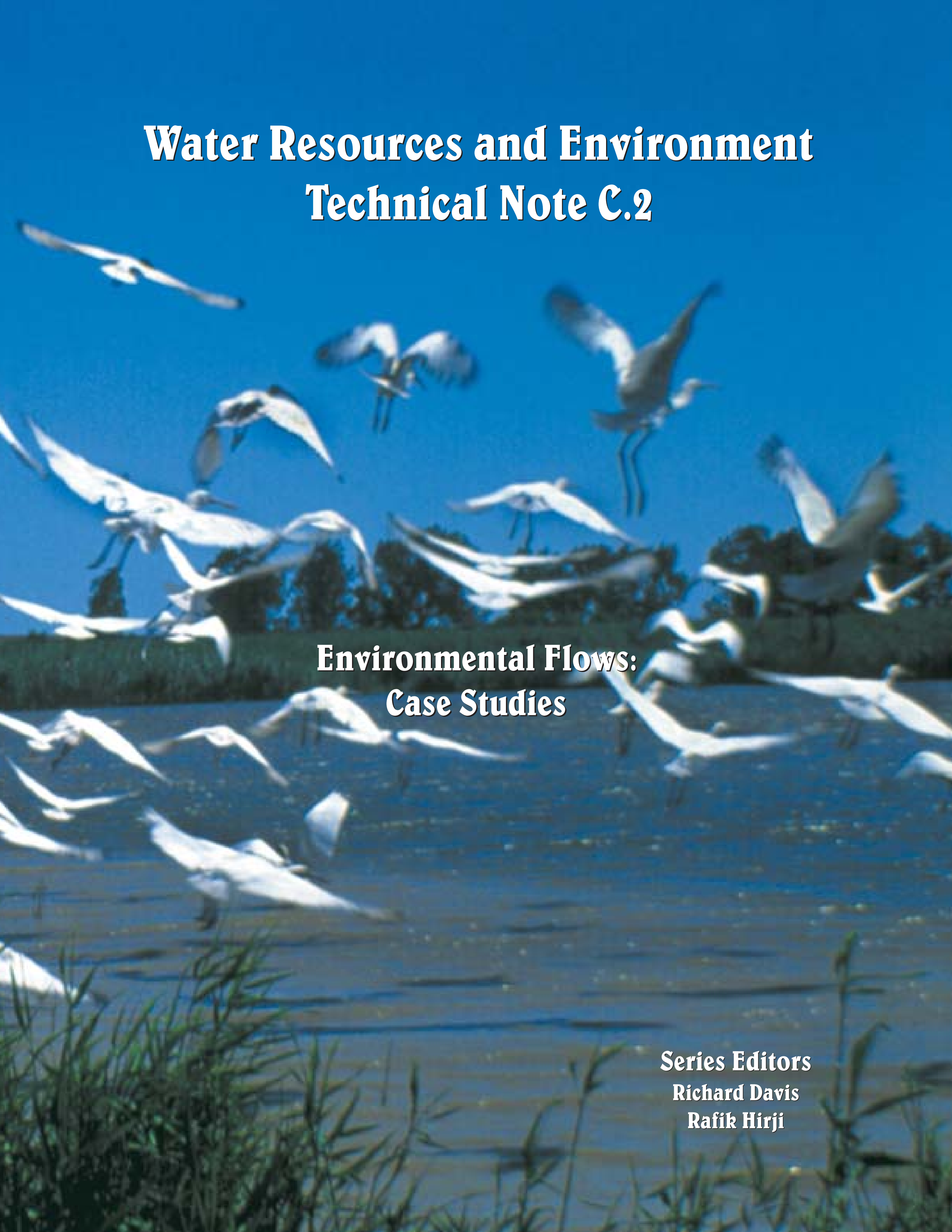
# Water Resources and Environment
# Technical Note C.2



## Environmental Flows:
## Case Studies

**Series Editors**
Richard Davis
Rafik Hirji

# Water Resources and Environment

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## *Environmental Flows: Case Studies*

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Richard Davis, Rafik Hirji

The World Bank
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## Water Resources and Environment Technical Notes






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**Cover photo by**
J. Turpie
Waterbirds, Berg River floodplain, South Africa

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# FOREWORD

The environmentally sustainable development and management of water resources is a critical and complex issue for both rich and poor countries. It is technically challenging and often entails difficult trade-offs among social, economic, and political considerations. Typically, the environment is treated as a marginal issue when it is actually key to sustainable water management.

According to the World Bank's recently approved Water Resources Sector Strategy, "the environment is a special 'water-using sector' in that most environmental concerns are a central part of overall water resources management, and not just a part of a distinct water-using sector" (World Bank 2003: 28). Being integral to overall water resources management, the environment is "voiceless" when other water using sectors have distinct voices. As a consequence, representatives of these other water using sectors need to be fully aware of the importance of environmental aspects of water resources management for the development of their sectoral interests.

For us in the World Bank, water resources management—including the development of surface and groundwater resources for urban, rural, agriculture, energy, mining, and industrial uses, as well as the protection of surface and groundwater sources, pollution control, watershed management, control of water weeds, and restoration of degraded ecosystems such as lakes and wetlands—is an important element of our lending, supporting one of the essential building blocks for sustaining livelihoods and for social and economic development in general. Prior to 1993, environmental considerations of such investments were addressed reactively and primarily through the Bank's safeguard policies. The 1993 Water Resources Management Policy Paper broadened the development focus to include the protection and management of water resources in an environmentally sustainable, socially acceptable, and economically efficient manner as an emerging priority in Bank lending. Many lessons have been learned, and these have contributed to changing attitudes and practices in World Bank operations.

Water resources management is also a critical development issue because of its many links to poverty reduction, including health, agricultural productivity, industrial and energy development, and sustainable growth in downstream communities. But strategies to reduce poverty should not lead to further degradation of water resources or ecological services. Finding a balance between these objectives is an important aspect of the Bank's interest in sustainable development. The 2001 Environment Strategy underscores the linkages among water resources management, environmental sustainability, and poverty, and shows how the 2003 Water Resources Sector Strategy's call for using water as a vehicle for increasing growth and reducing poverty can be carried out in a socially and environmentally responsible manner.

Over the past few decades, many nations have been subjected to the ravages of either droughts or floods. Unsustainable land and water use practices have contributed to the degradation of the water resources base and are undermining the primary investments in water supply, energy and irrigation infrastructure, often also contributing to loss of biodiversity. In response, new policy and institutional reforms are being developed to ensure responsible and sustainable practices are put in place, and new predictive and forecasting techniques are being developed that can help to reduce the impacts and manage the consequences of such events. The Environment and Water Resources Sector Strategies make it clear that water must be treated as a resource that spans multiple uses in a river basin, particularly to maintain sufficient flows of sufficient quality at the appropriate times to offset upstream abstraction and pollution and sustain the downstream social, ecological, and hydrological functions of watersheds and wetlands.

With the support of the Government of the Netherlands, the Environment Department has prepared an initial series of Water Resources and Environment Technical Notes to improve the knowledge base about applying environmental management principles to water resources management. The Technical Note series supports the implementation of the World Bank 1993 Water Resources Management Policy, 2001 Environment Strategy, and 2003 Water Resources Sector Strategy, as well as the implementation of the Bank's safeguard policies. The Notes are also consistent with the Millennium Development Goal objectives related to environmental sustainability of water resources.

The Notes are intended for use by those without specific training in water resources management such as technical specialists, policymakers and managers working on water sector related investments within the Bank; practitioners from bilateral, multilateral, and nongovernmental organizations; and public and private sector specialists interested in environmentally sustainable water resources management. These people may have been trained as environmental, municipal, water resources, irrigation, power, or mining engineers; or as economists, lawyers, sociologists, natural resources specialists, urban planners, environmental planners, or ecologists.

The Notes are in eight categories: environmental issues and lessons; institutional and regulatory issues; environmental flow assessment; water quality management; irrigation and drainage; water conservation (demand management); waterbody management; and selected topics. The series may be expanded in the future to include other relevant categories or topics. Not all topics will be of interest to all specialists. Some will find the review of past environmental practices in the water sector useful for learning and improving their performance; others may find their suggestions for further, more detailed information to be valuable; while still others will find them useful as a reference on emerging topics such as environmental flow assessment, environmental regulations for private water utilities, inter-basin water transfers, and climate variability and climate change. The latter topics are likely to be of increasing importance as the World Bank implements its environment and water resources sector strategies and supports the next generation of water resources and environmental policy and institutional reforms.

