November 3, 2009

Transmittal to Basin and Bay Expert Science Teams (BBESTs)

Report # SAC-2009-06

Title: Nutrient and Water Quality Overlay for Hydrology-Based Instream Flow Recommendations.

This working draft report completes a series of guidance documents offered by the Science Advisory Committee (SAC) to assist the BBESTs in carrying out their responsibilities to develop instream environmental flow regime recommendations. This document deals with the important issue of taking water quality into account in the flow regime development process. It presents sources and methods for the BBESTs to utilize water quality data and information to refine a hydrology-based flow matrix. It should be used in concert with the previous SAC report on Biological Overlay recommendations (SAC-2009-05) which identified numerous connections between biology and water quality.

The document provides an overview of established Texas water quality programs, with particular emphasis on those programs that involve data collection and analyses. It discusses various aspects of the relationship between water quality and subsistence flows, base flows, and higher flow conditions. It concludes with steps that the BBEST can take to consider water quality in their flow regime recommendations.

This report, as is the case with previous SAC documents, is published as a "working draft." We anticipate that these guidance documents will likely be updated and improved as the SB3 process matures. We acknowledge the helpful participation of the state resource agencies in preparing this and the other SAC reports. Finally, the SAC is hopeful that existing and future BBESTs will find this information useful in their deliberations, and we invite feedback as we all move forward with our respective responsibilities under SB3.

Robert J. Huston, Chairman, SB3 Science Advisory Committee

Nutrient and Water Quality Overlay for Hydrology-Based Instream Flow Recommendations

Senate Bill 3 Science Advisory Committee for Environmental Flows

SAC Members

Robert Brandes, Ph.D, P.E., Vice-Chair
Robert Huston, Chair
Paul Jensen, Ph.D, P.E.
Mary Kelly
Fred Manhart
Paul Montagna, Ph.D
Edmund Oborny
George Ward, Ph.D
James Wiersema

Draft Document Version Date: November 3, 2009

Report # SAC-2009-06

TABLE OF CONTENTS

LIST OF FIGURES

SECTION 1. INTRODUCTION AND BACKGROUND

SB 3 directed the development of environmental flow recommendations for Texas waters through a science-based determination and stakeholder process, followed by Texas Commission on Environmental Quality (TCEQ) rulemaking. Environmental flow regimes are defined as schedules of flow quantities that reflect seasonal and yearly fluctuations for specific areas of watersheds, support a sound ecological environment, and maintain the productivity, extent, and persistence of key aquatic habitats. The Science Advisory Committee (SAC) provides an overview of how hydrologic data might be used to develop hydrology-based flow regime recommendations (SAC 2009a) and describes one piece of the collaborative process envisioned by SB 3 for the identification of flows to maintain a sound ecological environment in rivers and streams. The document notes that other disciplines such as biology, geomorphology, and water quality also warrant specific attention to ensure that instream flow recommendations are based on the broadest set of information available. The approach taken by the SAC is to have these disciplines addressed as separate assessments or overlays on the hydrology-based analyses.

Water quality is the focus of this overlay document. Numeric and narrative criteria developed by the state address matter carried in suspension and solution, such as dissolved and suspended solids, as well as nutrients, toxics, indicator bacteria, temperature, pH, dissolved oxygen, and other parameters. Under some circumstances all might play a role in the determination of an environmental flow regime. Changes in a flow regime can be expected to produce changes in water quality conditions. The challenge is to ensure that the recommended flow regime protects water quality, particularly during low or subsistence flow conditions, and also considers water quality needs during higher flow conditions.

It is often assumed that under natural conditions, which may have existed prior to human impacts, the quality of the water supports the desired sound ecological environment. While this may be true it should be recognized that it may be impossible to return to the naturalized flow condition due to land use changes, point and nonpoint source discharges, water supply needs and operational constraints. In addition, ecological changes may have already occurred in response to altered land use patterns and flow regimes. It must also be recognized that natural conditions encompass a substantial range in all of the dimensions of water quality in response to hydrologic, seasonal and weather variations and include a full range of outcomes.

The Water Quality Overlay provides an overview of Texas water quality programs along with the programs that collect and make water quality data available. It then discusses various aspects of the relationship between water quality and subsistence flows and water quality and base and higher flow conditions. The document includes a specific example of the relationship between flow and various water quality parameters and provides steps the BBESTs can take to consider water quality issues in their recommended flow regimes.

SECTION 2. WATER QUALITY PROGRAMS IN THE TEXAS REGULATORY FRAMEWORK

Management and protection of water quality has been a primary mission of the TCEQ and predecessor agencies in Texas since well before the federal Clean Water Act in 1972. The TCEQ has established a set of Surface Water Quality Standards (TCEQ 2000) that includes uses, narrative and numeric criteria and an antidegradation policy. There are general requirements and those that are specific to water quality segments specified in each major river basin, including the Gulf of Mexico. As such, the standards attempt to account for the climatic and hydrologic variation of state waters. The evolution of water quality efforts has historically centered on control of wastewater discharges, partly through developing wastewater discharge permits. In cases where the Texas standards are not attained through normal wastewater permitting, special studies such as Waste Load Evaluations, Total Maximum Daily Load projects, or Watershed Protection Plans are required. In recent years, attention has also been focused on storm water quality and permitting that includes the control of runoff quality associated with construction, industrial activities, and municipal separate storm sewer systems (MS4). The standards are also periodically updated as data and knowledge are improved, and a revision process is underway at this time.

The Clean Water Act framework, implemented by the TCEQ, has five major components laid out in the following sequence: establish the uses of water that will be protected, determine the criteria necessary to protect those uses, base decisions on meeting those criteria, conduct ambient monitoring to ensure criteria are met and uses are maintained, and require corrective action when it is determined that uses are impaired. In order to protect the physical, chemical, and biological integrity of rivers and streams, relevant parameters must be defined and measured, the types and sources of pollution must be identified, and plans to protect and restore water quality must be implemented. Texas uses a varying cycle of activities to manage water quality based on statutorily determined time frames. These activities are coordinated through several programs within the TCEQ.

2.1 Clean Rivers Program

The Texas Clean Rivers Program (CRP) is a state fee–funded program for water quality monitoring, assessment, and public outreach. The program is a collaboration of 15 partner agencies (ex. San Antonio River Authority, Brazos River Authority, Houston-Galveston Area Council, etc.) and the TCEQ. The program provides the opportunity to approach water quality issues within a watershed or river basin locally and regionally through coordinated efforts among diverse organizations. The program has also helped to increase the amount of available water quality data. The CRP works as a hub for participating collaborators to provide data as well as coordinated watershed protection. For detailed information, visit: http://www.tceq.state.tx.us/compliance/monitoring/crp/.

2.2 Surface Water Quality Monitoring Program

The Surface Water Quality Monitoring (SWQM) Program monitors and assesses the quality of surface water to evaluate physical, chemical, and biological characteristics of aquatic systems with reference to human health concerns, ecological condition, and designated uses. In addition to periodic data collection, the SWQM program continuously monitors water quality parameters in real-time in selected watersheds throughout Texas. All water quality data obtained may be used for identifying impairments or concerns, water quality issues, setting water quality standards for water bodies, providing baseline data to support Total Maximum Daily Load (TMDL) studies, or TMDLs and Watershed Protection Plans. The data are also used to improve the science behind Texas Pollutant Discharge Elimination System (TPDES) wastewater permitting. More information can be found at: http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/mtr/index.html

2.3 Water Quality Standards Development

The Texas Surface Water Quality Standards can be found in Title 30, Chapter 307 of the Texas Administrative Code. The state and federal requirements for standards development are to establish uses, set criteria to maintain those established uses, and establish an antidegradation policy. The antidegradation policy protects existing uses and establishes extra protection for water bodies that exceed fishable/swimmable quality. Specific numerical criteria for 39 toxic pollutants, expressed as maximum instream concentrations, protect aquatic life. Human consumption of fish and drinking water are protected by numerical criteria for 65 toxic pollutants. Water Quality Standards also specify provisions for controlling total toxicity of permitted discharges, which involves exposing selected aquatic organisms to samples of a discharge effluent. The general criteria are narrative, and apply to all waters in the state. These standards address pollutants for which there are no specific established numerical criteria and also specify procedures for developing site-specific standards for small unclassified water bodies. The Texas Surface Water Quality Standards are available on the TCEQ website: http://www.tceq.state.tx.us/nav/eq/eq_swqs.html

2.4 Water Quality Standards Implementation

Water quality standards are used in assessing water bodies and in restoration and remediation efforts, and are implemented through state certification of US Army Corps of Engineers permits and through effluent limits established in TPDES permits that authorize discharges of wastewater into surface waters of the state. Technical guidance for the latter process is available in the regulatory guidance document *Procedures to Implement the Texas Surface Water Quality Standards,* RG-194 (Revised), January 2003. The document can be accessed from the following website: http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-194.html

2.5 Total Maximum Daily Load

The Total Maximum Daily Load Program works to improve water quality in impaired or threatened water bodies in Texas. The program is authorized by and created to fulfill the requirements of Section 303(d) of the Federal Clean Water Act. The goal of a TMDL is to restore the full use of a water body that has limited attainment in relation to one or more of its uses. The TMDL defines an environmental target, and based on that target, the state develops an implementation plan to mitigate anthropogenic sources of pollution within the watershed and restore full use of the water body.

