know that the temperature will go up, but when we ask about precipitation, they have no idea what will happen. They say that there will be more evaporation, but they don't know if there will be more precipitation or not. So now when we think about this adaptation process, it's quite difficult to think about how we will make this adaptation, since we don't know exactly whether we will have more water or not.

Alberto Garrido, Session Chair:

Do you want to answer, or anyone on the floor, about this issue? Modelling liability? No? Okay, Professor Messerli.

Bruno Messerli:

First, I want to thank Alberto Garrido for the excellent discussion. He certainly did a better job than I could have done. Thanks a lot. And now my short comment. I also am persuaded that we are confronted with dramatic changes in the future, but I think we also have the responsibility to analyze the past. We now have a 500-year analysis of extreme events in our region of the Swiss plateau on the mainland. It is unbelievable what we have found about what happened — I mean extreme events of a certain order of magnitude which we never thought could happen like that. It is in the past. These are very important indicators of the dimensions that we should perhaps manage in the future also. So the past is important; the present is important.

If I think of the mistakes we have made with our rivers, even our generation and the last generation — the Rhône Valley is a canal; it goes down the valley, it goes down to France, it is no longer a river, it is Rhône water between embankments, and we should realize what that means. The Po is an extreme situation: It's on an elevated bed, then there are the embankments, and the land around is much lower. And there, against the law, you find industrialization, farming and everything, and then we are astounded when an extreme event happens and the damage goes into the millions and the billions. So these damages, these figures say nothing, because we made the mistake; we produced it, knowing that what we are doing is so dangerous. I'd like to say that we have a lot of things in Switzerland also.

I think, therefore, that we should also analyze not only the past but also the present generations — what we have done wrong. And now, looking into the future, I think a very valuable instrument is risk mapping. It is a law in Switzerland that every commune must now have a map about the potential risk; but everything is late, the law has not really been fulfilled yet. The cantons — the equivalent of the provinces here — are responsible, and this is not finished. Last year, we had extreme events, and the results clearly showed: you have built in a red zone, and so these are the damages here. Even a schoolhouse was in a red zone, or in a between zone. Then we are astounded about the damages. But it could have been known, and if we had these risk maps, we could also include in this zoning, certain potential dangers in the future; we could introduce potential changes in climate in this risk mapping.

And now my question: Do these maps also exist, or are they missing, in France for the Rhône basin? To Claudia Pahl-Wostl: Does something like this exist for the Rhine basin? Because, these maps are an excellent tool to present to the community, to the political authorities, and say, "What are you doing? Look at these maps here." And then start the discussion between the authorities and the communes and all the economic interests; if someone wants to construct something somewhere, tourism, industry and so on are confronted with this risk. And this is missing completely. With this tool, we could plan better for the future.

Jean-Paul Bravard:

I fully agree with the statement that past changes did occur. We have good experience of that more and more, thanks to geoarchaeology especially. During the last decades, engineers and hydrologists, and many geographers too, thought that the climate was stationary and hydrology was stationary; it was not, in fact. What is most interesting now is that politicians or stakeholders who are reluctant to admit global climate change will go back to the past to justify, thanks to the past, that the changes that will occur will not be so important. So this is very interesting, because we are exactly at the crossing of science and myth, and we will have to cope with that as scientists: going back to the past to understand changes, and also letting people admit that it may be slightly different when dealing with future changes due to climate change and man-induced climate change. It will be a big challenge for us, and we still have a lot to do.

Jennifer McKay:

Thank you, Claudia, for your paper — I think you played to all of my biases as someone who runs participatory processes in water-resource management. I've found that it's quite easy to engage those stakeholders who either passionately oppose the science or are supportive of the science; they use that ambiguity you talked about to make strong cases. But how do you engage the larger public, who are usually apathetic, disinterested, don't want to participate for a range of reasons? How do we get their voice heard in decisions that largely affect them as much as the vocal stakeholders?

Claudia Pahl-Wostl:

I think that sometimes you really have to think: Do we need to involve the public at large in everything? Probably only in the things that they are concerned about, and you have to at least make the effort to make clear what certain decisions imply for their daily lives. And if this is clear for them in terms of water pricing, for example, then it's their option and they have to make their choices. But then, generally, you also get that everyone has at least some interest. But I think it takes an effort to provide information such that they can link the types of measures to be taken with things that are relevant for them, and options. But I still have to admit that I think in Europe it's easier to involve the public than, for example, in the U.S.; that was our experience when we worked with climate change. There was much more willingness or activity on the part of the public to engage in these things. But I think what you have to do is really make efforts; you don't get everyone, but at least you get a substantial community of people. But you have to make efforts to make very clear what it means for their daily lives.

Jean-Paul Bravard:

In France, thanks maybe to the latest floods in the Rhône River, the government has decided to implement two types of major dialogue: one is called Commission territoriale de Concertation, held by the state; the other one is called Etats Généraux (as in 1789 with the French Revolution) — Etats Généraux du Rhône, implemented by the regions. This is a big change. There have been many meetings over the last two years, and these meetings have provided the opportunity to make a Rhône master plan. It is a big change in the conception of participative democracy in France, which is a very centralized and authoritative country.

Mordecai Shechter:

Allow me to try — I probably won't be successful — to introduce a little bit of structure into some of the notions that have come up here, then ask the speakers to relate to it. We have heard a lot about uncertainty, and Professor Messerli talked about risk, and I think that was a very good contribution. In 1921, an economist called Frank Knight coined the distinction between risk and uncertainty. Risk is defined as having the probability distribution specified. Going back to what you said, we have data that we can analyze over centuries, for which we can get some hard data about the probabilities, or the probability distributions, of some events. So it's not just the veil of ignorance or complete uncertainty. Of course, there are cases where there is uncertainty — where we simply don't have these kinds of data and we have to use things like the precautionary principle or other softer approaches.

So this is for you, Claudia. I missed this kind of distinction. It's not: everything is uncertainty. There are cases — you made an analysis of science-based decisions — where we can make those decisions in a more structured way. I would also want to strengthen what Alberto said; there are cases where you can even use — excuse me for using the term — cost-benefit analysis. Economists now have contributed a lot of things that help us to value many of those things that in the past we didn't value or couldn't value or didn't want to value. So we can introduce a lot of things into a very structured decision-making process — call it adaptive management or what have you.

Now to you, Jean-Paul Bravard: Again, using the numbers — the Rhône, I imagine, is a system, an area where you have a lot of information, relatively speaking. So you gave us a very nice presentation of what's going to happen under climate change. What I missed — maybe it's more in the paper, but if I were a politician or a decision maker, I would like to hear more hard data from you. And I think it is available and it can be structured. Because, "Tourism will be affected," and "This will be affected" — those qualitative statements are not sufficient.

Jean-Paul Bravard:

Maybe I answered too quickly the question posed by the Rosenberg Forum: What are the changes I expected? Most of my job is dealing with what you are asking about. What can we do as scientists to reduce the time of implementation of solutions? We provide solutions; we have been hired for that. But my paper was strictly restricted to the change. Sorry.

Claudia Pahl-Wostl:

I agree that there are methods, but we have to be capable in certain areas. We also have situations where we simply don't have the probabilities. And then we also have to find methods where we can make decisions now, and that's why I think it's one element to structure our decision making, which I would prefer, but I think we also have to see that there are certain areas where it would be not good to wait until we find probabilities. But perhaps we can speak on this later.

Hans Schreier:

Water and energy are probably the most important issues we are facing, and France relies heavily on nuclear power. Has there ever been a public discussion on the water needs and the water impacts by nuclear plants in view of climate change?

Jean-Paul Bravard:

Not at all. The results I have given you are semi-confidential; I succeeded in getting some of them, and part of the results are, in fact, my personal expectations. Unfortunately, Electricité de France is a very powerful public corporation that is very — you understand what I mean — secretive. But I know that they are anxious. They cannot say that they are anxious, facing the energy market in Europe. It's a competition between private companies now.

Sekou Toure:

I like very much Claudia's presentation on this notion of adaptive management. My question is: As we are discussing issues of water and climate-related types of impacts, is there a risk, or a danger, or can one be in conflict, in trying to balance out adaptive measures versus mitigation measures?

Because, sometimes, it would be easier to just waste time and bide time until moving into adaptive measures, when we know that there are some hard choices we have to make in terms of mitigation areas.

Claudia Pahl-Wostl:

I think that as far as climate change is concerned, it is evident that mitigation has to be a global effort, and adaptation is, at the moment, something you can do at the regional scale. But it would be very unfortunate if there was some mitigation that would really work on the cause of a problem and these two elements were actually played out against each other. But if it is properly addressed in the policy process, I would expect that this would not happen.

Alberto Garrido, Session Chair:

Okay, I'm told that we are at the end of the session. So please join me in thanking Claudia and Jean-Paul for their presentations.

SESSION THREE: Case Study Four

Henry Vaux, Chair, Rosenberg Forum:

We come now to the fourth and final case study of our fifth edition of the Biennial Rosenberg Forum, and this case study is different from anything we have done before. Our case studies before have always focused on a river basin or an area of a river basin. One of the things we have seen emerge throughout our discussion in the previous four Forums is the sense that the institutions and the way in which we govern our water resources are terribly important and that revising them and generating them from scratch is terribly difficult. This Case Study Four is our first case study of an institution, of a water-management institution, and we were fortunate enough to find a water-management institution that has an enormously successful record of achievement. The International Joint Commission, which has a Canadian section and a U.S. section, and was established in 1909 for the purpose of resolving boundary-water disputes between the United States and Canada, has had some 55 — and don't pin me to the exact number — disputes brought before it; 52 of those have been resolved with a unanimous vote among the six members. That struck us as quite extraordinary, and we felt that it would be important to share with you the record of success of one institution intended to manage boundary waters. And so that's what this case study will be about this afternoon.

We have a distinguished member of the Canadian Section, and the distinguished Chair of the U.S. Section to summarize their presentations for you. They were asked, in effect, to answer two questions: First of all, to acquaint you a little bit with the history and what the operations of the International Joint Commission are, so that we're all on the same page in terms of what it is, what it does and where it has been. And then, secondly, to make some effort to explain to us what factors account for this extraordinary record of success.

It is my pleasure now to present to you the first speaker, Canadian Commissioner Jack Blaney, who was appointed to the Canadian Section of the International Joint Commission in 2001. In a career spanning more than 40 years, Commissioner Blaney has compiled a distinguished and enviable record as an educator, and I think it's fun to realize that Commissioner Blaney began his career in education as a schoolteacher in Osoyoos, British Columbia. I just think that's a terrific way to start. From those beginnings, he moved on to higher education and served at the University of British Columbia and at Simon Fraser University. At these institutions, he held progressively more-responsible leadership and administrative positions. Ultimately, he became President of Simon Fraser University; so in a way, it can be said that Professor Blaney's career has touched all elements of education in our society. In addition to that, he has held important public leadership positions on the Fraser River Basin Council, and he was the Chair of the Citizens' Assembly on Electoral Reform; the fact that the Assembly got out a report and Commissioner Blaney is still here, alive and well, seems to me to speak highly of his talents. He is obviously the recipient of many honours. Will you join me in welcoming Commissioner Jack Blaney.

