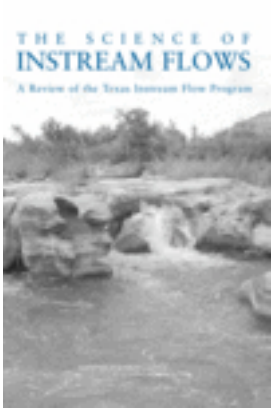
Free Executive Summary



The Science of Instream Flows: A Review of the Texas Instream Flow Program

Committee on Review of Methods for Establishing Instream Flows for Texas Rivers, National Research Council

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Across the United States, municipalities, counties, and states grapple with issues of ensuring adequate amounts of water in times of high demand and low supply. Instream flow programs aim to balance ecosystem requirements and human uses of water, and try to determine how much water should be in rivers. With its range of river and ecosystem conditions, growing population, and high demands on water, Texas is representative of instream flow challenges across the United States, and its instream flow program may be a model for other jurisdictions. Three state agencies—the Texas Water Development Board (TWDB), the Texas Parks and Wildlife Department (TPWD), and the Texas Commission on Environmental Quality (TCEQ)—asked a committee of the National Research Council (NRC) to review the Programmatic Work Plan (PWP) and Technical Overview Document (TOD) that outline the state's instream flow initiative. The committee suggested several changes to the proposed plan, such as establishing clearer goals, modifying the flow chart that outlines the necessary steps for conducting an instream flow study, and provide better linkages between individual studies of biology, hydrology and hydraulics, physical processes, and water quality.

Executive Summary

Texas has more than 190,000 miles of relatively flat, warm-water streams and rivers that sustain important habitat for some 250 species of fish and provide water resources for 20 million people. Rivers in Texas exhibit considerable biotic variability that reflects the state's varying climate, geology and soils, and topography. The patterns of water availability and water use across the state are not always coincident, leading to episodic water shortages.

Variable river flow conditions in Texas combined with rapid population growth and competing demands from irrigators, recreationalists, conservationists, and municipalities spurred the creation of a statewide instream flow program in 2001. Texas Senate Bill 2 (2001) instructed three state agencies—the Texas Water Development Board (TWDB), the Texas Parks and Wildlife Department (TPWD), and the Texas Commission on Environmental Quality (TCEQ)—to develop a state program for instream flows to support a "sound ecological environment" on priority rivers by the end of 2010. In response, the agencies drafted a proposed instream flow program that is described in two documents: the Programmatic Work Plan (PWP; TPWD, TCEQ, and TWDB, 2002) and Technical Overview Document (TOD; TPWD, TCEQ, and TWDB, 2003). The PWP outlines the programmatic elements of the instream flow initiative, and the TOD details scientific and engineering methodologies for data collection and analysis. The agencies arranged for the National Research Council (NRC) to evaluate the Texas instream flow program, including the PWP and the methodologies in the TOD and other supporting documents. The NRC appointed a committee to carry out this assignment. Its statement of task is given in Box ES-1.

INSTREAM FLOW SCIENCE AND PROGRAMS

The field of instream flow science has grown rapidly over the past few decades, with many research studies and initiatives in progress in the United States and around the world. Still, instream flow science and practice are

BOX ES-1
Statement of Task for Texas Instream Flows

The committee will appraise the scientific and engineering methods used to help establish instream flow recommendations in Texas rivers, and focus on the soundness and adequacy of the Programmatic Work Plan for developing instream flow studies developed by the TWDB, TCEQ, and TPWD. Specifically, the NRC committee will:

1. Evaluate the key documents that explain these scientific and engineering methods and their applications in setting instream flow recommendations. These documents are a) the 2002 Programmatic Work Plan, and b) a supplementary technical volume that describes these methods in greater detail.
2. Review and provide advice on several scientific and technical matters relevant to instream flow studies and recommendations, including:
    a. appropriate spatial scales of analyses in hydrologic and related models;
    b. use of habitat-flow relations in setting instream flow requirements;
    c. use of landscape ecology metrics in setting instream flow requirements;
    d. range of biophysical model parameters employed in the Texas State TMDL program;
    e. applicability of water quality models used in the Texas State TMDL program to instream flow studies.
3. Evaluate findings and recommendations of Tasks 1 and 2 for consistency with the requirements of Texas law for the study of instream flows