An implementation plan usually puts the TMDL into action by outlining the steps necessary to reduce pollutant loads through regulatory and voluntary activities. Implementation could include adjustment of an effluent limitation in a wastewater permit, a schedule for the elimination of a certain pollutant source, identification of any nonpoint source discharge that would be regulated as a point source, a limitation or prohibition for authorizing a point source under a general permit, or a required modification to a storm water management program and pollution prevention plan. Voluntary measures may also be included to address agriculture, forestry and other nonpoint pollution sources. In some instances, TMDLs are implemented through a plan that protects the entire watershed.

2.6 Assessment

The Texas Water Quality Inventory and 303(d) List describe the status of Texas waters based on historical data and identify water bodies that are not meeting standards set for their use. The Inventory also describes ground water monitoring and assessment activities and identifies constituents of concern in Texas aquifers. The reports satisfy the requirements of the Federal Clean Water Act for both Section 305(b) water-quality reports and Section 303(d) lists. The Inventory and List are produced every two years in even-numbered years, as required by law. A List must be approved by the EPA before it is considered final. A list of approved inventories can be found on the TCEQ website: http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/305_303.html

SECTION 3. WATER QUALITY DATA SOURCES

The collection of water quality data was uncommon prior to the 1960s and did not become widespread until the early 1970s. Initially, most water quality monitoring was performed by state agencies and the United States Geological Survey (USGS). Later, the number of organizations collecting data and the provisions for sharing these data have expanded and improved. In addition, the quality and level of quantification has improved for many parameters and there is a continued program of improvement in these areas. The following sections describe some of the key developments in the process of making water quality data available.

3.1 Surface Water Quality Monitoring

The SWQM Information System (SWQMIS) serves as a repository for quality assured surface water quality data and is maintained by the TCEQ. These data are collected by SWQM, contributing river authorities, cities, and other local, state, and federal agencies. TCEQ, CRP and other acquired data go through a quality assurance review prior to inclusion in the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database. SWQMIS also provides validation and reporting tools, a mapping interface, and modules for tracking information about analytical laboratories, quality assurance documents, and monitoring equipment. Water quality data is used by TCEQ to monitor the impact of anthropogenic and natural influences on Texas surface waters. TCEQ has received and maintained data since 1967, allowing for the assessment of short and long term trends. Existing water quality data can be compared to established water quality standards for stream, reservoir, and coastal segments. The public interface for SWQMIS can be found on the following website: http://www8.tceq.state.tx.us/SwqmisWeb/public/index.faces or http://www.tceq.state.tx.us/compliance/monitoring/crp/data/samplequery.html.

3.2 Clean Rivers Program

The Clean Rivers Program (CRP), established in 1991, provides a mechanism by which river authorities and other entities cooperate and partner with TCEQ in the collection, quality assurance, and sharing of water quality data. The CRP partners collect data and work with cities or other entities in their area to obtain and make data available.

In addition to data collection efforts, CRP partners perform analyses of data in their areas, conduct special studies to address particular issues and issue basin reports. Basin Summary Reports provide an extensive overview of the CRP activities and water quality trends over a five year period. A Basin Highlights Report is an annual update of events affecting water quality and projects performed by CRP partners.

To assure that water quality monitoring resources are used effectively, a statewide database is hosted by the Lower Colorado River Authority (LCRA) to coordinate water quality monitoring activities among CRP partners and the TCEQ. The Coordinated Monitoring Schedule (CMS) manages the monitoring activities of over 50 agencies statewide across 25 basins, and allows these agencies to administer and share their schedules. The CMS can be found on the following website: http://cms.lcra.org/.

3.3 USGS Data Sources

The USGS maintains a network of approximately 1,000 stream gages in Texas that measure and record a wide variety of hydrologic, climatologic and water quality based parameters. The types of data collected are varied, but generally fit into the broad categories of surface water and groundwater. Surface water data, such as gage height (stage), streamflow (discharge), temperature, rainfall, conductivity, dissolved oxygen, humidity, evaporation, etc, are collected from major rivers, lakes, and reservoirs. Groundwater data, such as water level, are collected at wells and springs. These data are made available electronically on a near real-time basis via the National Water Information System (NWIS), developed and hosted by the USGS. Information for a specific stream gage(s) can be downloaded directly from the website: http://waterdata.usgs.gov/nwis/sw

3.4 Water Quality Management Programs

In addition to the routine monitoring programs above, water quality data are also obtained from special studies or planning efforts. Typically, water quality data produced from these studies and efforts are housed within SWQMIS. Data that are not stored in SWQMIS can be obtained by contacting the respective TCEQ program areas that conduct or oversee the special studies or planning activities.

3.4.1 Watershed Protection Plans

TCEQ and the Texas State Soil and Water Conservation Board (TSSWCB) support the development and implementation of Watershed Protection Plans as a means to prevent or manage nonpoint source pollution. These plans are developed through local stakeholder groups with funding and technical assistance from the TCEQ or the TSSWCB, and the U.S. Environmental Protection Agency. The TCEQ is the State's lead agency for preventing and abating nonpoint source pollution from urban and other nonagricultural sources. The TSSWCB fulfills those responsibilities for agricultural and forestry lands. Both agencies administer grant funds that may be used to prevent or reduce nonpoint source pollution. Data collection efforts are focused on the constituent of interest (e.g. nutrients or bacteria) in an effort to determine pollutant loadings from nonpoint sources. More information can be found at the TCEQ website: http://www.tceq.state.tx.us/compliance/monitoring/nps/mgmt-plan/index.html

3.4.2 Use Attainability Analysis

Use Attainability Analyses (UAAs) are assessments of the physical, chemical, and biological, and economic factors affecting attainment of a water body use (40 Code of Federal Regulations §131.10(g)).[1] UAAs are used to identify and assign attainable uses and criteria to individual water bodies. In general, UAAs are performed on impaired

[1] Although economic factors may be considered, economic hardship has rarely or ever been employed in Texas UAA assessments.

water bodies as indicated in the Texas 303(d) List. UAAs that involve data collection typically involve a wide range of data types including biological (macroinvertebrates and fish), physicochemical (DO, temp, pH, specific conductivity, nutrients, TSS, BOD, etc.), and physical habitat parameters collected over multiple sampling events. 24 hr data for parameters such as DO, temp, pH, and specific conductivity is often collected. The TCEQ Water Quality Standards Development Program is responsible for the oversight of all UAAs.

3.4.3 Receiving Water Assessments

Smaller water bodies do not have specific uses or criteria established in the Texas Surface Water Quality Standards. Receiving Water Assessments (RWAs) may be conducted in order to establish appropriate uses and criteria for these smaller water bodies. RWAs are site-specific assessments of physical, chemical, and biological factors and are usually conducted when a regulatory action has been taken or is anticipated to be taken by TCEQ or because sufficient concern exists to provide an aquatic life use designation. Data collection for RWAs can include the same data types as for UAAs; however the sampling frequency is generally more limited. All RWAs are coordinated by the TCEQ Water Quality Standards Implementation Program.

3.4.4 Total Maximum Daily Load

The TMDL program is tasked with improving water quality in impaired or threatened water bodies in Texas. The TMDL program collects various types of data to further characterize water body problems such as impaired biological communities, depressed dissolved oxygen, and high levels of bacteria, metals, nutrients, dissolved solids, pH, temperature, organic chemicals, and sediment toxicity, although the specific data collected depends on the pollutant of concern. This program frequently conducts more intensive water quality data collection in support of modeling activities. More about TMDL projects currently under way or completed can be found at the TCEQ website: http://www.tceq.state.tx.us/implementation/water/tmdl/nav/tmdlprogramprojects.html

SECTION 4. RELATIONSHIPS BETWEEN WATER QUALITY AND FLOW

During initial development of a flow regime recommendation, a hydrology-based approach will probably be used (SAC 2009a) as a starting point. Water quality information can then be used as an overlay to make adjustments to the initial flow regime matrix. The flow components recommended through the hydrology-based approach will be similar to the Texas Instream Flow Program (TIFP) framework includes subsistence, base, high flow pulse, and overbank flows, seasonally adjusted as appropriate (TCEQ et al. 2008). Streamflow and water quality parameters are sometimes functionally related; therefore, it is necessary to consider water quality concerns during development and refinement of the flow regime.