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Director
Environment Department

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# INTRODUCTION

The flows of the world's rivers are increasingly being modified through impoundments such as dams and weirs, extractions for agriculture and urban supply, maintenance of flows for navigation, inflows of drainage waters, and structures for flood control. These interventions have had significant impacts, reducing the total flow of many rivers and affecting both the seasonality of flows and the size and frequency of floods. In many cases, these modifications have adversely affected the ecological and hydrological services provided by water ecosystems, which in turn has increased the vulnerability of people–especially the poor–who depend on such services. It is increasingly recognized that modifications to river flows need to be balanced with maintenance of essential water-dependent ecological services. The flows needed to maintain these services are termed "environmental flows" and the process for determining such flows is termed "environmental flow assessment" (EFA).

The recognition that modifications to river flows are an important source of riverine, floodplain and, in some cases, estuarine degradation is relatively recent. The World Bank acknowledged the issue in its 1993 Water Resources Management Policy, which included as an objective that "the water supply needs of rivers, wetlands, and fisheries will be considered in decisions concerning the operation of reservoirs and the allocation of water." An environmental assessment (Operational Policy 4.01) is triggered if modifications to river flows lead to adverse environmental risks and impacts. If changes in flow have the potential to cause significant loss or degradation of natural habitats, borrowers must comply with the Bank's natural habitats policy (Operational Policy 4.04) in order for a loan to be approved.

Technical Notes C.1 to C.4 deal with environmental flows. Although changes in flow will affect water quality–for example, by increasing or decreasing turbidity–the focus in these notes is primarily on the direct effects of flow on the ecological functioning of rivers and the management of water quantity. Note C.1 introduces concepts and methods for determining environmental flow requirements for rivers. Note C.2 reviews some important case histories, which provide examples of the increasing range of situations in which environmental flow assessments are becoming a water-management tool, and some of the legal, economic, social, and ecological implications of pro-active flow management for river health. Note C.3 describes the reinstatement of flood releases from reservoirs for floodplain inundation. Note C.4 addresses the downstream social issues arising from changes in flows.

Environmental flow assessments have evolved from the narrow purpose of describing flows for maintaining specific fish species to their present use as a tool in holistic catchment management. The case studies reflect this evolution. The first case study describes how a flow assessment was completed in the planning stage of a water development to aid decisions on which dams should be built and how much water should be allocated to protecting the rivers and subsistence users dependent on those rivers. The second case study illustrates how flows were set to mitigate impacts of an existing dam by modifying the downstream releases of water. Both describe advanced forms of traditional environmental flow assessments. The third case study describes another way that rehabilitation of a seriously degraded river was initiated, through placing a limit on current levels of water abstraction. This does not constitute an environmental flow assessment itself, but provides breathing space for flow assessments to be prepared. Finally, the report mentions three examples of how the concept of environmental flows is used in increasingly broader ways in water management.

Photo by Chilika Development Authority

Fishtrap, Chilika Lake, India

# RIVER ECOSYSTEMS AND ENVIRONMENTAL FLOWS

In this document, the term "river" is used to describe the complete river ecosystem of many interdependent nonliving and living components. Rivers are dynamic systems, sculptured by their flows, with dependence on different-sized flows at different times of the year for the inundation of various channel features and the completion of plant and animal life cycles. Rivers respond to both natural disturbances (such as drought) and man-made disturbances (such as dams) to flow; changes in the components are shown in Box 1. In general, the more the flows are changed for a specific river, the more the river will change.

Man-made flow changes can be caused by direct manipulation–such as damming or abstraction of water–or by activities in the surrounding catchment that affect river flow, such as deforestation and land use changes. The resulting changes to the river do not have to be left to chance, but can be predicted and managed so that they stay within acceptable limits. This is possible because rivers can be managed to exist at different levels of condition.

Undisturbed rivers are generally seen as healthy because their channels and species have evolved over long periods of time in harmony with their different environments, so that they process resources most efficiently. Their valued attributes include reliable, good-quality water supplies, floodplain fisheries, and stable banks. With increasing disturbance, rivers lose valued attributes and new attributes appear. Often, the new attributes are less welcome than the old; they could include, for instance, pest flies, unreliable water supply, and algal blooms. The trend is one of increasing degradation.

Many developed countries now regularly report on river health, using classifications for river reach conditions that are defined under national water or enviromental policies and legislation. Each class summarizes a different level of degradation (such as A=near natural or pristine; B=slightly modified; C=moderately modified; D=largely modified; E=seriously modified; F=critically modified). A number of developing countries are also adopting their own classifications for river health. National objectives may be to maintain a specified percentage of rivers in each category.

Technical Note C.1 provides more details on the responses of rivers to different flow events and options for managing flows. Information linking river flow with environmental assessment is provided through an environmental flow assessment. In the context of a proposed water-related activity, the flow assessment is a means of describing the potential trade-offs between development gains–such as increased access to water for agriculture or industrial use–and environmental losses–such as reduced habitat for waterbirds or reductions in the quality of life of subsistence users of the river. Environmental flows link water- or land-development objectives

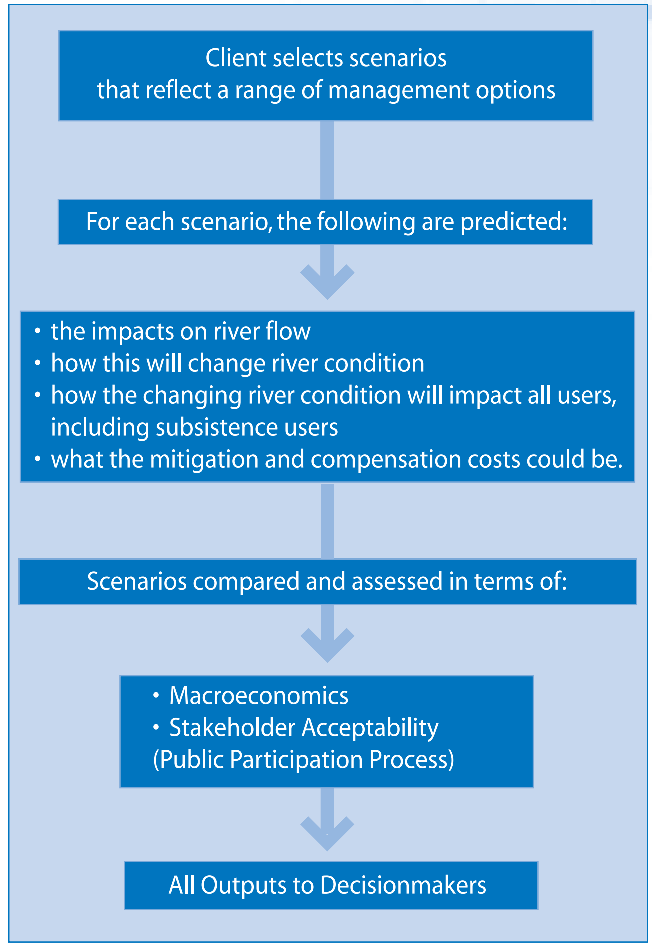
**BOX 1.**
**THE MAIN COMPONENTS OF A RIVER ECOSYSTEM**

| Nonliving | Living |
|---|---|
| Channel, source to sea<br>Banks<br>Floodplains<br>Linked lakes and wetlands<br>Estuary<br>Linked groundwater<br>Linked near-coast marine environment<br>Sediments<br>Water chemistry and temperature | Riparian, fringing and aquatic plants<br>Fish, including marine fish that use estuaries<br>Aquatic invertebrates<br>Aquatic mammals<br>Water birds<br>Amphibians and aquatic reptiles<br>Microorganisms |

with active management of river health. They are not just "flows for nature."

Scenarios showing these trade-offs should be assessed in terms of their wider macroeconomic implications–for example, for industry–and their acceptability to all interested parties (Figure 1). Ultimately, society chooses which scenario is most acceptable, and in this way identifies a river's desired future condition. The flows described in the chosen scenario will maintain that desired condition, and will become the environmental flow for that river. They are unique to each river.