relatively new, and basic premises of this field continue to evolve. How flow regimes influence the structure of aquatic and riparian ecosystems is largely unknown, although the management of these ecosystems is dependent on this knowledge (NRC, 2004a). Most instream flow programs specify a single, minimum value of stream flow that is required to (1) meet a legal standard or (2) sustain an endangered species or some other flow-dependent resource(s). However, current trends in instream flow programs are moving away from these single values and towards comprehensive river science. For example, instream flow hydrology and hydraulics now include the hydrologic regime with seasonal and inter-annual variation and not only a minimum flow value; biological aspects account for aquatic and riparian ecosystems and not just a single-species target species. In-channel and out-of-channel riverine physical processes are also considered, such as sediment dynamics and geomorphic processes, and water quality considerations in-

clude temperature, dissolved oxygen, nutrient loading, and toxics. In addressing stream flows across this broad spectrum of ecosystem conditions and processes, scientists now consider a fuller range of stream flow conditions beyond minimum instream flow needs.

This report recommends instream flow programs be designed to incorporate several key characteristics. First, instream flow programs need well-defined and measurable goals to frame instream flow studies and evaluate program progress. Clear goals are needed to increase efficiency and applicability of time- and resource-intensive technical evaluations. Stakeholder input in determining instream flow goals is important because there are usually many competing demands for water and competing opinions on how to allocate that water. Public support will be easier to garner when goals are easily measured and communicated.

Second, state-of-the-science programs use natural flow characteristics as a reference for determining flow needs. Natural river systems have variable flows (also called flow regimes) within a year and among multiple years. For example, in most Texas rivers, the lowest natural flows occur during warm, growing seasons of the summer and fall. During this same period there might also be some temporary high-flow peaks driven by storms, especially in those areas of the state subject to tropical storms. This natural variability is important to sustain aquatic and riparian biota and riverine processes.

Third, river science is not just for hydrologists anymore. Riverine science is now an inter- and multi-disciplinary science that includes biological, hydrological, geomorphic, and water quality aspects. Accordingly, successful instream flow programs will employ an interdisciplinary team of scientists to address the different elements of a river system. This team will include specialists in hydrology, biology, water quality, and physical processes who focus on whole functioning ecosystems and flow regimes.

Finally, a successful program will practice adaptive management in implementing instream flow recommendations over the long-term of the program. The processes of conducting instream flow studies will become better understood in Texas over the years it takes to complete the priority river basin studies and implement the flow recommendation(s). Some aspects of the current Texas programmatic approach may need to be modified as the results from the first studies are evaluated. Adaptive management is defined in the TOD as an "approach for recommending adjustments to operational plans in the event that objectives are not being achieved." Use of adaptive management will allow the agencies and other interested parties to test and revise the way that the instream flow program is implemented by assessing the ecological responses to new flow regimes. The adaptive man-

agement approach entails a long-term commitment to monitoring and anticipates corrections and revision over time.

EVALUATION OF THE PROGRAMMATIC WORK PLAN

The PWP makes clear that instream flow components—hydrology and hydraulics, biology, geomorphology, and water quality—form the core study elements needed to gain a minimal understanding of any river ecosystem. In crafting the PWP, the Texas agencies embraced an interdisciplinary approach that captures important aspects of instream flow studies consistent with the state-of-the-science. For example, the PWP explicitly includes a range of technical components and a multiple-step process. It also calls for monitoring to assure that the implemented flow regime meets study objectives and provides a basis for adaptive management.

Despite these strengths, the proposed instream flow program could be strengthened with revisions to the PWP. The PWP should be revised to: (1) define sound ecological environment, (2) assure statewide comparability with studies tailored to local conditions, (3) establish clearer goals, (4) embrace a two-step instream flow process, (5) modify the proposed flow chart, and (6) explain how indicators will be selected and used for specific river basins and statewide.