In this section, water quality concerns are addressed from two directions. First, the BBESTs should consider whether the recommended flow components are adequate to support water quality standards and support ecological functions related to water quality. Second, while improving water quality is not a specified goal of the SB 3 process, it is an appropriate consideration where a particular water quality problem or concern has been identified (e.g. through the State's 303(d) or 305(b) programs).

Water quality concerns associated with inflows are currently addressed on a case-by-case basis. For example, aeration of water releases may be required in situations where flows released from a reservoir during the summer may have relatively low dissolved oxygen (DO) content. Another example is TCEQ's use of a modified version of the Lyons Method (SAC 2009a) as the basis for establishing environmental flow restrictions for new water right permits and amendments when existing site-specific information is not available. A Lyons Method restriction requires minimum flows, calculated as 40% of the monthly median flow from October to February and 60% of the monthly median flow from March to September. TCEQ typically imposes a lower flow limit equal to the 7Q2 if the Lyons derived value is less than the 7Q2.

4.1 Water Quality Standards in Relationship to Flow

Water quality standards were developed largely in the context of addressing pollution due to human activity, such as wastewater discharges, and thus tend to be oriented toward providing protection under critical low flow conditions. Aspects such as providing pulses of higher flow or modifying the low flow distribution for ecological reasons have not been a focus of water quality standards up to now. Another limitation that must be recognized is that water quality records are available for a short period of time relative to the periods that flow measurements are available. Further limiting the duration of usable water-quality data is the fact that measurement techniques for some parameters are still evolving. Where that evolution is still in progress, we must live with censored data (values replaced by "nondetect" flags when below designated reporting levels).

4.2 Water Quality Considerations for Subsistence Flows

As noted in the Technical Overview document (TCEQ et al. 2008), subsistence flows are infrequent low flows that occur during times of drought or under very dry conditions. The primary objectives of subsistence flows are to maintain water quality criteria and prevent loss of aquatic organisms due to, for example, lethal high temperatures or low dissolved oxygen levels. Secondary objectives may include providing life cycle cues based on naturally occurring periods of low flow or providing refuge habitat to ensure a population is able to re-colonize the river system once more normal, base flow conditions return. Assuming that native fauna are adapted to survive brief periods of subsistence flows; these low flow levels can help to purge invasive species from a stream system. Subsistence flows can also sustain a minimum level of connectivity between pools during dry times.

This description suggests that variability in the flow regime is important and that subsistence flows should be considered in any flow regime analysis. HEFR incorporates a default hydrologic condition where subsistence conditions occur at approximately the 2.5th percentile of the flow record (SAC 2009a).[2] HEFR also allows the user to select other values for subsistence flows, such as the 7Q2. Consideration of the applicability of the default or other values is an important part of the overlay process. Note that having the subsistence flow at the low end of the flow spectrum and overbank flows at the high end assures a high degree of flow variability.

The 7Q2 was established several decades ago to be the practical minimum stream flow for the evaluation and permitting of wastewater discharges in Texas and was defined as a design dilution flow. Although the 7Q2 has not been explicitly evaluated for ecological relevance, its use recognizes that occasional low flow stressors occur naturally over time. As established in the Texas Surface Water Quality Standards, many of the numerical water quality standards for non-tidal streams and rivers do not apply when stream flow conditions are less than "critical low flow conditions", as determined by the 7Q2. The 7Q2 is used in modeling by the TCEQ to determine the allowable discharge load to a stream in Waste Load Evaluations, TMDLs and wastewater discharge permits. To be issued a wastewater discharge permit, an applicant must ensure that the level of treatment at the maximum allowed discharge flow value is sufficient to maintain the dissolved oxygen criterion at the 7Q2 streamflow. In some cases the 7Q2 plays a similar role for other parameters besides oxygen–demanding constituents.[3]

[2] For example, the IHA method uses a default of the 10th percentile of the Group 1 flows defined as those flows below the 25th percentile, although other flows could be classified in this category. In effect, this is approximately the 2.5th percentile flow.

[3] As stated in TAC §307.8(2) (a) (3) the 7Q2 flows are not intended to serve as minimum flow requirements. "Low-flow criteria in Appendix B of §307.10 of this title are solely for the purpose of defining the flow conditions under which water quality standards apply to a given waterbody. Low-flow criteria listed in Appendix B of §307.10 of this title are not for the purpose of regulating flows in waterbodies in any manner or requiring that minimum flows be maintained in classified segments."

7Q2 flows are periodically reevaluated by the TCEQ using the most recent available streamflow records; hence, 7Q2 values are sensitive to activities that might affect streamflows, such as wastewater discharges or hydroelectric releases that can sustain low flow conditions that would not exist naturally. Thus 7Q2 flows may be either flows that reflect natural conditions or artifacts of man-made conditions. Because the 7Q2 is calculated using the most recent flow data, it will tend to reflect the most recent streamflow alterations.

Another water quality factor in setting subsistence flows is the evolving nature of wastewater discharges. To some extent the 7Q2 is a legacy of a day when available dilution was an important part of wastewater discharge permitting. For example, the level of treatment required by the Clean Water Act in 1972 was secondary, defined as 30 mg/L of biological oxygen demand and total suspended solids, with no nitrification. Since that time there have been major changes. Most Texas wastewater permits have for many years required much better treatment, such as a BOD concentration of 20 mg/L or lower and essentially complete nitrification, irrespective of streamflow conditions. The effect of these much higher levels of wastewater treatment is that in dry weather conditions there frequently is very little oxygen demand contributed by wastewater discharges, and the traditional assumption that low flows produce low DO levels is often not supported with data. As a consequence relationships between water quality parameters and flow should be quantified with data to the extent that information is available. If data are not available, a valid alternative would be to employ existing water quality models. However, if this is done it is important that modeling employ representative dry weather effluent characteristics.

Depending on the information used in their development, subsistence flows developed based on pre-impact streamflow records may overemphasize the pre-development condition. The SAC (2009c) recommends that in the preliminary development of the flow regime matrix, the 7Q2 value not be used. A subsistence flow based on a more natural flow regime may be less than the 7Q2 at a given point. In some river systems, particularly when pre-impact flows are used in the analysis, the 7Q2 value can exceed not only the subsistence threshold value (e.g. 10th percentile) but also the values generated for base flow conditions. In this situation, the BBESTs should consider the difference between the current 7Q2 and more natural subsistence flows and determine an appropriate subsistence flow for current conditions.

In addition, subsistence flow values should be evaluated and adjusted to ensure water quality parameters such as dissolved oxygen and temperature are maintained in a suitable range to ensure aquatic life persists/endures (SAC 2009c). Relationships between water quality parameters and flow should be quantified to the extent that information is available.

4.3 Water Quality Considerations for Base and Higher Flow Conditions

Embedded in the use of a hydrology-based approach to develop environmental flow recommendations is the assumption that the flow components provide and support various ecological functions, several of which are related to water quality. As part of the water quality overlay process, it may prove worthwhile to further investigate the relationship between various ecological processes and other flow components such as base and higher flow conditions. It is important to recognize that other flow regime components are important for maintaining the assimilative capacity of the stream and its long term water quality.

Doyle et al. (2005) provides an overview of work on how different flow ranges affect different ecological aspects, drawing on the relation with sediment transport, where moderate flow pulses (1 to 5 year recurrence interval) tend to be the most effective in sediment transport. Doyle et al. investigated four ecological processes: sediment and nutrient transport, habitat regulator, process modulator and ecological disturbance, and found varying types of relations with flow. For example, with sediment and nutrient transport, there would be a difference in the effective flow range depending on the functional relation. With particulate matter (sediment and part of the nutrient pool), there is often an increase in concentration with flow so that the most effective flow for transport will be in the moderate pulse range. But in streams such as the Trinity River shown on Figure 11, where the total N concentrations are highest at the lower flows, which also tend to have the highest frequency of occurrence, the most effective discharge for total N will tend to be shaded more towards the base flows.

