November 12, 2010

Transmittal to Basin and Bay Area Stakeholders Committees (BBASCs) and
Basin and Bay Expert Science Teams (BBESTs)

Report # SAC-2010-04

Title: Consideration of Methods for Evaluating Interrelationships between Recommended SB-3 Environmental Flow Regimes and Proposed Water Supply Projects

As part of the process of developing environmental flow (E-flow) recommendations for the TCEQ to consider in the adoption of environmental flow standards pursuant to the requirements of Senate Bill 3 (SB3), the BBASCs are charged with considering the environmental flow analyses and environmental flow regime recommendations submitted by their BBESTs in conjunction with other factors, including the present and future needs for water for other uses related to water supply planning (Sec. 11.02362(o), Texas Water Code). Furthermore, in adopting environmental flow standards through rulemaking, the TCEQ is to consider human and other competing water needs and other factors (Sec. 11.1471(b), Texas water Code).

The attached guidance document presents tools and methods which can be employed by BBASC groups, and/or their BBEST if deemed appropriate, and the TCEQ to

- Evaluate to what degree a prescribed instream flow scenario (environmental flow regime or standard) is satisfied based on some current or future infrastructure/water rights assumptions (Section 3 of the report), and

- Analyze impacts of a proposed E-flow regime on a specific water supply project (Sections 4 and 5 of the report).

The focus of this effort has been primarily on evaluating E-flow recommendations for protecting instream environmental uses in rivers and streams. While the methods presented could also be applied to evaluate water supply project impacts of estuarine E-flow recommendations, certain reprogramming and restructuring of the analysis methods would be required to effectively represent the important freshwater inflow elements for bays and estuaries.

As has been the case for many of the previous SAC guidance documents, this report is very much a work in progress. The material and recommendations presented are the result of many hours of effort by a SAC workgroup that included resource agency personnel and hydrology and biology practitioners, many of whom serve on Basin and Bay Expert Science Teams. The work does not stop with this report, nor is there total agreement among the members of the workgroup on the best way to conduct these analyses.

Specific issues on which there are differing opinions include:

1) Use of daily versus monthly flows in the analysis of E-flow regimes with respect to both compliance with recommended frequency guidelines and impacts on proposed water supply projects;
2) Appropriate means for effectively representing and satisfying frequency guidelines associated with the different base-flow components of an E-flow regime;
3) Procedures for defining and implementing different hydrologic conditions as an approach for satisfying frequency guidelines associated with the different base-flow components of an E-flow regime; and
4) Varying methods for defining high-flow pulse and overbank flow events for purposes of both analyzing E-flow regimes with the WAM or other tools and implementing E-flow regimes in the real world.

The SAC is committed to continue its efforts to resolve these and other outstanding issues, and will report on those deliberations as appropriate.

Robert J. Huston, Chairman, SB3 Science Advisory Committee

CONSIDERATION OF METHODS FOR EVALUATING INTERRELATIONSHIPS BETWEEN RECOMMENDED SB-3 ENVIRONMENTAL FLOW REGIMES AND PROPOSED WATER SUPPLY PROJECTS

Senate Bill 3 Science Advisory Committee for Environmental Flows

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Document Version Date: November 12, 2010

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1.0 BACKGROUND

As part of the process of developing environmental flow (e-flow) recommendations for the TCEQ to consider in the adoption of environmental flow standards pursuant to the requirements of Senate Bill 3 (SB-3), the Basin and Bay Area Stakeholder Committees (BBASC) are charged with considering the environmental flow analyses and environmental flow regime recommendations submitted by the Basin and Bay Expert Science Teams (BBEST) in conjunction with other factors, including the present and future needs for water for other uses related to water supply planning (Sec. 11.02362, Texas Water Code). The scope of this charge suggests that certain analyses of alternative e-flow standards will be required to provide the BBASCs with information that can be useful in balancing the need for environmental flows within a river basin with the impacts of the different e-flow standards on the yield of proposed water supply projects. At the same time, it is also important to develop information describing streamflow variations and the extent to which they may provide protection of aquatic resources under conditions corresponding to different degrees of assumed water use. Tools for performing these evaluations include the state's Water Availability Models (WAM), and special purpose spreadsheets.

During the deliberations of the initial BBASCs for the Sabine-Neches and Trinity-San Jacinto basins, various efforts were made to analyze the impacts of the e-flow regime recommendations of the BBESTs on proposed water supply projects[1] and to examine streamflow conditions under varying levels of water use, including current conditions, with full utilization of existing water rights, and with proposed water supply projects implemented subject to prescribed e-flow requirements. Due largely to short time constraints dictated by the SB-3 schedule and the complexities of effectively representing the multi-tiered e-flow regime recommendations in the analysis methods, different approaches were employed with results sometimes questioned and/or not fully understood because of uncertainties regarding underlying assumptions and the actual analysis procedures employed.

Thus, it has become apparent to the Texas Environmental Flows Science Advisory Committee (SAC) that it would be helpful to undertake a special effort to investigate alternative methods for evaluating e-flow impacts on proposed water supply projects and, hopefully, to ultimately present a standardized approach that could be used in future e-flow impact analyses that may be undertaken by BBASCs in developing their standards recommendations[2]. These same procedures and methods also should be considered by the Texas Commission on Environmental Quality (TCEQ) in the balancing evaluations that it must perform pursuant to the development of final e-flow standards through rule making. This document specifically addresses the types of

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[1] In this document, proposed water supply projects include water supply strategies that may be included in Senate Bill 1 Regional Water Plans and water supply projects for which new permits and/or permit amendments may have been issued by the TCEQ on or after September 1, 2007.

[2] It is important to clarify that BBESTs may also find the use of the methods described in this document particularly useful. While BBESTs certainly should not be evaluating impacts of e-flow recommendations on firm yield, they must have an understanding of the flows that are likely to result from implementation of their recommendations in order to conclude that their recommendations maintain a sound ecological environment. Furthermore, the methods described herein provide time series information that may be particularly useful to BBESTs in formulation of estuarine inflow recommendations and performance of geomorphological overlays. For example, in the Nueces River basin, where zero flows occur for extended periods, time series may prove critical in the development of flow regime recommendations by the BBEST.

analyses that are likely to be required to effectively evaluate the impacts of the different or alternative e-flow recommendations as they might be imposed on proposed water supply projects within a particular basin and presents the general findings of analyses that have been undertaken of specific approaches that can be employed for this purpose. The balancing decisions required of the BBASCs and the TCEQ may also benefit by a more complete understanding of probable future flows in rivers and streams, including attainment frequencies of flow recommendations; hence, this document also provides guidance on analyses to assess effects of current and future levels of water use on instream flows.

The focus of this effort has been primarily on evaluating e-flow recommendations for protecting instream environmental uses in rivers and streams. While the methods considered could also be applied to evaluate the impacts of e-flow recommendations for bays and estuaries on proposed water supply projects, certain reprogramming and restructuring of the analysis methods would be required to effectively represent the important freshwater inflow elements for bays and estuaries.

