Review of Desk-top Methods for Establishing Environmental Flows in Texas Rivers and Streams

Final Report to the Texas Commission on Environmental Quality

Draft Final Report Submitted June 4, 2008
Final Report Submitted August 1, 2008

Technical Review Group Members:

Kirk Winemiller, Texas A&M University, TRG Chair
Tim Bonner, Texas State University
Bob Brandes, TRC Brandes
Steve Davis, Texas A&M University
Ryan King, Baylor University
David Maidment, University of Texas at Austin
George Ward, University of Texas at Austin

Agency Laisons:

David Bradsby, TPWD
Chris Loft, TCEQ
Greg Malstaff, TWDB
Kevin Mayes, TPWD
Doyle Mosier, TPWD
Bruce Moulton, TCEQ
Mark Wentzel, TWDB

Technical Support for TRG:

Eric Hersh, University of Texas at Austin
Joe Trungale, Texas State University
Carmen Montaña, Texas A&M University
Jose Montoya, Texas A&M University

Background

The Science Advisory Committees (SAC), created by the Study Commission on Water for Environmental Flows, a commission of appointed Texas Legislators and representatives of water-interest groups charged by the 78th Legislature with addressing the State's needs for environmental flows in riverine and estuarine systems, and by the Governor-appointed Environmental Flows Advisory Committee that was authorized by the 79th Legislature, presented a number of recommendations regarding methodologies for establishing appropriate environmental flow requirements for water bodies within the State. One of these, which is restated below, dealt specifically with improving what is referred to as the "desk-top" methodology for estimating the flow requirements in rivers and streams necessary for conserving instream uses and the aquatic environment.

> *The TCEQ, TWDB and the TPWD should engage as soon as possible the services of qualified professionals to review currently available instream environmental flow assessment tools and to develop one or more desk-top methodologies specifically applicable to Texas river and stream conditions.*

The present Technical Review Group (TRG), established by the Texas Commission on Environmental Quality (TCEQ), is an outcome of this recommendation. This TRG convened in August of 2007 to review and assess existing information and documents regarding instream environmental flow requirements and desk-top and other methodologies with the goal of making recommendations to the State as to how its current desk-top procedures could be improved to provide more appropriate estimates of environmental flow needs for rivers and streams.

Environmental flows: goals and specification

The last quarter century or so has witnessed increased awareness of the impacts of human activities on stream ecosystems due to the alteration of the natural flow regime, so that flow management has now emerged as a means of mitigating or compensating for these impacts. Flows that are required to achieve a goal of some environmental function are referred to generally as *environmental flows*. Because stream flow is in fact a function of time, "flows" in this definition can include not only the magnitude of the flow, but its patterns of variation, its seasonality, and its extremes. Environmental function can include dilution of wastewater, mixing and aeration of the water column, and the transport of essential waterborne constituents, such as nutrients, into a critical reach of a watercourse. In the present context, however, environmental function is generally taken to apply more narrowly to supporting the presence of naturally-occuring species in the watercourse.

Goals of inflow management extend from preservation of the extant aquatic system to its enhancement, and occasionally include restoration of the ecosystem that existed prior to human impacts. Such management goals require a means of determining the requisite environmental flows, based upon stream hydrology and the responses of aquatic organisms to their hydrological environment. Worldwide, an imposing literature has developed addressing various aspects of the technical problem of establishing a cause-and-effect connection of specific classes of organisms to specific characteristics of the hydrology of a stream (see, for example, Arthington et al., 2006, Tharme, 2003, Whiting, 2002, Petts, 1996, and many others). Of the methods developed for general application (see, e.g., Acreman and Dunbar, 2004, and Tharme, 2003, for summaries), a large class assumes that specific information on the response of local aquatic organisms will not be available, and therefore focuses on various statistics of stream flow (prominent examples being The Nature Conservancy, 2006, and Richter et al., 2007). A subset of these attempts to create (or restore) the "natural" streamflow regime, from either analysis of historical data or the application of "reference" streams (Poff et al., 1997). Another class of methods, referred to as wetted perimeter methods (or "rating" methods), is based upon the distribution of wetted channel width as a function of water depth, and hence streamflow, a natural extension of which is the habitat mapping of the Instream Flow Incremental Methodology (Bovee et al., 1998). Some of these utilize field observations to link specific organisms to water depths (e.g., juvenile fish, Freeman et al., 2001, or vegetation, Auble et al., 1994, Stromberg and Patten, 1996).

Typically, these methodologies embrace the entirety of the riverine system, *viz*. the channel, riparian corridor, hyporheic zone, and even the floodplain (e.g., Whiting, 2002), and extend over the full range of flows exhibited (e.g., Poff et al., 1997, Richter et al., 1997). Their applicability encompasses the range of stream geomorphologies and hydroclimatologies, from alluvial rivers to snow-melt-fed mountain streams. Specific application to the Texas region considerably narrows the hydrographic scope of an environmental flow methodology. The source of runoff in Texas is predominantly derived from thunderstorms, so the resulting streamflows are flashy, and there is a wide variation in flow magnitude from the humid east of the State to the arid west. Moreover, Texas rivers are drought-prone, a fact which underlies the strategy of water management in the state. The National Research Council (2005) surveyed the nature of instream flows specific to the Texas setting, and identified four components of the natural stream flow regime that govern the stream environment: subsistence flow, base flow, high flow pulses, and overbank flows (see Appendix 1). Moreover, many of the flow pattern influences in Texas are specific to certain species, communities, regions, and rivers, and it is because of this that sound instream flow policy lies in the successful integration of multiple spatial, temporal, and interdisciplinary considerations.

In the present context, the requirements for a desk-top methodology for the State may be narrowed even more. The intended application, as discussed further below, is in the evaluation of small water rights or minor amendments to existing permits. (Larger diversions and associated hydraulic structures will entail extensive engineering and permit evaluations, and therefore will require river-specific field studies and modeling to evaluate impacts.) The impacts of such small projects will almost always be confined to low-flow regimes of the affected stream, so the methodology should be most appropriate for channel conditions at low streamflows.

Technical Review Group Approach

A considerable compilation of information describing various procedures and analyses for establishing environmental flow requirements in streams throughout the United States and even in other countries has been assembled by the TRG (Appendix 1). The term *desk-top* methods refers to those procedures that can be applied using generally readily-available data and information without conducting site-specific field studies for evaluating and establishing appropriate levels of environmental flows for rivers and streams. Such desk-top methods generally are statistical in nature, typically relying on historical streamflow records to provide the basis for deriving numerical environmental flow values.

The primary focus of the TRG review was those *desk-top* methods that have been applied or specifically proposed for Texas streams. These included the Lyons Method (Appendix 3), the Consensus Criteria for Environmental Flow Needs (CCEFN, Appendix 4) that is used by the Texas Water Development Board for water supply planning studies and occasionally has been applied by the TCEQ for water rights permitting, the Texas Method that purportedly addresses the monthly variations in the associated hydrological and biological characteristics of Texas streams with warmwater fisheries, and The Nature Conservancy's Indicators of Hydrologic Alternation (IHA) Method that provides a statistical evaluation of daily streamflows based on historical records and categorizes these flows into different tiers of environmental flow requirements (Appendix 5). In addition, Mathews and Bao (1991) proposed a so-called "Texas Method" which is philosophically similar to the Tennant (1976) and CCEFN approaches, basing the seasonality on spawning seasons for a suite of 17 Texas fish, of which about a dozen are flow-obligate. This method does not appear to have had any practical application in the State.