From the perspective of habitat regulation, Doyle et al. (2005) found that flow was often a key factor in determining the amount of habitat in a river but that relations could be very different for different species. In relation to process modulation and disturbance, the most effective flow range can be defined for a specific ecological response function. The problem is that there are many different processes and disturbance mechanisms to consider. Developing the target or most ecologically important flow range to emphasize depends on defining the desired ecological response. Related information can be found in previous SAC documents on fluvial sediment transport (SAC 2009b) and biology (SAC 2009c).

Evaluating higher flow recommendations may be more difficult than the evaluation for subsistence flows described above, especially since implementation aspects are undetermined at this time. Because the method of implementation may not be known when the environmental flow regime is developed, the following section only addresses a simple method of assessing the relation between flow and water quality. In general, the level and detail of analysis should be geared to the knowledge of and immediacy of potential actions.

4.4 Developing Flow-Water Quality Relationships

Assuming that the environmental flow regime recommendations involve a change in the distribution and timing of flows that could lead to changes in quality characteristics, a first step is to understand the existing relationship between flow and quality parameters. A simple technique to assess this correlation is to examine plots of flow and water quality parameters. If anomalies in the relationship of flow to water quality are found using simple analyses, the use of more sophisticated statistics and/or modeling could be productive. For instance, considerable literature discusses using Spearman Rank Correlation tests or other statistics to examine flow versus water quality parameters. Routine analyses used by the USGS to examine relationships between flow and water quality can be found at: http://pubs.usgs.gov/circ/circ1173/Methods.htm.

As an example application of the simple overlay approach, we employ the same station used as an example station in SAC (2009a), the Neches River at Evadale, USGS gage 08041000. Figure 1 shows the location of the station and upstream reservoirs. B. A. Steinhagen Lake began impoundment in April 1951 and impoundment of the Sam Rayburn Reservoir began in March 1965. This station was selected because it had a long period of record (1922–present) that included a substantial period (January 1, 1922 to December 31, 1964 used in the HEFR example) when there was relatively little upstream reservoir development and thus could be taken to approximate natural conditions.

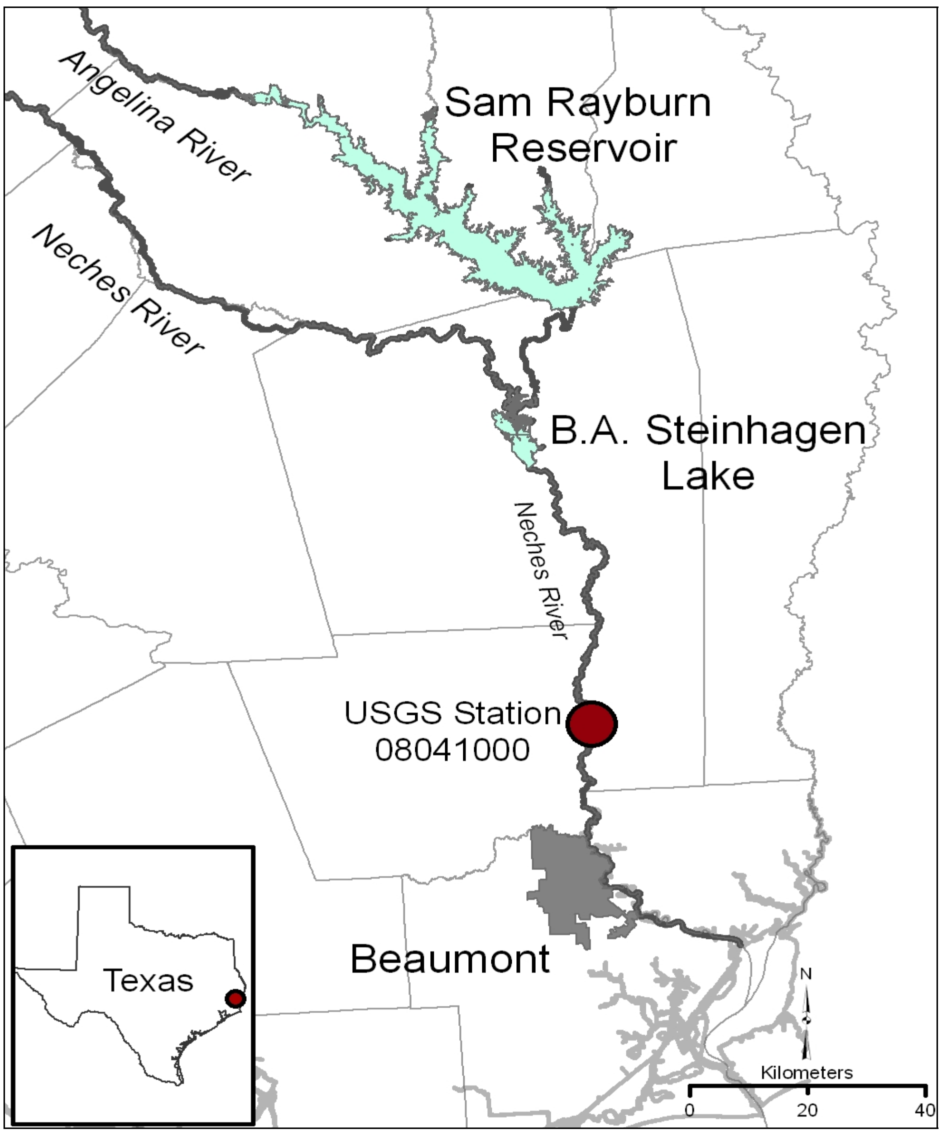

Figure 1. Location of Example USGS Gage

The differences in the flow distribution between the 1922-64 period and the period from 1965-present are shown in Figures 2 and 3. Figure 2 shows the time history of the log daily flows for the two periods, and Figure 3 shows the daily flow exceedance curves for the two periods. There are major differences in streamflow during the two periods due to flow regulation. From Figure 2 it can be seen that the range in flows is substantially reduced after 1965. The peak flows on the left side of Figure 2 are cut by roughly 50%. The average flows listed on Figure 3 for both periods of record are essentially identical, while the median flows after impoundment are higher by about a thousand cfs or 38%, possibly reflecting the effect of upstream hydroelectric releases.