**Figure 1.**
**Environmental flow assessments in the decisionmaking process**



# THE LESOTHO HIGHLANDS WATER PROJECT

The Lesotho Highlands Water Project (LHWP)–one of the world's largest water-resource developments–will eventually comprise six major dams and a weir on the headwaters of the Senqu River system. The project has been planned to be developed in 5 phases (Box 2). Phase 1A (Katse Dam) created social and ecological concerns that led (during phase 1B) to an environmental flow assessment for all phase 1 structures. The assessment produced scenarios of how the downstream rivers would be affected by various dam release options, as well as the mitigation and compensation costs for affected subsistence groups that use the river.

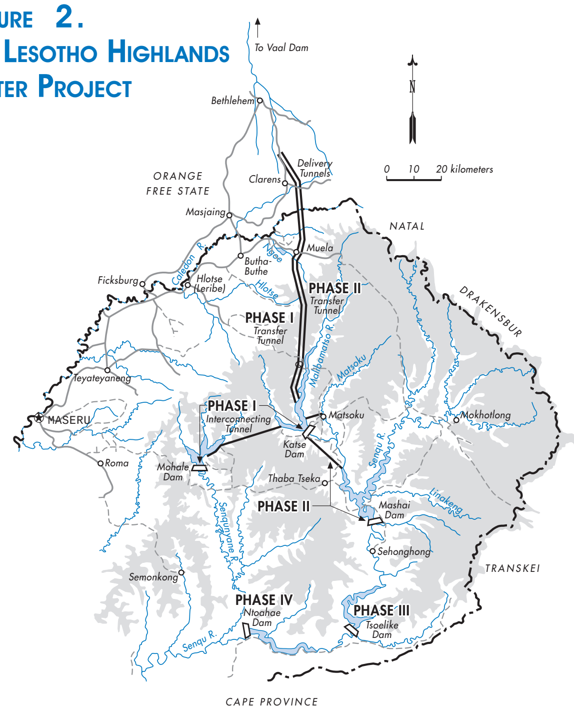
## BACKGROUND

Lesotho is a landlocked country surrounded by South Africa. The Senqu River system rises in the eastern Highlands, becoming the Orange River as it flows into South Africa (Figure 2). The Lesotho Highlands are mountainous and characterized by rainfall ranging from 700 to 1,500 mm annually.

The powerful rivers that drain the region had virtually natural flow until the 1990s, largely because the Highlands are remote and sparsely inhabited by rural communities, and the rivers flow through deep gorges that provide little opportunity for urban or agricultural development.

The river water was considered an important potential source of revenue for this small developing country, with South Africa's Vaal Region as a potential recipient of the water. The Vaal Region is the industrial heart of South Africa, and vital to that

**Figure 2.**
**The Lesotho Highlands Water Project**




**Box 2.**
**Phases of the Lesotho Highlands Water Project**

| Phase | Yield | Facilities |
|---|---|---|
| 1A<br>Completed 1998 | ■ 18 m³ s⁻¹ flow<br>■ 72-MW hydropower | ■ 185 m Katse Dam on the Malibamatso River<br>■ 55 m Muela Dam on the Nqoe River<br>■ Hydropower plant at Muela<br>■ Transmission lines to Maseru<br>■ Water delivery tunnels<br>■ Access roads and other infrastructure |
| 1B<br>Completed 2002 | ■ 9 $m^3 s^{-1}$ flow<br>■ 2 $m^3 s^{-1}$ flow | ■ 145 m Mohale Dam on the Senqunyane River<br>■ 20 m Matsoku Weir on the Matsoku River<br>■ Delivery tunnels to Katse Reservoir<br>■ Access roads and other infrastructure |
| 2<br>3<br>4<br>5 | Total estimated yield<br>for all phases<br>(1-5): 70 $m^3 s^{-1}$ flow | ■ Mashai Dam on the Senqu River and infrastructure<br>■ Tsoelike Dam on the Senqu River and infrastructure<br>■ Ntoahae Dam on the Senqu River and infrastructure<br>■ Malatsi Dam on the Senqunyane River and infrastructure |

country's national economy. In the 1950s, with few natural water resources and increasing industrial and urban demand, the Vaal Region was projected to be facing a water deficit–that is, a shortfall of supply compared to demand–of 106.7 $m^3 s^{-1}$ by 2023. Of the technically viable schemes to meet this shortfall, the least expensive was the gravity-fed transfer of water from the Lesotho Highlands.

Feasibility studies began in the 1950s, and in 1986 the LHWP got under way. The treaty between South Africa and Lesotho signed in 1986 embraced five Phases (Box 2) in concept, but committed the countries only to Phase 1. Although the scheme was conceived and begun during the apartheid era, the current democratically elected governments of both countries fully support the project, and the new Government of Namibia (through which the Orange River flows to the ocean) has no objection.

*Benefits and costs.* Both countries stand to benefit from the scheme, essentially through South Africa securing a reliable annual supply of good-quality water, and Lesotho acquiring revenue that, from Phase 1 alone, amounts to about 14 percent of current government income for the next 50 years (Box 3). Development costs are borne mainly by South Africa. The LHWP creates jobs and, indirectly, many other employment and development opportunities. Water stored in the scheme within Lesotho could lead to growth in agro-industry, forestry, fisheries, and tourism endeavors. Another important benefit for Lesotho is the generation of electricity using the transfer water at Muela.

*Management of the LHWP.* The Lesotho Highlands Water Commission (LHWC), which oversees the project, is a bi-national body answerable to both governments, with monitoring, advisory, and approval powers. Its main responsibility relates to project implementation in areas such as technical acceptability, design of works, tender procedures and documents, cash flow forecasts, allocation of costs, and financing arrangements. A parastatal body in each country runs the LHWP: the Lesotho Highlands Development Authority (LHDA) in Lesotho and the Trans-Caledon Tunnel Authority (TCTA) in South Africa. Identified stakeholders in the LHWP were represented on the steering committee guiding the environmental flow assessment.

### Box 3.
### Benefits and direct monetary costs of Phase 1 of the LHWP

| Lesotho | South Africa |
|---|---|
| ***Benefits:***<br>■ Annual revenue of $55 million from South Africa for 50 years<br>■ No financial risk for water-transfer component<br>■ Hydropower from Muela<br>■ Infrastucture such as roads and telecommunications to increase health, education, and trade services<br>■ 39,000 person-years of direct employment for local people<br>■ Additional enhancement of GDP through higher indirect employment, import duties, and tax receipts. | ***Benefits:***<br>■ Secures the cheapest substantial source of high-quality water<br>■ Lower water prices to consumers<br>■ Augmentation of water supply to newly enfranchised poor<br>■ Industrial growth in a water-scarce area of high economic importance. |
| ***Direct costs:***<br>■ Hydropower component. | ***Direct costs:***<br>■ Full costs of construction, operation, and maintenance of the project except for the hydropower component<br>■ Associated debt<br>■ Annual royalties payment to Lesotho of $55 million<br>■ Compensation and mitigation costs<br>■ Social and development programs. |

*Existing and potential water conflicts.* There were two potential water conflict issues: (1) the population at risk included about 39,000 subsistence users living along the targeted rivers and downstream of the dam sites; and (2) the scenic beauty of the mountain regions and their rivers suggested a potential for ecotourism.

Increasing the amount of river flow harnessed in dams increases direct revenue earned and the potential for a range of development opportunities, but also causes greater deterioration in the condition of the rivers, which impacts both the population at risk and ecotourism. A declining river condition also would pose an increased threat to the rare and endangered Maloti minnow, *Pseudobarbus quathlambae*.

The 1986 treaty stipulated that minimum compensation flows of 0.5 $m^3\ s^{-1}$ or higher should be released from Katse Dam and 0.3 $m^3\ s^{-1}$ or higher from Mohale Dam, representing approximately 3 to 5 percent of the total annual flow of the rivers at those points. These lower limits, which were the target level LHDA was initially planning to use to operate the system, would not support maintenance of the downstream rivers in their historical condition.