2.0 STRUCTURE OF E-FLOW STANDARDS

The basic structure that has been assumed for an instream e-flow regime includes all of the fundamental flow components that previously have been identified as being important for supporting a riverine ecosystem (SAC, 2009), namely:

- minimum *subsistence flows* to maintain water quality criteria and prevent loss of aquatic organisms due to, for example, lethal high temperatures, low dissolved oxygen levels or loss of critical habitats;
- *base flows* representing the range of "average" or "normal" flow conditions in the absence of significant precipitation or runoff events that provide instream habitat conditions needed to maintain the diversity of habitats and resources that support native aquatic and riparian species;
- short duration, high magnitude, in-channel *high-flow pulses* that occur during or immediately following rainfall events and provide spawning cues and transport of eggs and larvae of fishes and aquatic invertebrates, as well as helping to maintain important physical habitat features and connectivity along a stream channel
- *overbank flows* consisting of infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain to maintain riparian habitat

For the evaluation of different methods for analyzing e-flow regimes, it has been assumed that different values of *subsistence flows* could be engaged *monthly or seasonally* at a particular location, along with up to three different levels of *base flows* for *four different seasons*, with each level corresponding to a low-medium-high or dry-average-wet hydrologic condition during each season. For the higher flow requirements, up to three *high-flow pulses* for each of *four different seasons* which may be associated with defined hydrologic conditions and/or *one annual or semi-annual high-flow pulse* have been assumed could be engaged. Additionally, *one overbank flow* of specified frequency may be included in a particular e-flow recommendation at a given stream location. These general flow requirements are depicted in the example of an e-flow regime matrix presented in Figure 1. This particular e-flow regime has been developed using historical daily streamflow records from the gage on the Nueces River below Uvalde, and it is presented for illustrative purposes only. This particular example does show how some components of an e-flow regime may be left unspecified in accordance with actual streamflow characteristics (i.e., no winter high-flow pulse requirement and only one high-flow pulse for the other seasons).

2.1 Frequency Requirements for E-Flow Components

The application of e-flow requirements pursuant to implementation of an e-flow recommendation at a particular location generally involves ensuring that the individual flow components are satisfied with certain prescribed frequencies of occurrence (frequency at which a given flow magnitude is equaled or exceeded over a long period of time subject to varying hydrologic conditions). These frequencies of occurrence are referred to as e-flow "compliance guidelines" or "attainment frequencies", and they may be included as part of the e-flow regime associated with an e-flow recommendation. Typically, these compliance guidelines have been assigned to specific flow components of an e-flow regime based on the frequency at which the prescribed flow magnitudes actually occurred during a particular defined historical period. As an example, in the flow matrix in Figure 1, the percentages in parentheses adjacent to the subsistence and base flow values represent these historical flow frequencies by season, and these frequencies could be assigned as the compliance guidelines for satisfying the subsistence and base flow requirements.

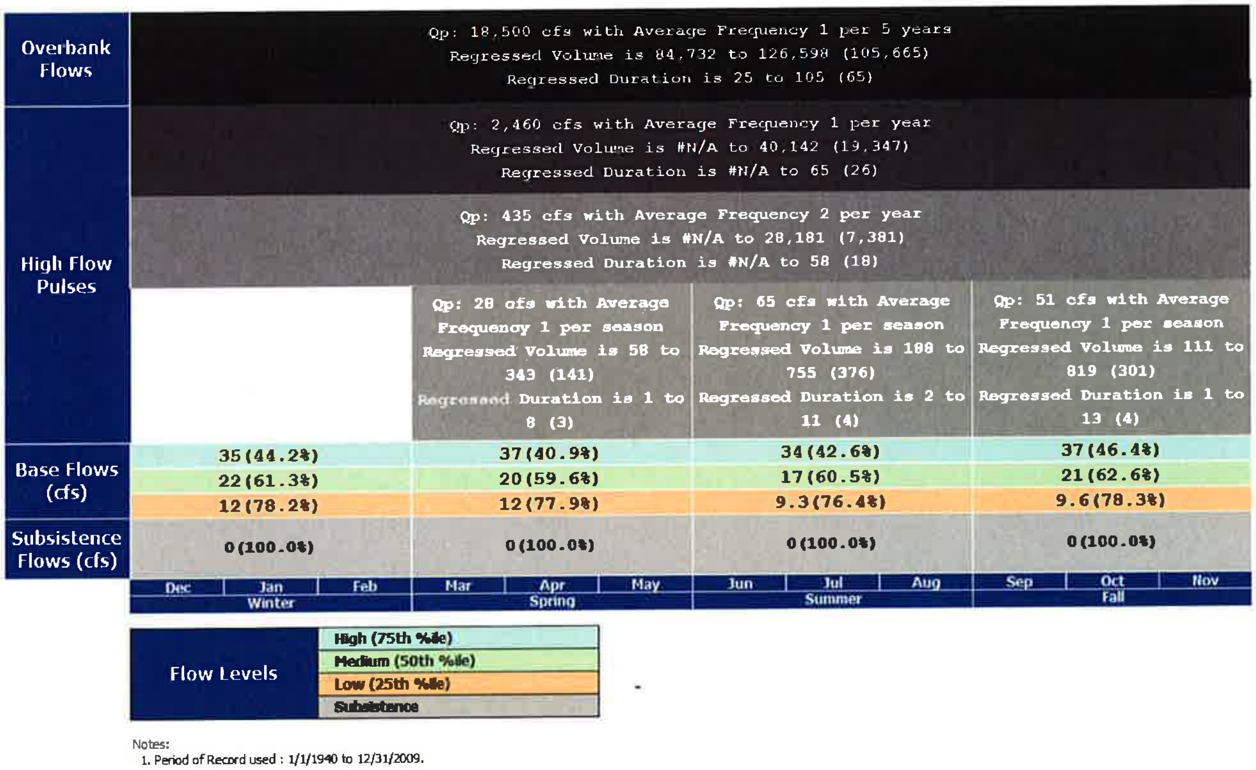

Figure 1 –Instream Flow Regime Matrix

While there may be a variety of ways for addressing how the compliance guidelines can be achieved as part of an implementation program for a particular e-flow recommendation, the procedures for the subsistence and base flow requirements generally are different from those applicable to the high-flow pulse and overbank flow requirements. For the subsistence and base flow requirements, which are characterized as minimum streamflow quantities expressed in cubic feet per second that must be passed downstream on a daily basis at a particular location before a new or amended upstream water right can impound or divert streamflow, the flow magnitude that has to be passed for satisfying the e-flow requirements is known in advance. Since the base-flow requirements can reflect different flow criteria depending on the hydrologic condition or state of the flow system, the existing hydrologic condition of the flow system, as determined by prescribed hydrologic indicators, also must be known for effective implementation of these particular e-flow components. For the high-flow pulse and overbank flow requirements, which generally are defined in terms of a certain volume of water over a specified period of days with a prescribed peak flow, the amount of flow that has to be passed downstream on any given day is dependent on how much flow has already been passed downstream on previous days during the current high-flow event, or even during the current season or year or past several years depending on the required attainment frequency. The important point to note here is that for subsistence and base-flow components, which are subject to daily compliance guidelines, the conditions for determining the magnitude of flow that must be passed in order to achieve stipulated attainment frequencies generally can be determined in advance, whereas for high-flow pulses and overbank flows, which are multi-day flow events with seasonal or annual compliance guidelines, the decision whether or not to pass such flows when they occur must be based on an analysis of the characteristics and frequency of antecedent daily flow conditions.

