Water Quality: Management of a Natural Resource

James Perry
Department of Forest Resources
College of Natural Resources
University of Minnesota
St. Paul, Minnesota

Elizabeth Vanderklein
Science Writer
College of Natural Resources
University of Minnesota
St. Paul, Minnesota

Consulting Editor:
John Lemons
Department of Life Sciences
University of New England
Biddeford, Maine

Blackwell
Publishing

WATER QUALITY

Water Quality: Management of a Natural Resource

James Perry
Department of Forest Resources
College of Natural Resources
University of Minnesota
St. Paul, Minnesota

Elizabeth Vanderklein
Science Writer
College of Natural Resources
University of Minnesota
St. Paul, Minnesota

Consulting Editor:
John Lemons
Department of Life Sciences
University of New England
Biddeford, Maine

Blackwell
Publishing

Blackwell Science

Editorial offices:
238 Main Street, Cambridge, Massachusetts 02142, USA
Osney Mead, Oxford OX2 0El, England
25 John Street, London WC1N 2BL, England
23 Ainslie Place, Edinburgh EH3 6AJ, Scotland
54 University Street, Carlton, Victoria 3053, Australia

Other Editorial Offices:
Arnette Blackwell SA, 224, Boulevard Saint Germain, 75007 Paris, France
Blackwell Wissenschafts-Verlag GmbH Kurfürstendamm 57, 10707 Berlin, Germany
Zehetnergasse 6, A-1140 Vienna, Austria

Distributors:
USA
Blackwell Science, Inc.
238 Main Street
Cambridge, Massachusetts 02142
(Telephone orders: 800-215-1000 or 617-876-7000; Fax orders: 617-492-5263)
Canada
Copp Clark, Ltd.
2775 Matheson Blvd. East
Mississauga, Ontario
Canada, L4W 4P7
(Telephone orders: 800-263-4374 or 905-238-6074)
Australia
Blackwell Science Pty., Ltd.
54 University Street
Carlton, Victoria 3053
(Telephone orders: 03-9347-0300; fax orders 03-9349-3016)
Outside North America and Australia
Blackwell Science, Ltd.
c/o Marston Book Services, Ltd.
P.O. Box 269
Abingdon
Oxon OX14 4YN
England
(Telephone orders: 44-01235-465500; fax orders 44-01235-465555)

Acquisitions: Jane Humphreys
Development: Kathleen Broderick
Production: Irene Herlihy
Manufacturing: Lisa Flanagan
Typeset by BookMasters, Inc.
Transferred to digital print 2002

Printed and bound in Great Britain by
Marston Lindsay Ros International Ltd,
Oxfordshire

Printed in the United States of America
96 97 98 99 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Perry, James A. (James Alfred), 1945–
Water quality : management of a natural resource / James Perry and Elizabeth Vanderklein.
p. cm.
Includes bibliographical references and index.
ISBN 0-86542-469-1
1. Water quality management—Government policy. 2. Water quality management—Social aspects. 3. Water rights. I. Vanderklein, Elizabeth. II. Title.
HC79.W32P44 1996
333.91—dc20 96-8574
CIP

Contents

Preface

The Aral Sea has been a pivotal feature of the Central Asian landscape for millennia, moderating the regional climate sufficiently to enable productive agriculture and civilization. Massive evaporation from the sea's 64,000 km^2 surface was lifted by the cold north winds and carried thousands of kilometers to the Pamir and Tyan-Shan mountains, where it was deposited as snow. From there, melting snows carried life-giving water throughout the Central Asian plains.

In the 1960s, Russian scientists and policy makers set out to drain the Aral Sea and reclaim the drained basin for cotton production. Scientists claimed that drying the Aral Sea would be far more advantageous than preserving it, that productivity of the reclaimed land would more than make up for lost fisheries and transportation industries, and that disappearance of the sea would not affect the region's landscape.

The result: the Aral Sea will disappear by the year 2010, leaving behind an ecological and social desert. Massive irrigation projects in the region have reduced the Aral Sea to less than 40% of its original volume and more than tripled its salinity. Ground levels have subsided (in some areas by as much as 8 m) due to groundwater pumping. More than 80% of the animals found in the region have disappeared. Increasing wind erosion has covered agricultural land with salt deposits from the newly exposed sea bed, and both daily and annual temperature ranges are increasing significantly. As a final injustice, draining the Aral Sea has changed the regional climate sufficiently so that it can no longer support the vital cotton crop for which the sea was originally sacrificed. The amazing story of the Aral Sea is not unique to Russia: worldwide, scientists and decision makers alike have a long way to go to understand the wide-ranging implications of managing water quality in a landscape.

The Need for a New Text: New Paradigms, New Tools, New Perspectives

Water quality management was once a purely technical subdiscipline of hydrology; its goal was accurate determination of water chemistry. While the current field of water quality management would not be possible without these technical roots, its scope has now expanded far beyond the laboratory. It is now a social and political discipline whose concerns range from ensuring adequate health standards to preserving biological diversity and ecosystem integrity. Both the evolution of the field and its elevation in societal importance have taken place rapidly. Consequently, the literature offers today's water quality managers and policy makers only technical manuals that provide little guidance or support for the everyday decisions they must make. Complementing these technical manuals is an increasing array of specialty publications that address water quality as a subset of water availability or environmental degradation. None of these addresses the field in its current broad context. This information gap constitutes the first reason for this book: *the technical aspects of the field are well understood, but the social, biophysical, land use, and policy considerations that are now part of the field are rarely addressed.*

The Need for an Integrated Approach

Historically, water quality has been studied by a loose association of specialists working in related fields: hydrologists, chemists, biologists, engineers, and policy makers all carved out pieces of the water quality puzzle. This reductionist approach has led to a long list of unidimensionally successful and multidimensionally tragic water projects. In the example of the Aral Sea, by focusing on only agricultural productivity, cotton harvests in Soviet Central Asia were increased temporarily but the Aral Sea has been reduced to a salt marsh and regional ecology transformed. In another example, through a desire to improve marketability of Lake Victoria fish, an introduced exotic provided a temporary increase in fish harvests but over the long term has resulted in a permanently altered and impoverished food chain of the lake and its surrounding riparian zones.