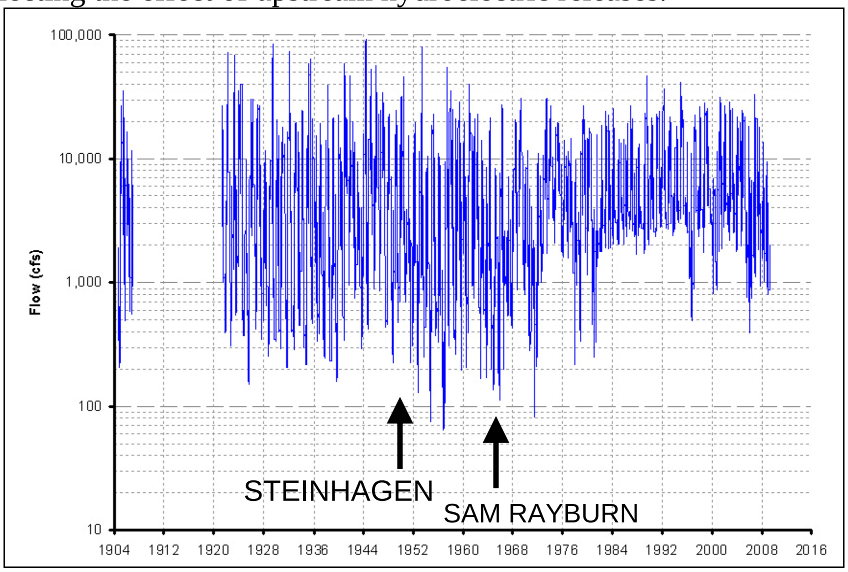

Figure 2. Daily flows at Evadale for period of record

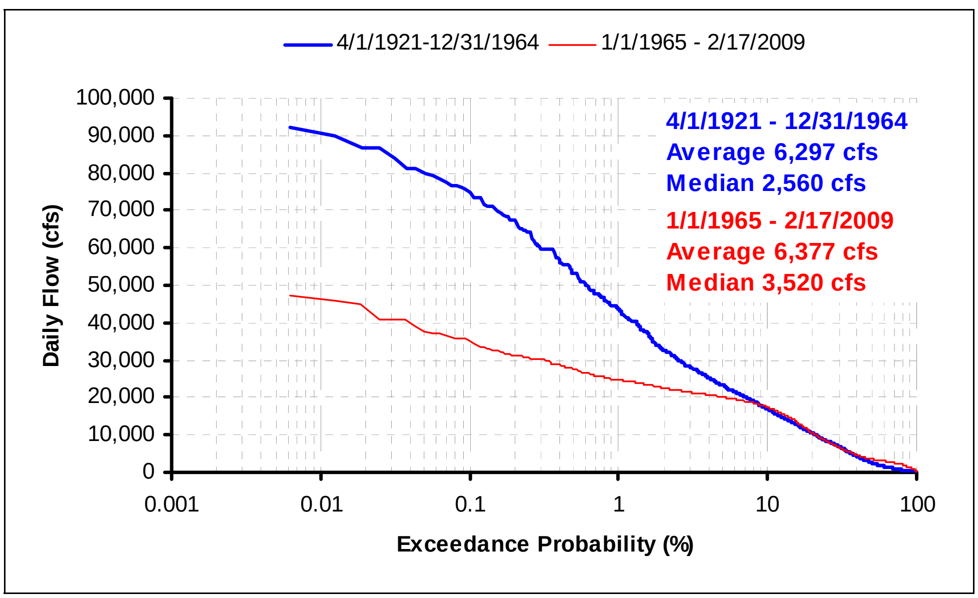

Figure 3. Flow exceedance plots for 1922-64 and 1965-2009

A first step in developing an understanding of how the relevant water quality parameters are affected by different flow conditions is developing correlation plots. To conduct the analysis, available water quality data at TCEQ Station 10580, which is at the same location as the USGS gage, were downloaded from the TCEQ's SWQM website. Figure 4 shows a plot of nitrite-nitrate-N along with flow data. The starting point in the mid-1970s is true for most water quality parameters, at least those that are readily available and thus suitable for an overlay analysis.

Another point to consider with this example is that over time there have been changes in our ability to measure this and other parameters. Figure 5 shows a similar plot of ammonium-N concentrations and flow that illustrates the period of record available and also the limitations and variability of laboratory reporting limits over time. Since 1998, most of the results are reported as <0.05 mg/L. A similar pattern of non-detects was found for nitrite-nitrate-N on Figure 4 and total phosphorus (not shown). Figures 6 and 7 are similar plots for copper and zinc, showing a pattern of decline over time. At this writing we have no knowledge of significant changes in the watershed that would affect the actual levels of Cu and Zn. The lower concentrations over time appear to be simply the result of better analytical techniques. Nevertheless, at this station at least, we still don't have the ability in routine monitoring programs to quantify the actual stream concentrations of many water quality parameters. These plots illustrate the point that at this station where flows consist largely of reservoir releases, the concentrations of most water quality parameters tend to be quite low with much of the data being reported as lower in concentration than can be measured with techniques routinely employed.