2.2 Definition of Hydrologic Conditions

As noted above, the matrix of an e-flow recommendation can include different levels of flow requirements for the base-flow and high-flow pulse components corresponding to different hydrologic conditions or states, typically referred to as low-medium-high or dry-average-wet conditions. Proper application of these flow components requires that there be specific rules for defining the hydrologic condition of a particular water body or flow system in order to know at all times which of the three levels of flow requirements currently is in effect.

While the definition and use of hydrologic conditions are essential and integral to the application of the base-flow components, they may or may not be necessary for implementing high-flow pulses depending on how a particular e-flow regime prescription is designed to function. For example, if the decision as to whether a particular current high-flow event has to be passed downstream is to be based solely on whether the attainment frequency for the currently effective high-flow pulse has been satisfied considering historical daily flows, then there is no need to develop hydrologic condition assignments for the different high-flow pulse components. This is the approach used by the Trinity-San Jacinto BBEST. However, if the e-flow regime prescription is designed whereby the different high-flow pulse components for a particular season are each associated with a particular hydrologic condition, then there must be some mechanism for determining hydrologic condition at all times, and the extent to which the achievement guidelines are satisfied for the different high-flow pulses based on previous historical flows is not considered as part of the actual application of the e-flow prescription. This latter approach was recommended by the Sabine-Neches BBEST using the combined storage in several reservoirs in the Sabine basin as the hydrologic indicator for defining dry-average-wet hydrologic conditions.

It should be noted that when implementing an e-flow regime the development of a mechanism for defining at any given time the hydrologic condition of a water body or flow system that effectively produces satisfactory achievement of the desired frequencies of occurrence for the high-flow pulse components is a very complicated, if not impossible task. Because of the episodic and variable nature of these flow events, it is very difficult to define accurate and meaningful hydrologic indicators that describe specific hydrologic conditions on a seasonal basis under which the prescribed individual high-flow pulses only occur, or even predominantly occur. This is why the hydrologic indicators determined for the different base-flow components of an e-flow regime often are used to also define the hydrologic conditions for high-flow pulses, but this is more of a matter of convenience rather than an accurate reflection of the conditions under which the high-flow pulse events actually occur. Aside from using the base-flow hydrologic triggers for defining high-flow pulse hydrologic conditions, using the approach whereby the decision as to whether a particular high-flow event has to be passed downstream is based solely on whether the attainment frequency for the currently effective high-flow pulse has been satisfied by the historical daily flows is considered the most reasonable and straightforward for implementing the high-flow pulse components of an e-flow regime. This, of course, avoids having to undertake a complicated investigation to attempt to define meaningful high-flow pulse hydrologic triggers for designating different hydrologic conditions.

For purposes of implementing the base-flow components of an e-flow recommendation, it is possible to predefine hydrologic conditions based on hydrologic triggers that effectively establish at any given time the particular hydrologic state of a water body or flow system. Ideally, a set of three hydrologic triggers would be used to define the three different hydrologic conditions (low-medium-high or dry-average-wet) associated with each of the three levels of flow requirements for base flows for each season, resulting in a total of 12 triggers. As a starting point, each of these hydrologic triggers can be derived by determining the magnitude of a particular hydrologic indicator, such as actual reservoir storage or antecedent streamflow volume over a prescribed time period (previous week, month or several months), that has the same frequency of occurrence as the compliance guideline for a particular base-flow component. To simplify implementation, however, it may be reasonable in many cases to use the annual average of all of the seasonal base-flow compliance guidelines for each hydrologic condition as the frequency basis for establishing the magnitude of the corresponding trigger for each hydrologic indicator (resulting in only three triggers). Using this simplification depends, of course, on the relative magnitudes of the individual seasonal compliance guidelines for each hydrologic condition. Still, assuming that the deviation among these seasonal compliance guidelines is not more than about 15 or 20 percent, the degree of accuracy lost relative to the level of complication required to implement the more complex system of seasonally-varying hydrologic triggers for a real e-flow regime application may not be that significant.

The result of the above process is a set of at least three hydrologic triggers each keyed to a specific indicator of the hydrologic condition of a water body or flow system that is hydrologically related to the river or stream for which e-flow requirements are being implemented. For example, if several existing reservoirs are located upstream or in the vicinity of the location where an e-flow recommendation or group of recommendations is to be implemented, the combined storage of these reservoirs at the beginning of each season could serve as the hydrologic indicator for each season, with three different levels of this combined storage used as the triggers for establishing the hydrologic condition or state (low-medium-high or dry-average-wet) of the overall system. Similarly, the antecedent flow volume for several months prior to the beginning of an e-flow season also could be used. In the simplified approach described above, the frequencies of occurrence of these three storage trigger levels would be equal to the seasonally-averaged compliance guidelines for the three sets of base-flow requirements corresponding to the different hydrologic conditions.

When developing the triggers for the hydrologic indicators, it is important to select an indicator parameter that is expected to vary in a manner similar to the hydrologic condition of the river or stream segment for which a specific e-flow standard applies. For consistency, it is important that the period of record used to calculate frequencies of occurrence for the hydrologic indicators generally be similar in length to the period of hydrologic record being used to perform the impact analyses of the e-flow recommendations.

It is also important to recognize that using the frequency of occurrence of a hydrologic indicator as the basis for establishing the hydrologic trigger for defining the hydrologic conditions (low-medium-high or dry-average-wet) associated with prescribed base-flow requirements does not necessarily ensure that the desired achievement guidelines will be satisfied. Typically, with this approach, as the flow magnitudes for the different base-flow prescriptions increase in accordance with hydrologic condition, i.e., from dry to average to wet, it may be less likely that the recommended achievement guidelines will be fully satisfied. This occurs because the frequencies of occurrence of the hydrologic indicators reflect all daily flows that occurred under all hydrologic conditions (dry, average, and wet) during a particular season, not just the daily flows that occurred during a particular hydrologic condition. Therefore, when actually applying a particular e-flow regime, if the decision to pass a particular base-flow quantity is limited to consideration of only those days when its associated hydrologic condition is in effect, it is likely that other days with flows that exceed the particular base-flow quantity will be excluded from consideration for passage because they fall outside the associated hydrologic condition. For example, for a particular season, while the "wet" base-flow requirement is engaged only when the trigger for the hydrologic indicator indicates that "wet" conditions are occurring, qualifying "wet" flows may also occasionally occur during periods classified as either "average" or "dry" hydrologic conditions, and these "wet" flows would not be required to be passed since the "wet" hydrologic condition is not engaged; instead they could be diverted or impounded subject to the effective "average" or "dry" base-flow requirement. This means that these excluded "wet" flows do not contribute toward satisfying the "wet" flow achievement guideline, and it is likely that the actual frequency of occurrence of "wet" flows that were actually passed downstream will be less than the prescribed attainment frequency. The degree to which such deviations may occur can be evaluated as part of the analysis of applying an e-flow recommendation, or set of recommendations, to proposed water supply projects. To minimize such deviations, where seasonal attainment frequencies are explicitly defined for base flows as part of a particular e-flow regime prescription, an iterative approach to developing hydrologic triggers designed to more closely satisfy the desired attainment goals might be necessary.