Sound Ecological Environment

The Texas instream flow program is predicated on legislative language in Texas Senate Bill 2 (2001) that directs the three Texas state agencies to "… conduct studies and analyses to determine appropriate…flow conditions [that]…support a sound ecological environment." A "sound ecological environment" is not defined in the legislation or the PWP. The meaning of a sound ecological environment ultimately will be reflected in all subsequent objectives, data collection, and analytical methods of the instream flow program. A clear definition of "sound ecological environment" will provide structure to the state's instream flow program and give context to the individual instream flow studies. **A clear definition of the phrase "sound ecological environment" needs to be provided to supply context for instream flows in Texas**.

State-wide Consistency and River Basin Specificity

Developing an instream flow program across a large and diverse state presents a special challenge. In Texas, the instream flow program is administered and overseen at the state-level, but instream flow studies are tailored for specific river basins. Therefore, the program must simultaneously establish methods specific enough to guide repeatable, technical evaluations at the subbasin scale and guidelines broad enough to apply to all rivers systems in Texas.

Consistency among individual studies at a high level will allow the state agencies to manage the instream flow program as a single program, not as a collection of basin-level instream flow studies. Basin-scale specific conditions can be accommodated in the individual studies that select methodologies and tools from state-sanctioned processes. This way, all methodologies used in the technical evaluations, regardless of subbasin characteristics, are approved at the state level so that results can be compared across subbasins, as applicable. Indeed, a statewide and state-sanctioned process for conducting individual studies would help ensure consistent method applications and consistent interpretation of instream flow recommendations. As written, the PWP provides a very limited structure to ensure consistent or comparable instream flow studies across the priority study sites. **The PWP should present a state-wide context for individual subbasin studies with two levels of oversight: one at the state level for management and program consistency and one at the subbasin level for goals and approaches that are tailored to the specific needs of the study basin.**

Goals

For both the state- and the basin-scales, the PWP needs more attention to the process of setting goals and the means to measure progress towards achieving those goals. Once "sound ecological environment" is clearly defined, goals can be established that will help riverine environments meet the criterion of "sound." State-level goals should define the objectives for the state's instream flow program and should encompass the broad-level milestones expressed in the legislative language of Texas Senate Bill 2. These programmatic goals should establish some of the parameters for the basin-level goals that will necessarily be more technical in nature. The PWP outlines one general goal of an instream flow study to "determine an appropriate flow regime…that conserves fish and wildlife resources while providing sustained benefits for other human uses of water resources." This goal does not give enough detail to guide consistent basin-level studies across

the state and may actually generate conflict because conserving fish and wildlife and providing for human use may be mutually exclusive. Basin-level goals should guide the technical evaluations and be consistent with the state-level program goals. Means to set basin-level goals are not mentioned in the PWP or TOD. Program implementation and conduct of individual studies will be enhanced to the extent that clear, specific goals at the state- and basin-levels are consistent with a "sound ecological environment" and communicated with resource agencies, managers, scientists, and stakeholders. The PWP should present clear and specific goals for the state-wide instream flow program and recognize the need to develop individual sub-basin goals that nest within the state-wide instream flow programmatic goal(s).

Two-Phase Instream Flow Process

Setting goals and measuring success toward those goals are important steps in a larger, two-phase process for establishing instream flow recommendations. The first phase is the study design that includes a review of all relevant existing information and the conduct of reconnaissance studies, if necessary, prior to undertaking detailed (and potentially resource-intensive) evaluations. These initial assessments should describe the major processes and dynamics of the river's physical and ecological environment, identify specific questions to be addressed in the detailed technical evaluations, and inform the selection of methods to be used in the detailed technical evaluations. **The PWP and the TOD should describe how existing information and reconnaissance studies will be used to guide the detailed technical evaluations of hydrology and hydraulics, physical processes, biology, and water quality.**

In the second phase, detailed technical evaluations address the questions from the initial technical evaluations within one or more technical areas. Results from the initial and detailed technical evaluations should be (1) used within the river basin to derive proposed instream flow recommendations; (2) communicated to the state-level; and (3) integrated at the state-level such that statewide approaches for initial and detailed technical evaluations emerge.