The fact that water quality management is not successful when divided among sectors constitutes the second need for this book: it is increasingly clear that dissecting water quality among specialties in this way yields an incomplete picture and results in more cases of management failure than success. Instead of taking the specialist's view and focusing on problems narrowly, it is now evident that understanding water quality requires an integrative and large-scale view: looking at whole landscapes and whole regions to see how hydrology, chemistry, biology, geology, land use, demographics, public attitude, policy, and an expanding world view all interact to determine the quality of our water resources. Consequently, *our second rationale for this book is to communicate a synthetic, landscape-scale perspective that will increase our ability to take appropriate remedial action in response to a given problem.* More importantly, it enables us to be proactive—to anticipate how ecosystems will respond to societal and natural pressures on water resources so that we may plan accordingly.

Management and Ecology on the Verge of Change

The third reason for this book is that significant developments in the field of ecology have changed the way in which management must be approached. Management reflects changes in both society and scientific understanding. Thus, the future of water quality management lies in the social and scientific paradigms of today, just as the management of today is based on the paradigms of 10 years ago. Today's science presents a unique opportunity, however. For the first time in the history of natural resource management, enough understanding exists in different fields that management might no longer have to be reactive. It is possible that management can begin to be, and remain, a proactive field that looks at anticipated needs, anticipated effects, and social values to plan management strategies and practices. *Our third rationale is to develop and present a proactive view, requiring an awareness of the social contexts within which management occurs, an awareness of new ecological theory with respect to ecosystem responses to stress, and an awareness of how policy is implemented in different situations and different countries.*

A Human Problem—A Global View

Finally, this book reflects changes in the way in which management decisions are made worldwide. International comparisons in natural resource management were once just interesting asides, but in today's globalized and internationalized world, it is critical to understand how decisions are made across boundaries. U.S. and European Community guidelines for water quality management each grew out of unique social and biophysical conditions, yet these standards increasingly are being applied in other countries where they often prove inappropriate. Additionally, an expanding dimension of water quality management deals with cross-boundary pollution. Both of these conditions require understanding the policy framework within which decisions are made and understanding which factors can and cannot be generalized. Another international issue of which managers must now be aware is the role of water quality in international and regional conflicts (e.g., it has been used both as a weapon, as in the case of the Persian Gulf War in 1991, and as a tangible factor contributing to ethnic and religious battles such as those between Israelis and Palestinians, or between North and South Koreans). *Thus, our fourth rationale is to "internationalize" the perspectives of scholars and students interested in water quality science and management.*

Consequently, this book offers four critical new dimensions to the existing literature on water quality management: (1) a *social dimension* and an understanding of how water quality management has evolved to its present state; (2) an *integrated dimension* in which the interactions among chemical, physical, biological, and social aspects are addressed; (3) an *ecological dimension* that uses new concepts of the hierarchical structure of ecosystems, new understanding of the response of ecosystems to stress, and a new frame of reference to ecological problems (e.g., regionalization) to yield a proactive management strategy; and (4) an *international dimension* that demonstrates the care required in applying water quality management across borders and regions as well as demonstrating similarities in different societies' approaches to water quality management.

The Structure of the Book

The specific goals societies have for their water resources stem from cultural traditions and perceptions of resource availability. From these goals emerge each society's water quality management needs and approaches. Consequently, a study of water quality must begin with a discussion of the ways societies use water and the regional, cultural, and historical factors that determine a society's valuation of its natural resources. We focus on these issues in the first section of the book.

Section two begins with a chapter that links the social dimension with the biophysical one: the importance of scale issues in ecology and in our perception of ecological problems. The section then presents background information on the biophysical environment. The approach used here is to highlight the characteristics of the hydrological cycle, lakes, rivers, coastal zones, and wetlands that are most important from a water quality perspective. This information on the basic water resources and their components provides vital background for understanding impacts of different uses on water quality and the management implications of those impacts.

Water quality is inherently an ecological science. Consequently, section three reviews important new developments in the fields of ecology—in particular, how ecosystems are structured as vertical and horizontal hierarchies and the fact that many ecosystems have similar responses to stress. This section also includes a chapter on the move toward management based on ecoregional characteristics of water quality and land use. Chapters in this section focus on our concern that water quality management must be implemented at a landscape or regional level. They are critical background chapters in which we give readers the conceptual tools with which to approach problems and dilemmas in water quality management.