## FUTURE OPTIONS

The 1986 treaty had a provision for renegotiating the terms after 12 years, i.e. after 1998. The terms of the renegotiated treaty were delayed pending completion of a flow assessment and the resulting environmental flow requirement (EFR) policy, which will be used to optimize flow-release patterns from Katse Dam, Mohale Dam, and Matsoku Weir. The new treaty will also be used to help decide which other dams should be built, what the water-release patterns from these dams should be, what design features should be incorporated to facilitate environmental releases, and what mitigation and compensation measures need to be instituted to offset ecosystem and social impacts and costs.

Terms of the new treaty will be based partly on predictions of the potential ecological and social impacts of the dams, with a balance being sought between development of the river's water resources and protection of river health.

## ENVIRONMENTAL FLOW METHODOLOGY

The flow assessment study covering Phases 1 and 2, commissioned by LHDA, began in 1997 and was completed in 2000. It was designed to maximize understanding of the rivers and human dependence upon them. Within a one-year data-collection period, an international team of 27 scientists (Box 4) collaborated to predict the changes in river condition that would occur if various dams were built and operated in specific ways, and the implications of these river changes for subsistence users. In 2001, with changes in water use and demand in South Africa, it became clear that Phase 2 would not be imminent, and a new report was prepared to cover the environmental flow impacts of Phase 1 only. The Phase 1 EFA report was issued in July 2002.

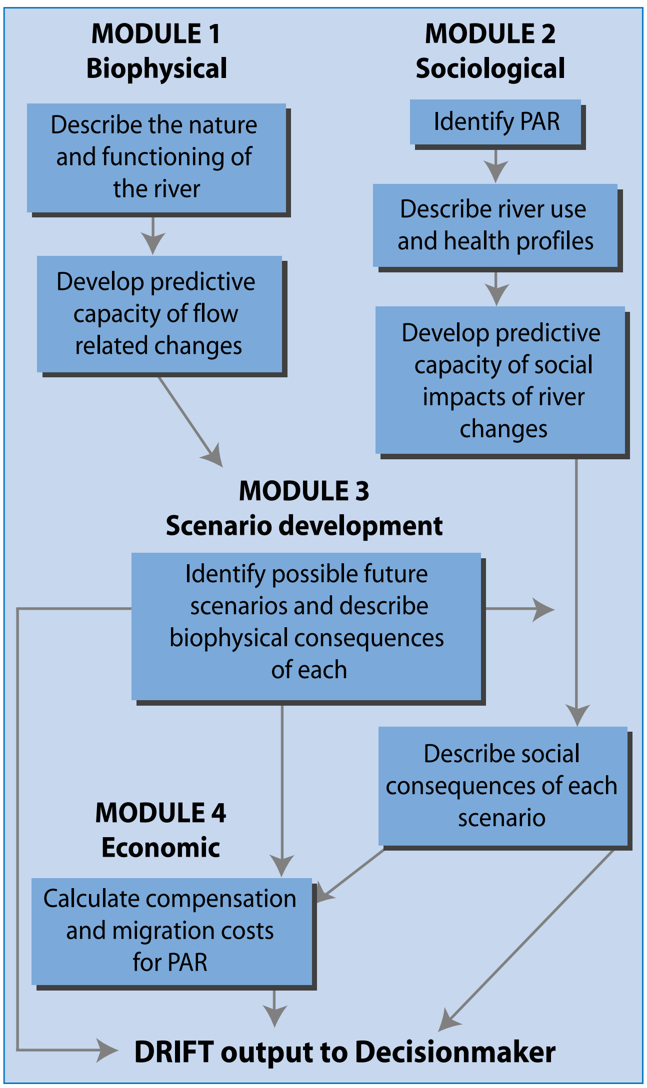
*Approach chosen.* A holistic interactive approach—Downstream Response to Imposed Flow Transformations, or DRIFT—with four modules was developed for use in the study (Figure 3). In Module 1, the changes to the rivers were described in response to flow changes. In Module 2, the population at risk was identified and their links to the rivers described (Box 5). In Module 3, four scenarios of interest to the client were developed. Each predicted a possible future flow regime; the resulting condition of the river; and the impacts on the Population at Risk (PAR). Module 4 dealt with mitigation and compensation issues.

A pilot study of the population at risk measured the widths of inhabited corridors on either bank and identified the river resources used. A follow-up study quantified resource use, estimated the costs of resources, and considered cultural links with the rivers. Medical and veterinary teams described the health profiles of the population at risk and their domestic stock, and estimated the cost of measures to mitigate potential additional health risks. The information was used to describe the

## Box 4.
## Specialists involved in the Lesotho Flow Assessment

| | |
|---|---|
| **Biophysical** | |
| *Channel form* | Hydrologist, hydraulic modeler, sedimentologist, fluvial geomorphologist, physical-habitat specialist |
| *Water quality* | Aquatic chemist, microbiologist |
| *Biology* | Botanists for riparian, fringing and aquatic plants; zoologists for fish, invertebrates, frogs, reptiles, water birds, terrestrial wildlife |
| **Subsistence use** | |
| *Social* | Sociologist, anthropologist, public health doctor, animal health veterinarian, water-supply specialist |
| *Economic* | Economist, resource economist |
| **Process** | Flow-assessment facilitators |
| | Scenario builders |

## Figure 3.
## DRIFT Modules




links between the riparian people and the rivers, and how flow changes might affect them.

The biophysical and socioeconomic specialists maintained strong links with each other during data collection. As an example, the botanists helped the social team identify river plants used by the population at risk, and then allocated each plant species to one of six vegetation zones occurring up the banks. All the zones were then studied to define their links with flow. The hydrologist and hydraulic modeler linked each vegetation zone with flow by determining how often it is flooded under current flows. Knowing the links between flow and vegetation zones, the botanist could then describe for each possible future flow regime, how the vegetation zones might expand or contract, and thus whether each plant species would increase or decrease in abundance. The social team then used this prediction to assess, for each scenario, the impact of vegetation changes on the population at risk.

Because of the complexity of rivers, any study of this nature–either in developing or developed countries–is necessarily undertaken with only limited knowledge. In the Lesotho study, this uncertainty was managed through the use of severity ratings, which allowed scientists to indicate within a coarse range how great each described change would be (Severity Rating 1 = negligible; Severity Rating 2 = Low; Severity Rating 3 = moderate; Severity Rating 4 =

Severe; Severity Rating 5 = Critically Severe). A specialist might predict, for instance, that under a certain future scenario, fish species A would show a moderate reduction in abundance (Severity Rating 3). If there was uncertainty about which severity rating to allocate to a predicted change, then a range of severity ratings was used–for example, fish species A would show moderate to critically severe reduction in abundance (Severity Rating 3-5). The final scenarios were thus illustrated as risk envelopes of predicted changes, with wider envelopes indicating greater uncertainty.

## MANAGEMENT IMPLICATIONS

The scenarios in Box 5 illustrate that the more water harnessed in the dams, the greater the impact on river health and on the people using the rivers for subsistence. The process for deciding between these scenarios is expected to include three major stages:

- identifying the range of an acceptable volume of water for environmental maintenance
- finding an optimum balance among flow regime, economic and social costs, and environmental impacts
- making a formal commitment to environmental flows in the form of an EFR policy.

Boy drinking from river, Lesotho

The EFA process and outcome has informed and improved project decisionmaking even though the EFA was carried out during project implementation. The design of the Mohale Dam outlet structure was changed in 1998, ahead of the result of the flow assessment, in anticipation of the likely requirement for "greater-than-treaty" flows. The dam outlet works now incorporate a large release pipe as well as a multi-level release facility for smaller flows and a larger low-level facility for flood release. The EF releases from Matsoko Wier, which is not governed by the 1986 treaty, were increased from 0.05 $m^3 s^{-1}$ to 0.6 $m^3 s^{-1}$. The draft final EFR policy has recommended the following initial bulk EFRs from (a) Katse Dam of 2.12 $m^3/s$, which was increased from 0.5 $m^3/s$ and from (b) Mohale Dam of 1.01 $m^3/s$, which was increased from 0.3 $m^3/s$. These flows will be distributed as seasonal releases and as small floods. The EFR policy will also describe a specific

### BOX 5.
### PREDICTED IMPLICATIONS OF FOUR POSSIBLE FLOW SCENARIOS FROM PHASE 1 AND 2 DAMS IN LESOTHO

| Scenario | Change in river condition from present | Social impact of river change | Costs of compensation and mitigation | Yield of water |
|---|---|---|---|---|
| Minimum change | Low | Negligible | Low | Very low |
| Design limitation | Moderate | Moderate | Moderate | Low |
| Treaty | Critically Severe | Severe | Very High | Medium |
| Fourth | Severe | Moderately severe | High | Very High |

***Minimum change*** = The maximum amount of water that could be removed by the dams before measurable change in river condition occurs.