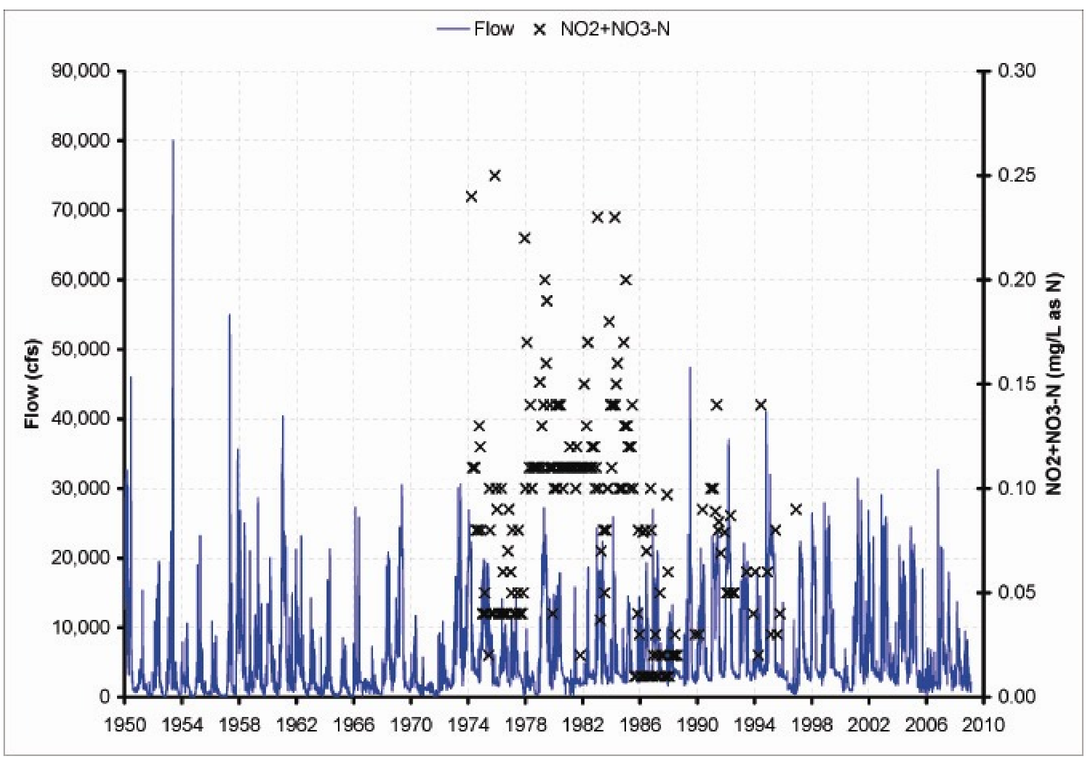

Figure 4. Nitrite-Nitrate-N observations over time with flows

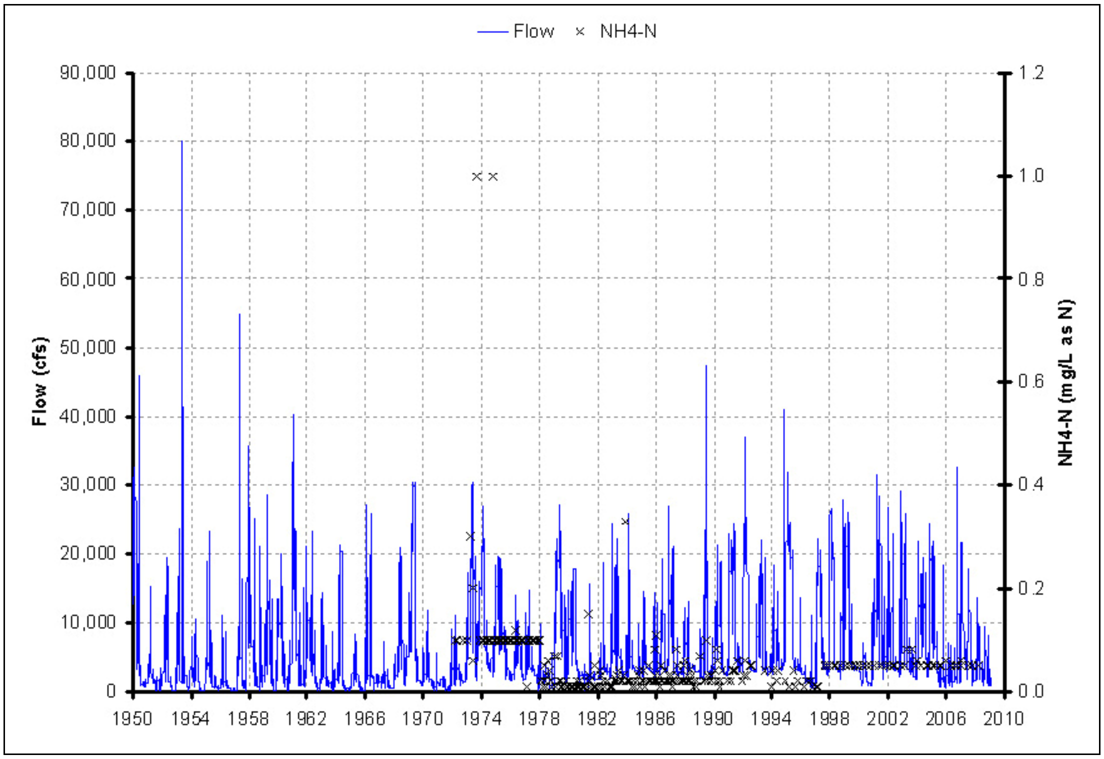

Figure 5. Ammonium-N concentration over time

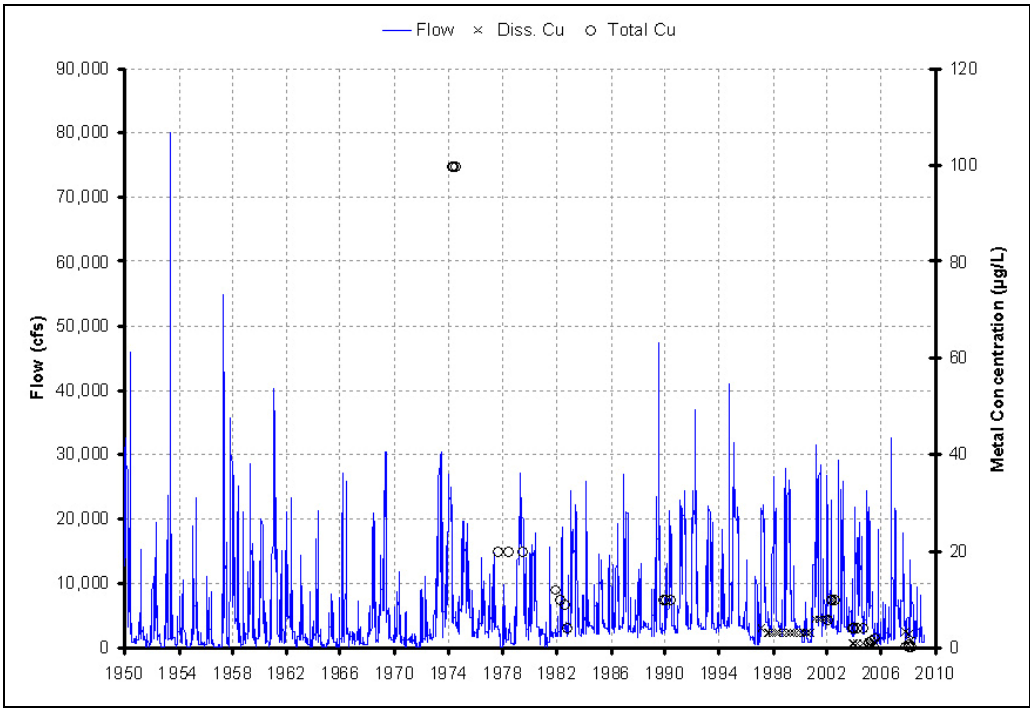

Figure 6. Total and Dissolved Copper data with flow over time

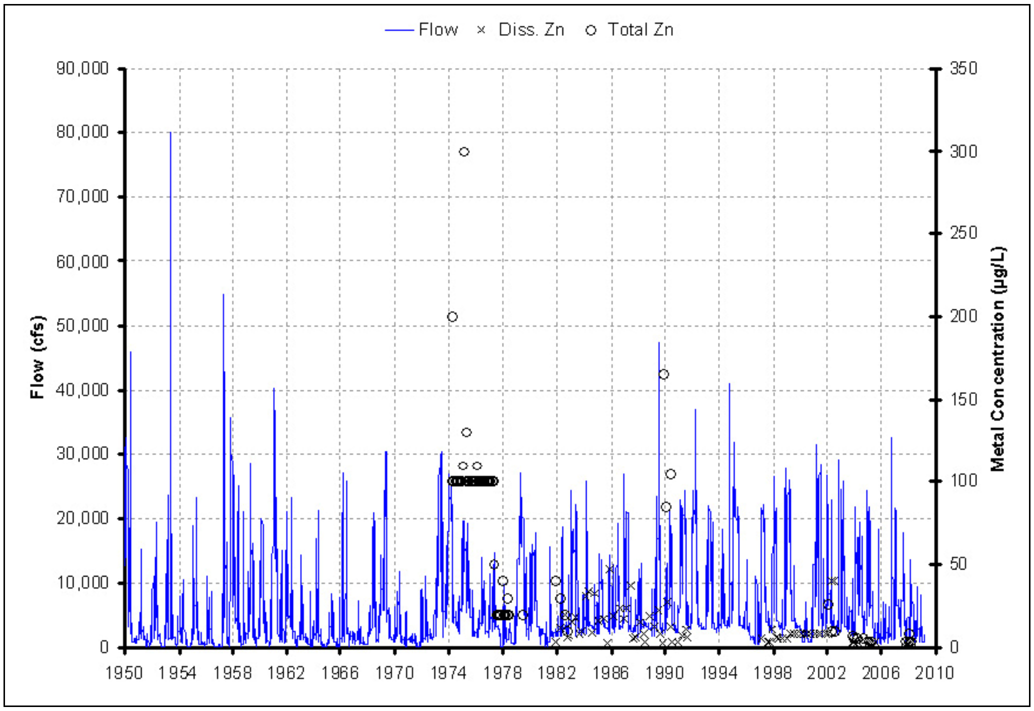

Figure 7. Total and Dissolved Zinc data over time

There are, however, some parameters that have been measured over a significant amount of time and that can be related to flow. Figure 8 shows a plot of conductivity versus log flow. There is a substantial pool of conductivity observations which show the expected decline in conductivity as flow increases. The regression relation explains about 15% of the observed variation. A similar type of relation is shown for the dissolved oxygen (DO) deficit (DO saturation concentration minus measured DO) on Figure 9. Using the deficit formulation has the effect of reducing the variation due to seasonal temperature differences, but in this case, the regression relation still explains only about 10% of the variation. It is interesting in that it indicates that as flow increases there would be a slight increase in deficit or decline in DO, opposite to the conventional water quality wisdom where higher flow brings more velocity and aeration and thus higher DO levels. Part of the explanation may lie with reservoir releases that are sometimes relatively low in DO, tempered by a substantial distance (roughly 60 km) from the reservoir to the station. Higher flows can also result in increased loadings of oxygen demanding compounds. There is also the situation of small but intense rains introducing organic matter from the watershed that decreases DO, but does not have a major effect on flow. The third relation shown is for TSS versus log flow on Figure 10. Here the data would suggest that there is no relation between TSS concentration and flow, and that very few observations over 100 mg/L are found. This is consistent with a regulated stream.

This example station, located in a relatively high precipitation part of the state with little development in the watershed, and a substantial amount of flow regulation, has specific water quality conditions. The concentration of nutrients, metals and suspended solids tends to be low and these parameters might not be greatly affected by changes in flow.

One might conclude from this situation that, based solely on streamflow, small modifications of streamflows not likely have a significant water quality impact. However, because of the number of other variables that influence water quality, predictions of how water quality parameters will change with future hydrologic conditions are difficult to make.