In section four, we introduce a series of water quality case studies involving different land uses and their impacts on water quality. This section begins with an overview of water quality concerns and the ways in which water quality is affected by land use activities. This overview is followed by more detailed chapters on water quality effects of forestry, agriculture, urbanization, and special issues such as exotic species, global warming, acidification, and eutrophication. In each chapter, we discuss how social contexts, biophysical constraints, and issues of scale affect responses to these problems in different parts of the world. Chapters in this section are divided among sectors for convenience, but each chapter is designed to demonstrate the ways in which the different areas of human management are integrated and inseparable. Each chapter is also structured to give an overview of the dimensions of the issue (e.g., land use), the ways in which it may affect water quality, and actual impacts and significance of those changes and solutions (i.e., physical remediation or policy actions). Each chapter concludes with management case studies that illustrate the complex contexts within which water quality decisions are made.

In section five, we return to the social context of management, looking at water quality policy issues and decision making around the globe. Chapter 25 discusses the cultural dimensions of policy making such as the influences of religion and philosophy, historical experiences with pollution, political structures, and socioeconomic status. Chapter 26 discusses the elements of integrated water quality management, analyzing both the enormous potential for integrated management as a new management paradigm and some of the serious constraints to its successful implementation. Finally, in chapter 27 we present a series of case studies that illustrate the principles outlined throughout the book: principles of biological appropriateness in management, of the importance of understanding user values, and of the nature of overarching political and social concerns in the application of water quality management.

Management—A Multidimensional Problem

Throughout this book, we present the perspective that water quality management is multidimensional, operating across spatial and temporal scales, across political and social boundaries, and across land uses. We stress that water quality impacts may result from an array of sources as varied as the choices of personal household items such as soaps and paints, to complex effluents from factories owned by multinational conglomerates, to the choices of crop and tilling patterns on agricultural lands. Thus, the biophysical changes in water quality are inseparable from the cultural practices that caused them and the social and cultural dimensions must be included in any effective management plan. We also stress that water quality changes cause both ecological and social chain reactions. The social chain reaction begins with ecological impacts and progresses through changes in land use practices brought about because of those impacts. This water quality chain reaction can affect every dimension of a society: changing its dominant economic activities such as fisheries or agriculture, changing recreation patterns, altering health conditions, and altering the distribution and success of industrial activities. Unequal impacts of poor water quality on different sectors of a society make social justice as much a part of water quality decisions as effluent standards for different industries. The concept of an ecological chain reaction is more familiar and few would be surprised to read that water quality changes can affect the long-term viability of ecosystems. Because of the range of areas affected by water quality, managers must be skilled technically, but must also be astute social scientists, able to observe and stave off inevitable conflicts among users and affected human and nonhuman populations. Societies must engage in productive discussions about "acceptable" versus "unacceptable" changes in water quality and to mediate disputes about costs and benefits of management choices.

Goals and Intended Audience

This book is intended to serve two audiences: third- to fifth-year students in water quality management, and applied problem solvers and decision makers interested in a broad and integrated approach to water quality management. We assume that the reader has some background in science (e.g., basic physics, chemistry, and biology at the college level) but not necessarily any previous exposure to coursework in aquatic sciences or natural resource management.

Anticipating that this material will be used in classes led us to choose a format of numerous short chapters rather than a few long ones. Each chapter treats a well-defined topic and contains appropriate reading material for a discrete section of a class. Each begins with a chapter overview and concludes with a list of review papers, texts, and primary journal articles that are suggested for further reading. A more extensive literature list, including all material referenced in the chapters, is presented at the end of the book.

The measure of a text such as this one is its utility: a text for managers must reflect the needs and experiences of its users. We urge our readers to write to us so that we may improve the book.

Acknowledgments

Many people have contributed immeasurably to this effort. We are especially grateful to our respective families (Peggy, Kendra, Leslie, and Ben; Dirk, Kim, and Ian) for their support and patience. Mary Kay Corazalla provided valuable assistance with figures and literature sources as well as ideas and editorial assistance. Many colleagues and students offered review comments, including Pam Davis, Gray Henderson, Bill McDowell, Brian Shelley, and Nels Troelstrup. John Hall designed the cover. Jane Humphreys and Debra Lance, both of Blackwell Science, provided valuable guidance. In addition, this project was supported in part by the Minnesota Experiment Station through Project 42-25 of the McIntirre Stennis Cooperative Forestry Act.

On a personal note, Leigh wishes to thank the Center for the Environment at Cornell University, and in particular the Center's former director, Jim Lassoie, for offering me a visiting position while I was away from Minnesota. Access to Cornell's libraries, internet system, lectures, and astounding gardens has made this possible. On an even more personal and fundamental level, I would like to thank Jim Perry. I owe him professional thanks for all we have written and talked about over the years, and personal thanks for his unending patience, support, and encouragement. He has been a true mentor and friend. Lastly, I would like to thank Kim and Ian for sharing their mom with the computer and for helping me keep my priorities straight; Dirk for being my partner; and my small, but increasingly intimate circle of family for banding behind me. I hope this can contribute in some small way to changes for Kim, Ian, and Marshall's generation.

1

Water Quality Management: An Evolving Field for Changing Values

Overview

The ways in which a society manages water quality is a telling reflection of political, cultural, and economic processes within that society. In many cases, the same approaches are used by different nations to achieve notably different goals. In other cases, differences in administrative traditions may cause countries with virtually identical water quality value statements to adopt radically different approaches toward implementing their goals. The variations in both goals and approaches are reflected in the earliest stages of water quality management: assigning use-oriented values to different water resources and planning for implementation of goals based on those values.