***Design Limitation*** = Highest attainable river condition with current dam structures and moderate water-supply commitments.

***Treaty*** = Very low downstream releases from the dams as per the original treaty.

***Fourth*** = A fourth position in the range of possible scenarios, between Design Limitation and Treaty.

mitigation and compensation program to offset the impacts on communities and their resources.

The LHWP Environmental Flow Assessment represents a major contribution to knowledge. It is the first comprehensive assessment by the World Bank in which downstream environmental analysis is explicitly linked to social analysis, and has had significant influence on project decision-making.

# THE SKAGIT RIVER HYDROELECTRIC PROJECT

Hydropower dams on the Skagit River in the United States provide electricity to the city of Seattle. An application to renew the operating license for the dams created an opportunity to incorporate environmental flows into the license to partially reverse past deterioration to the river, and negotiate a settlement that maximized benefits for a range of stakeholders.

## BACKGROUND

The Skagit River rises in Canada and flows 162 miles to its mouth in Puget Sound in the State of Washington in the United States. About 70 percent of its drainage basin falls under U.S. federal administration, including 550 square miles of U.S. Forest Service wilderness, 750 square miles of national park, 170 square miles of national recreation area, and 60 square miles in the National Wild and Scenic Rivers System.

The Skagit River Project (SRP), which began operation in 1927, consists of three sequential hydropower dams along the main stem of the river in the United States: the Ross, Diablo, and Gorge Dams. It is the largest of six hydropower projects in the basin, with an installed capacity of 689 MW of power.

The utility company for Seattle, Seattle City Light (SCL), holds the only water rights in the SRP, and uses them only to generate hydropower. The original operating license expired in 1977, and agencies and tribes concerned about fisheries and other environmental issues opposed re-licensing. As a result, operation of the SRP continued with annually renewed licenses, while intensive investigations and negotiations about re-licensing ensued among SCL; local, state, federal, and tribal governments; and environmental organizations.

After 15 years of studies, and 10 years of negotiations, a comprehensive Settlement Agreement was signed in 1991. The Federal Energy Regulatory Commission (FERC) then issued a new 30-year operating license to SCL in 1995.

## BASIS OF THE ENVIRONMENTAL NEGOTIATIONS

FERC has exclusive authority in the United States to license nonfederal hydropower projects on navigable waterways and federal lands. FERC gave equal consideration to the need for power generation and to issues related to energy conservation, fish and wildlife resources, recreational opportunities, and other aspects of environmental quality. FERC identified four major resources that could be directly affected:

- anadromous fish (species that migrate between sea and freshwaters)
- sensitive terrestrial ecological resources
- recreational and visual resources
- cultural resources.

Additional indirect impacts to these resources could occur through unstable slopes in reservoir drawdown areas, and continued transport of sediments to downstream rivers, which would change the nature of their channels. Only the combined water and fishery issues are addressed in this case study.

The Skagit system is one of the few Puget Sound basins in which salmon are managed on a natural-stock basis. The fish are a major component of the river ecosystem, an important fisheries resource, and attract one of the largest over-wintering populations of bald eagles in the United States.

The Skagit downstream of the lowest dam–Gorge Dam–receives migratory runs of all five species of Pacific salmon and three other anadromous game species. Historically, the upper Skagit River had abundant rainbow trout and other resident fish species, for which the dam reservoirs markedly increased habitat while reducing habitat for the flowing-water species. The rapid and large fluctuations in releases from Gorge Dam also had a major negative affect on the anadromous fish lower down the river. Low points in the fluctuations severely reduced aquatic habitat, dried out spawning grounds, left young fish stranded at water edges and in potholes, and created shallow areas through which adult fish could not migrate.

## FLOW AND FISHERIES RESEARCH

Research studies were undertaken on the impacts of the dam on the river. For example, a series of field studies between 1979 and 1982 were designed to determine the effects of flow fluctuations on the spawning behavior, egg deposition, incubation, hatching success, and tolerance to stranding of young steelhead trout and chinook and chum salmon. Supporting laboratory studies focused mainly on determining whether and under what conditions young fish migrate into the riverbed to avoid being stranded. Results indicated that more young fish survived if down-ramping (reduction) of dam releases occurred during daytime, and if the riverbed had coarse particles with large interstitial spaces for them to move into. These and many other findings led to interim agreements on flow management, which were negotiated without application of a specific flow-assessment method. A recommendation was made, however, that the Instream Flow Incremental Method (IFIM) (see Note C.1) be used to further guide flow management.

## THE INTERIM AGREEMENTS

The interim agreements between the SCL and resource agencies, reached before and during the period of annual licensing, later formed part of the Settlement Agreement (SA). These mainly addressed flow requirements for protection and improvement of fish habitat and fish production. For example, a 1968 license amendment required a minimum flow release from Gorge Dam, but within this constraint, releases still fluctuated with electricity demand. In 1978, through interim agreements, flow releases were modified to benefit downstream fish, including reduced flow fluctuations and limitations on the degree to which floods were controlled during the normal flood season.

Other interim agreements addressed:

- the impacts from fluctuating reservoir levels on fish spawning along shorelines and in tributaries
- the loss of fish habitat through water being diverted from the river through turbines
- the maintenance of favorable water temperatures for fish.

These flow-management measures, carried out mostly during the 1980s, correlated with an increased production of pink and chinook salmon.

## THE SETTLEMENT AGREEMENT

The SA listed environmental enhancement measures totaling about $100 million (Box 6). This included a Fish Flow Plan that formalized the flow-management activities already in force and added other flow-related measures to enhance fish habitat (Box 7). It also included several measures not related to flow management–costing more than $6 million–that would further reduce impacts of the SRP on fishery resources. This component focused on research and production programs and creation or improvement of critical fish habitat.

## REISSUE OF LICENSE

FERC concluded that the proposed SA struck a reasonable balance between the development values of the SRP and the values of the natural resources. Of the range of options considered, continued operation under the terms of the SA was FERC's preferred option. Cumulative effects would be no greater than under the present interim agreements,

## Box 6.
### Costs of enhancement measures in the Settlement Agreement.
### (All costs in millions of US dollars at 1990 value and mostly spread over the 30-year license period.)

| Category | Examples of measures | Cost (millions) |
|---|---|---|
| Geology and Soils | Erosion control at more than 50 sites | 3 |
| Fisheries | ■ Interagency coordinating committees<br>■ Revised management of water levels in Ross reservoir<br>■ Flow management to protect spawning and juvenile habitat (Box 7):<br>  ■ flow plans for drought years<br>  ■ advance scheduling of hourly hydropower generation during each calendar day<br>■ Monitoring<br>■ Nonflow measures such as research and enhancement of fish habitat. | 49 |
| Vegetation and Wildlife | Acquisition and preservation of wildlife habitat | 20 |
| Visual Resources | ■ Revegetation<br>■ Redesign, relocation, or removal of several buildings | 2.5 |
| Cultural Resources | Archaeological, historical, and architectural issues | 6 |
| Land-use and Recreation | Enhanced recreational facilities | 17 |

## Box 7.
### Examples of flow regulation protective measures for Chinook salmon in the new license for operating the SRP.
### (cfs = cubic feet of water per second, flowing past a measured point. Down-ramping = rate of change of decreasing power-plant water releases)

| Protected feature | Regulation |
|---|---|
| Spawning period | August 20 to October 15 |
| Incubation period | August 20 to April 30 |
| Spawning flow | During the spawning period, daily flows shall not exceed 4,500 cfs |
| Incubation flows | Minimum incubation flows each day of the incubation period as per a pre-agreed schedule. |
| Protection of Fry | The Salmon Fry Protection Period is February 1 to May 31. During this period, the City shall restrict down-ramping and adhere to minimum flows to protect fry. |

and in some cases would have new beneficial effects on resources. With the new environmental protection measures in place, the SRP would continue to be economically viable and provide a dependable and economic source of energy for its customers.

