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Transmittal to Basin and Bay Expert Science Teams (BBESTs)

Report # SAC-2009-01


The SB3 Science Advisory Committee (SAC) is charged to develop recommendations that help provide overall direction, coordination, and consistency in the work of the BBESTs. The referenced document is intended to begin fulfilling that mandate. The SAC envisions preparation and distribution of several “deliverables” that are intended to assist the BBESTs in carrying out their responsibilities under SB3. The spirit of these communiqués is not to dictate to the BBESTs, but rather to provide comprehensive guidance.

You should note that the attached document is characterized as a “Working Draft.” This is done purposefully to make clear that the piece is not declared to be completed, but rather is intended to evolve as the SAC and BBEST members continue to analyze and study the utility and application of the methods presented therein to the charge that each of us has been given. We fully expect that this document can and will be modified, improved and expanded as we work toward our respective goals and objectives. The SAC fully recognizes that this report is not perfect and in all ways complete. Perfection was not our target. Rather, our purpose is to get organized information “on the table” so as to facilitate the process of producing flow recommendations within the timeframe required by the statute.

The content of this report is focused on one aspect of the instream flow recommendations; namely, use of hydrologic data. Hydrologic data analysis is an important first step in developing an environmental flow regime, but it provides only an initial estimate of flow requirements. Consistent with the approach adopted in the Texas Instream Flow Studies (SB2), the hydrologic analyses should be complemented with overlays addressing water quality, geomorphology, and biology, a fact that is repeated numerous times in the attached report.

The report summarizes several hydrologic methods and discusses in some detail the Hydrology-Based Environmental Flow Regime (HEFR) methodology developed by the Texas Parks and Wildlife Department. The SAC believes that the HEFR methodology might prove useful as a first step in developing instream flow recommendations, and we recommend that the BBESTs consider its utility as you move forward with your deliberations. A technical workshop is being planned to provide additional details regarding the HEFR method and we encourage the BBESTs to have appropriate participants at this workshop.

Finally, the SAC contemplates preparing additional guidance documents that address the aforementioned overlays to the hydrologic analyses. Also, similar documents to provide insight into the development of freshwater inflow recommendations into the State’s estuarine systems are in the SAC development and review process.

In closing, the SAC looks forward to reaction and feedback from our BBEST partners as we move forward in carrying out the important work prescribed by SB3. We look forward to a healthy collaborative process.

Robert J. Huston, Chairman, SB3 Science Advisory Committee

Senate Bill 3 Science Advisory Committee for Environmental Flows

**SAC Members**

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

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SECTION 1
INTRODUCTION

Environmental flows, which include flows in rivers and streams and freshwater inflows to bays and estuaries, have not been addressed uniformly in water development project planning and permitting in Texas. Senate Bill 3 (SB 3), passed by the Texas Legislature in 2007, set out a new regulatory approach to protect such flows through the use of environmental flow standards developed through a local stakeholder process culminating in Texas Commission on Environmental Quality (TCEQ) rulemaking. SB 3 directed the use of an environmental flow regime in developing flow standards and defined an environmental flow regime as a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats.

This document provides an overview of how hydrologic data may be used in the identification of instream flow recommendations pursuant to the requirements of SB 3. As such, it 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. Other disciplines such as biology, geomorphology, and water quality, although not discussed directly in this report, also warrant specific attention to ensure that instream flow recommendations are based on the broadest set of information available.

It is important to recognize that the provisions of SB 3 dealing with environmental flows are structured specifically to provide a mechanism for protecting certain levels of flow for environmental purposes while at the same time allowing for the use of surface water to meet other needs, including human water needs. The discussion in this document pertains only to the scientific aspects of establishing appropriate environmental flow requirements for river and streams and does not consider the needs of other users or uses for which surface water flows may be required.

Section 2 of this document provides background information on relevant legislation, flow regime concepts, and hydrologic data. Section 3 highlights resources and methods that can be used to generate instream flow recommendations using hydrologic data. Section 4 introduces decisions that must be made when using hydrologic data to define flow recommendations. Clarifying examples are provided throughout this document to provide context to the reader. Such examples are solely intended to illustrate the types of factors that could be considered and should not be construed as recommendations.

This document originally was prepared by the Texas Parks and Wildlife Department (TPWD) at the request of the SB 3 Science Advisory Committee (SAC), with comments from the Texas

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1 Freshwater inflow recommendations for bays and estuaries are not addressed in this document. They are discussed in another companion document.
2 Section 4 is largely based on a previous document entitled “Decision Points Relevant to using Hydrology Data to Quantify Environmental Flow Recommendations” that was provided to the SAC in draft form in October, 2008.
Water Development Board (TWDB) and TCEQ. Members of the SAC have reviewed, edited, and expanded the document and have provided recommendations regarding the application of the information and procedures presented in the document pursuant to the requirements of SB 3.
SECTION 2
BACKGROUND

2.1 INTERSECTION OF SENATE BILLS 2 AND 3

In 2001, Senate Bill 2 (SB 2) created the Texas Instream Flow Program (TIFP) which mandated that TPWD, TWDB, and TCEQ conduct studies to determine appropriate methodologies for determining flow conditions in the State’s rivers and streams necessary to support a sound ecological environment.\(^3\) Priority studies of the lower Sabine, middle Trinity, middle and lower Brazos, lower Guadalupe, and lower San Antonio rivers are to be completed by December 31, 2016. The TIFP is intended to be transparent and to strive for compatibility with existing programs. The methodology provides a general framework for studies across the State but recognizes that individual studies must be tailored to address basin and stream conditions.

Senate Bill 3, passed in 2007, established an aggressive schedule for determining environmental flow standards adequate to support a sound ecological environment in the State’s river basins and bay systems.\(^4\) These standards must consist of a schedule of flow quantities, reflecting seasonal and yearly fluctuations that may vary by location.\(^5\) The SB 3 schedule does not allow for the development of multi-year site-specific instream flow studies such as those mandated by SB 2. Instead, SB 3 requires that environmental flow standards be predicated upon the best science and data currently available; it is intended that adaptive management be employed to refine the flow standards in the future.\(^6\) In order to effectively utilize the results from the TIFP studies through the adaptive management process, it is considered desirable for the initial SB 3 flow standards to be consistent with the environmental flow regime framework that is to be applied in the TIFP studies for structuring environmental flow recommendations.

The immediate task for developing the flow standards required under SB 3 is to identify in a short time frame and without the benefit of completed TIFP studies one or more scientifically-based methods for determining an environmental flow regime at a particular location on a stream that will support a sound ecological environment and maintain the productivity, extent, and persistence of key aquatic habitats. The extent to which such an environmental flow regime conforms to the basic structure of that being proposed for application in the TIFP studies is an important consideration. Incorporating the results of TIFP studies into SB 3 environmental flow regimes may be greatly facilitated if the initial environmental flow regime recommendations are consistent with the TIFP flow regime components.

2.2 INSTREAM FLOW REGIME COMPONENTS

Variations in the magnitude, frequency, duration, timing, and rate of change of stream flows are all critical components of a natural flow regime (Poff et al., 1997). Variability in stream flow is

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\(^3\) Texas Water Code § 16.059 (Vernon 2008).
\(^4\) Texas Water Code § 11.02362 (Vernon 2008).
\(^5\) Texas Water Code § 11.1471(c) (Vernon 2008).
\(^6\) See Texas Water Code §§ 11.02362(m) and (p) (Vernon 2008).
manifested to stream biota as a change in habitat availability. Consequently, the life histories of stream fishes and other aquatic organisms are adapted to the seasonal and interannual variability of low, base, and high flow components. Hydrologic pattern and variability are therefore key determinants of aquatic community structure and stability (Poff and Ward, 1989; Poff et al., 1997; Richter et al., 1996, Dilts, et al., 2005).

Alterations to a natural flow regime may result in decreased richness, diversity, and abundance of aquatic species inhabiting lotic systems. While the elimination of high flows can result in reduced species densities and community diversity (Robinson et al., 1998), stable flow regimes that lack seasonal and interannual variability may favor generalist and non-native species (Tyus et al., 2000). In addition, seasonal and interannual flow variability may benefit native species that have developed life history strategies in response to natural flows. Thus, providing a flow regime based on the natural flow paradigm should provide ecological benefits in stream systems (Dilts et al., 2005).

To date, most instream flow recommendations in Texas have used a single “minimum” flow standard, which may vary by month and location (see discussion on Lyons Method below). Conversely, instream flow recommendations based on a flow regime concept (such as the regime concept found in SB 3) consist of multiple flow regime components (or levels) with specific characteristics. Following the recommendation of the National Research Council (NRC, 2005), and consistent with Maidment et al. (2005), the TIFP (2008) uses a framework that consists of a set of four components of a flow regime intended to support a sound ecological environment. These instream flow regime components are:

1. Subsistence flows,
2. Base flows,
3. High flow pulses, and
4. Overbank flows.

Subsistence flows are low flows that occur during times of drought or under very dry conditions (TIFP 2008). 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.

Base flows represent the range of “average” or “normal” flow conditions in the absence of significant precipitation or runoff events (TIFP 2008). Base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers. Habitat quality and quantity are important for survival, growth, and reproduction of fish and other aquatic organisms (e.g., mussels and benthic macroinvertebrates, other vertebrates, and flora). Base flows can also support the maintenance of water quality conditions and can contribute to the alluvial groundwater that supports riparian habitats, which are important components of river ecosystems. The structure and function of riparian areas are dependent on flow regimes and these areas serve to connect surface and subsurface hydrology with adjacent uplands (NRC 2002). For riparian vegetation, if the water table drops below the stream level,
older, more mature trees may survive, but younger trees might die and seedlings may not successfully take root. Even mature vegetation might not survive if the water table remains below the root zone for an extended period of time.

High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events (TIFP 2008). High flow pulses serve to maintain important physical habitat features and connectivity along a stream channel. Many physical features of a river or stream which provide important habitat during base flow conditions cannot be maintained without appropriate high flow pulses. High flow pulses also provide longitudinal connectivity along the river corridor for many species (e.g., migratory fish), lateral connectivity to near-channel features (e.g., connections to some oxbow lakes), and can support the maintenance of water quality.