An Overview of the International Joint Commission

Jack P. Blaney,* Commissioner, Canadian Section, International Joint Commission, Ottawa, Ontario, Canada

I am very pleased to be attending this prestigious forum on Managing Upland Watersheds in an Era of Global Change. The Forum provides an excellent opportunity to exchange views on matters of increasing importance to all of us.

As a Commissioner appointed to the International Joint Commission of Canada and the United States, I am particularly pleased to have been asked to provide an overview of the Commission as an introduction to the fourth case study on Lessons in the Successful Management of International Waters. My colleague Dennis Schornack will then offer an analysis of the Commission's achievements, and the factors that have led to its successes.

It is particularly fitting to be focusing on the IJC at a forum in Banff, not only because we are relatively close to the Canada−United States border, but because we are very close to the site of one of the disputes that led to the negotiation of the Boundary Waters Treaty, which in turn created the International Joint Commission.

Although Canada and the United States are water-rich countries, this is not the case in the border region of Alberta, Saskatchewan and Montana. At the beginning of the 20th century, there was a very real threat of hostilities between settlers in Canada and the United States over use of the St. Mary and Milk rivers for irrigation. These rivers rise in the foothills of the Rocky Mountains in Montana and flow across the international border into Canada. The Milk River then re-enters the United States, where it joins the Missouri and Mississippi rivers and eventually flows into the Gulf of Mexico. The St. Mary River, on the other hand, joins the Saskatchewan River system, which flows into Hudson Bay.

Despite a shortage of water and strong competing claims in both countries, Canada and the United States were able to agree on provisions in the Boundary Waters Treaty of 1909 to settle their differences peacefully over the use of the St. Mary and Milk rivers (and over the use of the Niagara River between Lake Erie and Lake Ontario). These were the only two specific issues dealt with in the treaty. However, the St. Mary and Milk rivers have remained a source of controversy to this day.

The real importance of the Boundary Waters Treaty is that it created a comprehensive, rules-based regime with an effective dispute-avoidance and -settlement mechanism that has worked to prevent and resolve transboundary water disputes between Canada and the United States for almost 100 years. This regime has effectively dispelled the old adage often referred to in western North America that says: "Whiskey is for drinking; but water is for fighting." Instead, transboundary water disputes between Canada and the United States have been dealt with peacefully and, for the most part, amicably by pursuing the common good of both countries. (The Treaty has also been used to deal with air issues, starting in 1928 when the Trail smelter investigation was referred to the International Joint Commission.)

* I want to recognize the substantial contributions of Michael Vechsler to this paper.

The basic purpose of the Boundary Waters Treaty is to avoid or resolve disputes between Canada and the United States over waters that run along or across the international boundary. The preamble to the Treaty reads:

> The United States of America and His Majesty the King … being equally desirous to prevent disputes regarding the use of boundary waters and to settle all questions which are now pending between the United States and the Dominion of Canada involving the rights, obligations, or interests of either in relation to the other or to the inhabitants of the other, along their common frontier, and to make provision for the adjustment and settlement of all such questions as may hereafter arise, have resolved to conclude a treaty in furtherance of these ends….

Much of the Treaty negotiation on the Canadian side was carried out, not by the then U.K. ambassador — (later Lord) James Bryce — but by a Canadian lawyer based in London, Ontario — George Gibbons. On the U.S. side, Chandler Anderson helped Secretary of State Elihu Root develop Treaty texts.

In essence, the two countries wanted to settle two outstanding problems and to put in place mechanisms that would resolve future disputes.

The Treaty also created a unique international institution — a dispute-avoidance and dispute-settlement mechanism applied by the International Joint Commission of Canada and the United States (IJC) — to help the two national governments achieve the treaty's objectives.

The Boundary Waters Treaty is worded and applied, and the Commission operates, on the basis of absolute equality between the two countries. This may be considered remarkable given the disparity in size of their populations and economies — the United States being ten times the size of Canada in both its population and its economy.

The Commission has six members: three appointed by the United States and three by Canada. All Commissioners have equal authority and power. The Commission's Rules of Procedure (Rule 2) require that two Chairs, one for the Canadian Section and one for the U.S. Section, be appointed by the Commissioners of each section. However, in practice, the governments have selected who will serve as Chairs.

The U.S. Commissioners are appointed at the highest level in the U.S. federal government — that is, by the President with the concurrence of the Senate. Their Canadian counterparts are likewise appointed by the highest level in the Canadian federal government, the Governor-in-Council (the Cabinet).

The Treaty allows decisions by a majority of Commissioners, and the Commission's rules require that at least four Commissioners concur in any decision, so as to ensure that all decisions have the support of at least one Commissioner from each country. In fact, in current practice, the Commissioners usually reach decisions by consensus.

The Commission has dealt with almost 100 matters since its inception in 1911. Over that time, it has divided formally along national lines on only two occasions. And both occasions involved the arid western region.

Unlike many other international organizations, Commissioners do not formally represent their countries. Instead, on appointment, each Commissioner signs a declaration, based on Article XII of the Treaty, which states: "Each Commissioner … shall … make and subscribe a solemn declaration in writing that he will faithfully and impartially perform the duties imposed upon him under this treaty." The everyday application of this declaration is that Commissioners feel obliged to act in the best interests of both countries.

As already mentioned, the Boundary Waters Treaty created a comprehensive, rules-based regime for dealing with transboundary water issues between Canada and the United States.

Article I sets out rights to navigation of the ships and citizens of the two countries. Article II deals with jurisdiction and control over the use and diversion of waters that subsequently flow across the boundary or into boundary waters. Articles III and IV set out requirements for binational approval — either by the governments or the IJC — (1) for certain projects in boundary waters which would affect levels or flows in the other country, and (2) for certain projects in transboundary rivers or in waters flowing from boundary waters which would raise levels across the boundary in the upstream country. In cases where the IJC is asked to provide approval, the Commission must follow certain principles that have been agreed to by Canada and the United States as set out in Article VIII. These include that each country shall have equal and similar rights in the use of boundary waters on its own side of the border; that an order of precedence shall be observed among municipal, navigation, power and irrigation uses; and that, where obstructions in one country will raise the natural level in the other country, the IJC "shall require, as a condition of its approval thereof, that suitable and adequate provision, approved by it, be made for the protection and indemnity of all interests on the other side of the line which may be injured thereby."

Article IV of the Treaty also contains one of the most fundamental and far-reaching principles that governs water relations between Canada and the United States. In a clear, straightforward and unqualified sentence, the two countries agree that boundary waters and waters flowing across the boundary must not be polluted in either country to the injury of health or property in the other country. The environmental consequences of this declaration are remarkably prescient, and it took international law some time to catch up with the intent and purpose of this article.

The International Joint Commission is the key mechanism established by the Treaty to avoid and resolve disputes between the two countries over water and other transboundary environmental issues.

The treaty gives the Commission a number of responsibilities. First, it must respond to "references" — formal requests from the two national governments to look into a specific matter or problem along the border and to make findings and recommendations for action by the two governments to resolve the problem. (Although these references have usually been related to transboundary water and air issues, they can, in fact, be directed to any matter or problem along the border. In one instance, the Commission was asked to look at social and economic issues concerning Point Roberts, a small community that is part of Washington state but that can be reached by land only by going through British Columbia.)

Reports on references are not regarded as decisions and do not have the status or character of arbitral awards. However IJC reports are also released to the public at the same time as they are submitted to the two governments, and the force of public opinion can often be brought to bear in support of the Commission's recommendations. Also, by custom, the direction to the IJC to undertake a reference comes from both governments in the same terms, and at the same time. There is therefore an implied obligation on the part of both governments to provide the Commission with the resources it needs to carry out the reference, and to deal with the Commission's report in a responsive way. A high percentage of IJC recommendations have been acted upon by the two governments.

In addition to being asked to address specific problems, the Commission also receives long-term, permanent references from the two governments. These include requests to assist and oversee the way in which the governments carry out certain other international agreements between themselves. This is done in the Great Lakes Water Quality Agreement and in the International Air Quality Agreement. I will speak further about these permanent references in a few minutes.

The Treaty does provide, in Article X, for the governments to refer matters to the Commission for a binding arbitral award. Such references, however, require the concurrence of the U.S. Senate and the Canadian Governor-General-in-Council. No references under Article X have ever been given to the Commission.

As mentioned earlier, the Commission makes decisions on applications for approval to build certain structures in boundary waters, in waters flowing from boundary waters, and in transboundary rivers. Such applications for structures are submitted to the Commission through the government of the country in whose territory the project will be built. That government makes an initial determination as to whether binational approval is required under the Treaty and, if so, as to whether the IJC will be asked to approve the project or whether the project should be approved by a special agreement between the two governments. The apportionment of water under these IJC control orders (Orders of Approval) has obvious economic, environmental and social impacts. In these cases, the Commission can decide to allow the application, to deny it, or to allow it with conditions; the latter is usually what has happened. If an Order of Approval with conditions is made, the IJC then sets up an international control body (Board of Control) to oversee its implementation.

As a matter of practice, and consistent with the spirit of the Treaty, the Commission requires that all its boards and other advisory bodies be made up of an equal number of members from Canada and the United States. Further, these members serve the Commission in their personal and professional capacities and not as representatives of their governments, employers or other institutions. Most members are drawn from various levels of government or from universities. There are obvious benefits to be gained from having officials from both countries work out solutions to binational issues in the impartial atmosphere of an IJC board. The Commission, in turn, makes recommendations to governments; if the governments decide to act on them, the governments may call on the same officials to implement those recommendations. The boards play a vital role in joint fact-finding, which serves as the basis for building consensus at all levels.

The IJC has 15 such control bodies along the entire U.S.-Canada boundary. They govern the operation of dams on the Columbia, Okanogan and Kootenay rivers in Washington state and British Columbia, and on the St. Croix and St. John rivers in New Brunswick and Maine. They are also responsible for overseeing the operation of structures on the St. Mary's River at Sault Ste. Marie which control the outflows from Lake Superior into Lakes Michigan, Huron and Erie, and the operation of works in the international section of the St. Lawrence River — near Cornwall and Massena — which control the outflows from Lake Ontario. (The IJC also has a control board that oversees flows in the Niagara River, but it does so under a reference under Article IX rather than pursuant to an Order of Approval under Articles III and VIII.)

In a few cases, the governments have concluded special agreements such as the 1950 Niagara River Diversion Treaty and the 1964 Columbia River Treaty, which, in effect, establish special regimes for those rivers which supersede the general provisions of the Boundary Waters Treaty.

Even in these cases, however, the governments have often turned to the IJC for advice in developing. and implementing these special agreements.

There is no appeal from the Commission's decisions on Orders of Approval. However, the IJC may review and amend its own Orders, either on its own initiative or in response to an outside request. In 1997, the Commission informed the governments that because many of its Orders of Approval have been in place for a very long time, it intends to review all its Orders systematically as circumstances permit.

A special IJC study board has just completed a five-year examination of the Lake Ontario and St. Lawrence River systems to see whether the Commission's existing control order should be modified to take into account factors — such as the environment and recreational boating — that were either not considered or have changed since the Commission's Order of Approval was last amended in 1956. When the Commission receives the study board's report, it will consult governments and seek comments from interested members of the public before deciding whether to amend its existing Order of Approval. (Under Article XII of the Boundary Waters Treaty, the Commission is required to give all parties interested in a matter before it a "convenient opportunity to be heard", and the Commission must adopt rules of procedure that are "in accordance with justice and equity", as that phrase is understood in the two countries.)