One other point to note with regard to the application of multi-tiered e-flow regimes pertains to the fact that the compliance guidelines for the base-flow components normally are always less than 100 percent, which means that the hydrologic indicators for engaging these e-flows, if properly determined and selected, will cause these different base-flow components to be engaged only part of the time. The same thing can be true for subsistence flows as well (note that the Trinity-San Jacinto BBEST recommended subsistence flow quantities with compliance guidelines less than 100 percent). The issue that arises here is: when a particular base-flow level is in effect in accordance with a specified hydrologic condition and the actual flow in the stream is less than the effective base flow value, should flows in excess of the next lower level of base flow be allowed to be impounded or diverted by a water supply project or should the entire amount of streamflow be passed downstream, since it does not satisfy the effective base-flow requirement? The Sabine-Neches BBEST assumed that when this situation occurs with respect to the lowest level of base flow, then flows in excess of the lower subsistence flow level could be impounded or diverted, but for the medium and high base-flow levels, no impoundment or diversion would be allowed. The Trinity-San Jacinto BBEST recommendations stipulate that subsistence flows do not have to be satisfied 100 percent of the time, and there have been interpretations put forth that suggest all streamflow could be fully impounded or diverted when the subsistence flow requirement is not engaged (as well as none of the other e-flow components). For purposes of the analyses presented herein, the assumption regarding the Sabine-Neches BBEST's application of the subsistence flow requirement has been maintained for the evaluation of e-flow impacts on projects located in these particular basins, but for all other applications of e-flow regimes to proposed water supply projects outside the Sabine and Neches basins, it has been assumed that the impoundment or diversion of streamflows would be allowed only to the extent that the streamflows exceed the particular e-flow requirement that is currently engaged. Hence, when the streamflow is less than the particular e-flow requirement that is currently in effect, the entire amount of streamflow is passed downstream.

3.0 POST PROCESSING OF WAM FLOWS FOR E-FLOW COMPLIANCE

One question that arises when deliberating the adequacy of a particular e-flow regime for protecting the environmental resources of a particular stream or stream system is the extent to which the prescribed flow components of a particular e-flow regime are actually satisfied for a given set of streamflows that reflects a certain condition of water rights utilization. Answers to this question are particularly important to a BBASC when considering altering the e-flow regimes recommended by their BBEST in an attempt to balance available water supplies used to meet environmental flow needs with other needs for water, including human consumption. The flows used to perform these analyses typically must come from a water availability simulation using one of the existing WAMs, or some variation thereof, that has been developed for the different river basins of the state.

3.1 Existing Versions of WAMs

Different versions of WAMs typically are available for all of the river basins in the state. The TCEQ maintains official versions referred to as Run 3 and Run 8 for all basins. These versions of WAMs are used by the TCEQ for evaluating the availability of water as part of its analysis of applications for proposed new appropriations of water or amendments to existing water rights. In the Run 3 version, all existing water rights are exercised with their full authorized values specified for annual diversions and reservoir storage, and return flows are not included. The Run 8 version is considered to represent current conditions with regard to water rights activity. In Run 8, the annual diversion amount for each water right is set equal to the maximum quantity actually reported as having been diverted during the last 10 years or so, the maximum storage capacity of reservoirs is adjusted to reflect sedimentation conditions as of around the year 2000 (or adjusted to reflect the Texas Water Development Board's most recent survey), and return flows are included using the minimum monthly discharges for each month for a five year period.

The Run 3 version of the WAM is the model that TCEQ would use to evaluate water availability for a new water supply project to determine if sufficient unappropriated water exists to support issuance of a permit for the project after all existing senior water rights have been fully exercised. Hence, the Run 3 WAM is an important model to use for investigating e-flow recommendations. While the Run 8 versions do not provide information regarding the actual permitability of a proposed water supply project, results from this current conditions model with proposed projects implemented with different prescriptions for e-flow requirements can be very useful when considering the more near-term impacts (10 to 20 years out) of these projects on streamflows. Such information could indicate that a certain level of e-flow prescription could be adequate for environmental purposes over the next several years or decades with a particular proposed water supply project operating at a prescribed delivery capacity, but as overall demands for water increase and streamflows become diminished, the e-flow requirements for the project may need to be adjusted, causing the initial delivery capacity of the project to be reduced in accordance with special conditions stipulated in its underlying water right. In summary, both the Run 3 and the Run 8 versions of the WAMs can provide useful information regarding the extent to which recommended e-flow regimes may be satisfied and the impacts of e-flow requirements on proposed water supply projects, and both should be considered when developing information for the BBASCs to evaluate as part of their balancing of e-flow requirements with other needs for water.

The Texas Water Development Board (TWDB), through the Senate Bill 1 regional water planning program, has developed various versions of WAMs that incorporate one or more of the water supply strategies recommended by the Regional Water Planning Groups. In some cases, the Regional Water Planning Groups themselves have developed WAMs for their respective planning areas and basins that incorporate their recommended water supply strategies. Collectively, these versions of the WAMs have been referred to as Run 9. Typically, these models are based on either the Run 3 or the Run 8 versions of the TCEQ WAMs, with the annual diversions and the reservoir capacities associated with existing water rights adjusted to represent future conditions corresponding to a particular future decade within the current Senate Bill 1 planning horizon, i.e., out to the year 2060. Again, these models can be useful for examining future streamflow and water supply conditions with different e-flow recommendations engaged as demands change over the next several decades. Recent experience (Trinity-San Jacinto basin) has indicated that the available Run 9 versions of the WAMs typically have not included the most recently issued water rights and therefore generally must be updated to be consistent with the TCEQ's Run 3 and Run 8 versions of the model. Another issue with some Run 9 versions (derived from current-condition Run 8 models) is that the diversion amount for large run-of-river water rights is reduced to reflect the firm yield of that right. When there is a substantial difference between the calculated firm yield and the actual current use of a particular water right, a Run 9 version with the reduced yield-based demands could overestimate the frequency with which environmental flow recommendations could actually be met.

3.2 Analysis of Existing TCEQ WAM Flows for E-Flow Compliance

As a first cut, it is particularly informative to know how well the simulated flows from the Run 3, and/or Run 8 versions of a WAM satisfy the prescribed attainment frequencies of the flow components of the BBEST's recommended e-flow regimes. For example, if analysis of the regulated flows from a WAM Run 3 simulation indicates that these flows, with all existing water rights engaged as authorized, are substantially in compliance with the attainment frequencies of a particular e-flow prescription, then it is possible that some water may be available to support a new appropriation for a proposed water supply project subject to the same e-flow requirements. Conversely, if the analysis of regulated flows from a WAM Run 8 current-conditions simulation demonstrates substantial non-compliance with the prescribed attainment frequencies, there is a strong likelihood that there would be very little water available for a new project. Such information would be useful to the BBASCs in their deliberations trying to balance available water for environmental flow purposes with other needs for water.