All management decisions stem from the context of use-oriented goals. Consequently, in societies dominated by development goals such as improving riverways for transportation, constructing irrigation systems, and using water for waste disposal, water quality management is generally an afterthought in the planning process. Many societies around the globe, however, are no longer driven by unchallenged development pressures. Most now recognize a broader range of values, such as those involving public health, amenity, recreation, and ecological integrity (e.g., "environmental" values). As these sometimes compatible and often competing uses are balanced, water quality management is moving into a more primary position at the beginning of planning processes rather than as a tail-end consequence.

Water quality management is, as a result, a very fluid phenomenon: as society and societal values change, new values must be reflected in management directives and strategies. At any given place and time, water quality management goals will reflect a different balance between social pressures such as development status and economic priorities, perceptions of resource scarcity or abundance, environmental values, traditions of public incentives, or even experiences with pollution crises. In all cases, water quality management is a multidisciplinary field, whose practice requires knowledge of hydrology and chemistry, biology, sociology, and politics.

Coincident with the response of water quality management to value shifts and scientific knowledge, a larger-scale shift in water quality management is also occurring. Globally, water quality policies are undergoing a shift from linear planning in which goal statements define specific policies and tactics to a more integrated approach that incorporates ecological reality, demands for multiple-use planning, monitoring, and feedback. These elements are all critical in today's world, and their omission in the past has been at the heart of most failures of water quality management to date. New developments in ecological theory, coupled with new global awareness in society, necessitates development of a new management model for water quality. This model integrates multiple spatial, temporal, and political scales (hierarchies) and makes broad use of feedback loops to improve management actions continually.

Introduction: Why Manage Water Quality?

Water is the most basic natural resource. People subsist where there are no forests, where there are no fish, where soil cannot be utilized, and where wildlife cannot be found. Yet even in a desert, human society centers around the oasis, just as in the rain forest it centers around the rivers. For plants and animals alike, water is essential for life, making up as much as 65% of the human body (90% of an infant's body). It also provides homes for fish and animals, refuge, food, navigation, electricity and mechanical power, coolant, a waste stream, and opportunities for recreation. No body of water, however, can support all of these different uses without suffering some degree of degradation: under poor management, degradation may result from even one primary use.

Water quality management serves largely as an intermediary or interpreter between any water body and its users, balancing the biophysical capabilities of the water resource against the multitude of uses that may affect it. Notably, different societies, cultures, and regions all have different priorities based on their water-related needs so the water quality manager in each situation must balance a different set of considerations. For example, if a community's needs center around meeting minimum domestic uses, less concern will arise over specific quality considerations. For societies in which availability is not a critical limitation, however, valuation of water bodies will reflect a broader range of human uses. An important reality in water quality management is that no body of water can be all things to all people: uses frequently conflict, and valuation of water quality depends on the social, political, and cultural contexts of those uses.

Conflicts over water use are as old as civilization, and water laws mandating water use rights and outlining quality concerns related to this peculiarly "common" resource are among the most ancient of laws. While legal systems still form the framework for water use decisions and are the traditional form through which conflicts are resolved, changes in use patterns, population increases, industrial stress on ecosystems, and increasing pressure on water resources have created a revolution in water quality management. Water quality awareness and concerns have prompted managers and decision makers to consider water resources and water quality as part of a more integrated framework. Rather than the single-focus, deterministic model assumed by a long history of water development management, emerging models of water quality management recognize the contextual nature of water management decisions, the integrated nature of social and ecological effects, and considerations over a larger temporal and spatial scale.

This chapter stresses the human context of all water quality management decisions, and outlines both the traditional, deterministic approach to management and the evolving integrated approach. With this background, subsequent introductory chapters will consider global patterns of water availability and use in an historical context (chapter 2), how societal attitudes are reflected in goals and management strategies (chapter 3), and how goals and strategies are translated into designated uses (chapter 4). The final chapters of this introductory section are devoted to a discussion of environmental toxicology, the traditional science behind water quality policy statements (chapter 5), and the evolving use of bioindicators and other environmental assessments for policy and classification purposes (chapter 6).

From Unidimensional to Multidimensional Approaches

Traditionally, water resource management has been unidimensional, with actions designed to address single-purpose needs such as hydropower, irrigation, or navigation. If fisheries, biodiversity, agricultural, or other uses of the water resource were negatively impacted through construction of dams or navigation channels, it was generally seen as a necessary sacrifice to "progress."

Traditional, unidimensional water resource management is still practiced in areas throughout the world where multiple uses of water or ecological consequences of water development receive minimal, if any, overt valuation. Ribesame (1992), however, echoes a growing trend in water quality management: that the dominant feature of recent water resources planning around the world is no longer a technical or financial issue, but a "growing intolerance of environmental and social impacts." Consequently, changing global values increasingly demand that water quality integrate environmental, public health, recreation, and amenity values with economic ones. Consequently, present-day water quality management must be multidimensional, as managers must contend with the multiple ways in which land use practices affect water quality, and water quality's subsequent effect on land use, health, and economic and biological viability.

A corollary concern that distinguishes traditional and emerging water quality paradigms is the concern with ecological integrity of water bodies. More than a concern over specific ecological effects, ecological integrity implies the ability of a system to be self-perpetuating and sustainable. One important lesson learned throughout the history of water resource management has been that multiple uses cannot be ensured unless integrity of the entire system is maintained. Severely degraded water bodies can provide neither utilitarian nor aesthetic nor ecological benefits. Consequently, although emphasis on (or even awareness of) integrity is quite new from an historical context, it lies at the heart of how water quality management today is distinguished from traditional water resource management approaches.