The IJC is now just beginning a review of its control order at Sault Ste. Marie for the upper Great Lakes — Lakes Superior, Michigan, Huron and Erie.

The waters of the Great Lakes are one of the world's most precious natural assets. The quality of these waters is critical to the Great Lakes ecosystem and to the nearly 40 million people on both sides of the border who rely on it for drinking water, food, work and recreation.

In 1972, the Great Lakes Water Quality Agreement was signed by Canada and the United States in response to the growing concerns of the millions of people living around the lakes about the lakes' deterioration, and, more specifically, in response to IJC reports about their poor condition.

The 1972 agreement was replaced six years later by the current 1978 Great Lakes Water Quality Agreement, in which the two governments committed themselves "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem".

The Great Lakes Water Quality Agreement requires the IJC to assist the two governments in implementing the agreement. This includes making a major report at least every two years to the governments and to the public, assessing progress and providing advice and recommendations on how to achieve the agreement's objectives. Special reports on particular issues related to water quality may be issued at any time.

Significant progress has been made in restoring the lakes since the first Great Lakes Water Quality Agreement was signed in 1972. However, serious problems remain and new threats continue to emerge, such as new chemicals and pharmaceuticals, invasive species, and the effects of intensive agriculture and ongoing urbanization.

The agreement provides that every six years — after every third biennial report from the Commission — the two national governments must carry out a review of the agreement. The Commission's last biennial report, issued in September 2004, triggered the need for a new review by the governments, which is now underway. At the request of the governments, the Commission has held an extensive round of public meetings in the Great Lakes basin to obtain the views of the public, and it has passed these views on to the governments. The Commission is also in the process of preparing its own advice to governments.

The Commission has focused in recent years on the highly contentious issue of bulk removals of water from the Great Lakes Basin. In 1998, the IJC was called upon in a reference to report on whether the waters of the Great Lakes could sustain bulk diversions of water to locations beyond their basin, particularly to the United States. This reference followed an application to Ontario by the Nova Corporation in 1998 to export water by tanker from the Ontario side of Lake Superior. Although the Ontario licence for this export was later rescinded, the Nova application caused a great deal of public concern about other possible bulk water removals from the lakes.

The IJC issued an interim report in 1999 and a final report in 2000, entitled *The Protection of the Waters of the Great Lakes*. The IJC found that the Great Lakes are not a renewable resource and do not offer a vast reservoir for an increasingly thirsty world. The report noted that although the Great Lakes contain about 20% of the fresh water on the earth's surface, only 1% of this water is renewed each year from snowmelt and rain. If all interests in the basin are considered, there is never a "surplus" of water in the Great Lakes system. The Commission concluded in its 2000 report that existing international trade law obligations do not prevent Canada and the United States from taking measures to protect their water resources and to preserve the integrity of the Great Lakes Basin ecosystem. The Commission also concluded that removals of water from the basin reduce the resilience of the system and its capacity to cope with unpredictable stresses such as climate change. The Commission therefore recommended that governments take a number of specific measures to ensure that removals of water from the basin and consumptive uses in the basin will not endanger the integrity of the Great Lakes Basin ecosystem. The Commission confirmed these recommendations in a follow-up report in 2004.

The U.S. Congress had earlier passed the *Water Resources Development Act* of 1986, which said that no diversion is allowed from the lakes if the governor of any Great Lakes state objects, even if the project does not involve their state.

In 1999, Ontario enacted a water-taking and -transfer regulation that generally prohibits transfers out of Ontario's part of the Great Lakes and St. Lawrence basin. Quebec also generally prohibits transfers of water outside that province. In December 2002, the Canadian government proclaimed amendments to the *International Boundary Waters Treaty Act* (Bill C-6) and issued International Boundary Waters Regulations that prohibit new bulk removals from Canadian boundary waters, including the Great Lakes–St. Lawrence Basin.

On June 18, 2001, the eight U.S. Great Lakes states and the Canadian provinces of Ontario and Quebec concluded Annex 2001 to the 1985 Great Lakes Charter, a non-binding, good-faith arrangement among the Great Lakes states and provinces, designed to protect the lakes. After lengthy negotiations, the Great Lakes governors and premiers signed agreements on December 13, 2005, to implement the Annex and, with limited exceptions, to ban new diversions outside the Great Lakes–St. Lawrence River Basin. This water-resources agreement among the Great Lakes states and Ontario and Quebec will again be a non-binding, good-faith arrangement (because the states and provinces do not have the authority to conclude international treaties between themselves). However, the water-resources compact among the U.S. Great Lakes states alone will be binding under U.S. law. These agreements must still be implemented through state and provincial legislation, and the compact must also be approved by the U.S. Congress.

Although not expressly stated in the Boundary Waters Treaty, it has been recognized for some time that the Commission's inherent responsibility for preventing and resolving transboundary disputes requires it to alert governments to situations along the border which have the potential for transboundary conflict, so that early action can be taken to avoid or resolve such conflict. This can be one of the Commission's most valuable roles.

The duty to alert is explicit with respect to transboundary air issues. In 1966, the governments gave the IJC a reference that requested the Commission "to take note of air pollution problems in boundary areas … which may come to its attention from any source. If at any time the Commission considers it appropriate to do so, the Commission is invited to draw such problems to the attention of both Governments."

The Commission has also been given a number of other ongoing references that require it to look at air issues. These include a 1975 reference on the state of air quality in the Detroit-Windsor and Port Huron–Sarnia areas; a reference in the 1978 Great Lakes Water Quality Agreement with respect to reducing atmospheric deposition of toxic substances to the Great Lakes Basin ecosystem (Annex 15); and a reference in the 1991 Air Quality Agreement to invite public comments on progress reports and provide the governments with a synthesis of the public's views.

The Commission has come to clearly recognize that local people, given appropriate assistance, are best positioned to resolve local transboundary issues. The Commission also believes that effective trust-building and problem-solving capabilities at the local-watershed level will substantially prevent, reduce and perhaps eliminate the need to directly involve the two national governments or the IJC in a full, formal reference to resolve specific international watershed issues. In the Commission's view, creating such local solution-building capabilities will represent a significant investment in the management of the precious water resources that Canada and the United States share.

With these ideas in mind, the Commission reported to the governments in June of 2005, in *A Discussion Paper on the International Watersheds Initiative*, that the IJC's first priority under this initiative is to strengthen the watershed capabilities of its boards in the St. Croix, Rainy and Red river watersheds. The Commission expects that these watershed initiatives will be successful and that others will follow.

In conclusion, I would like to summarize what I have said by quoting from the Commission's Mission Statement, which captures succinctly the Commission's responsibilities. It says:

> The International Joint Commission prevents and resolves disputes between the United States of America and Canada under the 1909 Boundary Waters Treaty and pursues the common good of both countries as an independent and objective adviser to the two governments.
>
> In particular, the Commission rules upon applications for approval of projects affecting boundary or transboundary waters and may regulate the operation of these projects; it assists the two countries in the protection of the transboundary environment, including the implementation of the Great Lakes Water Quality Agreement and the improvement of transboundary air quality; and it alerts the governments to emerging issues along the boundary that may give rise to bilateral disputes.

In the words of one close observer: "An uncommonly good treaty."

Henry Vaux, Chair, Rosenberg Forum:

Our next speaker is the Chair of the U.S. Section of the International Joint Commission, Dennis Schornack, who was appointed to the Commission in 2002 and was simultaneously appointed to serve as the U.S. Boundary Commissioner for the northern border of the United States with Canada. His tenure with the IJC as Boundary Commissioner has been marked by his emergence as an international leader in a campaign to raise awareness about the problems of aquatic invasive species — and make no mistake about it, invasion by aquatic invasive species can be every bit as important, or even more important, as disputes over allocations and quantities of international water. I'm personally aware of an episode in the 1960s in which the aquatic ecosystem of the Great Lakes was essentially destroyed by the invasion of an aquatic species through the newly completed, at that time, Welland Canal; it's a terribly important topic. Mr. Schornack's appointment as U.S. leader of the IJC came at the end of a distinguished 25-year career at top levels of state government — in this case, the State of Michigan, where he served for half those years in senior positions supportive of Michigan Governor John Angler. Those positions included Senior Policy Advisor, Senior Advisor for Strategic Initiatives, and Director of the Office of Health Care Reform and Policy Development. Mr. Schornack also has a long record of leadership in the Great Lakes, being a leader in the development of Annex 201, which is an agreement between the eight Great Lakes states and two Canadian provinces to manage the Great Lakes water uses and diversion. Through a decade of leadership on the board of the Great Lakes Protection Fund, he pioneered efforts by the Great Lakes states to develop new technologies to stem the introduction of alien invasive species to the basin ecosystem and to restore natural hydrologic flows. Mr. Schornack was educated at Michigan State University and at my alma mater, the University of Michigan. He is, in addition to all of this, an avid trout fisherman and scuba diver. Would you join me in welcoming Chair Dennis Schornack.

The International Joint Commission: A Case Study in the Management of International Waters

The Honorable Dennis Schornack, Chair, U.S. Section, International Joint Commission, Washington, D.C., U.S.A.
John Nevin, Senior Adviser, U.S. Section, International Joint Commission, Washington, D.C., U.S.A.

Abstract
Created by the Boundary Waters Treaty of 1909, the International Joint Commission serves to prevent and resolve disputes relating to the use and quality of boundary waters and to advise Canada and the United States on related questions. The two governments have turned to the Commission on more than 100 occasions for assistance, including such issues as navigation and power generation in the St. Lawrence River, pollution in the Great Lakes, and apportionment of water in the St. Mary and Milk river watersheds. The IJC has largely been successful in its dual roles as regulator of projects that affect levels and flows on both sides of the boundary and as a non-binding advisor to the governments on controversial issues relating to both water quantity and quality. Several examples of the IJC's work are cited, including recommendations that have resulted in new treaties or binational agreement, resolving long-standing issues of concern between the two countries. Reasons for the success of the IJC are categorized into two types: first, those that are contextual and cannot be affected by the Commission; and second, those that are procedural and within their control. Contextual reasons include the provisions for equality in the Treaty; the importance of water; geography; the relatively comparable affluence of the parties; social, economic and cultural ties; and the fact that only two countries are involved, making consensus easier to achieve. Procedural reasons include the IJC's commitment to consensus; the binationally balanced, joint fact-finding process based on science; the independence of the Commission-appointed study teams; cross-border relationships built up over the years; the focus on public engagement; the skills and experience of the Commissioners; the ability to depoliticize issues out of the limelight; and the capacity to take the time needed to reach consensus without outside pressure. Under the right conditions, the IJC model may have the potential to work in other contexts.

Introduction

When you think of success and how it is achieved, the first step is defining success. Without a definition, you can't measure it and you won't know if you have achieved it or why. Sometimes defining success is easy. For example, in the corporate world, success might be defined in terms of market share or profits. To a politician, success might be defined as being elected to higher office, or making it onto "Meet the Press" or "The O'Reilly Factor".

In sports, for example, success is measured in games won and championships claimed. Recently, I was struck by the comments of a relief pitcher for a very successful Major League Baseball team. After just giving up a home run in the bottom of the ninth inning to lose a critical game against a key rival, he put it very simply. He said: "Sometimes you're the windshield and sometimes you're the bug." Measuring success couldn't be any simpler than that.