Since the simulated flows from a WAM are monthly quantities, the translation of the WAM monthly flows to daily flows is considered desirable and maybe even necessary in order to make a meaningful evaluation of whether compliance guidelines are met for a particular e-flow component since daily flow variations can significantly affect whether or not a particular e-flow component is satisfied. The translation of WAM monthly flows to daily flows for checking whether compliance guidelines are met is normally accomplished using the daily flow distributions embedded in historical streamflow records for measured flows from nearby gages considered appropriate for this purpose. In this process, it is important to use streamflow records that are most likely to reflect the hydrologic characteristics of the flow conditions simulated by the WAM at the location where the flows are being translated, which can be a significant challenge in a highly regulated river basin.

Once the monthly flows from the WAM have been distributed to daily values at all of the locations where e-flow regimes are available, the analysis of these daily flows to determine compliance with each of the e-flow components in a regime can be accomplished in a fairly straightforward manner using a spreadsheet. With the daily flows listed in chronological order usually beginning on January 1, 1940 for flows simulated with a WAM, checks for compliance can be made by simply comparing the daily flow values to the stipulated magnitudes of the e-flow components.

For subsistence flow and the different levels of base flow, these daily flow comparisons are relatively simple, except that they usually must be performed by season in accordance with the underlying e-flow prescription. Once the number of days that satisfy each of the prescribed subsistence and base flow components has been determined for the entire period of record of WAM simulated flows, then the frequency of occurrence for satisfying the flow criteria can be calculated for each flow component and checked for compliance against the corresponding attainment frequency of the underlying e-flow prescription. Again, these analyses normally must be performed in accordance with the defined seasons associated with a particular e-flow prescription.

Checking compliance for high-flow pulses and overbank flows is more involved because these e-flow components include, in addition to peak flow, the volume and duration of flow extending over several days as part of their basic definition. A relatively simple and practicable way to deal with determining these quantities for a flow record is to use the approach applied in the HDR Spreadsheet, which is described in Section 5.2.1. With this approach, once the stipulated peak flow for a particular pulse or overbank flow prescription occurs in a daily time series flow record, the high-flow event is assumed to be initiated and then continued either for the remaining days of the prescribed e-flow duration or until the prescribed e-flow volume is satisfied. While it is recognized that this procedure does not conform to the manner in which the pulse and overbank flow components of an e-flow regime were likely derived (assuming a more comprehensive and complicated hydrograph separation technique was employed when developing the underlying e-flow prescription), it nonetheless has proven to be useful. Furthermore, it should be noted that using the peak-flow day as the day for defining the beginning of a qualifying high-flow pulse event and continuing the high-flow event for either the remaining days of the prescribed e-flow duration or until the prescribed e-flow volume is satisfied likely precludes certain flow-days prior to the peak-flow day from being included in the pulse accounting, even though they likely satisfy the criteria used in developing the original high-flow pulse requirements. Typically, there could be one or two days of ascending flows prior to the peak-flow day on mainstem river segments that also would qualify as part of a high-flow event based on its original derivation. While this approach does introduce some inconsistency in the transition from a base-flow condition to a high-flow pulse or overbank flow event, and vice versa, this inconsistency probably doesn't make much difference in the overall accounting of the occurrence of the different high-flow events or in their likely ability to support certain ecological functions.

Another approach for defining high-flow pulse and overbank flow events is to consider all of the daily flows with magnitudes greater than a specified base flow value that occur on either side time wise of the first day that the flow satisfies the peak flow prescription. This designated base flow can be selected based on the hydrograph separation results from which the underlying e-flow regime was originally developed or simply by referring to the prescribed base-flow values comprising the prescribed e-flow regime. The group of qualifying daily flows then can be summed to check for volume compliance and further analyzed to check for duration compliance. Finally, as the TWDB has done for its analyses of e-flow compliance for the Trinity-San Jacinto BBEST e-flow recommendations, the record of daily flows can be input to a hydrograph separation computer program such as the IHA or the Base Flow Index (BFI) Method of the U.S. Bureau of Reclamation to define individual high-flow events using the same criteria and seasons that were applied when the underlying e-flow regime was originally developed. The frequency of occurrence of the different qualifying high-flow events then can be determined and checked for compliance against the corresponding event frequencies stipulated in the underlying e-flow prescription. While application of the hydrograph separation programs should provide information that is more consistent with the procedures employed in developing the underlying e-flow regime prescriptions, the level of precision gained in terms of identifying all of the qualifying high-flow events for the different pulse and overbank flow components may not substantially improve the results from the simpler and more straightforward spreadsheet methods described above, and certainly, the application of hydrograph separation programs is a less practicable approach for identifying qualifying high-flow events than either of the other methods for real world applications of actual e-flow recommendations[3].

The end result of all of these compliance analyses can be summarized in a simple table of compliance frequencies organized by individual e-flow component, with the stipulated compliance guidelines (or attainment frequencies) for the underlying e-flow components noted for comparison. This information should be useful to the BBASCs in their deliberations trying to balance e-flow requirements with other needs for available streamflows.

3.3 Analysis of WAM Flows With Proposed Water Supply Projects

Proposed water supply projects can be incorporated into any of the existing WAM versions available from the TCEQ, i.e., Run 3 or Run 8 models, or they can be analyzed using one of the TWDB's WAM Run 9 models under demand and reservoir sedimentation conditions corresponding to a future decade of the regional water planning horizon. Once the new water supply projects are properly represented in the WAMs, then the particular e-flow requirements that are to be imposed on the new projects must be specified and reflected in the WAM data files. Procedures for undertaking this work, either within the WAM simulation or external to the WAM simulation, are described in the next section of this document. The final phase of this effort is to operate the WAMs to simulate the operation of the new projects with the e-flow requirements engaged. The simulated flows from the WAM simulations with the new water supply projects in operation then can be analyzed to assess their compliance with the stipulated attainment frequencies associated with the recommended e-flow regimes at their respective

[3] It should be noted that the pending draft permit for the Brazos River Authority's System Operations Water Use Permit, which reflects a negotiated settlement among the Brazos River Authority and the TPWD and now is being formally protested by other parties, includes specifications for defining high-flow events that are consistent with the parameters used in applying hydrograph separation technique.

locations. Again, these results can be summarized in a simple table of compliance frequencies, with the stipulated compliance guidelines (or attainment frequencies) for the underlying e-flow components noted for comparison.

It is important to note that distributing monthly WAM flows to daily values using historical daily streamflow data inherently assumes that the diversion and impoundment of water by future water supply projects will not alter the daily pattern of flows that occurred historically. Certainly, this is not likely the case. Because of these inaccuracies, for the analysis of the impacts of a proposed future project on instream flows, it may be advantageous to use the HDR Spreadsheet method alone (see Section 5.2.1) and statistically analyze the predicted daily flows directly, although such analyses can only be performed at the location of the proposed project and not at a downstream location where one or more prescribed e-flow regimes or standards may actually apply. At the present time, this is only feasible for evaluating the impacts of a single project.