The Role of Societal Values

Management is a peculiarly human practice and the starting point of management is, almost by definition, a designated (human) use. A more useful frame of reference, however, is provided by recognizing that *uses* originate from the different *values* humans place on a given resource. Thus, the job of management is to ensure that the chemical, physical, and biological integrity of a water resource is maintained within the bounds required for a suite of human values. The value context explains why water quality management must draw heavily on social and managerial sciences in addition to biological, chemical, and physical sciences. It also explains some of the forces behind changes in the field of water resource and water quality management.

Because management occurs within the context of human valuation, each society develops unique management systems and unique management goals. Individual and societal perceptions of natural resources reflect biophysical realities (e.g., scarcity and abundance of a resource) but also reflect cultural values, historical experiences, and political realities (see chapters 2 and 25). In turn, water quality questions and answers change from society to society, and from region to region. Thus, the water quality manager asks the same question in each society and each instance: is quality (and quantity) sufficient to support a given mix of uses? The answers to that question change depending on the audience. Even within a single state, perceptions of water quality vary with the expectations of the users. For example, recreational users expect significantly higher clarity of lake water in the northern areas of Minnesota than in the South; awareness of those regional expectations is critical to the success of management actions.

Different value systems may also reflect economic realities. On a large scale, economic forces are often "averaged out" to a country- or region-wide set of accepted standards. Economic conditions of nations, as a whole, may create vastly different national standards. National standards are only one part of water quality decision making, however. In practice, water quality decisions are carried out at local levels where local economies and local resources may create vast discrepancies between the national "consensus" values and the true local valuation of a resource. For example, local-scale concern over long-term water quality degradation is often less important to people if their short-term survival is dependent on the polluting industry or land use practice. For example, high lead threatens health and productivity of whole communities in Poland, yet the factories continue to run because workers need tomorrow's meal; likewise, in the 1980s California farm workers judged the ecological and health threat of selenium poisoning—caused by farm irrigation—less important than the continued operations of the farms on which they worked. Equally common, however, is the scenario in which local communities become concerned over a quality issue and force more stringent controls into effect than would be expected under national level value systems.

In addition to broad societal differences in valuation of resources, each different use is associated with its own nested set of values and expectations. Water quality impacts on a body of water will be judged according to these unique value sets. For example, although fishing and swimming in a lake usually are compatible uses, each has its own set of standards and water quality may affect each use differently. Specifically, acid rain results in many changes in a lake, often including significant increases in water clarity. It also often leads to dramatic reductions in fish populations. To recreational swimmers or boaters, water clarity has a high value and the fish population may be largely irrelevant. Consequently, for these uses acidification may be perceived as an improvement in water quality; if swimmers constituted the only users of a water body, then the political and social forces to mediate effects of acidification might be low. While fishermen might consider clarity to be pleasant aesthetically, their judgment of water quality is more closely tied to the health and abundance of fish populations: to a fishing-dependent community, the lack of fish would certainly constitute low water quality. Because fishing values factor in with concerns over ecological integrity and possible health effects from acidified waters, remediating the effects of acidification is usually a high local priority.

While uses and users help define the values ascribed to different water bodies and water quality threats, water quality values are also a result of bias filters used by the decision makers. As described by Gerlach (1993):

> Many technocrats recognize that they also interpret reality through the cultural filters of their respective groups. They are not aloof bystanders to the decisions that follow from their measurements and calculations; rather, they hold stakes in such decisions—stakes of objective interest and subjective identity. Jobs and careers are at stake, as is pride in working to help the world. But officials and specialists are also biased by their group culture. Agreements and disagreements among specialists and between specialists and the public are a function of many factors, only some of which are rooted in the accuracy and plenitude of scientific research [p. 283]

Gerlach (1993) continues to describe how during a 1980s drought in the Midwest, public health officials, engineers, politicians, and natural resource managers all had vastly different interpretations of the same data, with regard to whether public supplies were low enough to constitute a threat and whether extra water should be released from reservoirs.

The Traditional Approach to Management Planning

Given value conflicts and the perceptual filters of different users, and decision makers, how does society decide which values to ascribe to a water body? That is, how does a community decide whether water clarity, as in the acidification example above, is significant or not? The planning process begins when these diverse values and uses are summed up in a societally determined goal statement. In the traditional approach to resource planning, translating these goals into actions was (and in many places still is) a linear process in which goals were used to define policies, policies were used to define objectives, objectives defined strategies, and strategies defined implementable tactics. Goals, therefore, constitute the top level in a multitiered planning process, representing the

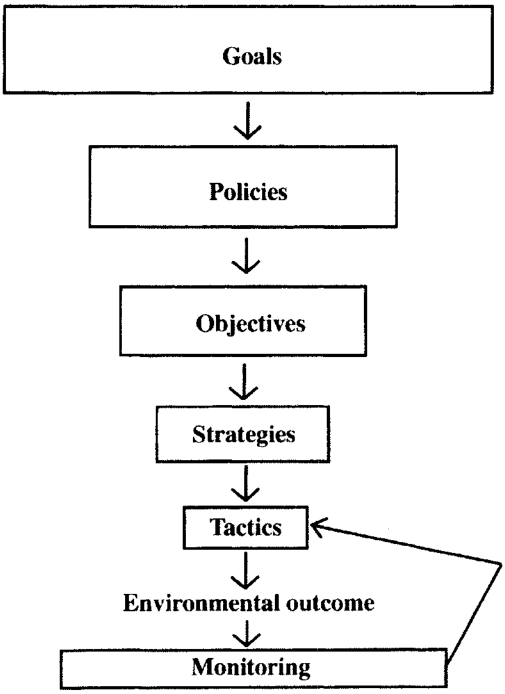

Fig. 1.1a. Traditional model of water quality planning. This approach follows a linear path in which feedback is limited and public input is minimal. Scientific advances and changing societal values, however, are forcing a change to hierarchical, iterative models (see Fig. 1.1b.).