But in the case of the IJC, what is success and how do you measure it? What are the performance measures?

Is it the number of disputes averted? But if they never happened, how would you measure disputes that never happened?

Is the absence of complaints a measure of success? Indeed, to our knowledge, no one has ever advocated abolition of the IJC. That is certainly an indicator of success.

Does the fact that the U.S. and Canada have not gone to war — at least not while the IJC has existed — reflect success?

Is success measured by popular perception? As some say, perception is reality nowadays. And certainly, our very presence here today is evidence of a widely held public belief that the IJC is an extraordinarily successful transboundary organization.

But what is the reality? Is the IJC truly as successful as its reputation would have us believe? If so, what are the reasons for that success? And is the IJC model one that can be transferred or translated to other contexts?

Measuring the Success of the Commission

Not surprisingly, my fellow Commissioners and I believe that the IJC has been a resounding success. The best way to measure that success, I think, is in the context of our various functions, so let's look at them one at a time.

First, applications. As my colleague noted, our most concrete work is done in approving and regulating dams in boundary waters or in transboundary rivers to the benefit of people in both countries.

In this regard, the Commission has been quite successful. Since 1909, there have been 61 applications, of which 49 were approved. In six cases, no action was taken or a decision was deferred, usually at the request of the applicant. The balance were either withdrawn by the applicant or dismissed for technical reasons. In 40 cases, the IJC retained jurisdiction by creating a board of control to manage or oversee the particular structure or by assigning the work to an existing board. In the rest, no board was necessary.

These projects range from structures on the St. Mary's River which are managed by our International Lake Superior Board of Control, to the Grand Coulee Dam on the Columbia River, the third-largest hydroelectric dam in the world.

Second, references. Since 1909, there have been 57 references, on topics ranging from "Pollution of Boundary Waters" in 1912, to the Alburg-Swanton Bridge and Causeway and its impacts on water quality in Mississquoi Bay of Lake Champlain in 2005.

As you might imagine, given the advanced stage of development in the transboundary region, the number of applications that might have an impact on levels and flows on the other side has declined steadily over the years. In fact, there has been only one such application since 1990 and there have not been many applications since the 1960s. On the other hand, the number of references seems to ebb and flow with the times, reaching a peak in the 1960s and '70s when the environmental movement was growing and concerns over water levels were also high.

Looking at both applications and references, over more than 118 "dockets", the Commission has rarely failed to reach agreement — that is, at least four of the six Commissioners willing to sign their names to a record of decision. Indeed, over nearly 100 years, the Commission has only divided along national lines and submitted separate reports to governments in two instances. Both relate to the same dispute: the apportionment of the St. Mary and Milk rivers and the related Waterton and Belly rivers.

The dispute over the allocation of the St. Mary and Milk rivers — shared by Montana, Alberta and Saskatchewan — was one of the original reasons the U.S. and Canada signed the Boundary Waters Treaty in 1909. Article VI of the Treaty sets out how the water was to be apportioned, but it was not until 1921 that the IJC issued orders to put that provision into effect. The state of Montana and the U.S. government have from time to time objected to the fairness of the order, most notably in 1927 when the U.S. asked that the order be reopened. Canadian Commissioners did not concur and separate reports were submitted to the governments. Furthermore, a related 1948 reference to study the use and apportionment of the Waterton and Belly rivers again resulted in division of the Commission along national lines and submission of separate reports. The controversy over the allocation of the St. Mary and the Milk continues to this day, though some argue that the IJC orders have at least provided some certainty and allowed the parties the ability to know their allocation of water and to plan accordingly.

It is interesting to note the adjudicatory function provided to the Commission in Article X, in which the two governments can refer questions for a binding decision, has never been used. Apparently, this is one tool in the Canada-U.S. tool box that the two countries have not found useful. On some occasions, they have chosen to avoid the IJC altogether, signing treaties that create other arbitral bodies. Even so, the parties have consistently turned to the IJC to address some of the thorniest issues that have arisen over the past century.

Everyone is familiar with the old adage regarding the three most important factors in valuing real estate: location, location, location. When it comes to determining the success of the IJC, the three most important factors are timing, timing, timing. A perfect example of this was a reference to the Commission in 1920 to study the potential for improving the St. Lawrence River between Lake Ontario and Montreal for deepwater navigation and power generation.

In response to IJC recommendations, in 1932, the U.S. and Canada signed the Great Lakes St. Lawrence Deep Waterway Treaty, also known as the Hoover-Bennett Treaty. However, in 1934 the treaty was defeated in the U.S. Senate and in 1941 an agreement for development of navigation and power in the Great Lakes–St. Lawrence Basin was signed by the two countries but not approved by the U.S. Congress. Clearly, the timing was not right; but after World War II, conditions changed and the project gained new life.

This time around, the issues were broken into three parts. First, the Niagara Treaty of 1950 set the minimum amount of water that flows over Niagara Falls at different times, and the IJC was given a reference to investigate and make recommendations concerning the nature and design of remedial works necessary to enhance the beauty of Niagara Falls while at the same time permitting the production of added power. Second, in 1952, application was made to the IJC by both governments for approval of works to generate electric power in the international section of the St. Lawrence River. And third, governments enacted legislation and entered into an agreement to construct the St. Lawrence Seaway through an exchange of diplomatic notes. Construction of the Moses-Saunders Dam was completed in 1958, and the Seaway was completed in 1959. All in all, the two projects employed 25,000 people and cost more than one billion dollars. The IJC continues to maintain a control order on the dam.

Focus on Results: Examples

As the foregoing example proves, the IJC has played a critical role in the development of transboundary regions. The results of the Commission's work evaluating and approving applications can be seen in walls of concrete, rivers diverted and reservoirs created. However, with respect to references, what have been the results? Have our recommendations been implemented?

In this regard, it must be remembered that the IJC does not have the authority to implement its recommendations. The IJC is not a program manager or a regulator for references, simply a recommender and advisor to the governments. The responsibility for implementation belongs to the governments of the U.S. and Canada, so it is somewhat unfair to judge the Commission based on the action or inaction of the two governments.

To my knowledge, a comprehensive assessment of the status of IJC recommendations has not been attempted, and maybe that assessment should be part of an overall look at the work of the IJC as we approach our 100th anniversary in 2009. Sounds to me like a great project for a hungry graduate student with an interest in transboundary water issues. Lacking that analysis, however, the anecdotal evidence seems to indicate a solid record of success. In addition, when we have assessed implementation efforts in specific cases, i.e. our recommendations regarding flooding of the Red River, the outcomes have been generally positive.

Other examples include the IJC's very first reference — on levels in Lake of the Woods — which resulted in a consensus report and recommendations in 1917. In response, the U.S. and Canada signed a treaty, known as the 1925 Lake of the Woods Convention and Protocol, which established elevation and discharge requirements for regulating Lake of the Woods, based on IJC recommendations. Another controversial issue resolved by the IJC involved the apportionment of the Souris River — shared by North Dakota, Saskatchewan and Manitoba. Responding to a 1940 reference, the IJC provided recommendations in 1941 that were implemented by the governments, as were further revisions in 1958, 1992 and 2000.

A capstone achievement of the IJC was our report to the governments in response to their reference in 1964 on "Pollution of the Lower Great Lakes". The Commission recommended urgent remedial action to arrest the degradation of Lakes Erie and Ontario and the international section of the St. Lawrence River. We also recommended that the governments work together to set water-quality objectives and to authorize the IJC to serve as a "watchdog" to monitor the effectiveness of government efforts to clean up the lakes. To implement these recommendations, President Nixon and Prime Minister Trudeau signed the Great Lakes Water Quality Agreement in 1972. Again, the times were right, and the Agreement coincided with a whole range of other environmental measures in both countries, including the *U.S. Clean Water Act*.

The success of the Agreement makes it a landmark in transboundary water co-operation and management. For example, it has resulted in steps by the governments of the U.S. and Canada to stop direct point-source inputs of pollutants into the Great Lakes and has worked to stop and reverse eutrophication. And the Agreement has worked to encourage the two countries to work together to protect their shared waters. I should note, however, that the Agreement was replaced by the governments in 1978, then subsequently updated in 1983 and 1987, but has not been revised since. Substantial gains in water quality made in the 1970s and '80s have slowed, and new threats — such as invasive species — have emerged. In this regard, the IJC will soon be providing advice to the governments on the review of the Agreement, providing some ideas on what a new water-quality pact should look like.

Much like the previously cited story of the St. Lawrence Seaway, I must mention a notable example in which the timing for the IJC's involvement just wasn't right. For example, from 1913 to '14, the IJC undertook what might be the largest water-quality study in human history, sampling boundary waters from Montana to Maine and Saskatchewan to New Brunswick. Nearly 1500 sites were sampled, and 17 laboratories were installed to analyze the nearly 18,000 samples. The study found that water supplies in the Detroit River, the Lower Niagara, the St. John River, the Rainy River and Lakes Erie and Ontario had the highest levels of bacterial contamination, making the water unfit to drink even with treatment. The science was flawless and the recommendations were visionary and far-reaching.

The recommendations of the 1914 Report were the following:

- Install collection and treatment facilities for waste.
  - Treatment of sewage before discharge
  - Fine screening or sedimentation + disinfection
- Disinfect vessel sewage.
- Develop regulations for protecting water intakes.
- Prohibit discharge of garbage and sawmill waste.
- Restrict discharge of industrial and other waste.

In 1920, at the request of the two governments, the IJC even submitted a draft treaty for implementing its recommendation. The treaty transformed the IJC from recommender to regulator and put it in charge of implementing a new, regulatory waste-water treatment regime on both sides of the border. The treaty was never signed, and it was not until after WWII that new references to the IJC finally resulted in the implementation of recommendations to address pollution in these boundary waters.

Were the IJC's 1920 recommendations ahead of their time, or did the IJC simply overreach? Today, such a transfer of domestic regulatory authority to an international body appears unthinkable and should be considered as a reflection of the idealism and progressivism of the times. We will never know if different, less bold recommendations for national action might have produced results sooner.

Some might consider that another example of the IJC overreaching was the reference in 1971 to investigate and recommend measures to improve the lifestyle of residents in Point Roberts, Washington. Residents of this community must travel through Canada to reach their homes, creating issues with the application of customs laws and regulations; delivery of health services; law enforcement; and electric and telephone service. Instead of answering the specific questions of the reference, the binational board set up by the IJC to study the issue recommended the creation of an international park system and the establishment of an international conservation and recreation area extending from Gabriola Island to Whidbey Island in the San Juan–Gulf Islands Archipelago, and from west to east from Vancouver Island to the mainland coast of Washington, including Point Roberts and its environs. The reaction to these recommendations was so negative that any further opportunities for co-operation to resolve the original issues were foreclosed and work on the reference was halted by the Commission in 1977.

By and large, however, despite some blemishes, the IJC's record is dominated by successful resolution of dozens of issues that could have poisoned relations between the U.S. and Canada.

Instead, the IJC has served as a vital link between the two countries, fostering good relations and promoting co-operation to the benefit of people on both sides of the border.

Reasons for Success

Having established, at least anecdotally, the success of the Commission, now we must delve into why it has been successful. In this regard, I divide the reasons into two basic camps: those that are contextual and beyond our control, and those that are procedural and within our control.