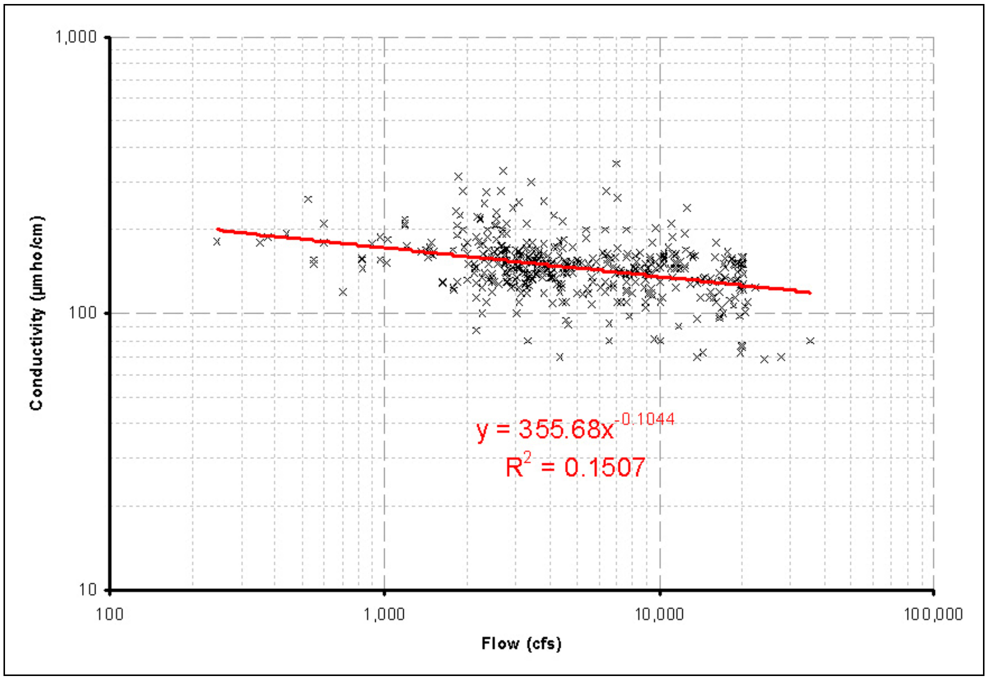

Figure 8. Conductivity versus Flow at Evadale

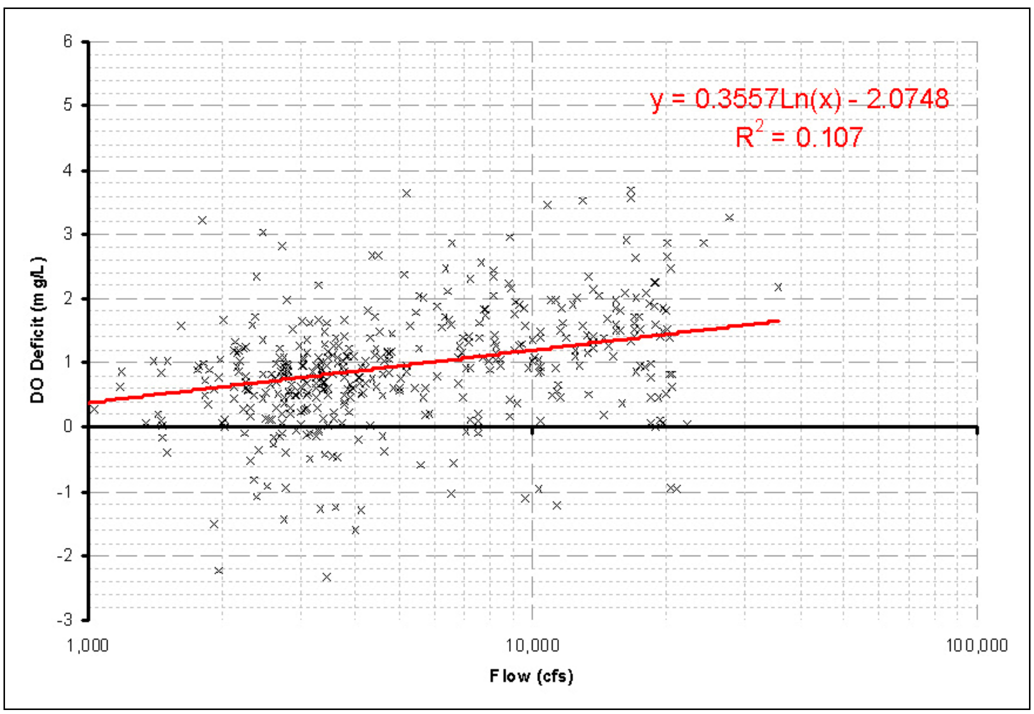

Figure 9. DO Deficit versus Flow

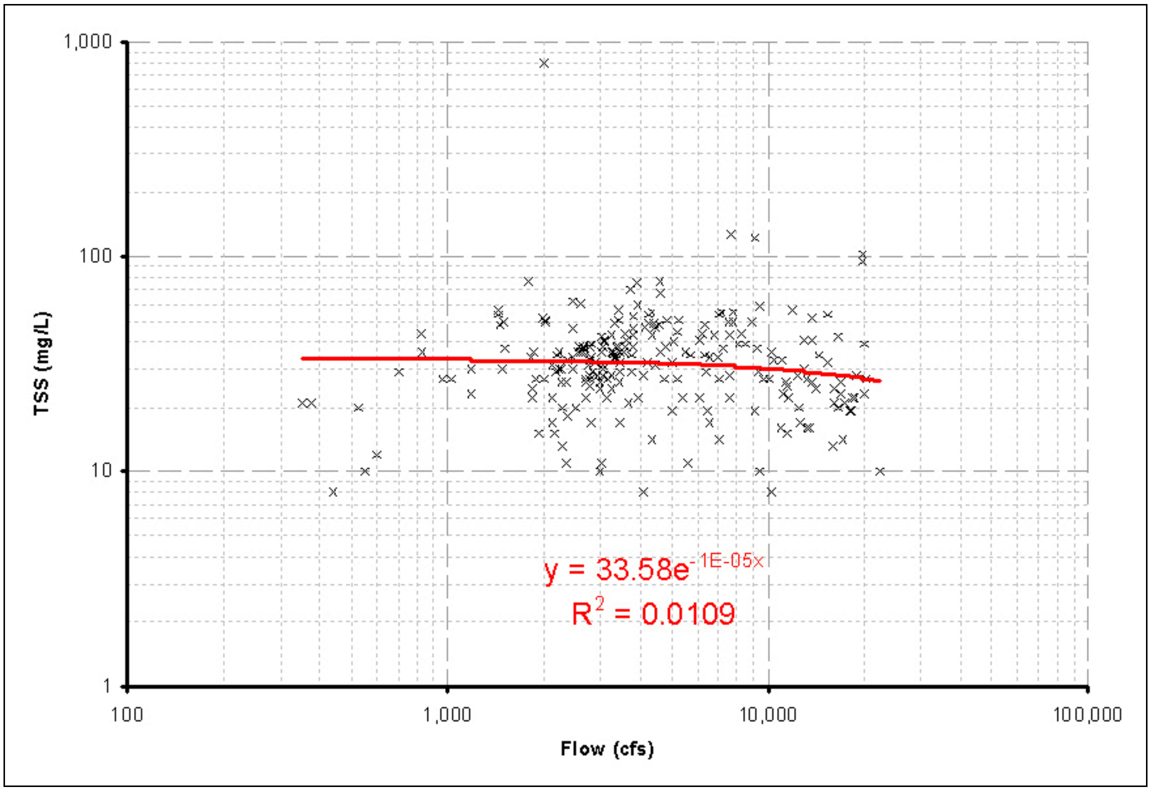

Figure 10. Total Suspended Solids versus Flow

While that may be the case for the Evadale example, it would not necessarily be true for other stations in other parts of the state or with different upstream conditions. A significant relation between flow and total nitrogen content in the Trinity River is shown in Figure 11. At this station, there is a substantial amount of upstream flow regulation and also the addition of wastewater discharges that are relatively rich in nitrogen. In this case, changes in river flow could have a substantial effect on the nitrogen concentrations and load transported.

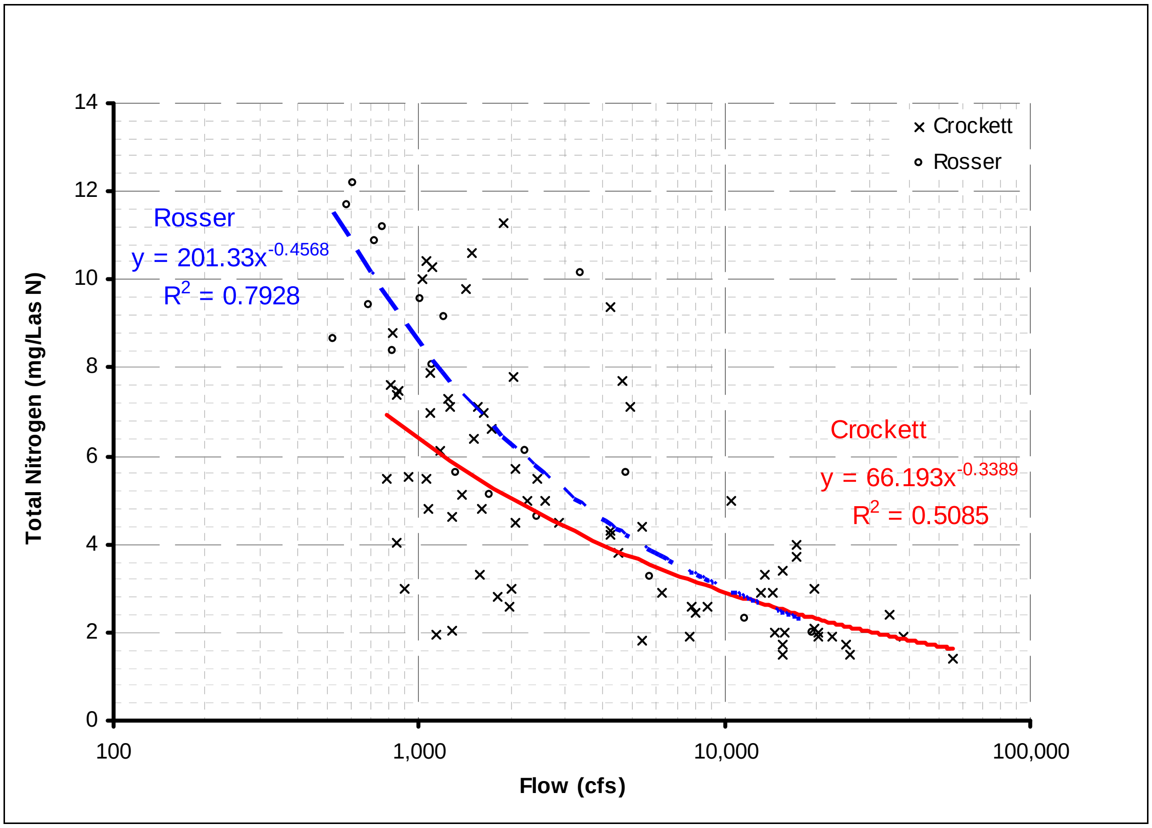

Figure 11. Total N and Flow on the Trinity River above Lake Livingston

The inverse relation between flow and total N concentration shown on Figure 11 is a consequence of a base flow nitrogen source from wastewater discharges and limited inputs from landscape sources. Without such an effect, an opposite pattern might be expected. This can be seen on Figure 12, TCEQ Station 10585, USGS 08033500, Neches River near Rockland, where there is relatively little upstream wastewater influence and no significant flow regulation. In this case, higher flow tends to produce somewhat higher total N concentrations, although there is a great deal of variation.