To date, the TCEQ has relied most heavily on the Lyons Method, especially for small water use permit applications, and the CCEFN in one or two specific cases involving reservoir planning. One criticism of these two Texas methods is that, in general, the CCEFN and Lyons Method result in protection of base flows and other flows at the lower end of the flow spectrum but offer little to no protection for high flow pulses and other flows at the higher end of the spectrum. Provided that the desk-top method is limited in application to small diversions, this criticism has little merit given that such diversions will have negligible impact on higher flows. Another, perhaps more significant, criticism is that there is no demonstrated validation for either method against biological data for a stream or river. Also, the existence of two different methods of environmental flow needs determination in Texas has been a source of confusion to some as the methods can often yield different results for the same river system (NRC 2005). A third method, the IHA Method noted above, has been employed recently by the TCEQ and other agencies to aid in establishing flow regime recommendations at locations in the Brazos River Basin with regard to one pending permit application. To date, this application is contested and has not been forwarded to the Commission.

After considerable discussion and deliberation, the Lyons Method and the IHA Method were identified by the TRG as the two desk-top methods that should be examined further for application for small water diversions, and tested to the extent possible using environmental flow information from available detailed studies. These two methods have been used recently by the TCEQ for permitting purposes. The IHA Method is capable of providing a multi-tiered set of environmental flow requirements that are representative of natural conditions. The CCEFN method, while having merit in terms of addressing the need to manage multiple flow components, may be too complex to deal with permit applications for small water diversions.

Comparisons of Desk-top Methods

For purposes of establishing environmental flow restrictions for permitting new, relatively small water rights or for amending certain existing water rights, the TCEQ has employed primarily the desk-top Lyons Method (Appendix 1). The Lyons Method was derived from the Tennant (1976) Method, which uses percentages of monthly streamflows and was developed for the coldwater fisheries of Montana and other western states. The Lyons Method specifies 40 percent of the monthly median flow from October to February and 60 percent of the monthly median flow from March to September as minimum flows, with the 60 percent level chosen to be more protective of the riverine ecosystem during the spring and summer periods, considered most critical to the warmwater fishes found in Texas. The median values are determined from available representative daily gaged flow data. The flow values of the Lyons Method were based on the amount of wetted perimeter (i.e., substrate) of the stream channel, supported by limited physiographic field measurements in the Guadalupe River below Canyon Dam.

One concern in the application of either the Lyons Method or the IHA method (or, for that matter, many of the other candidate methods summarized in the preceding section) is the source and processing of the flow data necessary for the computations. There are two problems. First, streamflow data, at a daily resolution, are needed at the point along the watercourse of concern for permit or water-rights evaluation. If there is a suitable extant gage record (i.e., proximate to the application site, within similar hydroclimatology, surficial geology, and topography), then methods of hydrological data transfer can be employed. If not, there may not be a satisfactory source of this information. One alternative is development of a simulated streamflow record from precipitation data and watershed-runoff modeling (such as the SCS curve-number method, Mockus, 1972, or a landscape model such as SWAT, Williams and Arnold, 1973, or HSPF, Donigian, 1984), which generally entails a level of effort incommensurate with the use of a "desk-top" method.

The second problem is the nature of the streamflow data in the record used for analysis. There are three possibilities: (i) the historical streamflow record through the present, (ii) the record prior to the imposition of human impacts on the streamflow, (iii) the "naturalized" flows. The historical streamflow through the present generally includes trends and impacts due to human activities in the watershed. Use of historical pre-impacts data presumes a record of data extending back in time, which rarely exists in Texas. In the absence of such data, "naturalized" flows would appear to represent a record without human impacts. The term "naturalized flows," however, refers to a specific type of data record generated by the State's Water Availability Model (WAM) for a river basin (Wurbs, 2003). These are monthly-mean gaged flows from which diversions and return flows have been algebraically restored or removed, i.e. the storage of water by major reservoirs has been subtracted and returned to the stream channel, and their evaporation added back to the record, and additional corrections made for channel losses (Wurbs, 2006). In effect, human "plumbing" is removed from the data record. This does not remove the totality of human effects on streamflow, however, because the considerable impacts on the watershed (deforestation, agriculture and ranching, roads and streets, urbanization, etc.) are not considered.

Because of limited validation of the Lyons Method for Texas streams, particularly against biological data, widespread application of the method by the TCEQ for water rights permitting across the entire State often has raised questions as to the appropriateness of the method's environmental flow values for stream-specific hydrological and ecological conditions. The basic intent of the above recommendation by the two previous SACs quoted in ***Background*** above was for the State agencies, through an appointed committee of experts, to perform limited analyses using available information describing stream flow versus ecological relationships for different parts of the State. Armed with this information, one should then be able to evaluate the ability of the Lyons Method to produce meaningful environmental flow requirements under a range of conditions typical of those found throughout the State. The assumption was that sufficient environmental flow data and associated water-quality and/or biological data from previous detailed field studies and analyses were readily available for a variety of streams to provide an adequate database for readily evaluating the appropriateness of the Lyons Method. For the TRG, this assumption has proven to be erroneous.

The State agencies informed our TRG that several biological field studies and analyses had been completed by local, state and federal agencies for streams throughout Texas for purposes of establishing meaningful and protective environmental flow requirements. Such investigations have been conducted for the following stream locations, apparently with most of these associated with a proposed reservoir project or other major water rights activity.

Brazos River at Palo Pinto	Lower Colorado River- LCRA
Middle Brazos River near Granbury	Lower Colorado River for LCRA-SAWS
Lower Brazos River near Allens Creek	North Bosque River at Clifton
Little Cypress Creek at Jefferson	San Jacinto River at Upper Lake Creek
Guadalupe River	San Marcos River

During the course of the TRG's evaluations, the State agencies were able to produce detailed information for only a few of these investigations. Because many of the studies were conducted prior to the coordinated efforts by Texas state agencies, they have employed a variety of methodologies, some deemed potentially unsuitable for interpretation of environmental flows requirements. Moreover, some of the reports were not available to this TRG. For the purposes of this TRG's evaluations, the most useful information came from a study conducted on the Lower Colorado River in the early 1990s by the Lower Colorado River Authority (LCRA) (Mosier and Ray, 1992) and the recent study conducted by BIO-WEST, Inc. (2008) for the LCRA as part of the ongoing LCRA/San Antonio Water System Water Project (LSWP). The latter project was associated with assessments of potential effects from a proposed inter-basin transfer of surface water from the Lower Colorado River to the city of San Antonio to supplement its water supply. These studies of the Lower Colorado River were the only ones to provide useful sets of detailed ecological information regarding environmental flow requirements for evaluating desk-top methods (Appendix 7). With detailed ecological/environmental flow information for just one reach of one river, the ability of the TRG to fulfill its fundamental goal of evaluating the appropriateness of various desk-top methods, including the Lyons Method, for estimating environmental flow requirements for stream and ecological conditions across the State has, at the least, been substantially impaired.