The new license was a notable example of what can be achieved through parties with different interests being willing to negotiate a win-win solution. SCL received the 1998 Public Service Award from the Nature Conservancy of Washington for its environmental stewardship of the Skagit River basin, and is seen by many as a model for any public agency seeking to combine energy production with protection of the natural environment. The Terror Lake Hydropower Project (Box 8) provides another example of how pre-licensing negotiations can produce an atmosphere of cooperation and mutual compromise, reducing conflict and costly delays.

### BOX 8.
### THE TERROR LAKE HYDROPOWER PROJECT

The Terror River, on Kodiak Island in Alaska, lies within the Kodiak National Wildlife Refuge. It supports commercially important runs of several species of Pacific Salmon. These fish are a vital food source for the Kodiak brown bear; the bear's protection is the main purpose of the Refuge.

The river is also a prime resource for generating hydropower. Between 1964 and 1981, negotiations took place between the Kodiak Electric Association (KEA), which wished to establish a hydropower plant on the river to meet the entire electrical demand of the city of Kodiak, and a range of government institutions and other interested parties. The project became the first hydropower project for which a license was held up due to concern over environmental flows. KEA initially used a rule-of-thumb approach (The Tennant Method—see Technical Note C.1) to assess flows for fish maintenance. The licensing agency, FERC, felt this method was inappropriate outside its area of development, and also was too coarse to assess the impacts of a range of potential changes in flow.

This led to a pioneering application of the Instream Flow Incremental Methodology (IFIM), which allowed the impacts of hydropower releases to be predicted and trade-offs to be considered. IFIM has two major features. First, it describes the changes in hydraulic conditions within the river with changing flows. Second, it evaluates these changing conditions in terms of suitable fish habitat. The IFIM assessment described how proposed flow changes could impact fish migration, salmon spawning, egg incubation, and rearing of juveniles. Because these activities took place at different times and required different kinds of flows, a key issue in the negotiations was the scheduling (timing) and volume of flow in the river at any time of the year.

Major factors leading to a successful agreement were the early agreement to use IFIM, and the receptiveness of all interested parties to its outputs once they knew what the methodology could do and were regularly updated on emerging results. Using IFIM, minimum stream flows to be released from the project were specified, and the parties agreed to an Instream Flow Mitigation Plan. In June 1981, a compromise agreement incorporating these and other concerns was signed by KEA, the U.S. Department of the Interior, the State of Alaska, the Sierra Club, the National Audobon Society, and the National Wildlife Federation. FERC issued the license to proceed with the project in October 1981, which included specifications for monitoring the fisheries for 9 years.

### COMMENT

Fish are but one component of an interdependent ecosystem (Box 1). Although productive fisheries might be the objective, managing without consideration for the other ecosystem components could result in, for example, poor food supplies for the fish, inappropriate water quality or temperature, or inadequate refuge areas, all of which will affect fish numbers. There is a widespread belief, probably underlying the Skagit River example, that if the flow is appropriate for fish, it will probably serve most other ecosystem needs. In different projects this may or may not be so. Flow management is best addressed for the whole ecosystem and not left to chance.

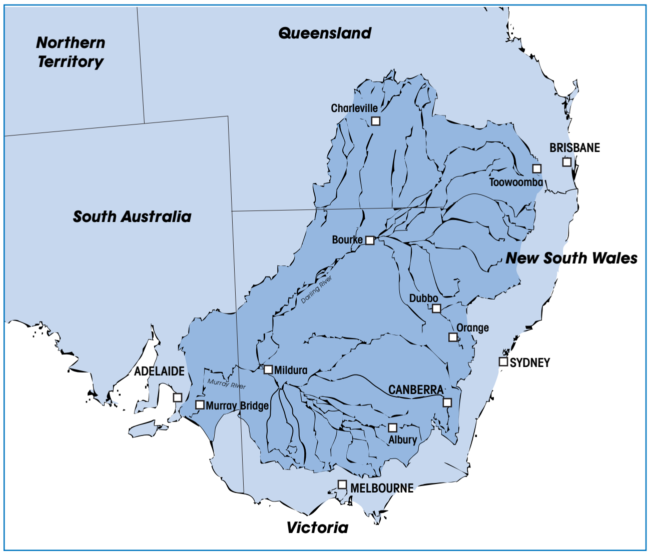
## THE MURRAY-DARLING CAP ON ABSTRACTIONS

The rivers of the Murray-Darling Basin in Australia are seriously degraded as a result of over-abstraction of water and increasing nutrient and salinity levels. As a first move to halt river degradation, a limit ("cap") has been placed on abstractions. If this, along with other initiatives, does not achieve the desired level of river health, water allocations to offstream users may be reduced and re-allocated for river maintenance. The cap is not an environmental flow, because it is not based on consideration of ecosystem functioning, but it represents an important policy decision to limit further degradation of the river until flow assessments can be completed and environmental flows implemented.

### BACKGROUND

Located in southeastern Australia, the Murray-Darling Basin covers one-seventh ($1.06 \times 10^6$ km$^2$)

**Figure 4.**
**The Murray-Darling Basin in Southeast Australia**




of the country's total area (Figure 4). It encompasses parts of four states–New South Wales, Victoria, South Australia, and Queensland–and the Australian Capital Territory (ACT). Some 2 million people live in the basin; another 1 million outside it are dependent on its water. It contains some of the country's best farmland, and use of its waters has allowed expansion of irrigated agriculture into the drier inland areas. The value of the basin's agricultural produce exceeds Aus$8.5 billion per annum, of which Aus$3 billion is derived from irrigated land. Jobs created and foreign income derived from the food-processing industry further enhance the importance of this area. The water is also used for domestic purposes in Canberra, Adelaide, and many small country towns; for plantations, which account for 15 percent of Australia's income from forest products; and for mining, which produces 6 percent of the country's income from minerals. Hydropower produced at the Snowy Mountains Hydroelectric Scheme meets 5 percent of the region's energy needs and diverts water across the catchment divide into basin rivers.

Development of the basin over the last 100 years has resulted in increasing abstraction of water from its rivers. Dams and weirs regulate about 80 percent of the approximately 17,500 kilometers of river length. The rate of abstraction sharply increased from the 1950s onwards, and at present the median annual flows from the basin to the sea are only 21 percent of those that occurred naturally. The lower Murray now experiences drought-like flows in more than 3-in-5 years, compared to 1-in-20 years under natural conditions.

*Projected growth in demand.* Until 1995, the water allocation system encouraged further development of the water resources of the basin, rationing water during droughts but not during normal or wet years. A significant level of under-use of allocations still existed. For example, in the period 1991-95, only 63 percent of the permitted abstractions actually occurred. If all existing water entitlements were fully used, the potential existed for long-term average abstractions from the whole basin to increase by a further 15 percent (Figure 5). This projected increase would have reduced the security of supply for existing irrigators and exacerbated an already grave decline in river health.

*Existing and potential water conflicts.* River-flow patterns have changed markedly, particularly in the lower reaches. The causes include flow regulation by dams and weir pools, and abstractions, primarily for irrigation areas. In certain seasons, far less flow than natural is available in these reaches to dilute and carry away increasing volumes of nutrient-rich agricultural runoff and urban wastewater. The construction of weirs for irrigation off-takes has created still, stratified conditions that promote the growth of blue-green algae, which sometimes increase to problematic proportions as algal blooms. The algae can produce toxins that cause liver damage, stomach discomfort, skin and eye irritations, and disorders of the nervous system. They can also cause livestock deaths, odorous and distasteful water, clog water-supply equipment and, when they decay, cause mass fish kills. The toxins can only be removed by advanced water purification systems. In 1991, the world's largest riverine bloom of blue-green algae developed along a 1,000-kilometer stretch of the Darling River, causing the New South Wales Government to declare a state of emergency.

Algal blooms are one very visible symptom of declining river health. They occur because the natural checks and balances of a healthy river system have been lost. In the Murray-Darling, some of the imbalance has been caused by the loss of natural communities of aquatic plants and animals and their replacement by introduced species, but arguably the major cause has been over-abstraction of water. Predictions that these activities would continue to increase indicate that costly problems related to river health could also be expected to increase in frequency and severity.