Revised Flow Chart

A proposed flowchart (Figure ES-1) is a modified version of the PWP flowchart. The proposed flowchart emphasizes certain important steps in

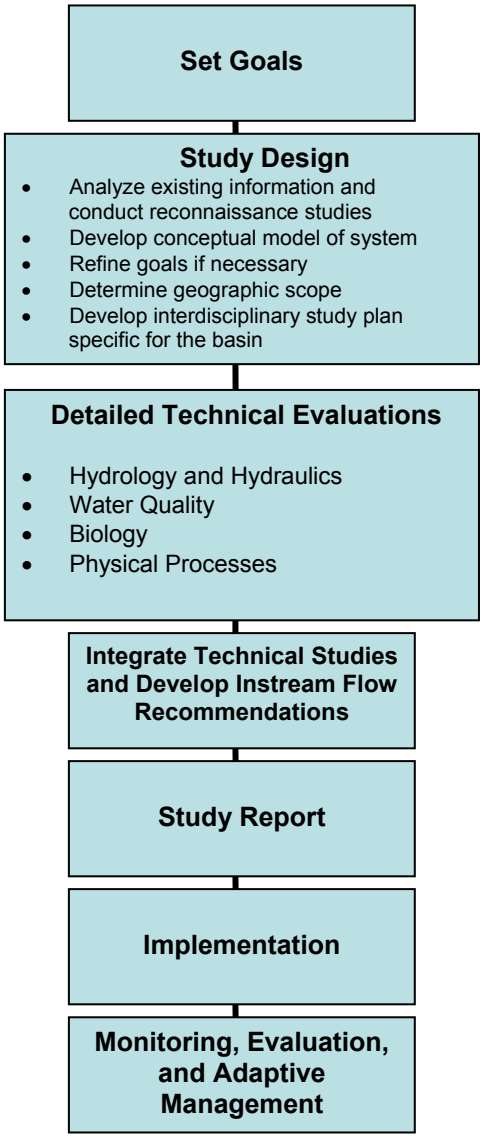

FIGURE ES-1 Recommended flowchart for instream flow studies.

conducting an instream flow study. The current PWP presumes goals and does not clearly articulate connections between existing information andreconnaissance studies and the detailed technical evaluations. **The PWP flowchart for instream flow studies should be revised to include several important steps in planning and conducting an instream flow study as suggested in Figure ES-1.**

Indicators

Indicators can measure progress towards achieving goals. Indicators related to flow characteristics could be used at the state-level in priority sites and in non-priority sites to identify and prioritize new studies. Once established, such indicators could be used to make quantitative comparisons among rivers segments. For example, the Lower Guadalupe River is considered more pristine than the lower San Antonio River, but this distinction has not been quantified. State-wide indicators, modified appropriately for regional differences, could also help track changes in the ecological conditions of Texas rivers over time in response to regulatory programs, such as the reduction in wastewater discharges from treatment plants or from management practices to address nonpoint sources.

At the basin-level, indicators are important connectors between basin goals and the instream flow recommendation. For example, if the basin goal is to increase the abundance of cottonwood trees (*Populus* spp.) in a riparian forest, then an indicator could be stem density of cottonwoods per unit area, and the flow recommendation would stipulate overbank flows at a certain level or frequency. In this case, the indicator is measurable and related to the flow recommendation, and adjustments could be made to the flow recommendation if the goal of increasing cottonwood abundance is not being achieved.

Developing accurate, reliable ecological indicators for the entire state will take several years. A workable and realistic set of indicators is likely to emerge only after several or all of the six priority instream flow studies have been completed. During the years required to conduct the priority studies, adaptive management methods should be employed to continually fine-tune ecological indicators through additions, deletions, and other changes. The PWP mentions the importance of monitoring and validation, but makes little reference as to how monitoring and validation would be conducted.

