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Freshwater Inflow: Science, Policy, Management

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ABSTRACT: The papers in this special issue were presented in a special session during the 2001 biennial conference of the Estuarine Research Federation held in St. Pete Beach, Florida. The session, "Freshwater inflow: Science, policy and management," was focused on issues related to reduced freshwater inflow to estuaries. The session brought together scientists, managers, and regulators, and included presentations on the estimation of freshwater input to estuaries, development of ecological indicators to assess changes in inflow, management strategies used to set freshwater requirements, and experiences with the reintroduction of freshwater to restore inflow.

Introduction

An estuary is defined as the area where salt water from the sea mixes with freshwater from rivers. Nothing is more fundamental to the functioning of an estuary than the quantity and timing of freshwater delivery to the mixing zone. Two major forces are reshaping freshwater flows to estuaries worldwide: demographics and engineering. The coastal population is large and continues to grow, resulting in increasing demand for freshwater. Approximately 60% of the people in the United States live within 60 km of the coast, and 17 of the 20 fastest growing counties are located in coastal areas (Culliton 1998). Freshwater is required for municipal, industrial, and agricultural uses. Water use in the United States has doubled since 1940 and is likely to double again by 2015 (Naiman et al. 1995). Globally, humans use about 54% of the runoff that is spatially and temporally available (Postel et al. 1996) and are having a profound effect on the water cycle (Vörosmarty and Sahagian 2000). As the population continues to grow, less water will be available to flow into estuaries.

Dams have been constructed throughout human history, but large dams are more recent. Large dams were first built in the 1920s through 1930s to provide hydroelectric power, not water resources. Since then many large reservoirs have been built to meet an increasing population's needs for water and energy. Except Alaska, the hydrology of nearly every river body of freshwater in the United States has been modified by dams, diversions, and withdrawals (Naiman et al. 1995), and similar trends are apparent worldwide (Dynesius and Nilsson 1994; Pringle et al. 2000). For the first time in human history, these large watershed-scale structures have severely limited inflow to many of the world's estuaries and consequently altered functioning of these ecosystems.

Not surprisingly, arid states with large coastal populations were among the first to face the freshwater inflow issue. In Texas, for example, a drought in the 1950s was so severe that many of the rivers finally stopped flowing. This resulted in hypersalinity, fish kills, loss of blue crabs and white shrimp, and invasions by stenohaline species (Copeland 1966; Hoese 1967). Legislation was passed in 1957 that required water plans to give consideration to the effect of upstream development on bays, estuaries, and arms of the Gulf of Mexico. This inspired a series of assessments of all Texas estuaries, which were summarized by the Texas Department of Water Resources (1982). Those reports were later followed up by a method to determine freshwater needs of Texas estuaries (Longley 1994).

Since Cross and Williams (1981), there has not been a compilation of papers on the topic of freshwater inflow. That symposium was convened to identify the issues regarding freshwater inflow to estuaries and identify potential solutions and recommendations to deal with the issues. Since the original symposium in 1981, the problems and issues related to freshwater withdrawal have increased with increasing coastal development and increased environmental awareness, and we have also made progress in terms of our understanding

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of the relationship between inflow and estuarine resources. We perceived the need for another volume on freshwater inflow.

The papers included in this special issue were presented on November 8, 2001 in a special session of the Estuarine Research Federation biennial conference in St. Pete Beach, Florida entitled ''Freshwater inflow: Science, policy and management.'' The session started with papers that described different approaches for estimating freshwater input to estuaries, identifying ecological resources or indicators of inflow effects, and setting freshwater requirements. The legal issues surrounding water withdrawal was also presented. Case studies on freshwater inflow were presented, including estuaries in Australia, South Africa, and the United States. The U.S. studies were broad and included California, Texas, Georgia, and Florida. Estuary restoration using reintroduction or diversion of freshwater was also examined.

Summary of Session Conclusions

Setting inflow policy in such a way as to preserve estuarine ecosystems encompasses many of the challenges of ecosystem assessment and management. The presentations given at the meeting sparked lively discussions that are common to other issues facing estuarine ecosystem scientists and managers. Several questions appeared repeatedly and are difficult to resolve: How can scientific issues be considered in a political process? How can ecosystem variability be captured in the management process? How can scientific consideration of uncertainty be presented to managers? Are there decision frameworks, such as adaptive management, that allow integration of new information as we assess the success of the management frameworks that have been implemented?

Determining the proper amount of freshwater inflow for reaching estuarine waters is as much a political as a biological process (Kimmerer 2002). Scientists can provide a wide range of approaches to setting inflow requirements and bring much data to bear on the issue, but resource managers and citizens are making societal judgments about the values we associate with different choices (Alber 2002). Because they are value judgments, it is important to have a decision-making structure that effectively integrates the social, economic, and political choices. For instance, the different Florida water management districts have adopted different strategies for regulating freshwater flows (Doering et al. 2002; Flannery et al. 2002) in response to different intensities of human engineering and societal expectations of water management (e.g., flood control versus water supply). In Texas, optimizing commercial and recreational species has been chosen as the benchmark (Powell et al. 2002). In California, the location of the 2 psu isohaline has been chosen as an indicator of estuarine habitat (Kimmerer 2002). The best example of adding explicit value judgments to the process of setting minimum flows is in South Africa, which has a multi-step process wherein values are of primary consideration (Adams et al. 2002).

These decisions are complicated by the natural variation of freshwater inflow seasonally and over decadal cycles. It is important that decision rules contain provisions to vary inflow amounts under different climatic regimes. The Texas Water Development Board uses different flow goals in dry or wet years (Powell et al. 2002), and California's regulations change seasonally and as a function of the salinity guideline (Kimmerer 2002).

The science-management link is also complicated by our evolving knowledge of the driving forces in estuarine ecosystems. One of the strategies for choosing an indicator is looking for clear break points in ecosystem response to salinity or flow regimes to use as decision goals. While this is sometimes easy, in many instances there is simply a linear response to freshwater inflows. Added to this complexity is the necessity to choose among multiple endpoints and prioritize the critical values of different ecosystem components (Doering et al. 2002; Mattson 2002); an indicator that is sensitive to inflow is not necessarily the one that is most valued by society (Alber 2002). The challenge to scientists is not only in making the best scientific judgments but also in explicitly communicating the significance of different scientific assumptions and the implications of trade-offs between different scientific choices.

An improved understanding of the functioning of estuarine systems has allowed for increased sophistication of freshwater inflow management techniques. Texas has developed extensive optimization techniques to address its quite limited water resources (Powell et al. 2002), and California has an extensive program to monitor estuarine resources (Kimmerer 2002). These sophisticated biological and modeling approaches are very data intensive and a few simple principles may be sufficient for making water allocation decisions when the competing demands are not extensive.

The nature of these decisions makes them amenable to using adaptive management, i.e., using the results of ongoing monitoring and assessment to modify and optimize the operating decisions (Kimmerer 2002; Montagna et al. 2002). Because we are still learning about the properties of these systems, we must develop ways to improve our understanding on how the systems we manage function and about the process of adaptive management so that our future capabilities can be improved. Hopefully the publication of this special issue will allow us to more quickly build on the techniques developed so far.

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