Overbank flows are infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain (TIFP 2008). A primary objective of overbank flows is to maintain riparian areas associated with riverine systems. For example, overbank flows transport sediments and nutrients to riparian areas, recharge floodplain aquifers, and provide suitable conditions for seedlings. Overbank flows also provide lateral connectivity between the river channel and the active floodplain, supporting populations of fish or other biota utilizing floodplain habitat during and after flood events. Other objectives for overbank flows include the movement of organic debris to the main channel, providing life cycle cues for various species, and maintaining the balance of species in aquatic and riparian communities.

In addition to identifying individual flow regime components such as the four discussed above, it is important to adequately characterize the components themselves. Important aspects of these flow regime components, particularly the higher flow conditions, may include flow magnitude (rate and/or volume), duration, timing, frequency, and rate of change. Each of these characteristics may have important ecological implications and thus may need to be quantified (Poff et al., 1997; TIFP, 2008). For example, rise rates that are too rapid may wash aquatic organisms downstream before they can find shelter along the river margins. Conversely, fall rates that are too rapid may lead to stranding of aquatic organisms in shallow areas. However, from the standpoint of achieving environmental flow requirements associated with a water right on a stream or river, it is also important to recognize that fully satisfying the need for the episodic (i.e., high flow pulse and overbank) flow regime components often may be dictated more by the natural stream itself and local hydroclimatology than the water right activity. The diversions authorized by a water right or group of water rights may be of such magnitude that they simply cannot significantly impact high flow pulses or flows that cause overbanking.

2.3 HYDROLOGIC CONDITIONS VARY THROUGH TIME

Hydrologic conditions vary through time (e.g., dry, average, and wet periods); recognition of this supports the development of commensurate instream flow recommendations. For example,

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7 Hydrologic conditions could also be referred to as “climatic conditions,” or “zones” in the parlance of the Texas Consensus Criteria for Environmental Flow Needs (CCEF; TWDB, 1997), or “water year types” in the parlance of the Klamath River Instream Flow Recommendations (Hardy and Addley, 2001).
base flow recommendations during wet conditions could be greater than base flow recommendations in dry conditions and fewer high flow pulses might be needed in average conditions than in wet conditions. This recognition can generate flow recommendations that appropriately balance the needs of both water users and the ecosystem.

In the Caddo Lake/Big Cypress Creek Collaborative Process, different low flow (i.e., base flow) requirements were established for wet years, average years, and dry years. A similar distinction was made in the Savannah River (Georgia) instream flow recommendations (NRC, 2005).

Hydrologic conditions do not have to be assigned on an annual basis; they can be associated with any assignment period of interest (see Assignment Period discussion below).

The refinement of flow recommendations considering these varying hydrologic conditions may avoid imposition of unnecessarily stringent flow requirements, particularly if these conditions can be related to biological needs.

### 2.4 AVAILABILITY AND CONSISTENCY OF HYDROLOGIC DATA

Hydrologic data have several advantages for characterizing riverine systems over many other forms of environmental data in that they are relatively consistently and continuously measured at numerous locations and are also easily obtainable from the USGS. These characteristics, along with the comparatively simple nature of the data themselves, mean that hydrologic datasets can be evaluated using fairly generic statistical approaches and tools. Thus, hydrologic data typically provide the most convenient, initial understanding of riverine systems.

While hydrologic data provide only one perspective, it can be an important one. In its review of the Texas Instream Flow Program, the National Research Council (NRC, 2005) stated that

> “Hydrology is potentially the most critical element of instream flow studies and has been considered the "master variable" because the biology, physical processes, and water quality components directly relate to it (Poff et al., 1997).”

Furthermore, the NRC (2005) noted that

> Hydrologic desktop methods can be very useful in obtaining a ballpark estimate of instream flow needs in rivers for which detailed instream flow studies have not yet been conducted.

In the context of SB 3, a reasonable approach might be to use hydrologic data to develop initial values for a flow regime and then modify selected values where additional information (e.g., water quality, biology, and geomorphology) is available. This is consistent with the approach taken on the Savannah River, as summarized in SAC (2004):

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8 October 1, 2008 presentation to SB 3 SAC
[The Savannah River program] include[s] the use of a desk-top method for establishing initial environmental flow values, an expert panel to review results and make decisions regarding what measures to implement, and adaptive management procedures to address scientific allowances for uncertainty... The environmental flow results from the desk-top analysis were treated as “place holders” for follow-on expert functional analysis of their site-specific ecological significance.

This approach is also consistent with current water permitting practices in Texas, as TCEQ frequently uses the hydrology-based Lyons Method (discussed below) for establishing environmental flow conditions for smaller water rights and more complex approaches for larger water rights.
SECTION 3
METHODS FOR USING HYDROLOGIC DATA TO DEVELOP INSTREAM FLOW RECOMMENDATIONS

3.1 AVAILABLE RESOURCES

There are several resources available for obtaining information on how to use hydrologic data for evaluating and establishing environmental instream flow recommendations. Two particularly relevant sources are briefly discussed here. Additional sources are provided as citations.

The Instream Flow Council has described and summarized a number of methods for assessing instream flow requirements (Annear et al., 2004). Over 30 techniques are grouped into three broad categories: Standard Setting, Incremental, and Monitoring/Diagnostic. Standard Setting methods (e.g., the Lyons Method) set limits to define threshold flow regimes and can be done relatively quickly using hydrologic data but are not considered as rigorous as methods that also use biologic data. Incremental methods (e.g., the SB 2 TIFP method) analyze one or more variables to enable assessment of different flow management alternatives. Incremental methods are often considered more scientifically accepted but also require more resources to execute since site-specific data must be collected. Monitoring/Diagnostic methods are those methods that can be used to assess conditions and how they change over time. An example of this type of method is the Nature Conservancy’s Indicators of Hydrologic Alteration method (IHA).

Based on recommendations from the Science Advisory Committee created by the Study Commission on Water for Environmental Flows (Senate Bill 1639 from 2003), TCEQ created a Technical Review Group (TRG) to review available instream flow assessment tools and to develop one or more desktop methodologies specifically applicable to Texas river and stream conditions. The term “desktop” refers to methods that can be applied using readily available information and do not require site-specific field studies.

The TRG focused its initial review on desktop methodologies that have been applied to Texas streams (TRG, 2008). These included the Lyons Method, the Consensus Criteria for Environmental Flow Needs, the Texas Method and IHA. After further deliberation the TRG chose to focus its final review on the Lyons Method and IHA.

Key observations relevant to SB 3 include

“...the Lyons Method has some scientific basis for its construction, but the degree to which its monthly flow factors effectively represent varying stream conditions across the State remains unresolved.”

and

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.
Furthermore, the TRG recommended 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.

The TRG operated under the (fairly safe) assumption that any recommended desktop method would only be applied to small diversions that have little possibility of impacting high flow pulses and overbank flows. Thus, the lack of high flow pulse and overbank information in the Lyons Method was not identified as a significant weakness; indeed, high flow pulse and overbank flow recommendations could be seen as a superfluous complexity in small diversion permits. While SB 3 contemplates a multi-tiered flow regime that protects a sound ecological environment, there still may be situations where all aspects of that flow regime, particularly the high flow requirements, may not be appropriate for inclusion as environmental flow conditions on a new water right because the water right activity is of such magnitude that it cannot significantly impact such levels of flow.

Other summaries of instream flow methods, including hydrology-based methods, include Acreman et al. (2005), Maunder and Hindley (2005), Acreman and Dunbar (2004), Arthington and Zalucki (1998), and Jowett (1997).

Several specific methods are discussed below. Each of these specific methods could be used in the context of a larger collaborative effort such as SB 3.

3.2 ADVANTAGES AND DISADVANTAGES COMMON TO ALL HYDROLOGIC METHODS

Hydrologic methods share certain advantages and disadvantages (relative to biological, geomorphological, and water quality methods) in common. Common advantages include: (1) relatively robust and consistent datasets at multiple locations, (2) the understanding that hydrology has been considered the "master variable" with regard to environmental instream flows (Poff et al., 1997), and (3) ease of use.

Common disadvantages include: (1) a lack of validation against biological, geomorphological, and water quality data (e.g., the methods are largely designed to mirror some fraction of historical hydrology and are not based on defined flow alteration - ecological response relationships), and (2) unsuitability where hydrologic data are lacking and cannot be synthesized.\(^\text{10}\) Because of these disadvantages, the hydrologic methods are only recommended when sufficient data to define flow alteration – ecological response relationships are unavailable. In Texas, such data are probably currently unavailable on all river segments with the exception of the lower Colorado River. However, even though comprehensive datasets to define flow alteration – ecological responses are generally unavailable, some biological, geomorphological,

\(^{10}\) Synthesizing hydrologic data involves a wealth of complexities that are beyond the scope of this document.
and water quality data will be available in each major river basin. Thus, following the application of any of these hydrologic methods, it is recommended that this available data be used to corroborate or refine selected hydrology-based flow recommendations, as appropriate.

Important advantages and disadvantages specific to each individual hydrologic method are provided below in the discussion of each method.

### 3.3 Lyons Method

The Lyons Method (Bounds and Lyons, 1979) is a standard setting desktop methodology that uses monthly median gaged flow records to produce monthly instream flow recommendations with the intent of approximating natural flow patterns. The Lyons Method specifies 40% of the monthly median flow from October to February and 60% of the monthly median flow from March to September as minimum flows. The Lyons Method is statistically weighted to provide higher flows during the spring and summer periods, considered most critical to the warmwater fishes found in Texas. The flow values (i.e., 40% and 60% of median) used in the Lyons Method were based on the amount of wetted perimeter of the stream channel supported by limited physiographic field measurements in the Guadalupe River downstream of Canyon Dam.

TCEQ frequently uses a modified version of the Lyons Method as the basis for establishing environmental flow restrictions for new water right permits and amendments when existing site-specific information is not available. TCEQ typically imposes a lower flow limit equal to the 7Q2 if the Lyons derived value is less than the 7Q2. The 7Q2 is defined as the lowest average stream flow for seven consecutive days with a recurrence interval of two years, as statistically determined from historical data, and has been used by TCEQ and others as a minimum flow threshold for protecting water quality. In addition, TCEQ often groups or averages similar monthly values together to produce a reduced number of environmental flow recommendations within the year.