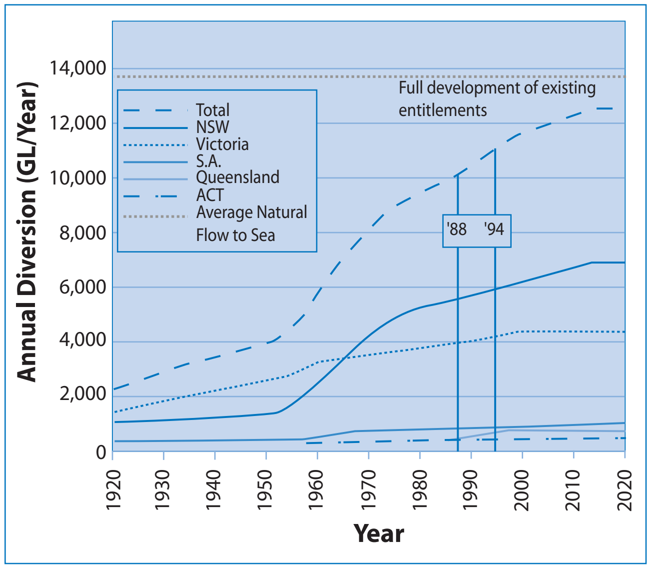
## BALANCING CATCHMENT DEVELOPMENT AND PROTECTION OF RIVER HEALTH

*The cap.* The Murray-Darling Basin Ministerial Council is the highest-level forum for interstate cooperation on management of the basin's natural resources. The council consists of relevant ministers from the five states and the national government. Being a political forum, the council has the power to recommend decisions for the basin as a whole. However, enactment remains the responsibility of each state. In 1993, in response to growing concern over water-use patterns, the Ministerial Council requested an audit of water use in the basin. The audit indicated that the patterns of existing and projected water use were unsustainable.

In 1995, in response to the audit, the Ministerial Council introduced an interim cap on abstraction of water from the basin for all consumptive uses. Seen as an essential first step in achieving sustainable use of the rivers' waters, this was confirmed as a permanent cap in 1997. The cap is presently defined as *"The volume of water that would have been diverted under 1993/94 levels of development. In unregulated rivers this Cap may be expressed as an end-of-valley flow regime."* The limit has no specific ecological significance, being simply the level of abstractions two years before the cap was introduced.

The objective was to strike a balance between the significant social and economic benefits of developing the basin's water resources, and the need for maintaining a healthy river system by safeguarding adequate river flow. As an initial move toward

**FIGURE 5.**
**GROWTH IN WATER USE IN MURRAY-DARLING BASIN**




sustainable use of the basin's waters, the purpose of the cap was to restrain abstraction but not necessarily development. New development would be allowed, provided the water was obtained by improving the efficiency of water use or by purchasing water from existing developments (water trading for highest-value use).

The council introduced the cap by unanimous vote, representing a consensus of government opinion and policy across the basin. Impetus was provided by the Council of Australian Governments, which in 1994 produced a Water Reform Agenda that *inter alia* redefined water rights and costs, and stressed the need for water allocations for environmental maintenance.

*Monitoring achievement.* An Independent Audit Group (IAG) advises on setting, implementing, and monitoring the cap. Abstractions are monitored in each of the 23 major sub-catchments of the basin to determine if the cap is being achieved. The IAG annually reviews cap implementation, and reports to the chairman of the Ministerial Council.

The methods used to determine whether usage in a sub-catchment has exceeded the cap have been modified with experience. The current rule is that if any sub-catchment in any year uses 20 percent more water than its 1993-94 usage, corrected for that year's climate, then that area has breached the cap. As an example, in the 1997-98 review of cap implementation, the IAG found that the Barwon-Darling sub-catchment within New South Wales had breached the cap. Following discussion at the March 2000 Ministerial Council meeting, New South Wales was requested to report to the August 2000 Ministerial Council meeting on the actions it is undertaking to bring abstractions in the Barwon-Darling within cap limits.

The current monitoring system addresses only volumetric abstractions with no attention to river health, a limitation recognized by the Ministerial Council. The current cap may not allow sufficient water to remain in the system to halt river degradation; as information about flow needs improves, the level may have to be re-set. At the March 2000 Council meeting, the Council requested that a sustainable rivers audit be prepared, with preliminary results on river health to be presented at the August 2000 meeting.

In October 2001, a pilot sustainable river audit was approved to test the feasibility and effectiveness of audit options and procedures in four basins. The pilot audit is expected to report to the Council by mid-2003.

## STAKEHOLDER AND EQUITY ISSUES

Implementation of the cap was a policy decision taken by all relevant governments. As such, the key policy stakeholders were involved, and they in turn worked with their constituencies.

From the outset, equity was an important implementation issue. The IAG developed six principles to assess equity:

- no further change to flow regimes that would contribute to deterioration of water quality and environmental protection
- water allocations to be made with extreme sensitivity to the effects on the environment (Precautionary Principle)
- water to be allocated to the highest-value use
- statutory and agreed property rights to be recognized
- water management processes to be transparent and auditable
- an administrative system that is easily understood and that minimizes time and costs.

Equity issues that may jeopardize management of the cap fall into two categories: 1) pre-existing; and 2) newly identified. Pre-existing equity issues included finalization of the cap limits for Queensland and ACT. If some jurisdictions were exempt, the cap could be undermined. Newly identified equity issues include conflicts between existing users and new developers, and the inclusion of farm dams and tree plantations in the relevant caps. Overall, effective management of these issues requires a total catchment management approach to water management that embraces the whole water cycle.

## DEFINING THE ENVIRONMENTAL FLOW REQUIREMENT

With the cap in place, the focus now is on ensuring the health of the rivers. The starting point is the assessment of river health that will be provided by the year 2000 Sustainable Rivers Audit. But beyond this, there is no basin-wide move to take the next step of defining and reserving environmental flows for all the rivers. Such flow assessments are being done for many sub-catchments (including by expert panels of river specialists–see Note C.1), but these are not being integrated to deliver environmental flows to maintain all the basin's

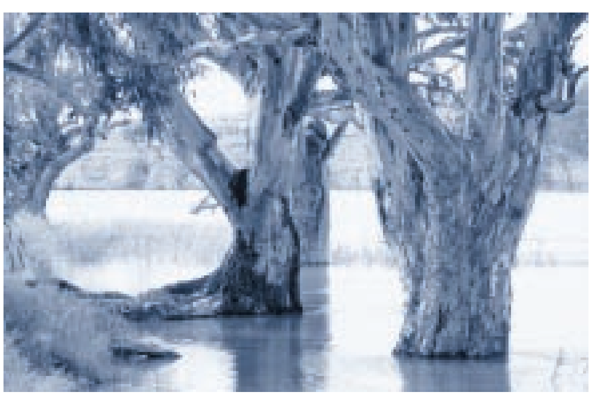


Photo by Willem van Aken, ©CSIRO

River Red Gums,Murray River, Australia

rivers—including the Murray and Darling Rivers—in a healthy condition.

There is growing recognition that this next step should be taken. However, any change in river management that requires more river flow for the environment would imply a reduction somewhere else, and this would be difficult politically. Nevertheless, the process is gradually gaining momentum, following precedents in other countries where historical water allocations have led to severe environmental problems (Box 9).

A further difficulty is likely to arise. The cap allows for irrigation development through improvements in water use efficiency as long as the water extracted from the river remains within the cap. These efficiency improvements will come partly from reduced leakage in distribution systems and on-farm. The consequence is that surface and subsurface return flows to the rivers of the Basin will decrease. Thus, the cap could have the perverse effect of decreasing river flows and placing greater pressure on the aquatic environment.

## WIDENING APPLICATION OF THE CONCEPT OF ENVIRONMENTAL FLOWS

The impact of flow manipulations is not reflected only in river channels. Wetlands, lakes, deltas, groundwater reserves and inland seas are all becoming degraded due to disturbance of their natural patterns of water movement. This section provides three examples—the Caroni Swamp in Trinidad and Tobago, the Lower Mekong River, and the Aral Sea—of problems that have emerged, and the moves to limit or reverse degradation of both the water bodies and the quality of life of the riparian peoples.