4.0 GENERAL PROCEDURES FOR E-FLOW IMPACT ANALYSES

The ability of a proposed water supply project to produce a usable supply of water for a particular use or group of uses is dependent upon the availability of streamflows at its respective location. This availability, of course, is hydrology driven, but often it can be significantly affected by other water users or uses with more senior priorities (water rights), particularly during low-flow periods when flows are limited such that all demands for water cannot be satisfied with available streamflows. The TCEQ's Water Availability Models (WAM), which have been developed for all of the Texas river basins, are specifically designed and structured to make such water availability determinations, taking into consideration actual hydrologic variations over long periods of time (~60 years) and the diversion/impoundment authorizations, priorities, and special conditions associated with all existing water rights.

The existing WAMs would be the modeling tool of choice for performing evaluations of the impacts of e-flow recommendations on proposed water supply projects except for one potentially significant drawback. The existing WAMs use a one-month time step to perform simulations of water availability, whereas the development and implementation of the various components of an e-flow regime are related to and associated with, to a large extent, daily fluctuations in streamflow. While WAMs using a daily time step are being considered for development by the TCEQ and one test case for the Brazos basin currently is being evaluated, there are no existing daily WAMs available that incorporate the various multi-tiered e-flow components and the procedures for applying these e-flow requirements to specific water supply projects. This situation has dictated that the current evaluation of the impacts of e-flow recommendations on proposed water supply projects be performed either: (1) using the existing WAMs directly with the various e-flow components analyzed within the WAM simulations and represented as monthly instream flow requirements at their respective stream locations, or (2) by extracting simulated monthly flows from the WAMs and then either using these directly or translating them to daily values for application and analysis of the e-flow regime requirements, which finally are applied either as monthly instream flow requirements at multiple locations for multiple proposed water supply projects within WAM simulations or as daily e-flow pass-through requirements in a daily spreadsheet analysis of the operation of a single proposed reservoir or water supply project. Both approaches can produce meaningful results, and certainly both have their limitations.

4.1 Direct Application of Monthly WAMs

The primary advantage of using the WAMs directly to evaluate the impacts of e-flow recommendations on proposed water supply projects is that the available streamflow for one or more specific proposed projects can be simulated in accordance with TCEQ permitting and analysis practices while subjecting the proposed projects to prescribed e-flow recommendations at one or more locations within a basin simultaneously. This is the likely approach for how the SB-3 e-flow standards will be applied once they are adopted and implemented by the TCEQ. Other approaches may involve the application of only one or two e-flow recommendations to a single water supply project, or possibly the translation of a particular e-flow recommendation from the location at which it was developed to a specific project location. Regardless, all of these scenarios can be represented and analyzed with the existing WAMs, albeit only on a monthly basis.

The main disadvantage, of course, relates to whether a particular e-flow recommendation with multi-tiered daily, monthly and/or seasonal flow components can be adequately represented using monthly flow volumes as simulated with the existing WAMs. In effect, this approach requires that all components of an e-flow regime be represented as monthly flow volumes in the WAMs. For example, a daily base-flow requirement of 10 cfs must be converted to the monthly quantity of 595 acre-feet, which then becomes the corresponding base-flow requirement in a WAM for the entire month. Certainly, there are circumstances where the flows on some days during a month would satisfy the daily e-flow requirement and consequently allow streamflows to be diverted by a proposed water supply project, whereas the total volume of flow for that same month may not be sufficient to satisfy the monthly volume equivalent of the particular e-flow component, thus disallowing flow diversions for the entire month in a monthly WAM. Conversely, if extremely high flows occurred only for a few days during a month but with enough volume to satisfy a monthly e-flow requirement, a monthly WAM could allow a proposed water supply project to divert more water than it otherwise could on a daily basis with a limited diversion rate. Also, while the volume requirement for a high-flow pulse certainly can be compared to a monthly flow volume within a WAM simulation, the peak flow requirement for the pulse cannot be evaluated.

The extent to which such inconsistencies may actually occur in a particular system is not known, but it is likely they occur with no discernable pattern within a basin and with considerable variation among basins. Such inconsistencies could be analyzed and quantified using historical daily flows from a particular streamflow gage, but these results would likely apply only to the particular data base examined and may not reflect future flow conditions after being altered by future water use changes and water resource development. Even with the disadvantage of a monthly time step, the use of the existing monthly WAMs to examine the relative impacts of different e-flow regimes on the water supply capabilities of proposed projects should be an important aspect of the overall evaluation of alternative e-flow recommendations, and such results should be useful to the BBASCs during their deliberations to develop recommendations for e-flow standards.

The difficult part of applying the WAMs directly to evaluate the water supply impacts of different e-flow regimes is not the actual operation of the models, but rather the coding of the input data in a way that allows the various components of a multi-tiered e-flow recommendation to be effectively represented and accounted for in a WAM simulation. At the present time, the only available version of such modeling is the WAM coding developed specifically for this investigation by Kirk Kennedy for purposes of evaluating e-flow prescriptions for specific water supply projects in the Sabine and Brazos basins. Recently, Dr. Ralph Wurbs of Texas A&M University released a new version of the Water Rights Analysis Package (WRAP) program (2010), which is the underlying computer program upon which all WAMs are constructed, that includes several new features specifically designed to more efficiently represent e-flow components in the WAMs. These features generally build on the applications such as those described above. Specifically, these features allow representation of seasonal and multi-year e-flow requirements, as well as incorporate coding efficiency into representation of pulse flow requirements. Information from actual applications of these new features to represent complex e-flow recommendations in WAM simulations is not currently available.

The steps involved in applying WAMs directly to evaluate the water supply impacts of alternative e-flow standards are relatively straightforward and generally involve the same procedures used to analyze any water supply project with a WAM. They include:

1) Select the proposed water supply projects to be evaluated in a particular river basin.

2) Select the WAM version (Run 3, Run 8, etc.) to be used for the impact analyses.

3) Establish the water rights priorities for the proposed water supply projects being evaluated based on expected permitting and implementation schedules for the projects.

4) Code into the WAM data input files the appropriate representations for the proposed water supply projects to be evaluated, i.e., annual diversion amounts, types of use, reservoir area-capacity data, maximum conservation storage capacities, etc..

5) Code into the WAM data input files the appropriate representations for the e-flow recommendations to be evaluated, i.e., monthly, seasonal and/or event e-flow magnitudes and frequency requirements. This is the step that is new to the WAM approach developed by Kirk Kennedy.

6) Operate the WAM and calculate diversion reliability statistics and firm annual yield for the proposed water supply projects for the following e-flow conditions, to the extent are appropriate for the particular analyses:

   a. No e-flow standards or restrictions implemented
   b. With Lyons e-flow restrictions implemented for each individual proposed water supply project
   c. With Consensus Planning Criteria e-flow restrictions implemented for each individual proposed water supply project
   d. With subsistence and base-flow components of e-flow standards implemented at all locations where available
   e. With subsistence, base-flow and high-pulse components of e-flow standards implemented at all locations where available
   f. With subsistence, base-flow, high-pulse and overbank flow components of e-flow standards implemented at all locations where available

   Alternatively, the WAM can be operated for the same e-flow conditions to simulate the proposed water supply projects with their annual diversions set equal to fixed desired annual demand amounts rather than their firm yield amounts.

7) Repeat Steps 4, 5 and 6 for alternative or modified water supply project definitions and or e-flow recommendations.