Advantages of the Lyons Method are that it is a simple, hydrology-based, desktop approach for determining minimum flow requirements for habitat protection and is used by TCEQ as the basis for setting restrictions in water right permits. A key disadvantage is that although the calculation generates a flow recommendation analogous to the base flow component, it cannot be used to estimate other flow regime components. There has even been some concern with regard to its potential use for the quantification of base flows. In their review of the Lyons Method, the NRC (2005) stated:

_use of monthly medians in a hydrologic desktop method can also yield inconsistent degrees of protection for base flows. Monthly medians are computed using all river flows during the month – base flows, high flow pulses, and even floods are all rolled into the calculation of a monthly median. As a result, it is often hard to predict how closely the median, or a method like Lyons, will compare to base flows._

Another possible disadvantage is that the Lyons Method does not generate different flow recommendations for different hydrologic conditions (e.g., dry, average, wet), which, particularly for larger water rights, is important.
3.4 CONSENSUS CRITERIA FOR ENVIRONMENTAL FLOW NEEDS (CCEFN)

The CCEFN was developed in the mid 1990s using a stakeholder process led by the TWDB to address water supply demands while recognizing environmental flow needs (TWDB, 1997). The CCEFN uses percentages of naturalized daily flow and provides a tiered set of recommendations for passing flows through reservoirs and past diversion points to provide downstream environmental flows based on calculations of naturalized flow. The CCEFN was developed for use in the water planning process and is used in regional and state water planning and by the TWDB for water supply planning studies and occasionally has been applied by TCEQ in water rights permitting.

The CCEFN defines three zones for the determination of applicable environmental instream flow requirements, with the delineation of these zones being different depending on whether the resulting environmental flows are being applied to a direct diversion from a stream or a reservoir on the stream. For direct stream diversions, Zone 1 conditions occur when streamflow is greater than the naturalized median flow, and this value of flow must be passed downstream before any water can be diverted. Zone 2 occurs when streamflow conditions are greater than the 25th-percentile naturalized flow, but less than the naturalized median (and the 25th-percentile naturalized flow must be passed downstream before any water can be diverted). Zone 3 applies when streamflow decreases to less than or equal to the 25th-percentile naturalized flow and prescribes the minimum flow needed for water quality maintenance. For Zone 3, the minimum flow requirement is a fixed threshold such as the 7Q2 or another flow value. For an on-stream reservoir, zones are defined based on storage in the reservoir at any give time, with Zone 1 conditions occurring when the storage is greater than 80% of the full conservation storage capacity. Zone 2 conditions occur when the storage is between 50% and 80%, and Zone 3 occurs when the storage is less than 50% of the full conservation storage capacity. The requirements for passage of inflows through the reservoir to provide environmental flows downstream for each zone are the same as those defined above for direct diversions, e.g., when the reservoir is in Zone 1, the naturalized median flow must be passed downstream.

The CCEFN is a desktop methodology that relies on naturalized flows to produce an environmental flow schedule for planning purposes.11 While the CCEFN does generate different flow recommendations under different hydrologic conditions (“zones”), it does not generate high flow regime components; the flow restrictions are all analogous to either subsistence or base flows. It is also questionable as to whether naturalized flows should always be used as the basis for establishing the different flow quantities.

3.5 ECOLOGICAL LIMITS OF HYDROLOGIC ALTERATION (ELOHA)

The Ecological Limits of Hydrologic Alteration (ELOHA) uses existing hydrologic and ecological databases from many rivers within a region to generate flow alteration-ecological

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11 Note that while the CCEFN method was developed for daily flow values, its implementation in water planning necessarily uses the State’s Water Availability Models (WAMs) that operate on a monthly time step.
response relationships and environmental flow targets. ELOHA envisions multi-step scientific and social processes that involve scientists and stakeholders:

**Scientific Process:**
Step 1: Build a hydrologic foundation
Step 2: Classify river segments
Step 3: Compute hydrologic alteration
Step 4: Develop flow alteration-ecological response relationships

**Social Process:**
Step 1: Determine acceptable ecological conditions
Step 2: Develop environmental flow targets
Step 3: Implement environmental flow management

Advantages of ELOHA include (1) a similarity to the SB 3 framework (e.g., scientific and social elements), (2) the use of existing data (e.g., daily gaged flows) and tools (e.g., TX-HAT to classify river segments and IHA to compute hydrologic alterations and develop environmental flow targets) to do a majority of the steps, and (3) application at a regional or basinwide scale.

A key disadvantage of ELOHA is that while some information for completing step 4 of the scientific process may exist, it is likely that sufficient information to effectively define flow alteration – ecological response relationships currently only exists on the lower Colorado River, and such information is not likely to be available on other rivers until more studies, such as the SB 2 TIFP, are complete. To date, ELOHA has not been implemented in Texas and no specific guidelines for how ELOHA can be used are available, thus it is uncertain how long this process would take.

More information on ELOHA may be found at www.Nature.org/ELOHA.

### 3.6 INDICATORS OF HYDROLOGIC ALTERATION (IHA)

The Nature Conservancy’s Indicators of Hydrologic Alteration (IHA) is a software package that is used to assess streamflow conditions and how they change over time. The package was developed to provide hydrologic analysis in an ecologically-meaningful manner. The software program assesses 67 ecologically-relevant (in the opinion of the IHA authors) statistics derived from daily hydrologic data. IHA requires an input file of daily streamflow data which typically can be obtained from the USGS. To adequately capture annual and inter-annual variations in the flow record, 20 or more years of continuous daily flow data are recommended (Richter et al., 1997). The USGS currently lists 480 active gages on their website; additional flow data may be available at selected locations from river authorities and other entities.

IHA also has a feature called the Environmental Flow Components (EFC) model in which each day is assigned one (and only one) of five flow regime categories: extreme low flow, low flow, high flow pulses, small floods, and large floods; an algorithm parses the hydrograph accordingly

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12 http://waterdata.usgs.gov/tx/nwis/current/?type=flow
based on user defined parameters and then generates summary statistics corresponding to each flow regime component.

To date the IHA method has not been fully implemented for any projects in Texas, although there have been applications elsewhere, often in conjunction with another method such as the Range of Variability Approach (RVA). In Texas, the EFC algorithm of IHA has been used in development of the Hydrology-based Environmental Flow Regime (HEFR) method (see discussion below) and in the Caddo Lake/Big Cypress Creek Collaborative Process. IHA software is readily available and relatively easy to use. Although the technique does not directly provide an environmental instream flow prescription, it can be used to support instream flow studies. It can also be useful in determining the characteristics of the natural hydrograph that have been most altered (Annear et al., 2006). While IHA statistics reflect conditions associated with intra-annual variations in hydrologic regimes, ecosystem processes that operate at longer time scales may not be adequately addressed (Annear et al., 2006).

More information on IHA may be found at www.Nature.org/IHA.

3.7 Texas Hydrologic Assessment Tool (TX-HAT)

The USGS Hydroecological Integrity Assessment Process (HIP) is a suite of software tools that can be used for stream classification, addressing instream flow needs, and assessing hydrologic alterations. A key computational foundation for HIP is a software package called the Hydrologic Assessment Tool (HAT). HAT was recently customized for Texas under a contract between the USGS and TCEQ and is known as TX-HAT (USGS, 2007). HAT and TX-HAT have identical statistical computations and are essentially synonymous for purposes of this discussion.

HAT has many of the same statistical features as IHA. Relative to IHA, it has an expanded list of statistics, but does not parse the hydrograph into flow regime components. A recent comparative review of IHA and HAT was performed by Hersh and Maidment (2006).

HAT/TX-HAT has not been applied in Texas for the purpose of developing environmental instream flow requirements and the stream classifications have not been thoroughly vetted.

More information on HIP/HAT may be found at www.fort.usgs.gov/Resources/Research_Briefs/HIP.asp.

3.8 Hydrology-Based Environmental Flow Regime (HEFR)

The Hydrology-based Environmental Flow Regime (HEFR) method is a new, relatively flexible computational approach for developing a flow regime matrix that is consistent with the Texas Instream Flow Program in the sense that it identifies multiple flow regime components and hydrologic conditions across different months, seasons, or years. HEFR was developed by TPWD with input from other agencies and organizations as an alternative to the Lyons Method for use in water right permitting. Although the method as a whole has not been peer reviewed, the EFC algorithm and IHA software have been used extensively. In addition, HEFR forms the
framework for the environmental flow recommendations in the Brazos River Authority’s Systems Operation draft water right permit pending at the TCEQ.

The method is based on simple summary statistics of individual flow regime components. The EFC algorithm in the IHA software is used as a convenient tool to parse a hydrograph into individual flow regime components. Microsoft Excel™ is currently used to efficiently develop summary statistics of these flow regime components. Other software tools could be used for either or both of these steps.

In the context of SB 3, the HEFR methodology has several advantages, including: (1) it is computationally efficient, allowing for repeated tests and exploratory analyses, (2) there is significant flexibility in setting parameters to parse the hydrograph as well as summary statistics of the flow regime components,¹³ (3) the results have the same format as expected results from the TIFP studies, and (4) it provides an initial set of recommendations that reflect key aspects of the natural flow regime including multiple flow components and hydrologic conditions (Poff et al., 1997). Disadvantages of this method are: (1) that there is no track record of application and (2) there are few precedents for some of the decisions that must be made by the analyst.

¹³ Two examples where this might be helpful include: (1) different options could be selected for stream segments corresponding to Exceptional, High, Intermediate, and Limited Aquatic Life Use subcategories, and (2) different options could be selected for small versus large watercourses, based on evidence that small streams require a larger proportion of average flow than large streams for an equal amount of protection (Jowett, 1997).
SECTION 4
DECISION POINTS WHEN USING HYDROLOGIC METHODS

This section introduces common decision points encountered when using hydrologic data to help define environmental flow recommendations.

The decision points herein are considered to be applicable to any hydrology-based instream flow method. Specific methods will generally require additional decisions related to the exact computations used.

Many of the decision points described herein have been discussed and addressed in other contexts, such as TRG (2008), the ongoing work being performed in support of the LCRA-SAWS Water Project, and applications of the Indicators of Hydrologic Alteration method (IHA) throughout the country.