Texas has an example of successful indicators in its existing water quality monitoring programs. Bacterial and dissolved oxygen content in water are used as indicators that quantitatively support Texas' assessment and regulation of water quantity and quality. Like these indicators for water

quality, a set of indicators is needed for the instream flow program and basin-scale studies. These indicators can be used in adaptive management, monitoring and validation activities to measure progress towards achieving a sound ecological environment in Texas rivers. **A suite of measurable, ecological indicators should be established for the state-wide program and each basin-specific study; the indicators should be responsive to instream flows.**

EVALUATION OF THE TECHNICAL OVERVIEW DOCUMENT

The TOD discusses sampling methodologies and modeling approaches proposed to conduct instream flow studies. Accompanying documents provide further detail on current Texas studies, processes to be considered, background information, and associated water-related programs, including information on the state total maximum daily load (TMDL) program. This study finds that the TOD appropriately identifies the relevant technical aspects of a comprehensive instream flow program (i.e., biology, hydrology and hydraulics, physical processes, and water quality) and mentions an approach to bring together these disparate elements (integration).

One strength of the TOD is its recognition of the importance of monitoring and validation, and the need for long-term, adaptive management. Adaptive management will be an important characteristic of an effective instream flow program, and the use of measurable indicators to monitor progress towards a sound ecological environment in Texas river basins is encouraged.

However, the TOD makes little distinction among individual basins and presents its methods as though each method is equally applicable across highly variable river basins. Furthermore, the TOD technical sections vary widely in quality and level of detail. Some sections present very detailed methods (e.g., the sections on hydrology and hydraulics and biological sampling), but other sections have little or no detail on the methods to be used, and others have significant omissions of important information. Rarely are methodologies presented in the TOD such that an instream flow recommendation could easily emerge. None of the technical sections refer to basin goals or a sound ecological environment.

The TOD discusses technical methodologies by discipline (i.e., biology, hydrology, etc.) and as separate studies, but does not describe how studies in different disciplines relate to each other or relate to an instream flow recommendation. This report suggests ways to connect various biological, hydrologic, and physical processes with water quality technical studies to

create an instream flow recommendation. The various technical assessments are recommended to be framed in terms of flow regime components: subsistence flows, base flows, high flow pulses, and overbank flows (see Table 3-2). With the technical evaluations presented in terms of flow, connections will be strengthened among the evaluations and between the evaluations and the flow recommendation.

The TOD needs significant revision to reflect (1) site-specificity at the (sub) basin-scale; (2) goals for the individual studies that relate to the definition of a sound ecological environment; and (3) linkages among individual studies of biology, hydrology and hydraulics, physical processes, and water quality.

The **hydrologic and hydraulic** section of the TOD reflects a significant understanding of hydrology, and hydrologic measurement and analyses commonly required for performing instream flow studies. To be efficient in hydrologic and hydraulic analyses and to avoid performing analyses that are either not necessary or are more detailed than is needed for making instream flow recommendations, hydrologic and hydraulic approaches should be closely aligned with the other technical evaluations and with the goals for the specific river basin.

The strengths of the **biology** section include a strong general discussion of the important issues of habitat scale, ecological processes, and species life histories. The biology section of the TOD provides highly detailed accounts of how to conduct some sampling or modeling methods, but gives scant attention to how modeled and empirical data are communicated, related to program goals, or integrated with other aspects of an instream flow study to derive a flow recommendation.

The TOD captures the importance of **physical processes** in forming the channel and floodplain and in providing habitat for aquatic organisms, but the physical process section needs augmentation to be consistent with the content depth and quality in the hydrology and hydraulics and biology sections. It also needs to discuss hydrologic regimes common in Texas rivers, GIS applications, sediment budget methods, and impacts of land use, population, and climate change in the watershed as relevant aspects of riverine physical processes.

The TOD ably describes the **water quality** programs in Texas. Instream flow considerations are not the focus of the state's water quality programs. Therefore, the instream flow program's elements that describe water quality must be aligned with the existing water quality programs, so as to avoid conflicting requirements for maintaining sound ecological environments in Texas rivers. A significant limitation of the water quality section of the TOD is that it does not outline how the water quality compo-

nent of an instream flow assessment should be conducted or how instream flow and water quality considerations can be integrated with each other.