broadest level of thought about a resource. From that point, the manager's task has always been to define increasingly focused answers to how to implement the goals (Fig. 1.1a). These tiers may be described as follows:

- *Goals* (e.g., portable water, fishable waters, electricity generation) are broadly defined and represent directions society wishes management to take. Goals are used to introduce laws and policies and to set the tone for major documents. For example, the U.S. Clean Water Act sets "fishable, swimmable" waters as its broad goal. In other cases, a goal may be expressed as "provide acceptable drinking water to 100% of households by the year 2000" or "ensure that fish inhabiting waterways in all major metropolitan areas are safe to eat."
- *Policies* are more specific statements that describe how an organization intends to accomplish its goals. They represent the current and currently obtainable practices. A policy under the "fishable, swimmable" goal might be "all municipal wastewaters shall receive at least secondary treatment." A policy under the drinking water goal might be "all citizens shall have

reasonable access to safe drinking water." In some societies (e.g., the United States), policies are legally binding and policy makers can be sued in civil court for failure to comply. In parliamentary governmental states (e.g., the United Kingdom), policies do not have the force of law.

- *Objectives* are more quantitative, shorter-term, and more specific; they are intended to represent steps to be accomplished in complying with policies. In other words, a policy constitutes a general directive to be accomplished, and objectives break down that directive into the components necessary to realize that policy. Generally, an organization will establish several specific, perhaps relatively quantitative, objectives that must be accomplished to comply with a policy. Exemplary objectives might be "establish a testing program for all city water by year's end" or "establish 1000 new hookups to new residences every 6 months for the next 10 years."
- *Strategies* are planning approaches that will be followed to achieve objectives. Each objective may have several attendant strategies, such as "ensure adequate staffing and facilities for water quality testing objective."
- *Tactics* are specific actions used to achieve a management strategy. For example, tactics might include "hire and train 15 laboratory technicians to implement testing procedures," "convert unused lab space into a water quality testing lab," or "raise city taxes to pay for new facilities." They may include both physical actions (e.g., a management practice) and administrative actions (e.g., meetings, discussions, reports).

Where a goal starts and a policy or objective begins is not, in practice, a clearly drawn line. The exercise of planning from the general toward the specific is, however, important in clarifying the goals toward which we are managing and in determining how we will conduct our management actions. Management is a problem-solving process; a clear statement of the problem and its attendant possible solutions is a prerequisite to good management. Yet it is not a guarantee that management will be implemented. A stepwise planning process has been adopted in most countries and regions of the world, but all too frequently plans remain on the shelves and legislation is rubber-stamped until some crisis provokes partial and ineffective implementation.

Even more importantly, this linear planning model does not leave sufficient room for incorporating biophysical realities, scientific input, or feedback and reassessment. It serves a valuable function in that it focuses questions and answers about societal needs. Yet, a manager might follow this linear model perfectly and still arrive at a management plan that is ecologically and socially disastrous. This fallacy is highlighted in the Aral Sea example at the end of this chapter, in which highly linear and sectoralized planning trivialized the ecological ramifications of decision making. Managers in today's world require a more complex, less linear model with which to make informed and sustainable decisions.

A New Conceptual Framework: Hierarchies and Issues of Scale

As natural resource management, including water quality management, evolves from unidimensional to multidimensional concerns, decision making must become less linear than in the past. In part, this change comes about because of multiple-use demands and the implicit necessity to arrive at management compromises. It also stems from recognizing the need to incorporate biophysical realities into management plans. Long ignored in natural resource management, the biophysical potential and limitations of a resource are at last earning equal footing with cultural values. Ideally, resource management actions represent a compromise between human goals and the physical and biological potential of a given water resource.

To achieve the goals of balancing use with ecological integrity, management must pursue planning along several lines: (1) an understanding of the current resource condition and its potential to deliver goods and services; (2) goals of society or the decision maker; and (3) the appropriate physical and institutional mechanisms to accomplish those goals. Throughout implementation of a management strategy, room must routinely be made for feedback and modification of goals or policies and for incorporation of new scientific evidence about the effects of management decisions.

The importance of explicit goals—*why* we wish to manage the water resource—is as important in multidimensional planning as in traditional linear planning. An important difference between the two models is that an accurate understanding of the characteristics of the water resource itself ranks on equal footing with goal definition in multidimensional planning. The failure of many management plans is traceable to a poor definition of goals; failure of the remaining plans is usually attributable to ignoring geologic, hydrologic, and biological realities of the water resource. Combining explicit and realistic management goals with a realistic assessment of biophysical conditions and potentials gives us the vital understanding of "where we are" and "where we want to be" in our management strategy. This knowledge, in turn, provides the framework for deciding "how to get there" (i.e., the appropriate institutional and biophysical mechanisms for management).