The key point is that the relation between flow and various water quality parameters can be quite variable. While the effects of major influences such as flow regulation and wastewater discharge are reasonably well understood, postulating a general relationship may be very difficult. The effort involved in examining the relationship with actual data is relatively modest and may be confounded without examining changes in land use patterns and other causative factors in the contributing watersheds. In light of the fact that the BBESTs may not know how actual flows will be affected, where there is any expectation that a hydrology-based flow recommendation would have the potential to affect actual flows, examining the relation to water quality should be performed. It is important that subsistence flow levels do not create conditions that would compromise water quality and that base and higher flow conditions continue to provide ecologically important functions.

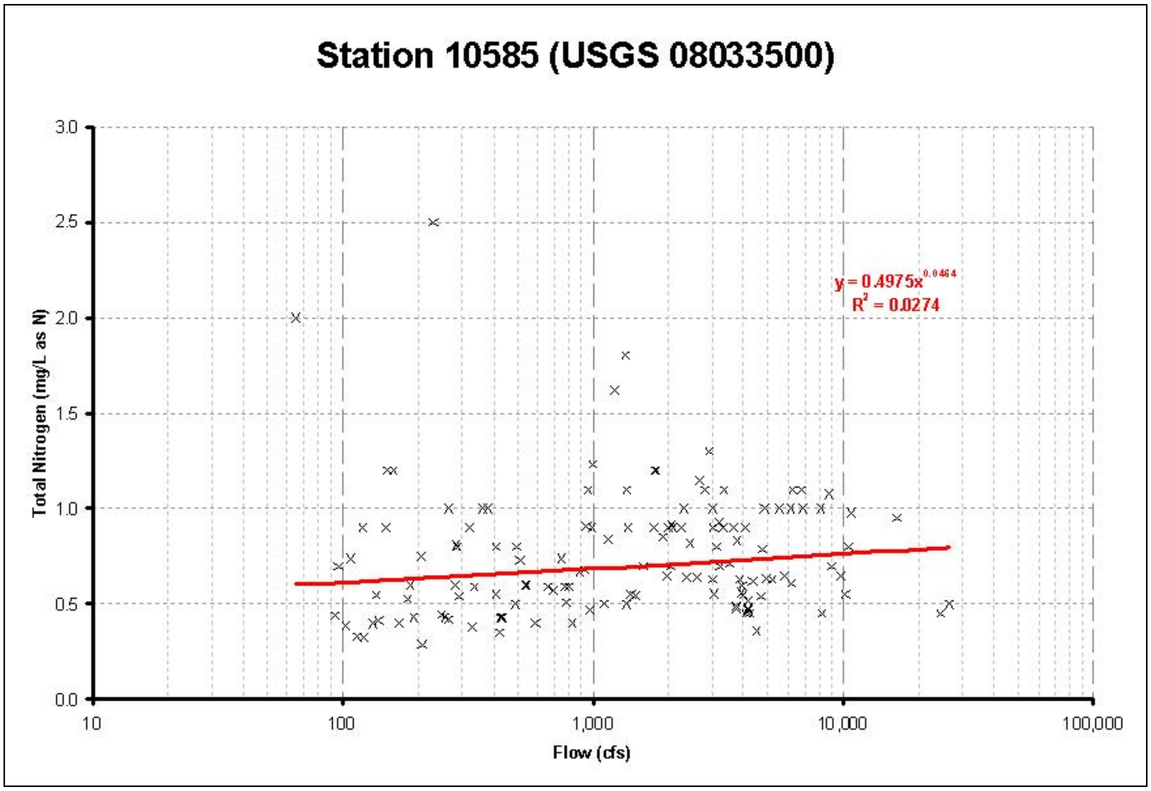

Figure 12. Total N versus log flow at TCEQ Station 10585, Neches River near Rockland

SECTION 5. SUMMARY AND RECOMMENDATIONS

The BBESTs will need to determine how the recommended flow regime affects water quality, consistent with maintenance of a sound ecological environment. In the absence of more detailed information, one alternative would be to use the 7Q2 value in lieu of the hydrology-based subsistence flow calculation. Evaluating higher flow recommendations may be more difficult, especially when considering unknowns, such as possible effects downstream of the point under consideration, associated with implementation of environmental flow standards.

The BBESTs may need to determine whether flow recommendations above the subsistence level, i.e. base flows and high flow pulses, are adequate to maintain water quality conditions. If a standards attainment problem or concern currently exists, then a more rigorous assessment of the recommended flow regime may be required. As part of that assessment, water quality data sources would need to be identified and evaluated. With sufficient data, a relation between flow and quality parameters could be developed.

Assuming that a suitable relationship between flow and quality responses has been identified, the next step would be to assess any potential effects of the initial hydrology-based flow regime on water quality to determine if an adjustment is needed. The assessment should consider the site (flow gauging station) where the environmental flow regime was developed as well as downstream areas. The downstream assessment should consider potential future changes, if known, in the distribution of water quality parameters and changes in the longer term loadings of somewhat conservative parameters such as solids, nutrients, and toxics. This loading dimension could be important if reservoirs were located downstream of the point under consideration, as they tend to retain and accumulate materials contributed in a range of flows.

In the case of the Evadale example, the effect of reservoir regulated flows and ambient water quality conditions has been to make the concentrations of most water quality parameters relatively low and stable. With that as a base condition at this example station, it is difficult to imagine that a change in flows would produce a significant adverse effect on water quality. However, that conclusion may well be different at other stations.

Determining water quality responses to a proposed flow regime poses some challenges. It is important that the recommended flow regime prevent degradation or non-attainment of existing water quality standards. But simply relying on the standards may not be sufficient. It is entirely possible that there could be a water quality effect that, although it did not produce a situation where the standards were not attained, could still be considered adverse to some degree in maintaining a sound ecological environment. In considering such adverse impacts, there may be situations where it is possible to define a change in a flow regime based on water quality improvements considered desirable.

It should be recognized that because this type of water quality assessment has not been routinely produced, site-specific procedures and details may need to be developed. In some cases, it may be possible to quantify an expected difference in a nutrient or trace metal input in response to a potential change in flows but have no quantitative means to assess the ecological significance of the change. This type of situation should be viewed as a step in the evolution of the process of developing a flow regime and encourage agencies and other workers in the field to sustain monitoring and research, which improves understanding of flow-water quality relationships in Texas aquatic ecosystems.

SECTION 6. REFERENCES

Doyle, M., E. Stanley, D. Strayer, R. Jacobson, and J. Schmidt. 2005. Effective discharge analysis of ecological processes in streams. Water Resources Research, Vol 41, W11411, doi: 10.1029.

Science Advisory Committee (SAC). 2009a. Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process and the Hydrology-Based Environmental Flow Regime (HEFR) Methodology. Report # SAC-2009-01-Rev1. April 20, 2009.

Science Advisory Committee (SAC). 2009b. Fluvial Sediment Transport as an Overlay to Instream Flow Recommendations for the Environmental Flows Allocation Process. Report # SAC-2009-004. May 29, 2009.

Science Advisory Committee (SAC). 2009c. Essential Steps for Biological Overlays in Developing Senate Bill 3 Instream Flow Recommendations. Report # SAC-2009-005. August 31, 2009.

TCEQ. 2000. Texas Surface Water Quality Standards, Texas Administrative Code, Title 30, Chapter 307.

Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, Texas Water Development Board, 2008: *Texas Instream Flow Studies: Technical Overview*. Report 369, Texas Water Development Board, Austin.

TRG (Technical Review Group). 2008. Review of desk-top methods for establishing environmental flows in Texas rivers and streams – final report to the Texas Commission on Environmental Quality. Austin, Texas.