In this section, the word “analyst” is used to generically refer to an appropriate decision maker(s). In the real world, this may include the Environmental Flows Advisory Group (EFAG), SAC, Basin and Bay Expert Science Teams (BBESTs), Basin and Bay Area Stakeholder Committees (BBASCs), or other persons or entities.

1. Number of Instream Flow Regime Components
   The analyst must decide how many flow regime components to use and what aspects of the hydrograph they should represent. As discussed above, the TIFP uses four flow regime components (subsistence flows, base flows, high flow pulses, overbank flows). IHA has five flow regime components (extreme low flows, low flows, high flow pulses, small floods, large floods), but can easily be constrained to fewer components.

   All selected flow regime components must subsequently be defined. Both NRC (2005) and TIFP (2008) include definitions that may be suitable (see also Section 2.2). Once results from the hydrologic analysis are available, it may be appropriate to revise either the number of flow regime components or the definitions of the components to better reflect site-specific circumstances and conditions.

2. Geographic Scope of all Instream Flow Recommendations and Spatial Extent of Individual Instream Flow Recommendations
   The analyst must identify the geographic scope of watercourses that will be assigned flow recommendations, as well as the spatial extent of each individual instream flow recommendation if such recommendations are applied to river reaches instead of point locations. Examples of information that may guide these decisions include (1) the reaches specified in the TIFP, (2) appropriately selected control points defining key hydrologic features such as major stream segments or downstream of an existing reservoir, (3) bodies of “state” water in the watershed of interest, (4) TCEQ classified segments (note that many classified segments exist within the pools

\[\text{\footnotesize 14 www.lcra.org/lswp/index.html}\]
\[\text{\footnotesize 15 The high flow pulse and overbank flow recommendations may include a range of flow magnitudes and characteristics.}\]
of major reservoirs), or (5) streams included in a particular GIS coverage (e.g., the NHDinGEO Dataset, http://nhd.usgs.gov/index.html). A flow recommendation quantified at a USGS gage may apply upstream to the next USGS gage, downstream to the next USGS gage, both, or other. One complicating factor that can arise when applying a hydrology-based flow recommendation (computed at a gage) to other locations is computing the influence of intervening drainage areas and tributaries.

It should be noted that the SAC, with support from the State agencies, also has prepared a separate document dealing with the geographic scope and spatial extent of instream flow recommendations. This document provides more in-depth information regarding the important factors that must be considered when establishing the locations within a basin where environmental instream flow recommendations are to be established (SAC, 2009).

3. Hydrologic Period of Record
In any hydrology-based method, the analyst must decide whether or not to use the entire data record, and, if not, the analyst must decide which period to use. While this decision can take many forms, the three most common are (1) natural (the closest to pre-human impact achievable), (2) post-human impact or regulated (beginning with identifiable changes in hydrology), or (3) the entire period of record. One perspective holds that the natural period of record provides information on the flow conditions that the ecosystem (including biological and geomorphological components) at the location of interest has evolved under (BIO-WEST, 2008). This perspective is purported to facilitate protection of a sound ecological environment as well as the potential restoration of the natural system or portions of the natural flow record that could be restored, as opposed to attempting to protect some modified version of the natural system, with the full knowledge that complete reconstruction of the natural system may not be realistic. As an example of this perspective, the TRG (2008) concluded that “whenever feasible, historical pre-impact flow records should provide the basis for evaluating environmental flow targets.” The key here is the word “feasible”, suggesting that the state of the hydrologic/ecologic system being considered may play an important role in determining which hydrologic record should be used for establishing environmental flow recommendations. As another example, the second recommendation in the NRC (2005) Executive Summary states that “state-of-the-science programs use natural flow characteristics as a reference for determining flow needs.” Conversely, depending on the extent of human impacts, certain aspects of the lotic ecosystem may have adapted to the more recent flow regime and some components of a natural flow regime may no longer be appropriate (e.g., large overbanking events in highly developed floodplains or downstream of a major reservoir). For locations with little to no human impact, it is generally recommended that the entire flow record be used in order to work with the most robust dataset possible. TCEQ frequently uses the entire flow record when applying the Lyons Method. These decisions regarding the hydrologic period of record should appropriately be made on a site-specific and case-specific basis.

A related issue is where to “break” the flow record if pre- or post-human impact is desired to be reflected in the environmental flow recommendations. Statistical tools, such as IHA and TX-HAT, have specific capabilities to help identify statistically different periods, although professional judgment and historical knowledge are also required. The analyst may also encounter breaks in a flow record that require concomitant decisions, such as choosing a period
of record without a flow break or filling in breaks using a nearby gage with an acceptable flow correlation. In addition, depending on project objectives, the analyst may have a specific reason to include, or exclude, the 1950s drought of record in their analysis; although, for conducting water availability evaluations for a proposed water use, the drought of record (which often is the 1950s drought) is always included to provide a meaningful representation of the anticipated variations in the available water supply. Finally, the analyst must decide if the desired period of record is long enough to support a hydrologic analysis and is representative of hydrologic variability at the site (this decision must be made on a site-specific basis; however, as generic guidelines, the IHA manual recommends at least twenty years and the TRG (2008) recommends 30 years; see also Huh et al. (2005).

The hydrologic period of record decision point includes many complexities and this discussion is not comprehensive. The goal of this section is simply to introduce the subject and provide examples of this decision made by other groups.

4. Hydrologic/Climatic Condition

This issue is relevant if the analyst believes that wet periods should have different environmental criteria than dry periods. If multiple hydrologic conditions (or “zones” or “climatic conditions”) are desired, the analyst must: (1) decide how many hydrologic conditions to employ, (2) define a “trigger” to determine which hydrologic condition a location is in at a given time, and (3) perhaps assign desired frequencies to each hydrologic condition. Examples of triggers include: (1) reservoir storage (i.e., percent full), (2) streamflow at the location of interest, (3) streamflow at a nearby relatively unimpacted flow gage, (4) near-term meteorological predictions, and (5) operating rules derived from a model simulation that predicts that desired flow frequencies will be met. Depending on the spatial extent of application of the calculated flow regime components, complicating factors may arise if different locations in the same basin have different hydrologic conditions at the same time; although, this usually means that different numbers of hydrologic conditions and triggers are needed to properly reflect conditions at different locations. Consideration may also be given to a distinct hydrologic condition appropriate for extreme droughts.

An example is helpful to illustrate the use of an unimpacted tributary as a trigger. The analyst may assume three hydrologic conditions, with dry occurring 25% of the time, average occurring 50% of the time, and wet occurring 25% of the time, with the trigger being nearby stream flows. When a nearby unimpacted tributary is flowing below its historical 25th percentile of flow, then the hydrologic condition at the environmental flow location would be “dry.” Similarly, when the nearby unimpacted tributary is flowing between its historical 25th and 75th percentile of flow then the hydrologic condition would be “average.” Flows above the 75th percentile indicate “wet” hydrologic conditions. It is important to note that the frequencies and triggers in this example are not universally appropriate; local hydrologic regimes will frequently necessitate other decisions.

5. Assignment Period

Flow regime components that consist of continuous flow recommendations may vary by time period (e.g., monthly or seasonal). Thus, the analyst must decide appropriate time periods for which to assign different values for these recommended flows. Complex episodic flow regime
components such as high flow pulses and overbank flows occur intermittently and thus must be associated with a recommended frequency of occurrence over the desired assignment period. The assignment periods need not be identical for all flow regime components. However, for all flow regime components where seasons are desired, the length and monthly assignments to such seasons must be decided.

6. Memory
The analyst must decide if there will be memory, or carry-over, from one assignment period to the next. If there is no memory, then each assignment period begins as a “clean slate” and the under- or over-achievement of episodic flow regime components in the previous assignment period(s) is moot. Conversely, if memory is included, then some or all of the previous assignment period's under- or over-achievement is carried-over into the current assignment period to either increase or decrease the current assignment period's requirements. Rules for how this memory is quantified must be clearly defined.

7. Flow Regime Component Characteristics Delineated
High flow pulses and overbank flows may be delineated using: (1) peak flow, (2) average flow, (3) duration, (4) volume, (5) rise and/or fall rate, (6) frequency, and/or other characteristics. The analyst must decide which of these (or other) characteristics are important to include in the environmental flow recommendations. Deviations between the characteristics used to computationally define these flow regime components and the characteristics explicitly included in final environmental flow recommendations may result in unintended consequences. For example, if high flow pulses are quantified in the historical record using a combination of average flow and duration, but recommendations simply specify average flow, high flow pulses of insufficient duration may result.

8. Subsistence Flows Less Than 7Q2
Some analytical methods may generate subsistence flows (or even base flows) that are less than the 7Q2. The analyst must decide if/when it is appropriate to recommend flows that may result in the contravention of water quality standards. In the modified Lyons approach frequently used by TCEQ, the 7Q2 flow is considered a minimum: “Where the 7Q2 value is greater than the Lyons numbers, 7Q2 is used” (Loft, 2008).

9. Number and Location of Control Points
The analyst must determine the requisite number and locations of control points at which to perform the hydrologic analyses. The previous discussion of the spatial extent of instream flow recommendations (item 2 above) and information contained in the document titled “Geographic Scope of Instream Flow Recommendations” prepared by the SAC and the State agencies provide additional guidance regarding the number and location of control points. However, the application of hydrologic methods, by their very nature, requires that the stream locations considered essentially be at streamflow gaging sites unless credible streamflow data can be synthesized.

10. Flow Recommendations in the Absence of a Flow Gage
There may be locations where instream flow recommendations are required or desired but a flow gage does not exist (e.g., tributaries that do not have a flow gage). In these cases, one option would be to translate the flow record at a nearby gage to the location of interest, e.g., using drainage area ratios (see, e.g., Asquith et al., 2006) and then perform the hydrologic analysis as usual. Another option would be to translate a flow recommendation itself from a nearby location. In either case, the analyst must determine that such translations are hydrologically realistic and meaningful; for many tributary/mainstem combinations, this may not be possible. The translation of either flow data or flow recommendations may be improved by limiting such translations to within a single stream classification. Information on stream classifications can be obtained from Hersh and Maidment (2007), Arthington et al. (2006), and Snelder et al. (2005).