8) Review and summarize results from all WAM simulations for all e-flow recommendations considered and for all proposed water supply projects analyzed considering:

- Firm annual yield of projects
- Maximum and minimum monthly/annual supplies with authorized diversions
- Diversion frequency statistics
- Monthly and annual period reliability of diversions
- Average volume diversion reliability

4.2 External Processing of WAM Flows for E-Flow Impact Analyses

External processing of monthly flows simulated with a WAM to assess the impacts of e-flow recommendations on proposed water supply projects allows daily variations in the flows to be considered for purposes of representing and quantifying e-flow requirements, even though the analysis of the flow availability for a particular project is still limited monthly flow variations. Of course, it is also possible to simply perform the external analyses of e-flow requirements using monthly flows from a WAM without any conversion to daily quantities, an approach that would appear to have little merit with the availability of a monthly WAM capable of directly and internally representing the different components of multiple e-flow recommendations as noted in Section 4.1 above and described in Section 5.2.5.

Regardless of whether daily or monthly flows are used in the analyses to determine e-flow requirements and their potential impacts on proposed water supply projects, the fact that these sets of flows are based on flows simulated with a WAM means that the conditions and assumptions included in the underlying WAM simulation are embedded in the simulated flows (and in the derived e-flow requirements) and cannot be changed without a re-simulation of the WAM with different conditions and assumptions specified. Hence, if changes should be made in a particular WAM as a result of permitting actions or updates to the flow sequences, then the previously determined e-flow requirements created for this analysis would not be accurate and possibly would need to be updated to reflect the changed flow conditions. While this may not occur often, it is important to recognize that such changes occasionally are made by the TCEQ and would need to be addressed with regard to application of previously determined WAM e-flow requirements for future applications. This issue is avoided with the direct application of a WAM that represents both the e-flow prescriptions and new water supply projects in the same simulation as noted in the previous section, but, again, at the present time this type of WAM application is limited to considering only monthly flows for representing and quantifying the different components of a recommended e-flow regime or standard.

External Processing of WAM Flows with Return to WAM for Water Supply Impacts Analysis

The basic steps involved in evaluating the impacts of different e-flow requirements on the water supply capabilities of one or more proposed projects generally include the following:

1) Select the proposed water supply projects to be evaluated in a particular river basin.

2) Select the WAM version (Run 3, Run 8, etc.) to be used for the impact analyses.

3) Select the stream locations with available e-flow recommendations that can be applied to the selected proposed water supply projects.

4) Extract from the WAM the time-series of simulated monthly "regulated" flows at each of the locations where e-flow recommendations are available and are to be applied to the selected proposed water supply projects – these regulated flows represent the total flows passing each of the locations.

5) Distribute the monthly values of regulated flows at each location to daily quantities using either historical daily streamflow patterns for each month from nearby and appropriate gages for the same period of record used in the WAM or other sets of daily natural flow patterns if available.

6) Establish the monthly and/or seasonal hydrologic conditions of the stream system for the same period of record as the WAM using for the hydrologic indicator either antecedent monthly regulated flows at one or more locations or reservoir storage for one or more reservoirs as simulated with the WAM, with triggers appropriately determined through frequency analysis using the prescribed annually-averaged compliance guidelines – values of 1, 2 or 3 should be assigned to each month of the period of record to designate a hydrologic condition corresponding to either low-medium-high or dry-average-wet, respectively.

7) Using the daily streamflows from Step 4 for each location with an e-flow recommendation and the hydrologic condition definitions from Step 5, analyze the relevant components of the e-flow recommendation relative to the daily regulated flow to determine the total flow magnitude that must be passed downstream on a daily basis to satisfy the e-flow requirements – usually this daily time series of calculations over the entire WAM simulation period can best be performed in a spreadsheet. Daily e-flow pass-through requirements should be determined as separate quantities for the following e-flow conditions:

   a. With both subsistence and base-flow components in effect
   b. With subsistence, base-flow and high-pulse components in effect
   c. With subsistence, base-flow, high-pulse and overbank (if available) flow components in effect
   d. With Lyons e-flow restrictions implemented
   e. With Consensus Planning Criteria e-flow restrictions implemented

8) Sum all daily e-flow pass-through requirements into monthly values for the WAM simulation period.

9) Code into the WAM data input files the appropriate representations for the proposed water supply projects to be evaluated, i.e., annual diversion amounts, types of use, reservoir area-capacity data, maximum conservation storage capacities, etc..

10) Copy into the WAM data input files the monthly time series of e-flow pass-through requirements as generated in Step 8 and code into the data files specifications for corresponding instream flow requirements.

11) Operate the WAM and calculate diversion reliability statistics and firm annual yield for the proposed water supply projects for the following e-flow conditions:

    a. With no e-flow requirements or restrictions implemented
    b. With subsistence and base-flow components of e-flow standards implemented at all locations where available
    c. With subsistence, base-flow and high-pulse components of e-flow standards implemented at all locations where available
    d. With subsistence, base-flow, high-pulse and overbank flow components of e-flow standards implemented at all locations where available
    e. With Lyons e-flow restrictions implemented for each individual proposed water supply project
    f. With Consensus Planning Criteria e-flow restrictions implemented for each individual proposed water supply project

    Alternatively, the WAM can be operated for the same e-flow conditions to simulate the proposed water supply projects with their annual diversions set equal to fixed desired annual demand amounts rather than their firm yield amounts.

12) Repeat Steps 6 through 11 for alternative or modified e-flow recommendations or water supply project definitions.

13) Review and summarize results from all WAM simulations for all e-flow recommendations considered and for all proposed water supply projects analyzed considering:

    - Firm annual yield of projects
    - Maximum and minimum monthly/annual supplies with authorized diversions
    - Diversion frequency statistics
    - Monthly and annual period reliability of diversions
    - Average volume diversion reliability

To date, there are two spreadsheets that have been programmed to perform the daily e-flow analyses required in Step 7 above. One was developed by the TWDB (2009) for the initial analyses of e-flow recommendations from the Trinity-San Jacinto BBEST (See Section 5.2.3), and the other was developed by HDR Engineering (See Section 5.2.1) and used to examine the impacts of the Sabine-Neches BBEST e-flow recommendation for Big Sandy Creek on the proposed Big Sandy Reservoir in the Sabine basin (Sabine-Neches BBEST, 2009)[4].

Given the proper input data with appropriate assumptions, both of these spreadsheet methods can be used to provide reasonable approximations of the daily e-flow pass-through requirements at a particular location based on a specific e-flow recommendation. It should be noted that the current version of the HDR Spreadsheet does not consider overbank flow requirements; the TWDB Spreadsheet does. The output from both the TWDB and the HDR Spreadsheets consists

[4] Provided via personal (email) communication of 6/9/2010 from Sam Vaugh to Bob Brandes, Kathy Alexander, and Ruben Solis.

of a set of daily e-flow pass-through requirements for the duration of the period of record used in WAM simulation. These daily e-flow pass-through requirements apply at the particular location (probably at a streamflow gage) where the underlying e-flow recommendation was originally developed. To assess the impacts of these e-flow pass-through requirements on multiple proposed water supply projects, they must be input back into the WAM and represented as instream flow requirements at their associated stream locations. The modified WAM then can be operated with the proposed water supply projects included to estimate the resulting water availability for this specific analysis.