Contextual Reasons

First, let's look at context. On this front, the reason for the IJC's success is the nature of water itself. Water is life. Water is essential. For some, water is a gift from God — as we see, for example, in the Bible and the Torah, where it says in Deuteronomy: "For the Lord thy God bringeth thee into a good land, a land of brooks of water, of fountains and depths that spring out of valleys and hills." And the Koran says: "We have created every living thing from water." It may even be that the existence of water helped to create the first communities as people organized to share it, carry it and use it. As Jerry Delli Priscoli (U.S. Army Corps of Engineers senior advisor on international water issues) has noted, "Indeed, water may actually be one of humanity's great learning grounds for building community."

Throughout the ages, people have learned to share water because there is no alternative. One might even say that when it comes to water, the imperative to consensus is virtually absolute. Indeed, the alternative is war. This realization leads me to agree with researchers who believe that water is not a source of conflict but a source of agreement. For example, as Yoffe and Wolf conclude:

> Accounts of conflict related to water indicate that only seven minor skirmishes have occurred in this century, and that no war has yet been fought over water. In contrast, 145 water-related treaties were signed in the same period. War over water seems neither strategically rational, hydrographically effective, nor economically viable. Shared interests along a waterway seem to consistently outweigh water's conflict-inducing characteristics. Furthermore, once cooperative water regimes are established through treaties, they turn out to be impressively resilient over time, even between otherwise hostile riparians, and even as conflict is waged over other issues. (Yoffe, S., and A. Wolf. 1999. Water, conflict and cooperation: geographical perspectives. *Cambridge Review of International Affairs* 12, 2: 197−213.)

So in our case, the resilience of the Boundary Waters Treaty of 1909 and the success of our Commission can in some measure be credited to the nature of water itself.

I should also note that related to this point is the volume of water involved. My point here is that it is much easier to manage abundance than scarcity. For example, the volume of the Great Lakes is in excess of six quadrillion gallons. Yet, even with the seeming abundance of water, reaching final agreement on a management regime for using or diverting Great Lakes water has still proven elusive. For example, it has taken governors and premiers more than five years to sign the Annex 2001 agreements, and it is expected to take at least that long for state and Congressional action to complete the deal. Such difficulty may be related to the fact that only one per cent of Great Lakes water is renewed each year. And in regions where scarcity is the norm — such as in the St. Mary and the Milk — conflict and controversy have bubbled for more than a century.

A third contextual reason for success is rooted in geography. Simply put, rivers run north and south. Along the U.S.-Canada boundary, many rivers flow north from the U.S. to Canada while others flow south from Canada to the U.S. — creating both upstream and downstream interests in both countries. At the same time, from the Great Lakes east, the international boundary cuts right through the lakes and ultimately along part of the St. Lawrence River, making both countries equally concerned about upstream and downstream interests.

You might call this geographical state of affairs a great example of "What goes around comes around." Since both countries have downstream and upstream interests, there is often an incentive to reach agreement; otherwise, an offending upstream party could face problems in another watershed in which they are the downstream interest. Or maybe the guiding principle here is the Golden Rule: Do unto others as you would have them do unto you. So when it comes to water, following the Golden Rule is a great impetus for agreement.

Next on our list of contextual reasons for our success in water management is success itself. What I mean is that both Canada and the U.S. have been successful economically, they can afford to invest in a wide range of measures to improve the management and conservation of the transboundary environment. Our countries are affluent, have advanced technologies and have the expertise and human resources to keep the environment clean or to manage problems when they arise.

The familiar inverted "U" of the Kuznets Curve can be adapted to an environmental context. As wealth, standards of living and economic development increase, so do pollution and the health concerns associated with it. But above a certain threshold, once basic needs are met and resources become available, society seeks to enhance environmental quality, pollution declines, and health improves. One might even argue that the inverted "U" is narrowed in free, democratic societies such as the U.S. and Canada where the public can demand investment in environmental protection. On the other hand, the inverted "U" is stretched in totalitarian systems such as the old Soviet Union or China today.

In more-specific terms, more-affluent nations can cook with natural gas rather than with wood or charcoal. Forests can be managed and replanted instead of simply cleared. Wealthy communities can recycle and reuse, and pay the costs of installing scrubbers and other pollution controls. And in the case of transboundary water, the important point is that the U.S. and Canada are at the same stage of development and thereby have similar abilities to invest in environmental protection.

The sixth contextual aspect also relates to the similarities between the U.S. and Canada. These are what might be called "the ties that bind". Our two nations share social, cultural and economic ties. And while some contend that U.S. values clash with Canadian values, on a very basic level we are certainly more similar than we are different. Indeed, with more than $1 billion in goods crossing our border each and every day, the economic incentives for co-operation are obvious and continue to grow. Other ties include binational associations of mayors, governors and premiers, as well as non-governmental organizations.

The seventh reason may make me sound like a numerologist, but bear with me here. When looking at systems of governance, numbers make a huge difference. My point is that the number 2 inherently defines the notion of fairness and equality. Think of how we describe deals — fifty-fifty, even-handed, a marriage, etc. — when it comes to fairness, an equal division in half is the easiest way to get it done.

The bottom line is that if your operating rule is consensus, the bigger the number, the harder it is to reach agreement. At the IJC, with only two countries, we do everything in twos. This process may take longer because a balanced and deliberate process takes time, but like the venerable tortoise, we achieve results superior to possibly speedier alternatives. When there are three or more parties, however, reaching consensus is far more difficult. Larger numbers make fair decision making more complicated and even more time-consuming and have the potential to dilute results.

The eighth and final contextual piece is the Boundary Waters Treaty itself. The IJC's success is rooted in commonality of interests in shared waters, and these are explicitly stated in the Treaty. For example, the IJC's role in dam management (levels and flows) is done in accord with specified water-use priorities, in order of precedence: sanitation and drinking; navigation; and hydro power and irrigation. Over the years, the value of such clear direction is reflected in the fact that, to our knowledge, no decisions with respect to levels and flows have been successfully challenged in the courts of either country or even through the legislative process.

The Boundary Waters Treaty says "equal use", and certain uses are enumerated, but not all possible uses of shared waters are listed. For example, missing are uses of shared water for recreational swimming and boating, riparian enjoyment, and protection from floods — and, of course, conservation of the environment. Clear direction allows the IJC to benefit other uses only where enumerated ones are not significantly harmed. Indeed, Article VIII of the Treaty stipulates: "no use shall be permitted which tends materially to conflict with or restrain any other use which is given preference over it…." In this case, we need to assume that the drafters of the Treaty intended that uses not listed would certainly fall below those that are specified. In addition, the Commission must require, as a condition of its approval, provisions protecting and indemnifying all interests from damages that might result from changes in levels and flows.

Most importantly, the Treaty created our commission based on complete equality, despite the difference in population and in size of our economies. At the same time, while providing for equality, the Treaty also protects national sovereignty and the ability of the respective governments to make decisions affecting their side of the boundary. For example, Article II guarantees each side "exclusive jurisdiction and control over the use and diversion, whether temporary or permanent, of all waters on its own side of the line which in their natural channels would flow across the boundary or into boundary waters". It is only when such use or diversion results in injury on the other side, that rights arise on that side — rights equivalent to those if the injury were on the same side as the diversion. Setting this balance in the Treaty has been a key to its effectiveness. And though some believed the Treaty didn't go far enough and didn't give the IJC enough authority or jurisdiction, the IJC's first century has, by most measures, been a success.

Procedural Reasons

Turning from context that is out of our control to factors that we control, let's dive into how the IJC actually operates. First and foremost, I think the IJC's success lies in the imperative to reach consensus. While it may not be written into our rules of the procedure, we endeavour at all costs to avoid minority reports or "split decisions". Indeed, the Commission, as I have known it, never votes on questions before it. We collect information and discuss issues until consensus is reached. This may take a long time, but the result is worth the effort. I should also note that, prior to the current Commission, there have been minority reports on occasion, but these have not detracted from the effectiveness of the Commission.

Second, the process by which we reach consensus is vitally important. For example, in response to a reference from governments, we normally start by appointing a board or a task force to conduct joint fact-finding. This investigative body includes equal numbers from each country and also attempts to pull in officials from the various levels of government with interest in the field of study. This same composition of members holds for our control boards, which manage structures under the IJC's continuing jurisdiction, and for specialized work such as the allocation of water in the St. Mary and Milk rivers. In addition, both section offices of the IJC have liaisons to the boards, who work together to facilitate progress and help build consensus.

Joint fact-finding based on scientific analysis is the core method employed by the IJC, giving our recommendations weight and credibility. As part of the process, study-team members agree on what is to be measured, how it is to be measured, and for how long. Just as important is the ability to look over each other's shoulder, to review published literature and to benefit from experiences on both sides of the border. The result is one set of science-based facts, arrived at in an agreed-upon way.

Most typically, the experts who serve on IJC boards work for their respective governments and are highly respected in their fields. Yet they do not represent their governments. They serve in their personal and professional capacity as experts in a given field of study but not as government officials. This construct is sometimes hard to understand, and sometimes it is hard for such individuals to take off their hats as government officials and put on their hats as independent experts, but the IJC affords them this opportunity to put governmental interests aside. Similarly, non-governmental members do not represent their organizations, either.

Another benefit of this arrangement is that government officials, even though they are not serving in that capacity, bring to the table knowledge and experience regarding the kinds of recommendations that will realistically be implemented by their governments. This "reality check" helps to ground the recommendations that the Commission itself ultimately submits to the governments, and enhances the prospect for their implementation.

All along the boundary, IJC control boards create a mechanism by which issues can be addressed binationally at the local and regional levels. Over time, and with a very small investment, much is accomplished through these boards. When issues arise, board counterparts are able to pick up the phone and call someone they know in the other country. The issues may not even be within the specific jurisdiction of the board, but the personal connection is more important.

A third factor within our control is the IJC's commitment to engage the public. The Boundary Waters Treaty affords "all interested parties a convenient opportunity to be heard". In this regard, once we have received a report from our board or study team, the Commission will hold hearings in order to hear from the public. Recently, we even held the first bilingual Web dialogue, in which 250 Great Lakes residents were able to offer their views, ask questions and interact with various experts with full translation in near real-time.

Fourth, and I say this with all modesty, are the skills and experience that Commissioners bring to the table. Indeed, presidents and prime ministers choose Commissioners because of their high level of confidence in them. Instead of feeling under the thumb of their governments, Commissioners are actually freed by this confidence to be independent. But let me be clear: independence does not necessarily mean that national interests will be disregarded or not considered; it means that decisions are made free of pressure from government interests.

The fifth controllable factor sometimes conflicts with the previous two, and that is the ability of the IJC to keep a low profile — to fly under the radar. Our work and the work of our study teams is conducted in drab conference rooms and workshops, not under the glare of the media. This is not to say that Commissioners shun publicity, but we only seek it to raise the awareness of the public about critical water-quality and water-quantity issues. Our Commissioners are not running for any office and do not seek the limelight. This approach, which focuses on depoliticizing issues, encourages the development of consensus, prevents positions from hardening and gives the governments the opportunity to accept and implement the recommendations of the Commission on its own terms.

The sixth factor is the ability of the Commission to take its time. The value of being deliberate and setting your own timetable cannot be discounted. But when asked to be expeditious, the IJC has been able to respond to the needs of governments, completing references within a specified time frame. For example, our latest reference — to solicit public comment on the review of the Great Lakes Water Quality Agreement — was completed on time in about six months and included comments from more than 4100 people.