11. Daily Average versus Instantaneous Flow Data
Daily average flow data are readily available and are generally satisfactory for subsistence flow and base flow determinations. Daily average data also may be satisfactory for developing high flow pulses and overbank flow recommendations, or a method using instantaneous flow data may be desired. Instantaneous flow data from the USGS are not as thoroughly quality controlled as daily average flow data, are not available at all stations, and typically start in the late 1980s. For these reasons, a pre-human impact flow record is unlikely to be available and a flow record in excess of 20 years is also unlikely. Typically, the more rare an event is (e.g., a large flood), the more important it is to use instantaneous data and the longer the period of record necessary to accurately quantify the expected frequency of the event. Previously developed flood models may be helpful to quantify flood events where data records are of insufficient duration.

While the use of daily average flow data is clearly unacceptable for the strict quantification of extreme flood events in the context of engineering and flooding impact determinations, the analyst may decide that, with some professional judgment, the use of daily average flow data is acceptable for setting realistic high flow pulse and overbank environmental flow recommendations.

12. Overbank Recommendations
Overbank flows are infrequent, high flow events that exceed channel banks and result in the inundation of the adjacent floodplain habitats. This periodic connection between the stream and the floodplain is critical for maintaining ecosystem health. It is important that overbank flows be recognized, to the extent practicable, in establishing instream flow recommendations to support a sound ecological environment in rivers and streams. However, instream flow requirements that would result in deliberate releases from reservoirs designed to produce overbank flows which would not otherwise occur naturally may raise issues of liability and may not be technically achievable in some situations.

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16 http://waterdata.usgs.gov/tx/nwis/current/?type=flow
17 http://ida.water.usgs.gov/
SECTION 5
HYDROLOGY-BASED ENVIRONMENTAL FLOW REGIME (HEFR)
METHODOLOGY

5.1 HEFR BASICS

HEFR was developed to efficiently use hydrologic data to populate a flow regime matrix. As a hydrologic method, it suffers from many of the same weaknesses as other hydrologic methods (see Section 3.2). However, unlike other hydrologic methods, HEFR can generate values for an entire flow regime in which the different flow regime components, hydrologic conditions, and component characteristics are internally consistent. The results are internally consistent in the sense that: (1) hydrologic conditions (e.g., dry, average, and wet) are tied to percentiles of a distribution, and thus the recommendation under average conditions is guaranteed to equal or exceed the recommendation under dry conditions (and similar for wet versus average). (2) the hydrographic separation that generates the flow regime component values is performed using a single software tool, and (3) high flow pulse and overbank flow characteristics of duration, magnitude, and volume are generated using a consistent set of quantified flow regime components, as opposed to different statistical measures of the entire hydrograph (e.g., as in TX-HAT).

HEFR begins with the selection of a flow gage and a period of record. IHA is then used to parse the daily hydrograph into the four (or more) flow regime components, based on seven user-specified parameters. This parsing results in each day of the hydrograph being classified as one of the four flow regime components. At the present time, Microsoft Excel is used to post-process the hydrographic separation and to generate summary statistics. These summary statistics are also specified by the user. Figure 1 on the following page outlines the important steps of HEFR.

Thus, the core foundation of HEFR is flow separation and statistical summaries of each flow regime component. The specific decisions and tools used in the current version of HEFR were identified through discussions and negotiations; however, they are not incontrovertible. Decisions and tools may change because of location, professional judgment, context, objectives, and/or convenience.

In the following sections, an example application of HEFR is presented as a convenient forum for describing the method itself. At each decision point, guidance is provided related to the actual decision made, possible ranges of parameter values, and associated advantages and disadvantages. In this example, it is important to remember that the thought processes and

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18 The flow recommendations corresponding to these hydrologic conditions can be conceptualized as small, medium, and large flow values appropriate for future dry, average, and wet periods. In the current version of HEFR, the recommendations corresponding to these hydrologic conditions are based on percentiles of the entire period of record used, not percentiles from historically-identified dry, average, and wet periods. Depending on the period of record used and the trigger definitions for the hydrologic conditions, identifying historical dry, average, and wet periods may not be possible.

19 Other hydrographic separation routines could be used based on professional judgment and basin characteristics.
guidelines are more important than the specific decisions and parameter values themselves; other locations, other contexts, and the identification of site-specific data may all lead to different decisions. This example was developed for illustrative purposes only and has not benefited from the level of background research, collaboration, and site-specific knowledge that would be appropriate for a real-world application of the method.

![Flow Chart of HEFR Methodology](image)

**Figure 1. Flow Chart of HEFR Methodology**

### 5.2 EXAMPLE APPLICATION OF HEFR: NECHES RIVER AT EVADALE

#### 5.2.1 Gage Selection

The Neches River at Evadale (USGS gage #08041000) was selected for this example because it has a long period of record (April 1921 to the present) and is located in a SB3 priority one basin.

As shown in Figure 2, this gage is located upstream of the City of Beaumont and downstream of both B.A. Steinhagen Lake and Sam Rayburn Reservoir (on the Angelina River). Deliberate impoundment of Steinhagen Lake began in April 1951 and deliberate impoundment of the much larger Sam Rayburn Reservoir began in March 1965. The surveyed volume at the top of the conservation pool for Steinhagen Lake is 66,972 ac-ft; similarly, the surveyed volume at the top of the conservation pool for Sam Rayburn is 2,876,033 ac-ft, or approximately 43 times larger than Steinhagen.


21
5.2.2 Period of Record

In the absence of site-specific data, for purposes of this example, it was decided to use the natural period of record. This period of record reflects the flow conditions that the ecosystem (including biological and geomorphological components) originally evolved under, but does not reflect contemporary changes (e.g., enhanced low flows due to reservoir operation) that certain aspects of the ecosystem have since adapted to. For a real world application of HEFR, both the natural and more recent hydrology, as well as the current configuration of the system and objectives of the analysis, should be considered (see Hydrologic Period of Record discussion above).

To eliminate unnecessary complexities in the statistical interpretations, only full years of data are used; partial years are omitted. Also, calendar years (instead of USGS water years) are used. Based on these considerations, the period of record was selected to begin on January 1, 1922. Because Sam Rayburn was impounded in 1965, the end of the period of record for this analysis was selected to be December 31, 1964. This results in 43 years of data, which meets the guidelines of the IHA software (in which 20 years or more are recommended) and the guidelines of the TRG (2008; which recommended 30 years). In a real world application of HEFR, the
analyst should consider the potential impacts of all upstream reservoirs (e.g., Lake Palestine in this case) and should perform additional analyses to establish that the selected period of record is representative of hydrologic variability at the analysis location.

5.2.3 Using IHA to Parse the Hydrograph

Figure 3 shows a close-up of the hydrograph of the Neches River at Evadale from April 1, 1936 through September 30, 1936. This figure will serve as an example of how the EFC algorithm can be used for hydrographic separation.

Figure 3. Hydrograph at Evadale, April 1, 1936 through September 30, 1936

In order to perform the analysis, the number of flow regime components must be selected. Though the TIFP and IHA both incorporate the flow regime component concept, the terminology is not shared and there are subtle differences. For this example, the four flow regime components used in the TIFP are selected. These correspond to subsistence flows (i.e., extreme low flow in IHA), base flows (low flows), high flow pulses (same), and overbank flows (small and large floods). For consistency in this discussion, the TIFP terminology is used throughout this document, even though screen captures of the IHA tool show the IHA terminology.

The next decision to be made is the parameterization of the EFC algorithm in IHA. Figure 4 is a screen capture of this tool, with the selections used in this example.
Figure 4. Screen Capture of EFC Tab in IHA

IHA sorts through all days in the period of record and assigns each date to one of two groups: (1) Group 1 contains potential subsistence and base flows, and (2) Group 2 contains potential high flow pulses and overbank flows. These assignments are performed using the first four parameters in Figure 4. The 75 percent designation for the first parameter forces IHA to classify all dates with flows in excess of the 75th percentile (of all flows) to be in Group 2. The second parameter, the 25 percent designation, forces IHA to classify all dates with flows less than the 25th percentile (of all flows) to be in Group 1.

The third and fourth parameters are the rate of change parameters. These parameters are relevant only for dates with flows between the 25th and 75th percentiles of all flows. In this middle 50% of the flow record, any given date can be assigned to either Group 1 or Group 2, depending on the rate of change and the previous date’s assignment. For Day i (i.e., any given day that is assumed to be between the 25th and 75th percentiles), if Day i-1 (i.e., the day before Day i) is a Group 1 day and the increase from Day i-1 to Day i is less than 50%, then Day i is also a Group 1 day. If this increase is greater than 50% then Day i begins a Group 2 event and is classified as a Group 2 day (i.e., a storm is assumed to occur between Day i-1 and i). Conversely for Day i, if Day i-1 is a Group 2 day, then Day i is also a Group 2 day, unless the flow from Day i-1 to Day i decreases by less than 5% (the algorithm is trying to identify the flat tail end of a storm pulse) in which case it is a Group 1 day.
At this point, the entire hydrograph is parsed into Group 1 and Group 2 days. Group 2 days are then distinguished using the fifth and sixth parameters in Figure 4. The fifth parameter sets the lower bound for overbank flows at the 1.5 year return flow in our example application. This value is based on a scientific and literature rule of thumb that the 1.5 year flow typically approximates a bank-full condition (Dunne and Leopold, 1978). A different return period could be chosen to reflect site-specific information on bank-full flow rates. The sixth parameter is set to 99 years, which effectively removes the “large flood” category from the hydrographic separation and forces IHA to assign all flows in excess of the 1.5 year flow as one category of overbank flows (“small floods”). In this way, the large flood flow regime component is eliminated from the discussion and all storm events that are estimated to be greater than bank-full are incorporated in the overbank flow component. In this example, the entirety of any Group 2 event (which consists of a consecutive series of dates based on the algorithm above) is classified as an overbank flow if any day of the event exceeds the 1.5 year return period threshold. If no dates in the Group 2 event exceed this threshold, the entire event is classified as a high flow pulse. It is sometimes helpful to think of high flow pulses and overbank flows as events, in the sense that not all days exceed the bank-full condition (in the case of overbank), or even have particularly high flow rates (in both cases). This is by design, but if it conflicts with the professional judgment of the analyst, it can be ameliorated by different parameter selections.