Another important distinction between traditional linear and hierarchical (multidimensional) planning involves the latter's use of feedback loops at each stage. These loops enable managers to monitor and evaluate not only program success but also the appropriateness of the original goals and the accuracy of scientific understanding. Imagine, for example, a popular trout stream in a national forest. The trout require clear, cool water and management of the forest requires revenue from fishing for part of its political support and managerial actions. Consequently, fishing becomes a protected or beneficial use. The qualities of water clarity and temperature upon which the fishing depends dictate management practices such as forest harvesting; harvests must be scheduled in such a way they do not violate temperature or sediment standards for the stream reach. In practice, management actions are conducted and results are monitored to ensure that there is actual compliance with applicable standards and that the standards applied to the water resource are effective in maintaining desired quality.

In addition to incorporating biophysical realities and feedback loops, another critical feature distinguishing linear from "integrated" planning is involvement of the local populace in the decision-making process. Decades of natural resource management failures and some notable successes clearly illustrate that unless the affected population has some "ownership" of a management plan, the plan will be disregarded and ineffective. When the affected community is fully involved in the planning process, however, significantly more cooperation is fostered toward achieving the specific objectives and general goals of a management plan. Consequently, resource management activities are more successful and more enduring.

Just as traditional linear planning has an identifiable sequence, modern hierarchical management also has a distinct planning sequence. The two models are marked by two vital differences. First, in the hierarchical model, consideration of biophysical conditions is on an equal par with goal-setting. Second, steps in this process are not linear; feedback loops in the decision pathway lead to a constant reevaluation of the goals as well as impacts and alternative strategies. The elements of hierarchical planning are best described in stages, where each stage includes a set of parallel activities and results of each stage are fed back into previous ones to maintain the balance between ecosystem integrity and human use (Fig. 1.1b).

- In stage one, for example, priorities are assessed. During this stage, managers and the participating community engage in preliminary discussions, surveys, and assessments to determine which uses or values have the highest priorities. The multiparticipant, interactive nature of this stage immediately sets a different tone for the ensuing planning, when compared with the more deterministic linear planning model.

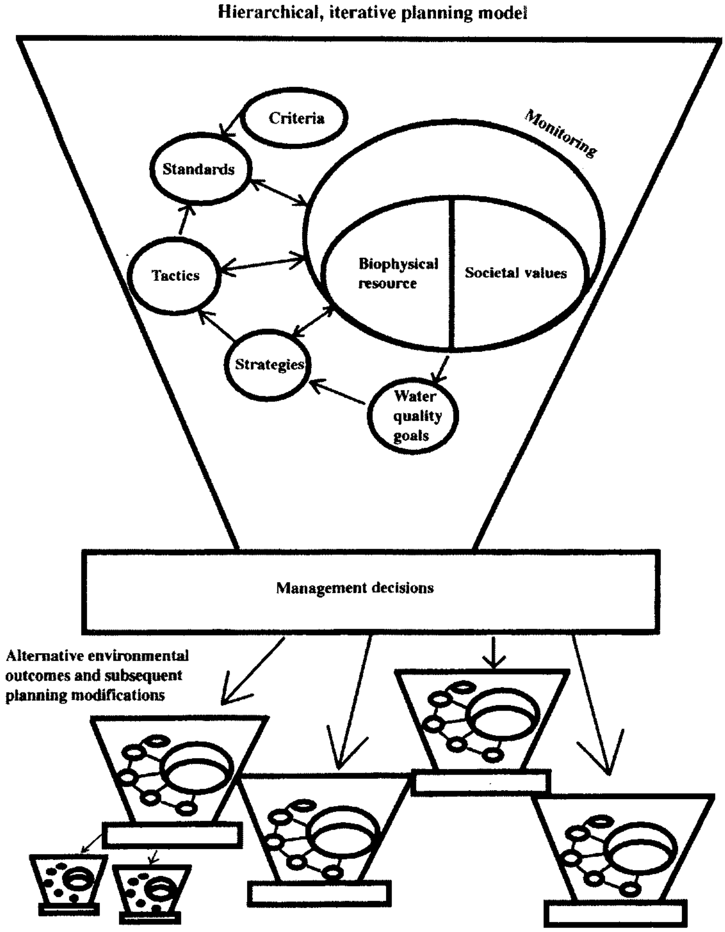

Fig. 1.1b Hierarchical, iterative planning model. In this diagram, societal values are composed of influences from history, economics, and culture as discussed in chapters 3, 25, and 26. The important considerations of the biophysical resource are discussed in chapters 7–13.

- Stage two is the point at which the preliminary discussions are crystallized into mutually agreeable, explicit statements of goals. Simultaneously, stage two is devoted to a biophysical assessment of the resources: are the stated goals suitable for the biophysical conditions, or should the conditions dictate a different set of goals? As the goals and the biophysical realities are compared, a need to reassess the stated goals often emerges. A feedback loop is created in which the stakeholders return to an assessment of priorities, with the new information in hand. The participants can then arrive at new goals and conduct new checks on the biophysical realities of the resource.