Comparisons of the environmental flow requirements derived using the Lyons Method and the IHA Method were made by the TRG for 72 stream gage locations across the State (Appendix 8), and as expected, the results from the Lyons Method generally tended to fall within the range of the lower to mid tiers of environmental flow regimes produced with the IHA Method. Since neither of these methods has been even moderately validated for the myriad of stream and ecological conditions that occur within the State, this exercise merely demonstrated the commonalities of the two methods, without any knowledge as to whether either of the two methods produces appropriate answers for the streams to which they were applied.

As noted above, the only meaningful set of environmental flow requirements based on detailed field studies and extensive analyses that were available to the TRG are those recently developed by LCRA for the LCRA/SAWS Water Project. Consequently, a substantial amount of time was devoted to comparing the results from this study to corresponding estimates of the environmental flow requirements derived with the Lyons Method and the IHA Method. This process did not produce any clear consensus among the TRG members as to whether the Lyons Method or the IHA Method might be more appropriate as a desk-top approach for estimating environmental flow requirements. Of course, it has to be recognized that with only one set of detailed information available for a single river located in the lower segment of a central basin of the State, making such a judgment with implications for other parts of the State is not justified and certainly would not be particularly meaningful.

Conclusions and Recommendations

1) Sufficient information was not available to the TRG to arrive at a consensus as to whether the Lyons Method, for purposes of a desk-top method, does or does not provide appropriate estimates of the instream environmental flow requirements for streams in Texas. It was generally agreed that the Lyons Method has some scientific basis for its construction, but the degree to which its monthly median flow factors effectively represent varying stream conditions across the State remains unresolved.

In the absence of any further information and primarily for the sake of continuity with past practices, we reluctantly recommend that the TCEQ continue to apply the Lyons Method as a desk-top approach for permitting purposes.

2) While the IHA Method offers an approach for establishing tiers of environmental flow requirements that are likely more consistent with and representative of actual hydrologic conditions, the statistical flows used to establish the different tier levels are not founded on detailed scientific studies but rather on consensus among scientists and interested parties as to what appears to be appropriate for protecting or supporting certain biological functions and habitat features. However, the real shortcoming of the IHA Method as a desk-top procedure is its complexity with regard to implementation for permits or permit amendments involving small water rights owned by individuals. The multi-tiered approach is simply too complicated to be effectively used for most permitting situations and may not even be necessary for protecting the normal range of stream flows that could be impacted by the smaller diversions and impoundments typically authorized in most permitting activities.

We recommend that the IHA Method may be utilized as a tool to provide guidance to TCEQ with regard to the different flow regimes that might be considered important for protecting instream environmental uses. Nonetheless this method appears impractical for use as the primary desk-top method for establishing environmental flow requirements for small-diversion *permits or amendments.*

3) The issue of the use of historical recent *versus* historical pre-impact *versus* naturalized (flow derived using the Texas WAM methodology) flows as the basis for establishing environmental flow requirements with desk-top methods continues to be unresolved. Clearly, the TCEQ has used historical flow records over periods of variable length when applying the Lyons Method. Various entities have applied the IHA Method using historical flows, naturalized flows, or both, although its original development contemplated the incorporation of historical pre-impact or naturalized flow records into the tiered-flow results. The environmental flow guidelines developed for the Lower Colorado River/LSWP by LCRA and BIO-WEST were based on comparisons of pre- and post-development historical flow conditions (pre-1940s), the former likely approximating naturalized flows. It is generally recognized that natural flow variations (i.e., flows similar to pre-impact conditions) are important for maintaining *a sound ecological environment* in the State's rivers and streams. Although it may be unrealistic to propose that all systems could be restored to their natural ecological conditions based on naturalized flows or historic flows as the criterion, the TRG recommends that, whenever feasible, historical pre-impact flow records should provide the basis for evaluating environmental flow targets.

For purposes of applying desk-top methods, we recommend that the TCEQ continue using historical streamflow records as the basis for establishment of environmental flow requirements, provided at least 30 years of record are available without major upstream modifications that would have significantly altered flow patterns. It would seem that this would be a long enough period of time to be representative of the conditions affecting biota in a particular stream. For stream segments modified by impoundments that regulate or otherwise alter instream flows, pre-impoundment flow records should be considered in desk-top methods. When less than 30 years of record are available for a stream segment, a shorter period of record, if available, obviously must be used by default. In such cases, nearby segments within the same fluvial system with longer periods of record should be consulted for insights and guidance regarding historical flows patterns.

4) Texas climate and hydrology vary extensively, which requires subdivision of the state for water planning purposes. Some combination of ecoregions, river basins, and biotic

provinces (e.g., Blair 1950) could be used in the regionalization process. According to Blair, a biotic province is "... a considerable and continuous geographic area and is characterized by the occurrence of one or more ecologic associations that differ, at least in proportional area covered, from the associations of adjacent provinces. In general, biotic provinces are characterized also by peculiarities of vegetation type, ecological climax, flora, fauna, climate, physiography, and soil."

We recommend that new field studies be undertaken as soon as possible to assess the appropriate spatial boundaries for regional adjustments to the Lyons method. These studies essentially would repeat the methodology employed by Bounds and Lyons (1979) on February 2, 1977 on the Guadalupe River below Canyon Dam. Cooperation from dam operators should be sought in order to obtain detailed data on stream wetted perimeter and depth in response to flow variation in an efficient, timely, and scientifically valid manner.

5) Finally, recognizing the inability of the TRG to effectively evaluate desk-top methods because of the lack of sufficient environmental flow information from detailed studies across the State, it is important that any future detailed studies undertaken by the State agencies and/or water rights applicants be structured to provide specific data and information that can be used to validate and/or refine the Lyons Method or some other desk-top method to extend their applicability to all parts of the State. This would include the ongoing investigations that are being conducted by the TCEQ, TWDB and Texas Parks and Wildlife Department on various streams pursuant to the Texas Instream Flow Studies program authorized by Senate Bill 2 as passed by the 77th Legislature.

New analyses that draw upon additional, widely available data could be conducted without delay. For example, Tennant (1976) recommended the use of USGS field measurement data for width, depth, and velocity to develop improved flow recommendations. An extensive database of such measurements exists at over 400 USGS stream gages across Texas at a frequency of approximately 10 measurements per year, often resulting in 300 to 800 measurements per gage. The inclusion of these important habitat parameters could be used to enhance the Lyons' Method, which uses only wetted width as an indicator, in that a consideration of both habitat quantity and quality is likely a more accurate predictor than simply the proxy metric for the amount of physically-available habitat currently used in Lyons. The USGS data provide actual width, depth, and velocity measurements across a cross section of the river channel and thus could be used to develop a more refined understanding of river hydraulics. Similarly, extensive field measurements are available from the TPWD REMAP project (e.g., Kleinsasser et al. 2004).

We recommend that any future detailed studies undertaken by the State agencies and/or water rights applicants be designed and conducted to provide information that would be useful specifically for validating and/or refining an appropriate desk-top method for the State.