Finally, the Group 1 days are distinguished using the last parameter in Figure 4. In this case, the bottom 10% of the Group 1 days are assigned to subsistence flows and the remaining 90% of Group 1 days are assigned to base flows.

Using these EFC parameters, Figure 5 shows the same data as Figure 3 with the flow regime components identified. For reference, the 25th percentile of all flows (i.e., the lower threshold for high flow pulses) is calculated by IHA as 860 cfs, the 75th percentile of all flows (i.e., the upper threshold for high flow pulses) is 8400 cfs, and the 1.5 year flow is 21,070 cfs. In Figure 5, the storm events appear to be reasonably well represented by the hydrographic separation algorithm, although the first storm event seems to be identified a little late (the rate of increase never quite exceeds 50%, so the high flow pulse is triggered only when the flow exceeds 8400 cfs) and the second pulse appears to end a little early (there are two dates on the trailing limb of the hydrograph with identical average flows, thus the rate of decrease is less than 5%, triggering the end of the high flow pulse). Figure 5 does not illustrate subsistence or overbank flow components because the flows in this time period were not low or high enough, respectively.

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23 The TIFP contemplates the possibility of various sizes of overbank flow recommendations. The capability of IHA to separate out “small floods” from “large floods” may be used to help identify different overbank flow sizes, although this was not done in the example presented herein.

24 This figure was generated in Excel. IHA can conveniently generate similar figures; however the analyst must recognize that in IHA the flow regime component correctly assigned to a particular date is actually designated by the color and symbol of the previous date. This is a recognized minor bug in IHA (personal communication, Tom Fitzhugh).
While IHA does not have infinite flexibility to parse the hydrograph, the analyst can tune the EFC parameters to improve the separation, based on their professional judgment. It is recommended that the analyst carefully inspect the hydrographic separation. However, it is also recommended that the analyst recognize that the HEFR methodology solely uses percentiles of each component’s distribution (typically the 25th, 50th, and 75th percentiles), thus values at the far tails of the distribution are not particularly relevant. It is possible that the analyst could be wholly dissatisfied with the separation, in which case another, most likely custom, hydrographic separation package would be required.

Thus, to parameterize the EFC algorithm in IHA, several decisions must be made. The first important decision is whether or not the analyst desires the distinction between Group 1 and Group 2 days to be based primarily on magnitude, primarily on rate of change, or a balance of both. For example, if the analyst wants this distinction to be based primarily on magnitude, then parameters 1 and 2 are set close to each other (or even identically), at a level that the analyst believes approximates the distinction between base flows and high flow pulses. Because parameters 1 and 2 are close to each other (or the same), the rate of change parameters are relevant to only a small portion (or none) of the hydrograph. If the analyst wants the distinction between groups 1 and 2 to be based primarily on rate of change, then the first parameter is set to a high value and the second parameter is set to a low value. In this case, a large fraction of the hydrograph is assigned based on the rate of change parameters. In the example provided here, 50% of the hydrograph is assigned solely due to the flow magnitude on that day and 50% of the hydrograph is assigned based on the rate of change. The 50% and 5% values (parameters 3 and 4) are selected, based on professional judgment, to have IHA classify significant storm pulses as high flow pulses, from beginning to end. It is very useful for an experienced hydrologist to look...
at several storm events in the flow record to ensure that the assignments are occurring as desired. If not, different parameters may be used.

The second important decision relates to the distinction between (in-bank) high flow pulses and overbank flows. Site specific data are very helpful here; it is possible that existing reports or a site visit and analysis may provide the flow magnitude associated with bankfull. In the absence of site-specific or regional information, a return period similar to 1.5 years is often used.

Some of these decisions also affect the high flow pulse frequency calculations in subtle ways. Combinations of a high lower high flow pulse threshold (i.e., the 25th percentile in this example) and a low overbank threshold (1.5 year return flow in this example) result in fewer overall high flow pulses. Fewer high flow pulses, especially when combined with short assignment periods (e.g., monthly), increase the likelihood that zero frequencies (per assignment period) will be generated using the existing methodology.

Finally, a distinction is made between subsistence flows and base flows using the last (seventh) parameter in Figure 4. This value should be selected such that the historical occurrence of subsistence flows is reasonably consistent with the recommended future occurrence of subsistence flows.

It is not expected that a single EFC parameter set would be applicable to all locations in Texas. Rather, some customization at the basin, or even sub-basin, level is to be expected. Different parameter sets might be useful for locations with distinctive variations in flow characteristics or known ecology.

Using the selected parameters, IHA is run and the outputs are saved.

5.2.4 Using the HEFR Excel Tool

The HEFR Excel tool is designed to import IHA output files, make additional modifications to the hydrograph separation, and generate summary statistics.

In HEFR, the user selects the folder corresponding to the desired IHA outputs. HEFR then automatically loads all of the relevant output files and performs statistical computations. To provide a balance between integrity of the calculations and ease of use for the analyst, Visual Basic for Applications (VBA) code is used to write the Excel functions (where possible) and perform calculations directly (where Excel functions are inadequate). In this way the analyst can follow most of the calculations by examining the associated functions in Excel, but the analyst cannot inadvertently corrupt the original model itself.

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25 IHA uses daily average flows and some adjustments may be necessary if bank-full is determined using instantaneous flow data.
26 IHA uses an empirical calculation of return interval and does not fit the hydrologic data to a distribution, e.g., as in USGS (1982).
In the development of this methodology it was decided that, using certain parameter sets in the EFC algorithm, unrealistically long high flow pulses were identified by IHA. This occurs, in part, because IHA does not identify a new high flow pulse on Day i, unless Day i-1 is a Group 1 day\textsuperscript{27}. Said another way, an existing high flow pulse does not end unless the flow drops below the 25\textsuperscript{th} percentile or the flow drops from one day to the next by less than 5\% (based on the above example). However, in the judgment of the analyst, multiple consecutive high flow pulses may be deemed more appropriate. HEFR has the capability to separate long high flow pulses into individual high flow pulses, based on the multipeaks multiplier parameter. When, in the midst of an IHA-designated high flow pulse that has declined from its initial peak flow rate, the flow increases from Day i-1 to Day i by more than 50\% (if multipeaks_multiplier is set to 1.5), a new high flow pulse is designated in HEFR. In this way, a long high flow pulse is broken into a series of shorter high flow pulses. Because overbank flows are simply high flow pulses where one or more days exceed the 1.5 year return flow magnitude, overbank flows can also exhibit the same behavior and can be separated using the multipeaks_multiplier for overbank flows.

The multipeaks_multiplier is more sensitive for smaller, flashier rivers. For larger rivers like the Neches River at Evadale, when the flow is already high (as in a high flow pulse), it is rare for the flow to jump up by an additional 50\% from one day to the next. Probably for this reason, the multipeaks_multiplier value of 1.5 has little effect on the flow separation at Evadale. As an alternative example, Figure 6 shows a more flashy location where the multipeaks_multiplier calculation in Excel is used to split a long high flow pulse identified in IHA into four distinct, consecutive, high flow pulses.

When contemplating the use of the multipeaks_multiplier option, the analyst should carefully consider if there actually is a problem to be solved. Long high flow pulses and overbank flows may be appropriate for a particular location and may not need to be separated. The analyst should also evaluate if long high flow pulses and overbank flows are caused by multiple discrete storms or a single storm across tributaries with different travel times.

\textsuperscript{27} This perceived problem also occurs more often when the Group 2 lower threshold (25\textsuperscript{th} percentile) is low and the rate of decline (5\%) is also low.
Currently in HEFR, subsistence flows are conceptualized as both a flow regime component and a hydrologic condition. The hydrologic conditions of subsistence, dry, average, and wet are selected to occur 2.5%, 22.5%, 50%, and 25% of the time, respectively\textsuperscript{28}. The implication is that during the driest 2.5% of the time, only subsistence flows are recommended. In the other 97.5% of the time, a combination of base flows, high flow pulses, and overbank flows are recommended. While this means that high flow pulses are recommended during dry periods, the recommendations are typically for relatively small high flow pulses, commensurate with the hydrologic record. Overbank flows are less frequent events and may not be associated with specific dry, average, or wet periods, depending on the desired return interval of such events and the assignment period used.

HEFR generates results on a monthly and/or seasonal basis (see below). HEFR assigns seasons as follows: Winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Aug), and Fall (Sep-Nov). Months were aggregated into seasons based on traditional seasonal definitions but also to group months with flows that might provide similar ecological/biological cues and functions. At this time, modest recoding of HEFR would be necessary to assign months to other seasons, which may be necessary in some areas of Texas.

HEFR performs the following calculations.

\textsuperscript{28} The sum of these frequencies must be 100%. Based on site-specific evaluations of the flow record, alternate selections for the number of hydrologic conditions, and their associated frequencies, should be considered.
**Subsistence Flows**

All subsistence flows are binned by month and the median for each month is calculated. The recommended subsistence flow is the greater of the calculated flow and 7Q2, as entered by the user; the published 7Q2 value was used in this example.

At this time, it is helpful to quantify the frequency at which historical flows were equal to or less than the subsistence flow recommendations. This information can help to guide the selection of the appropriate recommended frequency for subsistence flows in the future. In this way, HEFR can be self-centering. If the subsistence flow recommendation is a relatively high flow value, then it should be recommended to occur at a relatively high frequency and vice versa.

Subsistence flows are generated in HEFR on a monthly and seasonal basis. The analyst can choose to use either.

**Base Flows**

All base flows are binned by month and the minimum, 25th percentile, 50th percentile, 75th percentile, and maximum for each month are calculated. The recommended base flow for the dry hydrologic condition corresponds to the greater of the 25th percentile flow and the 7Q2 flow. The recommended base flow for the average hydrologic condition corresponds to the greater of the 50th percentile flow and the 7Q2 flow, and the recommended base flow for the wet hydrologic condition corresponds to the greater of the 75th percentile flow and the 7Q2 flow.

The correspondence of dry, average, and wet to the 25th, 50th, and 75th percentiles is based on professional judgment and is deemed consistent with the recommended frequencies of 22.5%, 50%, and 25% of the time, respectively. Different percentiles may be needed, depending on the hydrologic and climatic conditions in different parts of the state. If different percentiles are selected, it may be appropriate to also select different frequencies of occurrence.