### THE CARONI SWAMP OF TRINIDAD AND TOBAGO

The Caroni Swamp is the country's largest mangrove swamp, supporting 157 bird species, including migratory waterfowl and the national bird, the scarlet ibis. Over the last few decades, various abstractions and other catchment activities have sharply reduced the freshwater inflows from groundwater, overland flow, and its four rivers. In

**Box 9.**
**The Central Valley Project, California, U.S.A.**

In 1937, the Central Valley Project (CVP) was launched to divert water from the Sacramento-San Joaquin River delta to southern California. This was supplemented in 1960 by the State Water Project, with the two schemes providing 10 million acre-feet of water to southern California and enhancing the welfare of rural areas and industrial growth. However, there were massive ecological impacts, including a serious decline of sport and commercial fisheries, loss of 95 percent of the state's wetlands, decline of migratory bird and waterfowl populations from 60 million to 3 million, and enhanced salinity levels in the donor systems.

Policies and laws to mitigate this include the CVP Improvement Act of 1992, which placed environmental restoration and protection on an equal footing with offstream water demands. Operation of CVP facilities is changing to allow re-allocation of an additional 800,000 acre-feet of water yield from offstream users to the environment. An $80 million temperature control device was added to Shasta Dam to aid Sacramento River salmon, and more than $100 million has been spent on environmental rehabilitation.

By 1997, debate over major sections of the act continued, including management of the environmental water allocation and the Anadromous Fish Restoration Program. There was dispute over the definition of yield and where it should be measured; whether downstream flows could be re-captured and exported; and how and where the water could best be used for the environment. The amount of water needed at the delta to double fish populations was questioned, as was the adequacy of the underlying science. Renewed contracts for water allocations now cost more and require water conservation plans and payment into a restoration fund.

addition, pollution from various industries and rum processing plants have increased waste discharges into the Caroni River. Flood protection works, embankments, and canals have prevented floodplains from being inundated and allowed increased inflow of marine waters. Increasing salinization and loss of a range of habitats has resulted in an overall decline in biodiversity and a falling abundance of plants and animals, including the scarlet ibis.

The World Bank-supported Trinidad and Tobago Water Resources Management Strategy recommended measures for the rehabilitation of the swamp, including increasing freshwater and sediment inflows, retarding drainage of water from the swamp, excluding seawater intrusion, and controlling point and nonpoint sources of pollution. Two critical considerations will be 1) restoring flushing floods and not just increasing base flows; and 2) ensuring the extra water is of high quality, brought from high in the catchment. A further consideration is that all remedial work should be simple and not require highly skilled professionals to maintain it. The ultimate aim is to reverse the decline in biodiversity and ensure sustainable use of the swamp's valued ecological attributes.

## THE LOWER MEKONG RIVER

In 1995, the four riparian countries of the lower Mekong–Cambodia, Laos, Thailand, and Vietnam–signed an "Agreement on Co-operation for the Sustainable Development of the Mekong River Basin." Although all parts of the system will be addressed, two critical areas will receive special attention. These are the delta in Vietnam and the Tonle Sap Lake in Cambodia. The delta covers about 12 percent of Vietnam's land area, supports about 17 million people, and produces half of the country's rice. With catchment and other changes, the river's flow is becoming increasingly subject to floods, with "excessive" floods occurring about every 30 years instead of every 200 years, and consequent lower flow in the dry season. As a result, there is increasing saltwater intrusion into the delta, which adversely affects delta residents, domestic water supplies, and up to 2 million hectares of agricultural land.

The Great Lake, or Tonle Sap, is of exceptional ecological, economic, and cultural importance. Situated in Cambodia, it is linked to the Mekong River by the Tonle Sap River. In the dry season, the Great Lake drains into the Mekong. In the wet season, the Mekong reverses the flow of the Tonle Sap River, which expands the lake from about 3,000 km$^2$ to 16,000 km$^2$. Gradual drainage of the lake in the dry season significantly contributes to dry-season low flows in the delta. The annual fish catch of the lower Mekong, some 1.5-2.0 million tons, is largely dependent on the annual flooding and draining of the Tonle Sap.

In 2000, the Mekong River Commission (MRC), which is charged with implementing the Mekong Agreement, received $10.8 million from the Global Environment Facility to develop "Rules for Water Utilization," including rules for cooperation in the maintenance of flows in the main stream. Article 6 of the agreement requires that the following flows be adhered to, except in years of historically severe droughts or floods:

- not less than the acceptable minimum monthly natural flow during each month of the dry season
- the natural reversal of flows into the Tonle Sap in the wet season
- average daily peak flows that are not greater than would naturally occur on average during the flood season.

Agreed flows will be based on a process of transboundary analysis, which began in 2000. Minimum flows for the dry season are due to be set by 2004. The World Bank is providing technical assistance for the determination of environmental flow requirements for the Mekong River Basin.

## THE ARAL SEA

Until the 1960s, the Aral Sea was the fourth largest inland body of freshwater in the world, and was vital to life in the Central Asian states of Tajikistan, Kyrgyz Republic, Uzbekistan, Kazakhstan, and Turkmenistan. Irrigated agriculture has been practiced for thousands of years in the Aral Basin and currently supports 40 million people. Irrigation, mostly of rice and cotton, has been both the means of survival for the people, and the main cause of the decline of the Basin's water resources. The irrigated area has more than tripled in the last hundred years, to the present 8 million hectares. To support this, more than 90 percent of the river flow into the Aral Sea has been diverted, and its present volume is 70 percent less than historical levels. The remaining lake has split into a smaller northern section, with some inflow remaining, and a larger southern portion that is hypersaline and mostly biologically dead. Increasing salinization is also a major problem in the surrounding irrigated land.

It is probably economically, socially, and ecologically impossible to restore the Aral Sea to its original condition. A new balance needs to be struck to maintain the water bodies at agreed levels of health that will also address the needs of millions of poor people. This is being addressed through efforts of the Global Environment Facility, the World Bank, and many other multilateral, bilateral, and national organizations. Efforts will focus on two main objectives. First, the irrigation infrastructure will be rehabilitated to increase its efficiency. Second, the northern Aral Sea will be isolated and, through managed environmental flows, an attempt will be made to restore some of its original ecosystem attributes.

# CONCLUSION

There is growing awareness that catchment and water resource developments that alter the pattern of water movement in aquatic ecosystems will cause the systems to change. These changes do not have to be left to chance, but can be anticipated and limited to a level that society finds acceptable. Many techniques have evolved for environmental flow assessments (see Note C.1). As the examples described here reveal, these techniques can be used in different ways to provide advice on development options . World Bank experience in EFA is evolving slowly.

The availability of these flow assessment techniques is a step forward, but in isolation can achieve little. All too commonly, and irrespective of the chosen method, there are few relevant data, limited funds, few specialists with relevant skills and experience, poor understanding of the targeted aquatic system, and development needs that are so urgent that decisions cannot wait until all of the preceding are fully resolved.

If responsible environmental management, and the concept of sustainable use, are to succeed, scientific advisors, water managers, and decisionmakers could benefit from a working relationship based on a six-point strategy:

- Development of appropriate policy and legislation on resource protection (legitimizing sustainable use)
- Directed national programs of research on the links between ecosystems and flow (increasing the knowledge base)
- Use of best available knowledge from these programs, together with directed short-term research, to answer management questions (moving ahead with limited knowledge)
- Use of structured, transparent processes for options assessment and decisionmaking that equally address economic, ecological, social, and engineering concerns (assessing the full implications of all options and negotiating tradeoffs)
- Monitoring the outcome of the chosen option (learning by doing)
- Adjustment of management plans where indicated by monitoring results (employing strategic adaptive management).

To achieve this strategy, five factors for success are apparent in the case studies. First, downstream communities have an important role to play in the decisionmaking process, which is likely to impact and alter there livelihoods. Second, the water authorities need to move from being providers of water to becoming holistic managers of water resources. Third, scientists and managers need to agree to work together in an environment of limited knowledge. Fourth, emerging legislation on sustainable resource use, either from within the country or from outside, needs to be implemented to provide impetus for and legitimacy to the environmental flow assessments. Fifth, the move toward sustainable river use, though difficult, is typified by negotiation, transparent decision making, and attention to equity and conservation issues.

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