In the past, the process for completing study and reaching agreement has taken several years. Sometimes, conditions have changed and the question being addressed is no longer an issue. But in others, the passage of time allows for positions to soften, for science to provide new evidence and for political and other pressures to ease. As I noted earlier, timing is everything. Currently, though, references are typically concluded within a year, and we are committed to expeditious consideration of any future references.

Finally, the IJC is successful because we don't have to address every problem. Indeed, under the Treaty, governments retain the right to resolve disputes between themselves. This is a right they exercise on occasion simply with an exchange of diplomatic notes — with examples including the construction of the St. Lawrence Seaway; and, most recently, an agreement for a Canadian company to pay $20 million for a U.S., EPA-led study of heavy-metal pollution in the Columbia River and Lake Roosevelt in Washington state. Such notes might even expand the role of the IJC, as did recent notes giving the IJC additional responsibilities in the Souris River.

This is another example of the power of two, because such deal making is much easier between two countries than it is among three or more. Over the years, many issues have been settled this way without engaging the IJC; at the same time, however, the very existence of the IJC facilitates such resolutions because the parties want to avoid elevating the issue to the Commission.

Conclusion

Is the IJC model transferable to other contexts — to the Middle East or to the African Great Lakes? Based on the preceding analysis, you can certainly surmise that I believe the IJC is not a model for everyone. Not every treaty can be born to be successful the way the Boundary Waters Treaty has been. In particular, as I have noted, consensus is much more difficult with three or more parties, and the realities of geography can usually trump any particular process that is successful elsewhere. But given the right circumstances, I do believe strongly that the processes I have outlined here can work.

For example, a new agreement regarding the sustainable development of Lake Victoria was recently signed by the governments of Tanzania, Kenya and Uganda. The pact creates the Lake Victoria Basin Commission, which could serve in a similar capacity there as the IJC does here. These developments hold great promise, and the IJC is investigating ways to help the Lake Victoria Basin Commission find its own path to success.

Looking forward to the IJC's second century, how do we maintain our record of success? I believe that the key is thinking small and local, watershed by watershed, strengthening local capacity to address and resolve issues. Our success or failure in the future will depend on how well we pursue this agenda — that is, we can avoid issues reaching our desk by helping local bodies solve problems at the early stages before they become full-blown international disputes.

For the IJC, this watershed initiative is a new approach to dispute prevention. If we are successful, it will mean fewer references to the Commission; that's good, however, because it means that problems are resolved before they boil over and demand national and international attention. This new, preventive approach is important, because all disputes are local in nature, and so is the capacity to resolve them.

Henry Vaux, Chair, Rosenberg Forum:

Now we have time for open discussion.

Pieter Heyns:

I've now heard a lot about the tricks of the trade, both in cases where you only have two countries in a commission, and where some commissions face other difficulties, as in the Danube. In the Okavango basin, we have what we call a basin-wide forum that comprises people at the grassroots level. The statement was made that people have national interests but connect with the basin. And we have had this experience with the grassroots people, where they are — let's call it — a mini-commission. There are language differences, they discuss issues at the grassroots level, across the borders between themselves, and then they have access to the commission and they can sit in on commission meetings; they also have an opportunity, through their chief, to address the issues that concern them to the commission. Now, we see that they have taken two possible avenues: in each country, you have a political system where the wishes of the people can be brought to the attention of each government, but then at the commission level, these concerns are brought collectively to the commission, and because the commission has a system of informing the governments, it is made sure that all the governments also take note of the grassroots requirements of the people in the other countries. Thank you.

Prachoom Chomchai:

Having seen the IJC in black and white, I feel very happy and privileged to see it in the flesh. In the face of Commissioner Schornack's and Commissioner Blaney's convincing exposés, I hesitate to intervene, but I want to make just a few points. The first one is that, coming from the Third World, we see here two affluent economies running a very advanced river-basin organization with lots of money to spend. We feel that in areas like the Mekong, we cannot afford such machinery; and in fact if we cannot afford it, we may end up having to wait until there is a crisis. So, for many of us, I think, machinery like this, and studies and so on, are a luxury we can ill afford.

And let me turn to something else, in the context of the Mekong Committee. We started in 1957; our model was not the IJC but the TVA [Tennessee Valley Authority], transplanted to Southeast Asia. I think two points emerged from that experience. First, political will: Are the governments willing to give the committee the political power to work things out? Are they willing to give it supranational authority, or simply a pseudo-political sort of authority? The second point is the spirit of co-operation. There has been in the Mekong context a lot of give-and-take; the spirit is known as the Mekong spirit, and it has filtered upward and downward. Thank you very much.

David Schindler:

I have a question for the Commissioners. I agree with much of what has been said, but the Commission's net isn't 100 per cent. I say this as a citizen of both Canada and the U.S. There are some cases that don't get referred to the IJC. Probably my pet peeve is the one you're going to visit tomorrow, the Columbia, where ecological damage was not even considered — and the ecological damage was huge. Second is the recent one, where the U.S. took unilateral action in the Devils Lake Diversion, sending it across into Canada. No reference to the IJC. And I hear that two more are on the table, with good rumour that there will be Great Lakes water shipped to South Dakota and that there might be another extension to Devils Lake which would effectively connect the

Missouri system with the system we're sitting in right now. And I wondered if any of you have any ideas of how we can improve the political net so that *all* of the cases, not just the politically insensitive ones, go to the IJC.

Henry Vaux, Chair, Rosenberg Forum:

Jack, do you want to respond?

Jack Blaney, Commissioner, Canadian Section, IJC:

Well, I'm going to respond, but I want to point out that we have four Commissioners also in the audience — Irene Brooks, Allen Olson, Robert Gourd and Herb Gray — and Herb Gray seems to be quite anxious to respond to this one, so I'm going to let him do it.

The Right Honourable Herb Gray, Chair, Canadian Section, IJC:

I'm not anxious, but I'm delighted to be given the opportunity. Moving very quickly, it's true that references to the IJC have to come from the governments, and if people come to us and say, please look into this, we do bring the matter to the attention of the governments and express our views to them — not publicly, necessarily — about references. Now, about the specific cases mentioned by Dr. Schindler. I don't know what will happen at this point with respect to the issue of pollution of the Columbia; I guess it's by the Teck Cominco people in Canada. The present approach is that both B.C. and the adjacent American state want to try to resolve that under a non-binding agreement, so the story is not finished there. Second, with respect to Devils Lake, it turns out that there is nothing coming out of Devils Lake, because the North Dakota Health Department said that the level of sulphates is too high under their own rules, and the [undecipherable] isn't working. In the meantime, the Canadian and American governments reached an understanding, not to give a formal reference to the IJC but to ask it to carry out a monitoring role, and the terms and conditions are being finalized. Finally, with respect to water being shipped from the Great Lakes to North Dakota, this is contrary to both current Canadian and American law. There is an American act that says that if any Great Lakes governor objects to a removal from the Great Lakes, it can't happen, even if it's not from his state; and there's federal and provincial law in Canada dealing with the Canadian side of the basin.

David Schindler:

Sorry to interrupt you, Mr. Gray, but it wasn't the Great Lakes I meant, it was Lake of the Woods.

The Right Honourable Herb Gray, Chair, Canadian Section, IJC:

When it comes to Lake of the Woods, it's my understanding that there's a separate convention between Canada and the U.S. which effectively would prevent water from being removed from Lake of the Woods for North Dakota. And to do that, by the way, even if there weren't a convention, it would have to be moved through pipelines or ditches across the adjacent American States, and I understand they aren't that interested in facilitating such a step.

Jack Blaney, Commissioner, Canadian Section, IJC:

I think we would all agree with Herb's responses. But it is a fair comment, by the way; people have made the claim that you have, Dr. Schindler — that there should be some other means by which issues could come to the International Joint Commission. You'll see some of this in the literature, in books about the Great Lakes Water Quality Agreement, or whatever. So some have raised that, and the governments, I think, or at least some of those in government, are aware of those suggestions, and I don't think that we're going to comment on that. But it's out there, and there are some cases where we wish that references had been given to us. On the other hand, as Mr. Gray has indicated, we sometimes very quietly alert the governments to various issues, and sometimes we have an effect that is almost equivalent to a reference.

The Honorable Dennis Schornack, Chair, U.S. Section, IJC:

As Dr. Schindler noted, our net is not 100 per cent, and in order for work to come to the Commission in the form of a reference, two governments do have to agree. In the specific case of Devils Lake, I'd like to add a little bit to what Chair Gray noted, and that is that the IJC is indeed playing a significant role in that dispute, where there is an attempt to have it resolved by the two governments in a quasi-diplomatic way. We have been asked to engage our joint fact-finding ability, our sort of core method, and develop a plan to monitor discharges — should they commence again from Devils Lake, if they can meet their sulphate standard in North Dakota — in order to assess pathogens and parasites and the possibility of those being transferred, of course, north into Lake Winnipeg. We've developed a plan through a joint task force, an Aquatic Ecosystem Health task force of the IJC, under the auspices of the Red River Board, and that plan is being implemented as we speak. So even though the governments attempted to sort of circumnavigate the IJC, they found they needed us, in the end. And you have to admit that for *two* governments, especially, to refer a matter to the IJC is tantamount to an admission that they were unable to resolve this diplomatically between themselves; so there is somewhat of a disincentive for elected officials to refer matters to the IJC.

To get to your specific question, though: Are there, or have there been discussed, other methods of invoking the IJC? I'm not going to say whether I support or oppose these methods, but some have talked about references coming to the IJC by way of public petition. That might be another way; it might save the governments some embarrassment of not being able to resolve it themselves and might further engage the public, which are generally the ones directly involved in the dispute, at the local level.

Davaa Basandorj:

Mongolia is the world's highest country, with an average elevation above sea level of about 1200 metres. In ancient times, Mongolians were very friendly to the environment; now, in the last ten years, the average temperature has increased by about 2°C, and 700 rivers have dried up, some small lakes and springs have dried up. This is the kind of impact there has been on the environment. On the other hand, we have had some impact on the human side. Water management is not so developed in Mongolia — Mongolia is a developing country. There are difficulties in policy implementation and policy planning, because policy implementation and policy planning require political commitment; politicians, if they have money, can decide the issue.

Last year we did a case study in the Tuul River basin, which covers an area of about 50,000 hectares. The Tuul River basin feeds into Lake Baykal, and there is pollution and a decrease in the river level, and negative impacts. Mongolia is sandwiched between China and Russia, as you know, and more than 200 rivers cross our boundary. There is a joint commission, China-Russia-Mongolia, which I chaired for a time, and we could not decide some kinds of issues with this commission. We understand that our designation of transboundary rivers means just surface water. I would like to ask: What is the decision for groundwater aquifers between Canada and the U.S.; how can you decide that issue?

The Honorable Dennis Schornack, Chair, U.S. Section, IJC:

Our treaty, the Boundary Waters Treaty, doesn't address groundwater; it's limited fairly strictly to surface water. But that much said, there is another provision in the Treaty which allows the International Joint Commission to address any matter the two governments might put before it, and that could include groundwater. We're aware of some cases along our boundary where groundwater may indeed be a serious concern. And it's certainly a serious concern on the U.S.-Mexico boundary. But in the Treaty itself, we're largely managing surface water.