To assist the analyst in assessing the HEFR base flow recommendations, these flows are automatically presented in a plot with Lyons values (as entered by the user) as a basis of comparison. This feature may be helpful to analysts for whom the Lyons Method is a well-known point of reference.

The published 7Q2 value at Evadale (1,839 cfs, based on data from 1966 to 1996) lies at the 43rd percentile (57th percent exceedance level) of the 1922-1964 period. This 7Q2 value is relatively high, likely due to releases from Sam Rayburn for downstream water rights, leading to all of the HEFR-calculated subsistence flow recommendations and many of the HEFR-calculated base flow recommendations being replaced with the 7Q2 value in this example (see discussion of 7Q2 above).

Base flows in HEFR are generated on a monthly and seasonal basis. The analyst can choose to use either. In this example, seasonal base flows are presented (Figure 7 below) for brevity and because they reasonably mimic the monthly HEFR outputs.
**High Flow Pulses**

For each high flow pulse the duration, volume, and minimum, 25th percentile, 50th percentile, average, 75th percentile, and maximum flows are determined. In addition, the date of the peak flow (the daily flow with the greatest magnitude rather than from a peak flow file) is identified for seasonal assignment. Currently the high flow pulse is assigned to the season during which the peak flow of the event occurs; this may be modified if site-specific conditions warrant such a change.

From this population of high flow pulse events, the 25th, 50th, and 75th percentiles of duration, volume, and peak flow are determined. These are used to assign each event to the dry, average, wet, or none categories. If an event exceeds the 75th percentile of all three characteristics (duration, volume, and peak flow), then the event is classified as a “wet” high flow pulse. If the event exceeds the 50th percentile, but not the 75th percentile, of all three characteristics, then it is classified as an “average” high flow pulse. If the event exceeds the 25th percentile, but not the 50th percentile, of all three characteristics, then it is classified as a “dry” high flow pulse. If the event does not exceed the 25th percentile of all three characteristics, it is classified as “none.” Because of the nature of joint distributions, fewer than 25% of the high flow pulses will be categorized as wet. Similarly, fewer than 50% will be average and fewer than 75% will be dry.

It is important to recognize that even though the upper threshold of high flow pulses is set at the expected bank-full value (in this example, the 1.5 year flow), the recommended high flow pulses are significantly less than bank-full. Only the maximum high flow pulse peak flow approximates bank-full. Because of the skewed nature of the peak flow distribution, the 75th percentile can be as low as 20% of bank-full flow. Thus, in this categorization, even “wet” high flow pulse recommendations are well below bank-full. This behavior may lead the analyst to select higher percentiles for flow recommendations, and/or modify the high flow pulse recommendations based on other disciplines (e.g., geomorphology and biology).

At this point the dry, average, and wet high flow pulses are binned by season and year (e.g., two dry pulses in winter 1940, one dry pulse in winter 1941, and no dry pulses in winter 1942). The median and 75% percentile of frequencies are presented to help the analyst make a frequency recommendation. In this instance, the median frequency is one high flow pulse per winter season. HEFR uses the 75th percentile of frequencies for the recommendation on account of the skewed nature of this distribution. Only those high flow pulses that meet the dry, average, and wet criteria are included in the frequency calculation, thus the frequency recommendations are, by definition, based on historically observed patterns of dry, average, and wet high flow pulses.

In the current version of HEFR, the flow regime component characteristics of high flow pulses that are delineated are peak flow, duration, volume, and frequency. Statistics describing the rise rate and fall rate are not included, but could be added.

High flow pulses in HEFR are currently generated on a seasonal basis.

**Overbank Flows**

Overbank flows are calculated similarly to high flow pulses, with the exception that multiple hydrologic conditions are not considered. The overbank flow recommendation corresponds to
the median duration, volume, and peak flow of all overbank events. The recommended frequency is simply based on the number of observed events over the period of record (e.g., if 20 overbank events were identified in a 28 year period of record, the recommendation would be a return interval of 1.4 years).

In this example, the overbank flow multipeaks_multiplier was set to 1e9. This value is used to turn off additional processing of the overbank flows identified by IHA.

When IHA is parameterized with an overbank peak flow return interval of 1.5 years, overbank-sized flows will occur somewhat more frequently than once every 1.5 years. This is because the 1.5 year flow is calculated (as is customary) using the distribution of annual maximum flows. Relatively wet years may have multiple large events, but only the largest from each year is used in the calculation. Depending on the results of the calculation, several events in that wet year might actually exceed the calculated 1.5 year flow. This is the same statistical subtlety that causes the 7Q2 flow to occur across seven consecutive days more often than about once every other year.

The overbank flow recommendation in HEFR is associated with a return interval (as opposed to a monthly or seasonal frequency) and is independent of hydrologic (dry, average, wet) conditions.

5.3 EXAMPLE MATRIX

Figure 7 shows the resulting populated flow regime matrix for the Neches River at Evadale.
Figure 7. Example Flow Regime Matrix for the Neches River at Evadale

If this were a real application, a couple of characteristics of this matrix would require further thought:

1. Many of the high flow pulse frequency recommendations are zero. Given that most locations in Texas can be assumed to have within-bank storm flows, a recommendation of zero high flow pulses may imply a poor representation of the hydrology in the flow regime matrix. Frequencies of zero are probably a result of some combination of several factors:
   - Frequency calculation methodology is too restrictive. Options other than the methodology described herein may be more appropriate.
   - Qualifying high flow pulse criteria are too stringent. The methodology described herein requires “wet” high flow pulses to meet all three of the “wet” criteria for magnitude, duration, and volume. This limits the pool of qualifying “wet” high flow pulses with which to determine recommended frequencies. Similar arguments can be made for “average” and “dry” high flow pulses. Lower criteria (e.g., 15th, 40th, and 60th percentiles for dry, average, and wet, respectively) may result in smaller but more frequent high flow pulse recommendations.
   - Window of hydrograph that IHA can designate as high flow pulses is too narrow. In the example described herein, high flow pulse days are constrained to days with a flow greater than the 25th percentile that are also not part of an overbank flow event (i.e., a Group 2 event with a peak flow greater than the 1.5-year flow rate). Decreasing the 25th percentile to a lower value may increase the number of high flow pulses (and the
resulting frequency recommendation), although it will also tend to reduce base flow recommendation values. Similarly, increasing the overbank cutoff (e.g., 1.5-year to 2-year return period) may increase the number and size of high flow pulses.

- Assignment period is too short. Instead of three-month seasons, four- or six-month seasons may be used.

It is likely that “flashy” locations characterized by short, intense storm events will require different options than those applicable to mainstem locations with very large drainage areas. It is recommended that these options be explored to identify high flow pulse recommendations with reasonable magnitudes and frequencies at each location of interest.

2. All of the subsistence flows and many of the base flow values were replaced with the 7Q2 value (1,839 cfs). This 7Q2 value should be double-checked and its use as a minimum flow for protection of water quality may be reevaluated in light of its location at the 43rd percentile of flows in the period of record used. Or conversely, consideration may be given to using post-development hydrology, instead of the natural hydrology, for the HEFR analysis since this more recent hydrologic record was used by TCEQ to calculate the 7Q2 value.

3. Soar and Thorne (2001) have estimated bank-full at this location at approximately 7,770 cfs. The National Weather Service has estimated bank-full at this location at approximately 7,200 cfs, with minor lowland flooding at about 30,000 cfs. This site-specific information suggests that some of the recommended high flow pulse magnitudes exceed the bank-full condition. This, and other site-specific information, should be used to select the most appropriate demarcation between high flow pulses and overbank flows in the EFC hydrographic separation algorithm.

These items are in addition to the blanket recommendation of guidance from site-specific data, other disciplines, etc.

5.4 IMPLICATIONS OF HEFR CALCULATIONS

Many of the calculations described in the example above are hard-wired into the current version of HEFR, however, in many cases changes to the calculations are relatively straightforward.

The percentile and frequency decisions in HEFR are often internally consistent in the sense that higher flows are naturally associated with lower frequencies. In this way, HEFR attempts to mimic (with a limited number of flow regime components) fractions of the period of record used. Site-specific data may be used to guide percentile and frequency decisions in HEFR and/or used to replace HEFR-generated flow recommendation values.

User-defined values in the HEFR methodology are based on existing data and information relevant to the location of interest, professional judgment, and (at times) the context under which decisions are being made. Because the recommended frequency is based on the historical

frequency of occurrence, the HEFR flow recommendations are internally consistent. For example, if the analyst sets parameters to specify larger “wet” high flow pulses, fewer such high flow pulses will be observed in the historical period of record and the recommended frequency will consequently be diminished.

As an example of this, consider Figure 8 on the next page, which is a flow duration curve for the USGS gage “Neches River at Evadale” from January 1, 1922 through December 31, 1964.

In Figure 8, the y-axis represents flow and the x-axis represents the percent of time that each flow value is equaled or exceeded in the flow record. In HEFR, a flow recommendation that mimics some pattern of historical hydrology (e.g., natural, regulated, or otherwise) is desired. Suppose that the analyst made decisions that resulted in a high flow pulse peak flow of 15,000 cfs (the solid red line in Figure 8). In this case, the historical frequency (approximately 7%) is used to guide the assignment of recommended future frequencies for this flow magnitude (i.e., presumably 7% or less frequent). Similarly, if the analyst made decisions that resulted in a high flow pulse peak flow of 13,000 cfs (the dashed green line), the historical frequency of 15% is used to guide the selection of recommended future frequencies. Either way, the magnitude and frequency recommendations can be made to be coherent and thus the recommendations are internally consistent. This is not to say that all flow recommendations are inherently equal; some high flow pulse magnitudes provide different ecological benefits than others. However, in the absence of site-specific data, it is reasonable to identify a finite number of flow regime components and recommend them at reasonable frequencies – this is the goal of HEFR.
Similarly, the decisions regarding hydrologic conditions are internally consistent. In the example described herein, the wet hydrologic condition occurs during the wettest 25% of the time, and is set at the 75th percentile of the flow regime component characteristics. If the analyst wanted to select a “soaked” hydrologic condition that occurred during the wettest 10% of the time (i.e., that supersedes the wet condition in that portion of time), then flow regime component characteristics commensurate with the 90th percentile would be appropriate. In this way, hydrologic conditions are realistically tied to appropriate flow levels.