Scaling Issues

The physical, chemical, and biological processes of a stream ecosystem operate at different spatial scales and are expressed differently over different time periods. In instream flow work these different spatial and temporal scales must be reconciled so that integrated, individual studies can be conducted to derive a flow recommendation. At present, the TOD does not specify what length of a river must be studied, how study reaches are selected, or how data from study areas will be extrapolated to unstudied areas. These shortcomings of the TOD are non-trivial and not easy to address. Scaling issues remain a major research focus for instream flow science, and effective methods for reconciling different scales are not well documented. Despite the difficulty in doing so, the various components of a study need to be compatible in terms of spatial scale. **Overall, the biological, physical processes, water quality, and hydrology and hydraulics instream flow studies should be designed at commensurate spatial and temporal scales to improve the ability to integrate findings from the various technical evaluations into a single flow recommendation.**

Integration

Integration is the process of combining the different technical components of instream flow studies into a flow recommendation. Integration is an important, complicated step in instream flow science, and while integration methods are being generated empirically, they are not well documented in the literature. The TOD presents a different way of doing integration at the end of the study process, where the results from the detailed technical evaluations are used to derive a flow recommendation. The TOD presents an integration framework (Figure 5-1) diagram to illustrate integration, but this diagram is complicated and not thoroughly explained. Thus, how results of the individual studies are to be combined into a recommendation is not clear in the TOD. **The TOD integration framework needs to be revised to include sequential steps and clearer direction of how to derive flow recommendations from the results of the technical evaluations.**

PROGRAMMATIC ISSUES

Linkage to Other Texas Programs

Several water-related programs already exist at the state-level, including those associated with water quality, stream flow, bays and estuaries, and water permitting. The instream flow program can build upon or augment existing, related water resources programs in Texas, and potentially share data, methods, and procedures with those programs. For example, Texas collects state-wide data on temperature, dissolved oxygen, and other chemical constituents, as well as biology, as part of its water-quality program. In this program, four levels of aquatic life use are defined (exceptional, high, intermediate, and limited). The Texas Administrative Code establishes water quality aquatic life use goals for all 225 classified stream segments. At a minimum, the existing aquatic life use goals could be considered in implementing instream flow recommendations to avoid conflict or establish support between the instream flow and water quality programs.

Integrating the instream flow program with existing water quality and quantity programs will provide clear and consistent direction for both decision makers and stakeholders. Streamlining related programs will also reduce the potential for inconsistent recommendations among the programs, reduce costs, and eliminate redundant analyses. **The instream flow program should be integrated with the water quality, water permitting, and other water-related programs in Texas**.

Peer Review

Maintaining scientific excellence in the Texas instream flow program could be facilitated with access to and open communication with technical experts from instream flow-related disciplines. An important role for reviewers is to evaluate the results and methods of the individual technical studies, as well as the progress of the overall instream flow program development. Results from these reviews should be communicated to the scientists involved in the Texas studies, the instream flow scientific community at large, and stakeholders. Review by an independent group of scientists will help track the progress and efficacy of the instream flow program over time, just as the initial peer review was designed to provide, "the highest level of confidence… that the framework [for]… these studies… is scientifically sound" (TPWD, TCEQ, and TWDB, 2002). In order to fulfill this comprehensive program objective that involves scientists from a variety of

disciplines, state agencies, and other stakeholders, **the creation of an independent, interdisciplinary, periodic peer review process for the instream flow program is recommended.**

Implementation Issues

This report focuses on the scientific and technical aspects of the Texas instream flow program as presented in the PWP and TOD. Nevertheless, several practical implementation issues arose during the course of this study. The act of implementing an instream flow program or study requires deft balance among disparate and competing uses for river water. Large-scale, state-wide instream flow programs, like the one in Texas, are often implemented over a numbers of years. Over the life of the Texas instream flow program, and through adaptive management, many changes may be made to instream flow methodologies, implementation, or goals of the program. The Texas instream flow program has identified six priority river basins to initiate the instream flow program. These priority basins represent a small subset of the total number of rivers and streams in the state, and the state may wish to expand the instream flow program to other rivers as it develops instream flow experience. Preserving the status quo, especially on important rivers, may be important at least until the initial period is over and focus can be turned to non-priority river systems' instream flow requirements. Ideally, a priority-setting methodology would help water managers determine the order in which additional rivers will be evaluated for instream flow recommendations and weigh a range of alternatives to maximize the state's future opportunities to protect adequate instream flows.