Johannes Smienk:

I'm glad you brought that issue up, because I understand that there was an air-shed issue that was also referred to the IJC many years ago. The question I have is on revisiting orders: Does this require agreement by both countries? The reason I'm addressing that particular issue is because the First Nations have asked to have the order on Grand Coulee [Dam] revisited because salmon passage was not considered at the time. And I just want to also pass on some information — that as the representative of the two dams directly upstream from the Canadian border, behind Grand Coulee, we have built those projects with salmon passage in mind.

Jack Blaney, Commissioner, Canadian Section, IJC:

As I understand it, we have been approached by a First Nations group that asked us to revisit the order — or at least to provide some kind of mitigation — because, of course, the Grand Coulee Dam has not allowed salmon to travel the river up to British Columbia, as they once had done prior to a dam being constructed. That has been before us, and we've had advice on that one, and I believe that is still under consideration. We've had a public-comment period; anyone could have sent us advice or their views on this. We've also consulted the governments in terms of their views, but it's still under consideration.

Moneef Zou'bi:

Science, I think, is probably too important to be left to scientists alone, and policy is also too important to be left to politicians alone. Now, in the case of the International Joint Commission, for the lack of a better phrase, I think that we have a marriage of convenience, if you will, between the science and engineering elements and the policy. Clearly, we're looking at a success story. I think that of the elements mentioned by Mr. Schornack, I would underline independence as a key to the success of the Commission. To my mind, being independent of either government gives the Commission a great deal of strength. I think I would also add continuity. The Commission has been there for a hundred years, so clearly there is commitment on the part of both countries to have this commission succeed.

I wonder if the IJC has plans to share its experience with other similar set-ups around the world, such as perhaps the Mongolian one or some other commission, because I think we can learn a lot from the success of the IJC — more specifically, perhaps, in terms of providing training to potential commissioners, of providing best practice, or just sharing the experience of the IJC internationally.

The Honorable Dennis Schornack, Chair, U.S. Section, IJC:

Yes, we do. We do work very hard, I think, not only to manage domestically our matters between the two countries, but also to look externally. We participate, for example, in the World Water Forums; Chair Gray and I just returned from World Water Week in Stockholm; we've been to Africa and shared with the Lake Victoria Basin Commission our model, and we continue to work with them. And we're hoping, of course, that we get the opportunity to go to the Expo in 2008 and share our experience there as well.

Robert Gourd, Commissioner, Canadian Section, IJC:

I want to say that we are part of INBO, the International Network of Basin Organizations, which I've attended for the past five years. Even though we're a commission between the two countries and our funds are limited for those extra activities, we're willing to share our expertise. If people want to come to our office in either Ottawa or Washington, we're very much interested in sharing our experience. On the other hand, if you want to pay our travel expenses, we're willing to travel all over the world.

Governor Allen Olson, Commissioner, U.S. Section, IJC:

I'd like to comment on the most recent question. I believe that we're most successful in ensuring the credibility of the scientific findings because the scientific advisory panels are equally divided between the two countries and they operate under the same sort of independent auspices as does the Commission. So I think that this gives a certain level of credibility to the findings. And I think we're going to find that with Devils Lake; we have finally been able to be a part of that process, and we are presently empanelling the scientists who will work on that. They will be independent and they will be equally divided between the two countries.

Bob Sandford:

Thank you very much for your most enlightening presentation. The IJC has a remarkable history, and my question relates to that history. You've mentioned that local solution-building capacities are critical to dispute resolution. In 2014, it will become possible to begin reconsideration of the Columbia River Treaty. This treaty, while important as a means of establishing flood control and building hydro-power capacity, as was already mentioned, destroyed one of the largest and most culturally important salmon fisheries on this continent. The 1964 treaty only invited the most superficial local input, and First Nations were not consulted. My question is this: Will local solution-building capacity be granted any form of standing in the renegotiation of the 1964 treaty, and will the IJC be involved in deciding if and to what extent that voice will be heard?

Abdel Fattah Metawie:

I know how difficult and stressful it is to work on a commission; it is not an easy job. My question is: In the agreement, is there an article that describes the relation between the states in each country and the federal government, or is it between the two federal governments? Because sometimes the interests of one of the states might be different from those of the federal government.

The Honorable Dennis Schornack, Chair, U.S. Section, IJC:

We do operate under a treaty, and only the federal governments of Canada and the United States enter into treaties. That much said, the second agreement that Dr. Blaney mentioned and that others have mentioned here, the Great Lakes Water Quality Agreement, engages the eight states in the U.S. and two provinces in Canada; the IJC has worked there to establish a structure that in effect creates a forum for the environmental ministers in the provinces and the agency directors in the states to meet on a regular basis to exchange information and to learn from each other's successes and, indeed, from their failures. There has been some suggestion, and certainly within the Great Lakes Basin, where the Commission believes that the role of not just the states but municipalities is increasingly important; municipalities are largely in charge of waste-water treatment plants and water-distribution systems, and the runoff from hardened surfaces — city streets — is probably one of the largest sources of pollution to the Great Lakes these days. In our advice that we are now submitting to the two governments with respect to the revision of that agreement, we are encouraging that these mechanisms be pushed down to the state, and indeed the more local level involving municipalities.

The Right Honourable Herb Gray, Chair, Canadian Section, IJC:

I just want to add a gloss to what you said. The present treaty provides for a dispute-settlement mechanism to be run by the IJC; it has never been invoked since the treaty was signed. Second of all, the Boundary Waters Treaty says that if the two governments, through a separate agreement, decide to handle something bilaterally rather than sending it to the IJC for a decision and a control order, then the IJC will not receive an application. And that's what happened with the Columbia River Treaty: We had already been given the reference and made an order on the huge dam on the Columbia, which I think is the third-biggest in the world. But by the time they got to the Columbia, they decided to have the treaty, and they only involved us in the dispute-settlement mechanism. Now, as Chairman Schornack said, I'd be very surprised to learn that the State Department in the U.S. and the Foreign Affairs Department in Canada are directing their minds at this point to the Columbia River Treaty; they're basically, I think, focusing more on what Chairman Schornack mentioned — the updating and renewal of the Great Lakes Water Quality Agreement. But I'd like to publicly suggest to my colleagues and the two secretaries who are listening, to make a note of this; it would be interesting to find out if I'm right or wrong on whether work has begun on the review of the Columbia River Treaty, which was very contentious at the time it was signed.

Rathinasamy Saleth:

I'm so impressed that, since the morning, when we started with the Jordan River, and now ending with the International Joint Commission, it covers the whole range of conflicts between borders. But the most important thing from the perspective of upland water management is the conflict between economic and environmental considerations, which is between sectors. Actually, some kind of arrangement for dealing with that, which is basically intranational conflict, is an interesting and important area in which I am much interested.

Mordecai Shechter:

Reference was made to the first case study, the Jordan River, by Philip [Weller] and, I think, by Dennis [Schornack], and I would like to ask you the following question, although maybe it's hitting below the belt. We heard about the situation in the Jordan Valley with respect to water issues: the mere survival of people, the disappearance of entire ecological systems — things of that proportion. Now, I would like to hear your honest opinion — not advice of applying the IJC or the Danube procedures, but you are now in the role of Palestinians, Israelis, Jordanians — do you honestly believe that the systems you have instituted, which you so well described, both in Europe and here, would have worked there?

Henry Vaux, Chair, Rosenberg Forum:

That asks for a yes or no answer.

Unidentified IJC Commissioner:

I learned a long time ago never to give yes or no answers, but I certainly believe that some of the principles we operate under could be beneficially applied in the situation you've just described. I was personally rather stunned this morning to listen to the discussion on the Jordan and to understand the huge amount of sophistication, the mathematical modelling, the computerized distribution systems for irrigation, the sophisticated management of water in this water-scarce part of the world, but being done in a very unilateral fashion by either Jordan or Israel. And I was going to ask the question, but then we ran out of time in that session, about whether there had been any contemplation of extending the model that was developed for the upper Jordan, whether there has ever been a discussion of doing some joint modelling, some joint fact-finding and joint characterization of that basin, and whether that might leverage into joint decision making over some of the use of some of that resource. I think there are elements, but as I say, I don't believe that the IJC model works everywhere.

Philip Weller:

If I could just make a short response from my own experience in the Danube River basin. I would concur with what has just been said; I would point to the fact that in the Danube River basin, we had war in the mid-'90s where water was the first agreement that was reached among the conflicting parties, and it was the basis for an agreement — what's called the Sava River Agreement — between the former countries of Yugoslavia, where they used water as a basis of a building block for peace in that particular region.

Henry Vaux, Chair, Rosenberg Forum:

Let me ask you to join with me in thanking the panel for a series of very interesting presentations.

CONFERENCE SUMMARY

Henry Vaux, Chair, Rosenberg Forum:

Now we come to the end of our two days together, and we are fortunate to have my really good friend and colleague Peter Gleick to summarize this conference. Peter is the co-founder and president of the Pacific Institute for Studies in Development, Environment and Security, which is located in Oakland, California; it is a non-partisan policy-research group addressing global environmental and development issues, especially in the area of freshwater resources, and I expect that everybody in this room has probably at one time or another seen a report put out by Peter and his institute. Dr. Gleick's research and writing address the hydrologic impacts of climate change, sustainable water use, desalinization, privatization, globalization, and international conflicts over water resources. Peter Gleick is much honoured: in 2003, he was designated as a MacArthur Fellow, and this past spring he was elected a member of the U.S. National Academy of Sciences. Will you join me in welcoming Peter Gleick.

Peter Gleick:

Hello everybody, Honourable Ministers, Commissioners, colleagues. I'm very honoured to be here. Henry says I'm a friend; I'm not sure whether he's punishing me for something I've done in the past, by having me try and summarize the incredibly rich conversations and discussions and talks that we've had over the last couple of days. I'd like to start by adding my thanks to the many that you've heard already — to everyone involved in organizing the Forum; to Richard Rosenberg; to Henry, of course; to the staff of the Centre here; and to all of you, who've been very patient and tied into the conversations in a very, very active way.

It took me only a few hours, when I got here several days ago, to get into my first heated discussion with someone. For me, that's the sign of a good conference. I don't want to go to any more conferences where I agree with everybody; they're boring. And this *hasn't* been, in any sense of the word. I'm not going to try and summarize. This has been an incredibly rich conversation; you've heard the talks, you've read the papers, you've been sitting here quite patiently. What I'd like to do is try and do a little bit of synthesis, perhaps to distill out some of the ideas and some of the threads that we've heard, although I would note that in any distillation process — like, for example, desalination — you get some good things and you get some bad things. Hopefully, I'm going to give you the good things and not the bad ones.

Many global and national and local water problems are getting worse — either getting worse in scope or getting worse in magnitude. But, as was expressed very clearly early on, not all the news is bad; we've made enormous progress worldwide in a lot of things. I think it's also clear to everybody in this room, and everybody who has worked on water, that we need to make a lot more progress. I would also like to suggest that the world of water is undergoing a pretty fundamental transition; we're in the 21st century now — that was an interesting transition for many reasons — but along with that transition has come a whole set of new ideas in the way we think about water, for a number of reasons that I'll touch on.