Ultimately, this internally consistent behavior of HEFR reduces the likelihood of illogical or nonsensical combinations of flow recommendations.

5.5 HYDROLOGIC DECISIONS NOT NEEDED TO RUN HEFR

The decision points listed below are necessary for a realistic application of the HEFR methodology, but are not explicitly needed to run the HEFR computations and therefore were not discussed in the Evadale example given above.
**Geographic Scope of all Instream Flow Recommendations and Spatial Extent of Individual Instream Flow Recommendations**

**Number and Location of Control Points**

**Flow Recommendations in the Absence of a Flow Gage**

In a given application of HEFR, only one flow gage is used. Therefore any decisions regarding the geographic scope of all instream flow recommendations, the spatial extent of individual instream flow recommendations, the number and location of control points, and how to synthesize data at a location without a flow gage, are made outside of the HEFR methodology.

**Memory**

Memory from one assignment period to the next is conceptualized as an implementation question and is not included in any HEFR calculations. An advantage of having memory is that extended wet periods could reduce near-term future instream flow requirements, allowing increased water diversion or storage under a new water right. Conversely, extended dry periods could increase near-term future flow requirements and help an ecosystem recover from drought conditions. A disadvantage is complexity. An accounting system for tracking changing flow requirements and associated over- or under-achievement would have to be developed.

**Daily Average Versus Instantaneous Flow Data**

IHA solely uses daily average flow data; therefore, the HEFR methodology solely uses daily average flow data. This implicitly assumes that if the 1.5-year flood flow corresponds to bank-full (on an instantaneous flow basis), then the 1.5-year flood flow using daily average data will also be associated with a bank-full condition, even though the actual flow values are lower on a daily average basis than on an instantaneous basis.

**Hydrologic/Climatic Condition – Trigger**

As discussed above, HEFR has four hydrologic conditions built in to the methodology. However, in the current version of HEFR, the trigger for determining which condition is occurring at a particular location at a given time is independent of the HEFR flow analysis and, thus, is not included in HEFR. An example of how this could work is as follows. Reservoir storage could be used to determine the appropriate hydrologic condition at any given time. If the four hydrologic conditions are subsistence, dry, average and wet, and their associated desired frequencies of occurrence are 2.5%, 22.5%, 50%, and 25% of the time, then reservoir storage volumes (or elevations) that occur with exceedance frequencies of 97.5%, 75%, and 25% could be determined and used as the designated trigger values for determining whether the subsistence, dry, average or wet hydrologic condition is in effect. All of this is independent of the IHA and HEFR calculations.

**5.6 SUMMARY**

HEFR is a new calculation methodology for populating a flow regime matrix consistent with the TIFP environmental flow regime framework. The core of HEFR is hydrograph separation (performed by IHA for convenience) and summary statistics of the resulting flow regime components (calculated in Excel). Reasonable changes to specific parameter and statistical decisions, established in a collaborative manner, are an integral part of the HEFR approach. Parameter selections presented here are for example purposes only. Actual selections should be
made through collaboration between the analyst and a multidisciplinary workgroup based on existing site-specific information and professional judgment.

Figure 7 illustrates how a flow regime matrix with multiple flow regime components and hydrologic conditions may look for a rather complex representation of the environmental flow requirements at a particular location on a stream. Although this is the type of flow regime that would be expected for most locations on major streams and rivers, under special circumstances, such as recommendations applicable for a small stream, a less complex flow matrix could be appropriate. In addition, for permits such as those involving only small run-of-river diversions, permit conditions likely would only need to include a subset of the flow components in this matrix.

As described herein, application of the HEFR program requires the specification of a number of parameters to define different flow levels and conditions that are used to describe a resulting environmental flow regime at a particular location on a stream or river. Determining optimal values of these parameters is not a straightforward process and depends on: (1) basin and site specific characteristics of hydrology, biology, geomorphology, and other related disciplines and (2) project specific objectives based on environmental, stakeholder, legal, management, and other concerns. Still, it is important to establish initial values of these parameters that can provide at least a starting point for the application of the HEFR methodology in the absence of all of the information that ultimately might be needed and considered in arriving at a final environmental flow recommendation. Appendix A presents such “default” values for the most important input parameters needed to initially apply HEFR. Again, it is anticipated that these parameter values very likely could change as the determination of final environmental flow recommendations at a particular location proceeds through the overall process.
SECTION 6
CONCLUSIONS

This document provides an overview of how hydrologic data can be used in the identification of instream flow recommendations as part of SB 3 efforts. As such, it describes one piece of a collaborative process envisioned by SB 3 for the identification of instream flow regimes to maintain a sound ecological environment. It does not address assessment techniques for environmental freshwater inflow determinations for bays and estuaries. In addition, information from other disciplines such as biology, geomorphology (physical processes), and water quality will be necessary to guide hydrologic analyses, address decision points, and refine/replace instream flow recommendations that are based on hydrologic data alone. It is important to remember that the hydrologic methods discussed herein have not been validated against biological, geomorphological, and water quality data and are not based on defined flow alteration - ecological response relationships. However, information from other disciplines can and should be used to corroborate or refine hydrology-based instream flow recommendations. The hydrologic analyses discussed herein constitute simply the first, and perhaps the easiest, step in the process of developing instream flow recommendations.

Specifically with regard to the establishment of instream flow recommendations for rivers and streams, the SAC offers the following observations:

- Pursuant to the requirements of SB 3, instream flow recommendations developed by the BBESTs must represent a flow regime that includes a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats.

- In order both to implement the SB 3 requirements and to effectively utilize the results from the TIFP studies through the adaptive management process, it is recommended that the initial SB 3 instream flow recommendations be consistent with the environmental flow regime framework that is to be applied in the TIFP studies, including, as appropriate, the following four flow regime components:
  - Subsistence flows
  - Base flows
  - High flow pulses
  - Overbank flows

- From the standpoint of achieving environmental flow requirements associated with a water right on a stream or river, it is important to recognize that fully satisfying the need for the higher flow components often may be dictated more by the natural stream itself than the water right activity, e.g., the diversions authorized by a water right or group of water rights may be of such magnitude that they simply cannot significantly impact high pulse flows or flows that cause overbanking.
• Environmental flow recommendations structured in accordance with a flow regime framework can incorporate, as appropriate, different levels of flow requirements to reflect monthly or seasonal variations and different hydrologic conditions (subsistence, dry, average, wet).

• Depending on local stream conditions and water rights characteristics, different aspects of the flow regime matrix can be used to describe environmental flow requirements for purposes of water rights permitting.

• In the absence of known flow alteration – ecological response relationships for specific locations or stream reaches within a basin, the application of hydrology-based instream flow methods to statistically define an environmental flow regime offers a useful approach for initially establishing instream flow recommendations consistent with the requirements of SB 3.

• For purposes of SB 3, the use of hydrology-based instream flow methods for establishing environmental flow recommendations in the absence of appropriate flow alteration – ecological response relationships assumes that maintaining the occurrence and frequency of certain key flow characteristics derived from historical records provides a flow regime that is adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats.

• However, it is recognized that with more rigorous scientific data and information such as that being developed through the TIFP studies, the environmental flow recommendations derived using hydrology-based instream flow methods are subject to revision and updating through the adaptive management process provided for in SB 3.

• The period of record selected for application of hydrology-based instream flow methods typically represents one of three conditions: (1) natural, pre-human impacts, (2) post-human impacts or regulated conditions, or (3) all historical development as reflected in the entire available flow data base, and the selection of the most appropriate period of record should consider such factors as the length of available daily flow records, historical changes in the basin that have influenced hydrologic conditions, the characteristics of historical and existing ecosystems, and the likely flow conditions under which the existing ecosystem evolved and has become adapted.

• Application of hydrology-based instream flow methods for establishing environmental flow recommendations requires numerous decision points regarding parameter values and assumptions and necessarily involves considerable expertise, experience, and professional judgment to achieve meaningful results.

• The Hydrologically-based Environmental Flow Regime (HEFR) methodology, developed by the TPWD with input from other agencies and organizations, provides a relatively flexible computational approach for developing a flow regime matrix this is consistent with the TIFP multi-tiered flow framework for describing key and essential instream flow requirements. In some cases, where data are available, it may be possible to use information on biology, water quality and sediment transport to adjust or refine the hydrologically-based flow regime recommendations.
• With application of the necessary expertise, experience, and professional judgment, the HEFR method can provide useful results that potentially can be used to structure appropriate environmental flow recommendations for rivers and streams that are consistent with and responsive to the requirements of SB 3.


Contributors and Contact Information

Hydrology:
Daniel Opdyke, dan.opdyke@tpwd.state.tx.us
Praveen Kokkanti, praveen.kokkanti@tpwd.state.tx.us

Biology:
David Bradsby, david.bradsby@tpwd.state.tx.us
Kevin Mayes, kevin.mayes@tpwd.state.tx.us

Policy:
Cindy Loeffler, cindy.loeffler@tpwd.state.tx.us
Colette Barron, colette.barron@tpwd.state.tx.us

Commentors and Contact Information

TWDB:
Mark Wentzel, mark.wentzel@twdb.state.tx.us
Ruben Solis, ruben.solis@twdb.state.tx.us

TCEQ:
Todd Chenoweth, tchenowe@tceq.state.tx.us
Kathy Alexander, kaleand@tceq.state.tx.us
Lann Bookout, lbookout@tceq.state.tx.us
APPENDIX A
DEFAULT VALUES FOR HEFR

This appendix contains suggested default values for developing a preliminary HEFR analysis. These values are suggested simply as a place to start. Optimum final values will depend on: (1) basin and site specific characteristics of hydrology, biology, geomorphology, and other related disciplines and (2) project specific objectives based on environmental, stakeholder, legal, management, and other concerns.

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<tr>
<th>Characteristic</th>
<th>Default Value</th>
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<td>IHA EFC – HFP Lower Percentile Threshold</td>
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<td>Excel – Multipeaks Multiplier for Overbank Flows</td>
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<td>25% for wet conditions</td>
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<td>Spring – Mar, Apr, May</td>
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<td>Summer – Jun, Jul, Aug</td>
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<td>Wet: 75th percentile of base flows</td>
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<td>Excel – HFP Frequency Recommendation</td>
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