Broader Context and Additional Considerations

The agency should articulate clear and concise statements about the objectives and intended applications of their desk-top methods for water rights permitting. For example, the Final Report of the Science Advisory Committee Report on Water for Environmental Flows; Senate Bill 1639 78th Legislature (October 26, 2004) states the following objective: "A varied flow regime that mimics natural historical patterns and that maintains adequate sediment loadings is the key to sustaining the fish and wildlife resources within and adjacent to Texas rivers and streams. Those environmental flows must include inter-annual and intra-annual variations at appropriate frequencies to maintain the inherent complexity of habitats and physical-chemical conditions upon which biological communities depend. Flows during drought periods can be especially critical with respect to maintaining biological resources in rivers and streams."

The TRG recommends the agency consider some additional concepts. 1) Diversions should never cause flows to cease. 2) No artificial changes in initial streamflow greater than 50% from day to day and none greater than 12.5% within a six-hour period. Down-ramping (abrupt termination of high dam discharges) is of greater concern than up-ramping. 3) For within-channel maintenance purposes, peak (flushing) flow events need to occur at irregular intervals that approximate historic frequencies. 4) Surface water quality standards for segments and reaches should be maintained except during periods of declared public emergency. The 7Q2 should be used as a default value unless water quality modeling determinations have been made that specify the instream flows necessary to maintain state water quality standards. 5) Impoundments and diversions should not artificially increase the severity (frequency and/or duration) of low (drought) flows to a significant degree. Drought contingency triggers and drought relief measures need to be evaluated on a site-specific basis to incorporate the natural variation that occurs within hydrologic regimes in Texas. Drought triggers for water development projects should include both capacity (reservoir content) and streamflow levels to incorporate the overall conditions within the watershed into drought planning. Reservoir content is the best indicator for water supply whereas streamflows are an excellent indicator of the severity of drought conditions.

Provision of an ‘ideal’ hydrologic flow regime is probably impractical or even infeasible. Most river ecosystems are believed to be relatively resilient. Thus, the goal of a desktop environmental flow methodology should be to provide a level of flow sufficient for environmental protection in light of current and future water demands. Furthermore, it is acknowledged that flow prescriptions from an improved desktop methodology will not likely be able to improve upon current riverine conditions in Texas. Their intent is to ensure that future (new) water demands will not cause undue additional harm to the ecosystem. This objective is a result of the longstanding water rights system in Texas in which ‘senior’ water rights holders, many of which were granted water rights permits prior to legislation requiring environmental reviews of applications, are granted rights in perpetuity. As such, new environmental flow prescriptions will not set the floor, that is, the actual minimum amount of flow present in a river, but only the floor for new applicants. Thus, there are river systems in Texas which, when ecosystems needs are considered, are likely fully allocated or even over-allocated. Environmental flow prescriptions on new permits will not restore these river systems.

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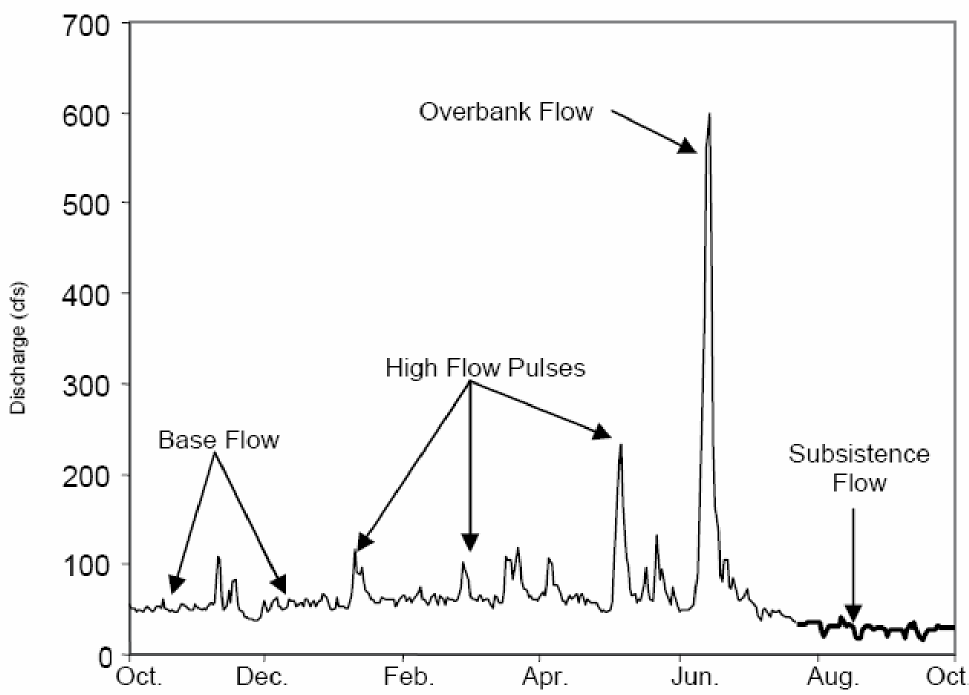
Appendix 1. Flow Components

The National Research Council of the National Academy of Sciences performed a scientific peer review of the Texas Instream Flows Program in which, among other recommendations, they put forth a conceptual model characterizing the natural flow regime as four flow components: subsistence flow, base flow, high flow pulses, and overbank flows (NRC 2005). According to the NRC (2005):

> Subsistence flow is the minimum streamflow needed during critical drought periods to maintain tolerable water quality conditions and to provide minimal aquatic habitat space for the survival of aquatic organisms. Base flow is the ‘normal’ flow conditions found in a river in between storms, and base flows provide adequate habitat for the support of diverse, native aquatic communities and maintain ground water levels to support riparian vegetation. High flow pulses are short-duration, high flows within the stream channel that occur during or immediately following a storm event; they flush fine sediment deposits and waste products, restore normal water quality following prolonged low flows, and provide longitudinal connectivity for species movement along the river. Lastly, overbank flow is an infrequent, high flow event that breaches riverbanks. Overbank flows can drastically restructure the channel and floodplain, recharge groundwater tables, deliver nutrients to riparian vegetation, and connect the channel with floodplain habitats that provide additional food for aquatic organisms.



An example daily streamflow hydrograph depicting flow components for the Guadalupe River at Victoria, Texas (USGS Gage No. 08176500) for water year 2000 (from NRC 2005).