I think we really have two major challenges. The first is to find new ways of tackling old problems. We entered the 21st century having solved many, many water problems, but with many water problems unsolved — some really big ones, as you all know. From my point of view, the biggest remains the fact that there are a billion people without access to clean drinking water and there are two and a half billion people or more without access to adequate sanitation services. We didn't solve that problem in the 20th century, and we'd better solve it now. And that's going to require old solutions applied more enthusiastically, but I think it's also going to require new thinking. But we also have some new problems. There are some new things coming along, ranging from new kinds of chemical contaminants in our water which we didn't recognize in the past, all the way up to things like global climate change. And that is going to require a new kind of effort and new kinds of solutions.

So, in trying to synthesize all that we've heard, I've put things into four themes. The first is that I think we need to move away from ideology and fixed ideas — and I'll come back to each of these briefly. We need to improve communication. We need to understand vulnerability and we need to manage risk, together. And we need to integrate; rather than addressing the problems in isolation, or offering solutions in isolation, I think it's increasingly clear that we need to integrate the kinds of thinking around water.

And so let me touch on each of these. Public versus private. Big debate in the water area: you go to international conferences, and it's the thing they're fighting about in the halls. Public versus private. The bright line of success for water systems — municipal water systems, waste-water treatment, water provision — is not whether it's public or private; that's the wrong idea. And so, if we can move away from the public-private, and we heard this a little bit earlier, then we can move forward.

Is water a human right, or is it an economic good? Well, I believe very, very strongly, and I've written about this, that water is a human right. I also believe that water is an economic good, and I don't think that's the bright line between success and failure in solving our water problems, either, and I think we heard that here pretty clearly. Let's respect the human-rights aspects of water, and let's treat water as an economic good where it's appropriate. And if we can integrate the two, we can address aspects of both.

It's a fundamental idea — taught to me as a hydrologist and an engineer when I was trained that way, taught in economics classes — that there's a very close tie between economic well-being and water use. I would like to argue that in fact the tight link between economic well-being and increasing water demand may not be so tight. And if that's the case, it opens up a whole new range of thinking and a whole new range of possibilities.

We also heard quite a bit of talk about challenging some other fundamental beliefs. The stationarity of climate. Again, I was trained as a hydrologist and I have an engineering degree as well, and I was taught in my classes how to design a big dam. The fundamental assumption behind those design classes is that climate is stationary. And if there's anything we heard during this session, it's that that fundamental assumption is no longer accurate. Climate is not stationary, and if we design our systems and manage our systems with that assumption, we may be making mistakes.

I probably shouldn't mention this, because this wasn't an energy meeting, but there was some discussion about energy and the connections with water, which were very important. There was a little bit of reference to tar sands, given where we are holding this meeting. And so I would just like to throw out a fundamental idea that we hear over and over again: that we're running out of oil, we don't have enough fossil fuels. Maybe another way to think about this is not that we don't have enough fossil fuels; maybe the problem facing us is that we have too many fossil fuels and that if we didn't have as many fossil fuels as we do, the transition to a non-fossil economy might occur faster and might permit us to address some of the environmental problems associated with that in a somewhat different way. Let me just throw that out there.

The broad issue of climate change is by itself challenging some fundamental beliefs. I truly believe that this isn't a Democratic or a Republican issue, it's not a Conservative or a Liberal issue — I think we heard quite clearly that there are certain aspects of the science that are very well understood — and that the debate about climate change really needs to shift to a debate not about the science but about the integration of science and policy, and I'll come back to that in the water area.

A graph of the gross national product of the United States from 1900 to 2000, shows what some economists love to see: exponential growth in the economy. A graph of total water withdrawals in the United States over the same period, shows in the first part of the century — up till about the late 1970s, early 1980s — that lockstep assumption that with economic growth and population growth comes increased demand for water. But in the 1980s, we split those two curves apart, and today the United States uses less water for everything than it used in 1980. On a per capita basis, it uses much less water for everything than it used in the 1980s. And that new idea — that we could break that link — I think has enormous ramifications for new thinking about water management and is worth pursuing to a much greater degree. I could talk for a long time about why these curves broke apart, but I just thought I'd mention it for now.

Improved communication. This is another great topic that's a favourite of mine. We've heard that scientists need to be better at communicating with policy-makers and that policy-makers need to be better about communicating with scientists and asking scientists for better information, or certain kinds of information. We all need to be better at communicating with the public. One could also say that the public needs to be better at communicating and being brought into the discussion about water issues with us.

Understanding vulnerabilities, managing risks. We heard very clearly from many, many people the special vulnerability of upland regions — or mountainous regions — to development, to external forces, to climate change. I would argue that the conclusions of many of the talks were very similar in identifying the kinds of vulnerabilities — particularly to climate change, where there are fewer uncertainties about the impacts of climate than in other parts of the world, because of the vulnerability of snow, of glaciers, of these regions to temperature. But I would like to also argue — and we heard this, again, in many of the sessions — that all areas have special vulnerabilities. The sessions could have been focused on lowland areas or coastal areas or semi-arid or arid areas; we're all vulnerable from the water point of view to development, to external forces, to climatic change. Just as all regions have special vulnerabilities, many speakers very clearly pointed out, I thought, that all regions also have special skills and special tools for managing those vulnerabilities; bringing an understanding of the vulnerabilities and an understanding of the ability to manage those vulnerabilities together was an important theme here. We could have focused on any one of the regions we talked about, we could have focused on any one of the vulnerabilities, and had much more detailed, much more enlightening conversations, but I though those were great.

The fourth one is this question of integration. I think this was in many ways the most important one. Sustainable water solutions inevitably come from a merging of approaches, and this, again, is a little bit different from what we did in the 20th century. There were different terms used: adaptive watershed management, integrated water resources management, interdisciplinary solution; the soft path was mentioned. All of these are a little bit different in the way that they are defined by different people; but all of them have the same idea, and that is that we can no longer manage our water resources in isolation: in isolation from energy or from food-policy questions or from land use — I'll come back to some of these — or in academic isolation. Unless we integrate — and all of these ideas have at their core the philosophy, the concept of integration — we're not going to come up with sustainable solutions. The positive way to say that is that we are learning to integrate, as we heard at this conference, and that's producing sustainable solutions.

Some ideas that came out of the conference: A more comprehensive view of hydrology. Blue water and green water, or however you wish to describe it — we can no longer deal just with surface water. Or, we can no longer deal just with surface water and groundwater. We now have to integrate the entire hydrologic cycle into our management. We can no longer develop models for planning three to ten years out; we need to develop models that are applicable and useful immediately.

Public versus private approaches. I've touched on it; it came up. Let's integrate: the best solutions take advantage of the public responsibility to protect water resources — the public-good aspects of water — and may adopt the efficiencies that the private sector may also offer.

Let's integrate political entities: nations, neighbours, competing uses. The last panel we heard is a great example of that, but there were many examples throughout of integration of the political aspects of water. We're not going to solve water problems unless we understand that piece of this.

Needs from other sectors. Water is not water by itself; water is tied to everything we care about — the way we produce and use energy, the way we produce food. It's tied to health, it's tied to natural ecosystems. Speaker after speaker touched on the need for that, in the developed-world context and in the developing-world context also.

Energy and water policy. It takes a lot of energy to do the things we want to do with water: to move water, to treat water, to clean water, to pump water, to heat water. The largest single consumer of power in California is the pumps required to pump the water over the Tehachapi Mountains from northern California into the Los Angeles basin; it's a fact. At the same time, it takes a tremendous amount of water to produce energy. The tar sands example came up because of our context here; it's true for heating and cooling, nuclear plants and fossil-fuel power plants. Understanding those links is critical.

Land, ecosystems and water. We can no longer manage water without thinking about land development or impacts on ecosystems, and this was described very clearly many times.

Let's integrate institutions and laws.

Let's integrate technology and non-technical solutions. I've done some writing about the soft path; that's something I believe in, but I would want to clarify that the soft path for water, the way I define it, does not mean no technology. It does not mean not building new dams. The soft path integrates technology with non-technical, non-structural aspects — with proper use of economics, with integration of ecological questions, with institutions and local communities. There are places around the world where new infrastructure is desperately needed, and integrating old expertise and old ideas with new ones has got to be part of this.

Integrate communities and local populations into decision making — a key factor. One of the things we heard about is that when things fail in the water-policy area, they often fail because we didn't involve communities in decision making. And conversely, to say it more positively, some of the most successful, really innovative things going on in the water area were designed by local communities.

So, in the end, I think it was pretty clear, from the wonderful conversations we've had, that there are solutions to water problems — that in fact there are smart things being implemented every day and that what we need to do is build on them. And that the successful solutions are going to be those that move beyond ideology and fixed ideas, that understand and manage vulnerabilities and risks, that integrate concepts rather than isolate concepts and that communicate results to policy-makers and to the public.

Finally, I wasn't asked for this, but I thought I would try and draw out some things that I heard about suggestions for future forums from speakers and from comments I've heard outside these sessions:

- Emphasize solutions not just problems; we understand the problem. Sometimes we focus on problems because sometimes the people we talk to *don't* fully understand the problems. But from a policy point of view, the emphasis on solutions may be more effective.
- Let's explore, in more detail, specific ideas of integration and interdisciplinary tools.
- Let's explore new ideas for communicating — some of the things that we've talked about.
- Let's continue integrating science and policy. I've been to lots of technical meetings where policy-makers aren't there, I've been to some policy meetings where the scientists are not invited; and it was a thrill to see the dedication of the provincial Ministers at this meeting, the participation of the Commissioners. It's an opportunity that is all too rare, I think, in the water world, to have science and policy-makers talk freely. So, continue to invite policy-makers.

And that's really it. Thank you very much.

Henry Vaux, Chair, Rosenberg Forum:

Thanks, Peter. A good job, as usual. We come now to the end of our formal sessions. I want to say that, as we go back to our regular lives, the materials from this session, the papers, after further revisions, will be published in an international water journal as a particular symposium. We will prepare and ultimately send to you summaries of your discussions and a set of conclusions that will rely heavily on Peter's fine presentation. I want to tell you that this is a better job than we have done before in terms of getting out the results of this Rosenberg symposium, and it's made possible by Max Bell Foundation, which gave us a very generous grant to provide general support for the Forum, but also to allow us to do some new things in terms of outreach and getting the information and ideas from this Forum widely disseminated. I am deeply appreciative of Max Bell Foundation because this is something we needed to do; time and money prevented us from doing it in the past, and Max Bell Foundation gave us the wherewithal to do it, and the wherewithal to continue doing it.

I want to say, in front of all of you, how much we appreciate the support of the Columbia Basin Trust, the sponsor of the post-Forum field trip.

Finally, I indicated earlier that there were three people who had a vision and a dream about holding this Forum in Banff. I told you who two of them were, and the third is Bob Sandford, who is the Canadian member of the Rosenberg Advisory Committee. I can't imagine anyone working harder than Bob Sandford, and he plumb wore me out. To give you one example, I came to Calgary on a Monday morning, and beginning Monday night, I flew to Ottawa, flew back to Calgary, flew to Regina, flew to Edmonton, flew back to Calgary, flew back to San Francisco, and that was all in three days and two flight cancellations. This is the kind of routine you have to go through if you're going to keep up with Bob Sandford. Bob, you really set a high standard for all of us.

Finally, I want to thank you all again for participating so fully in this Forum and I wish you all a safe journey home.