CONCLUSIONS AND MAJOR RECOMMENDATIONS

Developing instream flow recommendations for rivers is one of the most difficult and important challenges in the applied ecological and physical sciences today. The Texas agencies are commended for proposing a prospective, comprehensive instream flow program. Implementation of a statewide instream flow program will involve many agencies, significant resources, and time; nevertheless, the program will provide enormous benefits to the state over the next several decades and beyond.

The Texas instream flow program will need to be flexible to meet the unique challenges and opportunities presented by the state's rich mixture of river ecosystems, culture, water law, and water development. Clear and

specific programmatic and scientific instream flow goals need to be set at both the state and river basin levels, and methods used in setting instream flow recommendations need to be consistent for the several river systems that will be studied across the state. The Texas instream flow framework should elicit comparable results at the basin level in order to realize state-wide consistency, maintain continuity over the long term through proper delegation and delineation of responsibilities among the various involved agencies, and incorporate scientific findings as well as social and economic concerns by involving stakeholders during key phases of the design and implementation process.

Major Recommendations

1) The PWP should present a state-wide context for individual sub-basin studies. This can be accomplished with two levels of oversight: one at the state level for management and program consistency and the second one at the subbasin level for goals and approaches tailored to the specific needs of the study basin.

2) A clear definition of the phrase "sound ecological environment" needs to be provided to supply context for instream flows in Texas.

3) The PWP should present clear and specific goals for the state-wide instream flow program and recognize the need to develop individual sub-basin goals that nest within the state-wide instream flow programmatic goal(s).

4) The PWP and the TOD should describe how existing information and reconnaissance studies will be used to guide the detailed technical evaluations of hydrology, physical processes, biology, and water quality.

5) The PWP flowchart for instream flow studies should be revised to include several important steps in planning and conducting an instream flow study as suggested in Figure ES-1.

6) A suite of measurable, ecological indicators should be established for the state-wide program and each basin-specific study; the indicators should be responsive to instream flows. These indicators can be used in adaptive management, monitoring and validation activities to measure progress towards achieving a sound ecological environment in Texas rivers.

7) The Technical Overview Document should be revised to provide for consistent spatial scale and level of detail for the hydrology, biology, physical processes, and water quality technical evaluations.

8) Clearer direction should be provided for the process by which the individual technical evaluations will be integrated into instream flow recommendations.

9) The instream flow program should be integrated with the water quality, water permitting, and other water-related programs in Texas.

10) The creation of an independent, interdisciplinary, periodic peer review process for the instream flow program is recommended.

THE SCIENCE OF INSTREAM FLOWS

A Review of the Texas Instream Flow Program

Committee on Review of Methods for Establishing
Instream Flows for Texas Rivers

Water Science and Technology Board

Division on Earth and Life Studies

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Preface

Instream flow science is an evolving field that brings together aspects of hydrology and hydraulics, biology, physical processes and geomorphology, and water quality. Instream flow programs are being developed to answer the often politically-charged question, "how much water should be in the river?" To balance ecologic and economic uses of water, instream flow programs rely on scientific input within a legal, social, and policy context.

The act of combining science and policy into a coherent, operational instream flow program is a challenging task. Across the United States, municipalities, counties, and states grapple with issues of ensuring adequate water in times of high demand and low supply. Texas has developed a prospective instream flow program to address these challenges. With its range of river and ecosystem conditions, growing population, high demands on water and episodic water scarcity, Texas in many ways is a microcosm of instream flow challenges across the United States, and its instream flow program may serve as a template for other jurisdictions.

Our NRC committee was charged to evaluate the Texas Instream Flow program as described in the Texas Instream Flow Programmatic Work Plan (PWP) and the Technical Overview Document (TOD). This report is the result of the National Research Council's (NRC) Committee on Review of Methods for Establishing Instream Flows for Texas Rivers review of the Texas instream flow program. We were asked to comment on a technical work that already had been prepared by scientists and engineers in the state agencies. (See *http://www.twdb.state.tx.us* for the full text of the documents). In addressing our charge, the committee resisted the temptation to produce an overly prescriptive report, as it was not our assignment to (re)design the Texas instream flow program or to write an instruction manual of how to conduct an instream flow study. A prescriptive approach, which could involve detailed recommendations about techniques and methods or even a rewrite of the technical documents, would not have been appropriate. Furthermore, an overhaul of these documents did not prove necessary because the state agencies set forth a proposal with most of the important elements of a comprehensive instream flow program. The committee's review, instead, identifies missing parts and recommends bolstering the skeletal pieces of Texas' proposed program.