- Stage three is a time for integration and focusing. At this stage, policies and laws are written that express the goals of the participants, and preliminary strategies are set. This stage also includes the assessment of environmental impacts of the proposed strategies. Based on the language of the laws and policies, as well as on the results of environmental impact statements and reviews, managers and stakeholders may have to return to stage one to reassess priorities and arrive at goals that have fewer negative impacts (or at lower costs), or they may return to stage two to refine their marriage of goals with the biophysical realities of the resource.
- Once goals, policies, and strategies meet the needs and expectations of stakeholders, the planning process proceeds to an implementation stage. As with the previous stages, implementation may bring to light a need for fine-tuning either the strategies, the policies and laws, or the goals themselves. At its best, this planning model would allow for sufficient flexibility such that feedback would be continuous among the stages, without unduly delaying or interfering with management implementation.
- Finally, monitoring is a critical part of the hierarchical model, but it is distinguished from the monitoring in traditional planning models by being integrated throughout the stages. Rather than referring to only a biophysical assessment of whether the implementation has met its goals, monitoring in this framework refers to the continuous checks between and among participants. Do the goals reflect the needs and desires of the community? Can the resource support the stated goals? Will any environmental impacts outweigh the benefits of the proposed management actions? These questions, which serve to link the stages in the process, are all part of the monitoring process. They complement the more familiar role of assessing changes in water quality parameters as a means to determine the success of different management strategies, and the newer role of monitoring the public's satisfaction with the management plan, and with its results.

In many ways, this model represents a marriage of two nearly parallel approaches to resource policy (i.e., a policy approach and a scientific approach). Because it incorporates feedback loops and multilayered planning, it is well designed to detect ecosystem and social impacts while allowing for balance among management concerns. Thus, this model is attractive because it is sensitive to planning needs and accurately reflects social and ecosystem structures.

Traditional linear planning has a distinct advantage in facilitating efficient decision making. Because all decisions follow from the goal statement, management planning can be as simple or as complex as a manager chooses to make it. In contrast, hierarchical planning loses efficiency as it requires increased

Fig. 1.2a Well-managed water resources, such as this Massachusetts coastline, present opportunities for diverse multiple uses while ensuring the integrity and sustainability of the water resource. (Photo by L. Vanderklein)

levels of evaluation and continuous reassessment. What it loses in efficiency, however, it gains in enabling sustainable management and improved water quality. It constitutes integrated thinking and may work precisely because it forces a multiscale view. As the relevant contexts expand, so does the potential for effective management (Fig. 1.2).

Because water quality management is on the cusp of a paradigm shift from traditional linear management toward hierarchical management, the literature is replete with examples of traditional planning and nearly silent on examples of hierarchical planning efforts. The remainder of this chapter is devoted to three case studies. The first looks at the consequences of linear,

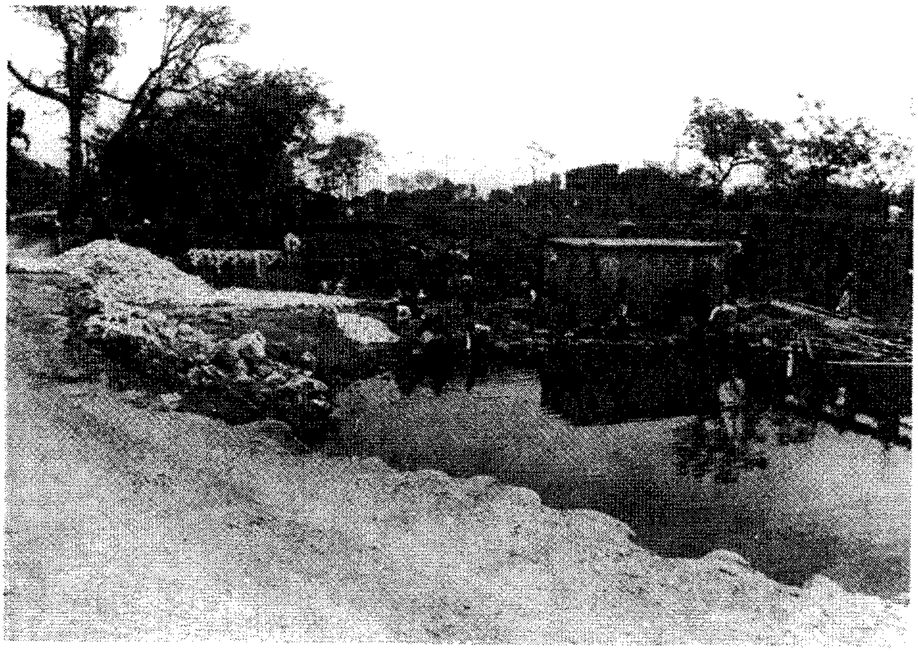

Fig. 1.2b When goals focus on only one purpose, or a resource is used without consideration for the impacts of that use, water quality can become severely degraded. In this photo from a village in the Kathmandu Valley, Nepal, a local small lake is used for washing wool, washing clothes and dishes, and as a source of drinking water. It also receives run-off from construction activities and a dirt road. The lake supports no aquatic life, is shrinking from siltation, and is a medium for the transfer of diseases. (Photo by D. Vanderklein)

unidimensional planning to the Aral Sea region of Central Asia. The second reviews efforts by managers of the Laurentian Great Lakes to respond creatively to continued degradation of the lakes. The third stresses that water quality debates are ongoing issues for all societies, and that the structure of management planning itself will have a significant influence on the resolution of future water quality decisions.

Unidimensional Management and Tragedy: The Aral Sea

Among the most infamous examples of water planning gone awry is the truly tragic draining of the Aral Sea, a consequence of a single-minded focus on the goal of increased cotton production in Central Asia. It represents unidimensional, sectoral planning at its most extreme, and constitutes a severe cautionary tale for the sort of feedback-free and biophysically removed planning that has typified traditional water quality and water use planning.