Appendix 2. Brief Summary of Instream Flow Approaches

Hundreds of methods and models have emerged over the last half century that seek to answer the question of how much water a river needs (Jowett 1997, Richter et al. 1997, Tharme 2003, Annear et al. 2004). Based on available data and resources and desired goals and confidence level, scientists have developed and applied methodologies in four broad categories:

1) Hydrologic (Desktop) Models
   - Simple, inexpensive
   - Use flow as an indicator for ecological and biological functions

   Examples:
   - Indicators of Hydrologic Alteration (IHA), The Nature Conservancy (1997)
   - Hydrologic Assessment Tool (HAT) (Henriksen et al., 2006)
   - Tennant (Montana) Method, U.S. Fish and Wildlife Service (1976)
   - Lyons Method, Texas Parks and Wildlife Dept. (1979)

2) Hydraulic Models
   - Correlate flow with available habitat area based on river channel geometry
   - Physical proxy for *in-stream* ecology and biology, i.e., does not account for overbank processes

   Examples:
   - Wetted Perimeter Method, Montana Dept. of Fish, Wildlife, and Parks, 1970s
   - R2-Cross Method, Colorado Div. of Wildlife, 1980s

3) Habitat Models
   - Complex, data intensive
   - Use target species population data with hydraulic data to determine optimal habitat
   - Mainly used for economically valuable or endangered species
   - Has proven legal credibility in the United States

   Examples:
   - Instream Flow Incremental Methodology (IFIM),U.S. Fish and Wildlife Service, 1970s. Includes Physical Habitat Simulation Model (PHABSIM) (Stalnaker et al., 1994, 1995, Bovee et al., 1998)

4) Holistic Models
   - Very complex, resource and data intensive
   - Comprehensive ecosystem assessment
   - Based on multidisciplinary scientific consensus

   Examples:
   - Building Block Methodology (BBM), South Africa Dept. of Water Affairs and Forestry and Univ. of Cape Town, 1990s (Tharme and King, 1998)
   - Downstream Response to Imposed Flow Transformation (DRIFT), South Africa Dept. of Water Affairs and Forestry, Univ. of Cape Town and Southern Waters Ecological Research and Consulting, 1990s

Appendix 3. Synopsis of Lyon's Method

The Lyons Method (Bounds and Lyons, 1979) was derived from the Tennant method (1976), which uses percentages of monthly streamflows and was developed for the coldwater fisheries of Montana and other western states. The basic objective is minimum flow targets that maintain a healthy looking stream under normal base flow conditions. The main features are a longitudinally connected wetted stream bed containing pools, riffles and other essential habitat features that ensure short-term maintenance of fish populations.

Flow targets were based on Tennant's recommendations, and "validated" with measures of wetted channel perimeter vs. flow (discharge in cfs) at two sites on the Guadalupe River downstream from Canyon Dam on Feb. 2, 1977 when flows were manipulated to provide a range of values (9–784 cfs).

Based on these extremely limited data, the established environmental flow targets were as follows:

- During October–February: 40% of the median flows by month
- During March–September: 60% of the median flows by month

The 60 percent level was chosen to be more protective of the riverine ecosystem during the spring and summer periods that are considered most critical to the warmwater fisheries found in Texas (Bounds and Lyons 1979, NRC 2005).

Advantages—

Easy to understand the basic rationale for the targets
Easy to estimate flow targets (40% or 60% of median monthly flow)
Easy to communicate the flow requirements to the layperson
Easy for layperson or regulators to monitor flow targets

Disadvantages—

Flow targets are based on a simplistic concept of river ecology that lacks consideration of requirements for periodic high flow pulses
Flow targets were established based on extremely limited data for one river on one day
As employed currently, uses recent gage data to calculate monthly medians
No consideration of riparian biota or bay and estuarine needs

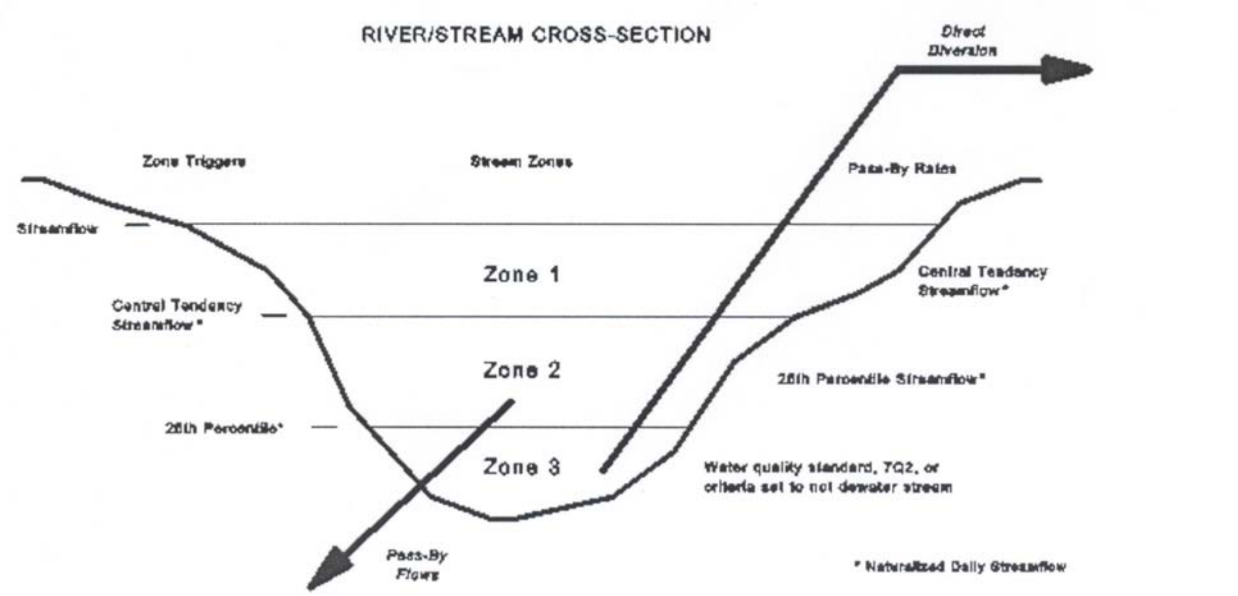
Appendix 4. Synopsis of the Consensus Criteria for Environmental Flow Needs

The Consensus Criteria for Environmental Flow Needs (CCEFN) are developed using percentages of monthly naturalized flow data from the Water Rights Analysis Package (WRAP) Water Availability Models (WAM). Naturalized flow is the "estimated flow that would be present in a watercourse with no direct manmade impacts in the watershed" (Wurbs, 2003, NRC, 2005, TCEQ, 2006). The CCEFN provides a tiered set of recommendations for passing flows through reservoirs and past diversion points to provide environmental flows downstream based on calculations of naturalized flow:

- If the naturalized flow is greater than or equal to the monthly median flow, the monthly median flow is protected;

- If the naturalized flow is less than the monthly median flow but greater than the 25th percentile flow, the 25th percentile flow is protected;

- If the naturalized flow is less than the 25th percentile flow, a fixed threshold, such as the seven-day average, two-year recurrence interval discharge (7Q2), is protected (TCEQ, 2004, NRC, 2005).



Appendix 5. Synopsis of Indicators of Hydrologic Alteration Method

According to The Nature Conservancy's Sustainable Waters Program website (TNC 2006):

> The Indicators of Hydrologic Alteration (IHA) is a software program that provides useful information for those trying to understand the hydrologic impacts of human activities or trying to develop environmental flow recommendations for water managers. More than 1,000 water resource managers, hydrologists, ecologists, researchers and policy makers from around the world have used this program to assess how rivers, lakes, and groundwater basins have been affected by human activities over time, or to evaluate future water management scenarios.