In preparing this report, the committee benefited greatly from our conversations with Texas State agency personnel who helped us understand the background for the Texas instream flow program. Without exception, they were open and responsive to our queries about Texas water resources and the multiple demands on water in the state. State agency personnel also helped us gain a better understanding of how the PWP and the TOD were prepared, including the difficulties of producing a plan by three agencies with three different missions.

The committee felt it would be a disservice to the Texas state agencies if we neglected to comment on the need for clear and measurable goals and a discussion of implementation. Clear, measurable goals and pragmatic ways to achieve those goals are critical to a successful instream flow program. Goal setting is the realm of policy makers, stakeholders, and other decision makers, but scientists have an important role in setting goals of an instream flow program as well.

Implementation of instream flow recommendations in Texas occurs in a complex setting where there are multiple and competing needs for water. Means to implement instream flow recommendations are necessary to prevent wasted time and resources of conducting technical evaluations of hydrology, biology, physical processes, and water quality. Oftentimes, programmatic aspects of implementation are not directly tied to the technical pieces of an instream flow recommendation. However, programmatic aspects establish important legal and pragmatic boundaries for the instream flow scientific studies and, thus, are discussed in this report.

A variety of water resources stakeholders in Texas including river basin authorities, municipal agencies, the academic community, non-governmental organizations, agricultural interests, and other citizen groups helped us understand the importance of stakeholder involvement in setting instream flow goals and establishing instream flow recommendations. The committee held three of its four meetings in Texas. During the open sessions of these meetings we heard public comment on the state's instream flow program; we learned that the public holds strong conviction on river management priorities. In all, the public participation experience of this committee in Texas, in keeping with experience in other parts of the country, underscored the import of stakeholder participation and a fair, open, transparent process for determining instream flow in Texas.

Because instream flow science is new and still evolving, we provide a short tutorial (Chapter 3) that reflects the most current thinking on the subject. Texas' prospective and systematic plan for its instream flow program gives the state an opportunity to establish a benchmark instream flow program and make significant contributions to the science. Our

committee hopes that the findings and recommendations contained in this report will help the state and others realize this advancement.

We have many people to thank for their help over the course of this project and in the preparation of this report. The Texas agency personnel were incredibly supportive of our committee and its progress towards report completion. They were particularly instrumental in organizing and leading field trips for the committee to see and experience the beauty and complexities of Texas river ecosystems. We express appreciation to Barney Austin and Bill Mullican, Texas Water Development Board; Kevin Mayes, Texas Parks and Wildlife Department, and Doyle Mosier, Texas Commission on Environmental Quality; and the staff of Texas State University at San Marcos, Joanna Curran, Marshall Jennings, and Andrew Sansom. We also thank panel participants Mary Kelly, Richard Kiesling, Barbara Nickerson, Dianne Wassenich, and William West, Jr.; and other guest presenters Todd Chenoweth, Kevin Craig, Mark Fisher, Ronald Gertson, Myron Hess, Kenneth Kramer, Ren Lohoefener, Greg Rothe, and Kenny Saunders. The report and the study process would not have been possible without the hard work of NRC study director Lauren Alexander and project assistant Dorothy Weir. Finally, I would like to recognize my fellow committee members for their long hours and dedication to advancing the science and art of instream flows in Texas.

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with the procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: David Ford, David Ford Consulting Engineers, Inc.; Jim Geringer, former Governor of Wyoming; Douglas James, National Science Foundation; Ronald Kaiser, Texas A&M University; Robert Milhous, U.S. Geological Survey; Bruce Rhoads, University of Illinois; Clair Stalnaker, U.S. Geological Survey (retired); and Peter Whiting, Case Western Reserve University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Kenneth Potter, University of Wisconsin. Appointed by the National Research Council, he was responsible for making certain that an independent examination of the

report was carefully carried out in accordance with the institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Gail E. Mallard, *Chair*

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