IHA was originally developed as a result of work done by Brian Richter and others from 1996 through 1998, and is intended to model "what the fish feels" (Richter et al., 1996, Richter et al., 1997, Poff et al., 1997, Richter et al., 1998). IHA requires an input file of daily streamflow data; in the United States, these data are typically obtained from the USGS National Water Information System (NWIS). To adequately capture annual and interannual variations in the flow regime, 20 or more years of continuous daily flow data are recommended (Richter et al., 1997). Currently, there are NWIS records for 957 stream gauging sites in the State of Texas, of which 406 have 20 or more years of daily flow data.

Under the IHA Environmental Flow Component (EFC) model, all daily flows fall within one of five categories: extreme low flow, low flow, high flow pulses, small floods, and large floods; a complex algorithm parses the hydrograph accordingly based on delineated thresholds. The program separates flow into base flows and flow pulse periods (i.e., partitioned in time) using a base flow separation method. Pulses are classified by the rate of change of flow (percent difference over prior day) and base flows are classified by magnitude (from recurrence intervals).

IHA tabular output is displayed on-screen and can easily be exported. The output includes tabbed pages for: (1) annual summary statistics, (2) (non-) parametric IHA summary scorecard, (3) linear regression, for identifying trends in the data, (4) IHA percentile data, (5) EFC daily flow characterization, and (6) messages and warnings regarding the results generated. IHA graphical output includes numerous plotting options for various indices with various presentation styles. Plots are displayed individually on-screen and can be readily exported.

The IHA does not explicitly establish environmental flow targets, therefore these must be based on other criteria. To date, when IHA has been used as a tool to explore environmental flow scenarios (see Appendix 5), the criteria have been arbitrarily established as flow percentiles to establish wet, average, dry, and drought condition targets.

Appendix 6. Lower Colorado River – San Antonio Water Authority Project (LSWP) Study

Excerpt from Executive Summary: BIO-WEST, Inc., 2008. Lower Colorado River, Texas Instream Flow Guidelines - Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker. Prepared for Lower Colorado River Authority and San Antonio Water System. 108pp.

In order to meet the environmental principles set forth for the LSWP and remain consistent with the TIFP objectives to conserve biodiversity and maintain biological integrity, the project team followed the recommendations of the National Research Council (NRC, 2005) which has subsequently been endorsed by the Texas Instream Flow Program (TIFP, 2008). The integration process involves five components of the hydrologic regime: subsistence flows, base flows, high flow pulses, channel maintenance and overbank flows. Hydraulic and habitat modeling, sediment transport analysis, and water quality modeling were used to support the development of subsistence and base flow guidelines. Pulse, channel maintenance and overbanking flow recommendations were based on sediment transport analysis conducted during this study and a hydrologic analysis of existing and pre-1940 flow regimes.

To establish instream flow guidelines, physical habitat times series were computed based on two flow scenarios. These included the existing condition (1975 to 2004) and pre-1940 (from 1898 at Austin and from 1916 at Columbus through 1939). The existing flow scenario was included in the habitat time series analysis because 1) the field data (physical and biological) used for the hydraulic and habitat models, sediment transport analysis, and baseline riparian conditions were all collected under the existing flow regime, and 2) the present day geomorphic conditions, riparian zone, water chemistry, aquatic habitat, and biological resources have all been imprinted by the existing flow regime. Additionally, the water quality and biological data collected by LCRA over the past decade reflect good water quality and diverse biological communities. Therefore, an examination of the existing flow regime was deemed necessary to evaluate the potential for maintaining similar conditions. The pre-1940 "natural" flow scenario was included to be consistent with the guidance of the TIFP and Natural Flow paradigm. Even though the data collected for this study was done under the existing flow regime, using natural flow conditions as a reference for comparison often provides insight into the ecological variability of riverine systems.

An evaluation of the hydrology, habitat time series modeling results, sediment transport analyses, and water quality results indicated that the pre-1940 flow regime is different from the existing flow regime. Simulated habitat conditions for the pre-1940 regime show a greater diversity of habitat conditions year round (i.e. a more equitable distribution of the variety of habitats available), an improvement in edge habitat, and better conditions for pre-spawning migration for adult blue suckers. Conversely, the pre-1940 regime provides considerably less deep, fast habitat in the summer months which could be critical relative to potential water quality impacts during these time periods. From a regulatory standpoint, water quality exceedences are to be avoided, thus making this scenario unfavorable. However, under a natural flow regime, these periods did occur, thus crafting the ecological makeup of the river system. The ecology of a river system is defined by extreme events on both the high-flow and low-flow end of the spectrum, and having occasional extremes supports populations of native species who have evolved life history strategies in response to the natural flow regime.

The TIFP proposes, "The goal of ensuring a 'sound ecological environment' has been equated to maintaining the ecological integrity and conserving the biological diversity of riverine ecosystems. In order to meet these goals, the Agencies recognize the importance of maintaining the natural habitat diversity, hydrologic character, and water quality of river systems." For the ecological advantages and to be consistent with the goals of the TIFP, the pre-1940 time period was selected to be used for the development of instream flow guidelines.

Instream flow recommendations for five categories (subsistence, base, pulse, channel maintenance, and overbank flows) specific to the LSWP are recommended for the lower Colorado River (Table ES.1). The subsistence flow recommendations represent minimum conditions at which water quality is maintained at acceptable levels and aquatic habitats are expected to resemble those found during extreme conditions in a more natural setting. The base flow recommendations provide a range of suitable conditions with the goal of maintaining year to year variability and the ecological functions associated with this level of variability. Pulse flows provide a myriad of ecological functions including but not limited to nutrient and organic matter exchange, limited channel maintenance, flushing, vegetation scouring, and seed dispersal. Channel maintenance flows provide for the maintenance of channel capacity, while also flushing accumulated fine sediments from important gravel bar and riffle habitats, and scouring accumulated sediments from pool habitats. Overbank flows inundate low floodplain areas adjacent to the river providing for lateral floodplain and riparian connectivity, floodplain maintenance and nutrient deposition, and recruitment of organic material and woody debris.

Table ES.1. Instream Flow Guidelines for the lower Colorado River specific to the LSWP.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AUSTIN REACH												
Subsistence	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**
BASTROP REACH												
Subsistence	**208**	**274**	**274**	**184**	**275**	**202**	**137**	**123**	**123**	**127**	**180**	**186**
Base-DRY	**313**	**317**	**274**	**287**	**579**	**418**	**347**	**194**	**236**	**245**	**283**	**311**
Base-AVERAGE	**433**	**497**	**497**	**635**	**824**	**733**	**610**	**381**	**423**	**433**	**424**	**450**
COLUMBUS REACH												
Subsistence	**340**	**375**	**375**	**299**	**425**	**534**	**342**	**190**	**279**	**190**	**202**	**301**
Base-DRY	**487**	**590**	**525**	**554**	**966**	**967**	**570**	**310**	**405**	**356**	**480**	**464**
Base-AVERAGE	**828**	**895**	**1,020**	**977**	**1,316**	**1,440**	**895**	**516**	**610**	**741**	**755**	**737**
WHARTON REACH												
Subsistence	**315**	**303**	**204**	**270**	**304**	**371**	**212**	**107**	**188**	**147**	**173**	**202**
Base-DRY	**492**	**597**	**531**	**561**	**985**	**984**	**577**	**314**	**410**	**360**	**486**	**470**
Base-AVERAGE	**838**	**906**	**1,036**	**1,011**	**1,397**	**1,512**	**906**	**522**	**617**	**749**	**764**	**746**

COLORADO RIVER DOWNSTREAM OF AUSTIN

PULSE FLOWS	
Base	**MAGNITUDE (2,000 to 3,000 cfs); FREQUENCY (8–10 times annually); DURATION (3–5 days)**
High	**MAGNITUDE (@ 8,000 cfs); FREQUENCY (2 Events in 3 year period); DURATION (2–3 days)**
CHANNEL MAINTENANCE	**MAGNITUDE (27,000 - 30,000 cfs); FREQUENCY (1 Event in 3 years); DURATION (3 days)**
OVERBANK	**MAGNITUDE (> 30,000 cfs); FREQUENCY and DURATION (Naturally Driven)**

Appendix 7. Comparisons of base flow targets derived from Lyons, IHA, LSWP, and 7Q2 methods for the Lower Colorado River.

• LSWP produced three estimates of monthly base flow targets based on analysis of habitat time series. These flows were initially defined by the requirement that they mimic the amount of habitat, for each component of the aquatic community, that would be expected assuming natural flow regimes.

Subsistence (95% habitat exceedence)
Base-Dry (80% habitat exceedence)
Base-Average (60% habitat exceedence)

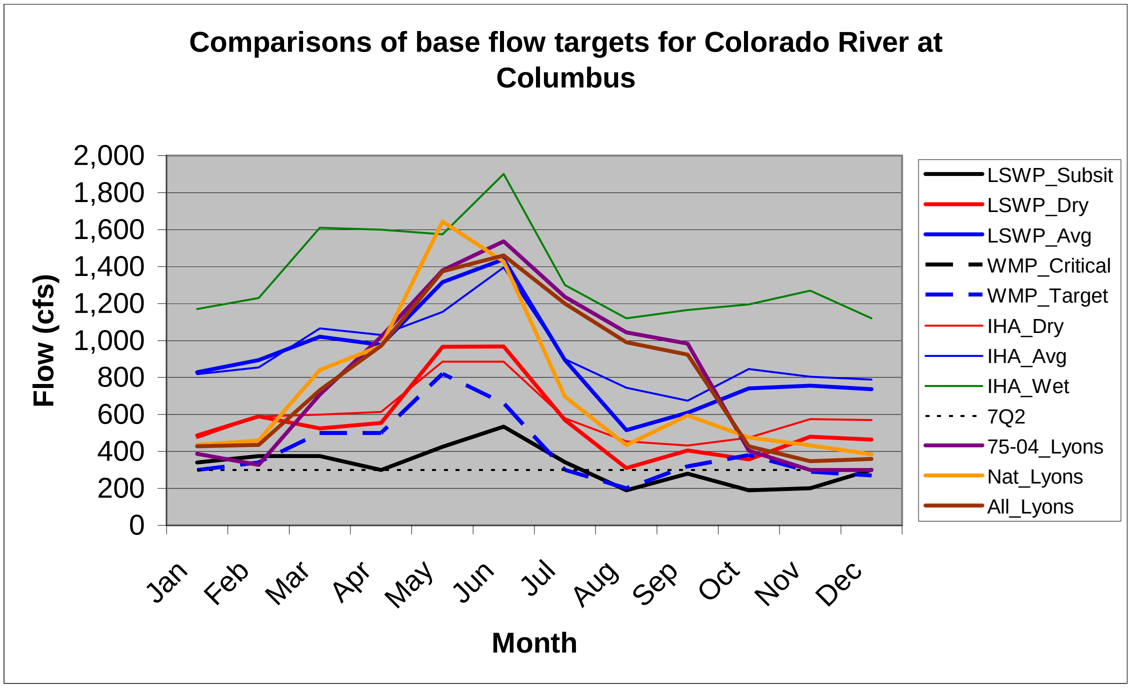
Targets were refined based on the need to maintain water quality and sediment transport functions, as well the habitat needs of specific species of concern (Blue Sucker) .

• The LCRA Water Management Plan (WMP) includes two sets of instream flow needs. These flows were developed in the Instream Flows for the Colorado River study (Mosier and Ray 1992). Subsistence flows are defined as those flows necessary to “sustain fish populations during drought conditions.” Target flows are defined by the “range of flows that provide adequate habitat for the entire fish community.”

• The Indicators of Hydrologic Alteration Software was used to calculate IHA monthly flow benchmarks based on the 25th, 50th, and 75th low flow percentiles based on naturalized discharge data.

• Lyons monthly flow benchmarks were computed based on both recent (regulated) and naturalized discharge data.

• 7Q2, which is the minimum flow over seven consecutive days recorded during a two-year interval, is the flow standard for maintenance of minimum water quality standards in the State.



(Appendix 7, cont'd.)

Summary of findings for study locations

Bastrop & Smithville sites:

• IHA-dry and LSWP-dry are very similar.
• IHA-average and LSWP-average are very similar.
• Lyons gives much lower flows during Nov–Feb (near 7Q2), but higher flows than the other methods during April–Oct

Columbus site:

• LSWP-subsistence dips below 7Q2 during Aug–Dec.
• IHA-dry and LSWP-dry are very similar.
• IHA-average and LSWP-average are very similar.
• Lyons gives flows below LSWP-dry and IHA-dry during Oct–Feb
• Lyons gives flows similar to LSWP-average and IHA-average during Apr–July, but much higher flows than these during July–Oct.
• Lyons computed with naturalized data gives benchmarks for low-flow months that are similar to LSWP-dry and IHA-dry, but Sept. has a small peak not seen in IHA-dry.
• Lyons computed with naturalized data gives benchmarks similar to LSWP-average and IHA-average during the high-flow months of Apr–July.

Wharton site:

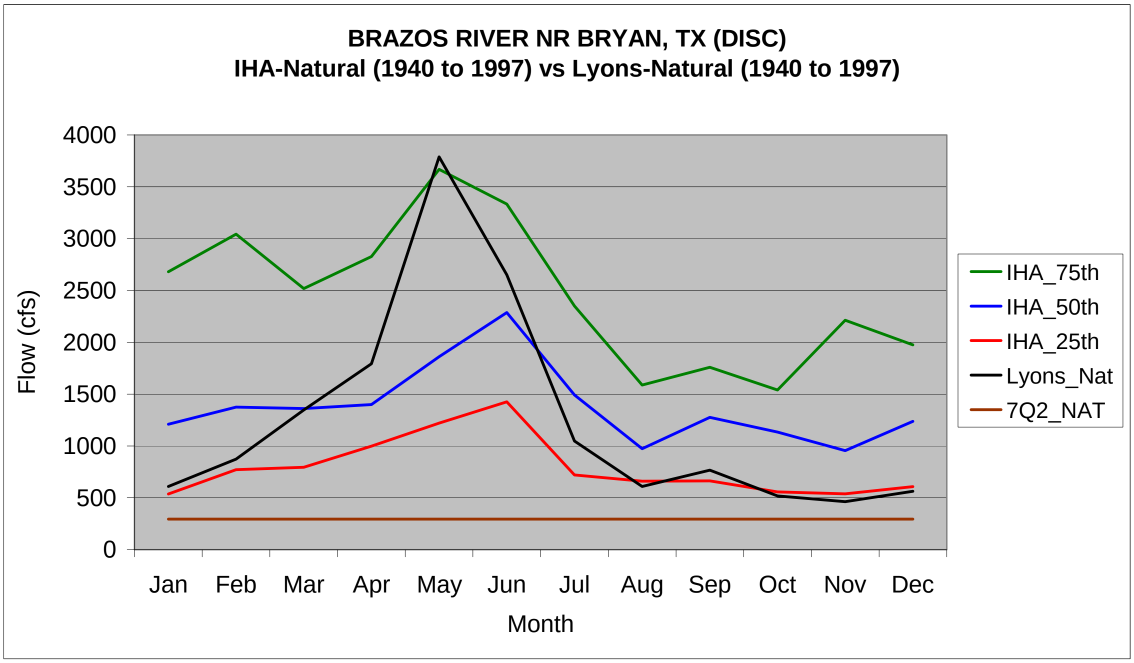
• LSWP-subsistence is below 7Q2 every month.
• IHA-dry and LSWP-dry are very similar.
• IHA-average and LSWP-average are very similar.
• Lyons benchmarks are intermediate between LSWP/IHA-dry and LSWP/IHA-average during Nov–July.
• Lyons is similar to LSWP/IHA-dry during Oct–Jan
• Lyons is below dry but equal to 7Q2 during Oct–Dec and Feb

Austin below Longhorn Dam:

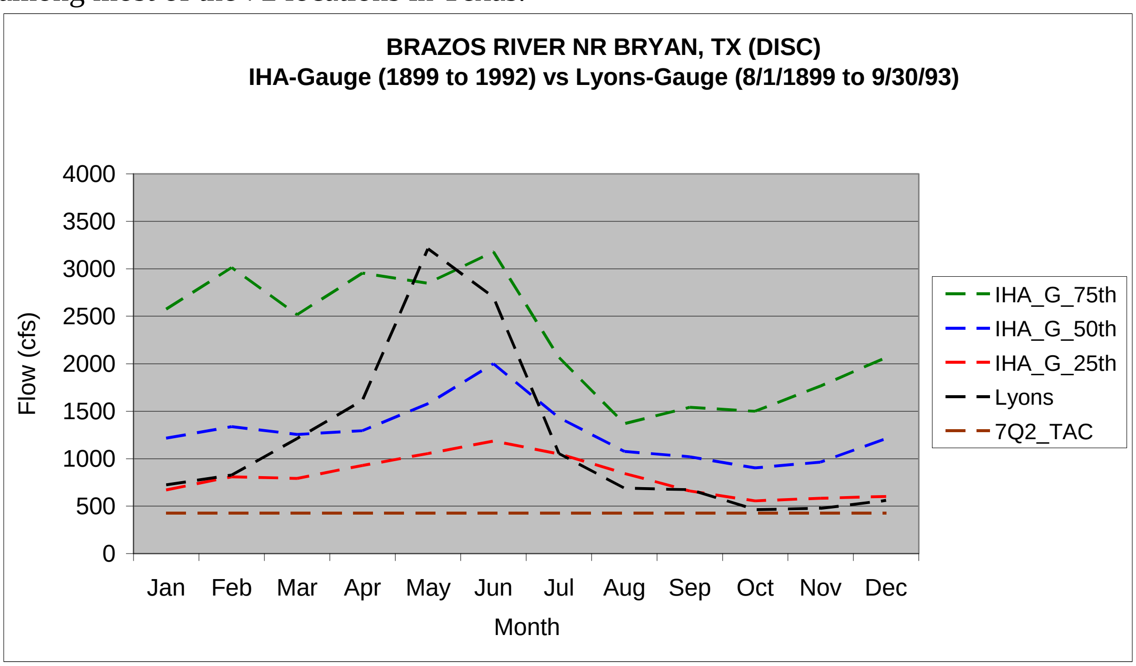
• in general, the relationships are similar to those observed for Smithville and Bastrop sites.

Appendix 8. Comparisons of IHA, Lyons, and 7Q2 benchmarks for contemporary gaged data and for naturalized data.

This Brazos River site displays the general pattern that is obtained based on naturalized data among most of the 72 locations in Texas.



Again, this Brazos River site shows the general pattern that is obtained based on gaged data among most of the 72 locations in Texas.



(Appendix 8, cont'd.)

Brazos River nr Bryan (#45)
• Lyons is very similar to IHA-dry during July–Feb
• Lyons is very similar to IHA-wet during May-June

This relationship is observed repeatedly in the dataset, especially for rivers in the eastern and northern parts of the state (Trinity, Sabine, Little Cypress, Sulphur, Red, Palo Duro Creek, etc.)

For the Red River near Childress (#5), the gaged data result in a different pattern, with Lyons much higher than IHA-wet during the early summer period.

Naturalized data-- Lyons tends to peak at higher levels than IHA-average.

Gaged data-- Lyons tends to be lower than IHA-dry and 7Q2 during cold months.
This trend is observed at many sites, especially in the central and western parts of the state, suggesting that Lyons criteria for Oct–Mar may be too low of a percentage of median monthly flow.

It should be noted that in a few cases (e.g., Nueces @ Mathis, #72) IHA gaged data yielded higher flows than IHA naturalized data.

Appendix 9. Chronology of TRG meetings.

Meetings History

May 10, 2007 (Austin) - Meeting of Science Advisory Board members with TCEQ Chair Kathleen White and representatives from TCEQ, TPWD & TWDB
Discussion of need for review of desk-top methods for instream flows, objectives of review, solicitation of technical review group members

Sept. 27, 2007 (Austin)- Meeting of TRG and agency liasons
Review of tasks, timetable, initial discussion of Lyons Method,
David Maidment presentation of Eric Hersh's integrated stream classification system for Texas. Discussion/refinement of objectives/tasks

Dec. 12, 2007 (Austin)- Meeting of TRG and agency liasons
Discussion of history of desk-top methods for instream flows in Texas (Lyons, 'Texas Method', IHA, CPC). Eric Hersh summary of Lyons method.
Explanation by Wendy Gordon of how TCEQ uses desktop methods

Feb. 19, 2008 (San Marcos)- Meeting of TRG and agency liasons
Review of flow data-- Guadalupe, Colorado River in context of Lyons and CPC targets
Further discussion of how TCEQ uses Lyons and CPC information
Discussion of issues (periods of record, dry/wet periods, observed vs. naturalized flows, comparison with fish hydraulic habitat estimates)

Apr. 22, 2008 (Austin)- Meeting of TRG and agency liasons; Todd Chenoweth in attendance
Reviewed available information, consider alternative desktop methods, discussed recommendations for improving the Lyon's and CPC methods-- specific changes, information needs, etc.

May 14, 2008 (Austin)- Meeting of TRG and agency liasons
Discussion of available information for comparisons, reviewed a set of evaluations, discussion of conclusions and recommendations. Discussion of 1995 technical review of desk-top methods. Assignment of tasks for preparation of final report. Discussion of timetable for final report.