AECOM (2010) also has developed a spreadsheet approach for analyzing and determining e-flow pass-through requirements using monthly simulated flows from the WAM and multi-tiered e-flow prescriptions. This spreadsheet was developed to analyze the impacts of e-flow recommendations from the Sabine-Neches BBEST on the firm yields of Big Sandy Reservoir and Toledo Bend Reservoir. The spreadsheet performs all calculations of e-flow pass-through requirements using only monthly flow quantities; the different component flows of an e-flow regime are converted to monthly volumes for this purpose. Once the e-flow pass-through quantities are determined with the spreadsheet, they are read in as input data to the WAM. The WAM then is operated with these e-flow pass-throughs imposed on specific water supply projects as instream flow requirements at the specific locations of the e-flow recommendations, and the impacts of these pass-through requirements on project yield can be evaluated. Since the AECOM approach uses only monthly flow quantities, and not daily, to assess e-flow impacts on proposed water supply projects, its results should not differ appreciably from those generated directly by coding the e-flow recommendations directly into the WAM, assuming similar data inputs and assumptions.

External Processing of WAM Flows Without Return to WAM for Water Supply Impact Analysis

E-flow impacts on a proposed single reservoir or diversion also can be examined directly with the HDR e-flow spreadsheet without requiring re-running of the WAM; however, this type of analysis currently is limited only to situations where there is a prescribed e-flow regime at the location of the proposed project. As part of its normal calculations, the HDR Spreadsheet simulates the behavior of a prescribed reservoir with a specified daily diversion subject to the calculated daily e-flow pass-through requirements, again assuming that these e-flow requirements apply immediately downstream of the reservoir itself. This means that an e-flow regime prescription must be available for the stream generally at or downstream of the reservoir.

As with the WAM, to simulate a reservoir with the spreadsheet, the area-capacity table for the impoundment must be specified along with the maximum conservation storage capacity. Also, the daily net evaporation rate for the reservoir must be included as input data – usually monthly values of this quantity are specified as uniform daily values for each month of the entire simulation period. For a proper representation of the daily inflows available for storage in the reservoir, the daily flow pass-throughs necessary to satisfy all downstream senior water rights also must be accounted for. These pass-through quantities can be derived from the simulated monthly flows from the WAM, with all calculations made at the location of the proposed reservoir.

The specific procedures for applying the HDR Spreadsheet (instead of using the WAM) to analyze the impacts of an e-flow recommendation on the potential ability of a proposed reservoir to produce a firm water supply are identical for Steps 1 through 3 above; however, the procedures begin to differ starting with Step 4. The steps are as follows:

1) Select the proposed water supply projects to be evaluated in a particular river basin.

2) Select the WAM version (Run 3, Run 8, etc.) to be used for the impact analyses.

3) Select the stream locations with available e-flow recommendations that can be applied to the selected proposed water supply projects.

4) Extract from the WAM the following time-series of simulated monthly flows at the location of the proposed reservoir:

    a. "Regulated" flows representing the total flows passing the reservoir site
    b. "Unappropriated" flows representing the flows that are considered to be available for diversion and/or impoundment

    Subtract the monthly unappropriated flows at the location of the proposed reservoir from the corresponding regulated flows – these flow differences, referred to herein as "senior pass-throughs", represent the monthly flows simulated with the WAM that have to be passed through the reservoir to satisfy the demands of all downstream water rights with senior priorities.

5) Distribute the monthly values of regulated flows and senior pass-throughs at the location of the proposed reservoir to daily quantities using either historical daily streamflow patterns for each month from a nearby and appropriate gage for the same period of record used in the WAM or other sets of daily natural flow patterns if available.

6) Establish the monthly and/or seasonal hydrologic conditions of the stream system for the same period of record as the WAM using for the hydrologic indicator either antecedent monthly regulated flows at one or more locations or reservoir storage for one or more reservoirs as simulated with the WAM, with triggers appropriately determined through frequency analysis using the prescribed annually-averaged compliance guidelines – values of 1, 2 or 3 should be assigned to each month of the period of record to designate a hydrologic condition corresponding to either low-medium-high or dry-average-wet, respectively.

7) Using the daily regulated streamflows from Step 5 and the hydrologic condition definitions from Step 6, operate the spreadsheet to analyze the relevant components of the e-flow regime prescription relative to the daily regulated flow to determine the total flow magnitude that must be passed downstream on a daily basis to satisfy the e-flow requirements. Daily e-flow pass-through requirements should be determined as separate quantities for the following e-flow conditions:

    a. With both subsistence and base-flow components in effect

b. With subsistence, base-flow and high-pulse components in effect
c. With subsistence, base-flow, high-pulse and overbank (if available) flow components in effect
d. With Lyons e-flow restrictions implemented
e. With Consensus Planning Criteria e-flow restrictions implemented

8) Using the daily senior pass-throughs from Step 5 and the daily e-flow requirements from Step 7, operate the spreadsheet for the following e-flow conditions to: (1) determine the total flow magnitude that must be passed downstream on a daily basis to satisfy the greater of the senior pass-throughs or the e-flow requirements, and (2) simulate the behavior of the reservoir on a daily basis subject to a specified daily diversion amount, net evaporative losses, and the required flow pass-throughs, and determine the firm annual yield of the reservoir:

   a. With no e-flow requirements or restrictions implemented
   b. With subsistence and base-flow components of e-flow standards implemented at all locations where available
   c. With subsistence, base-flow and high-pulse components of e-flow standards implemented at all locations where available
   d. With subsistence, base-flow, high-pulse and overbank flow components of e-flow standards implemented at all locations where available
   e. With Lyons e-flow restrictions implemented for each individual proposed water supply project
   f. With Consensus Planning Criteria e-flow restrictions implemented for each individual proposed water supply project

   Alternatively, the spreadsheet can be operated for the same e-flow conditions to simulate the proposed reservoir with its annual diversion set equal to a fixed desired annual demand amount rather than the firm yield amount.

9) Repeat Steps 6 through 8 for alternative or modified e-flow standards or reservoir definitions.

10) Review and summarize results from all spreadsheet simulations for all e-flow standards considered and for all reservoir definitions analyzed considering:

   - Firm annual yield of reservoirs
   - Maximum and minimum monthly/annual supplies with authorized diversions
   - Diversion frequency statistics
   - Monthly and annual period reliability of diversions
   - Average volume diversion reliability

5.0 TEST CASES FOR DIFFERENT METHODS OF EVALUATING E-FLOW IMPACTS ON WATER SUPPLY PROJECTS

Because of the different ways to not only interpret e-flow recommendations but also to represent the e-flow requirements for analysis purposes, it is informative to consider different test cases for proposed water supply projects subject to different hydrologic and climatic conditions and modes of operation. For this purpose, three proposed projects have been evaluated: Big Sandy Reservoir on Big Sandy Creek in the Sabine basin, Allens Creek Reservoir on the lower Brazos River, and Cedar Ridge Reservoir on the Clear Fork of the Brazos River in the extreme upper part of the Brazos basin. These projects have been selected because they are subject to vastly different hydrology, and, consequently, substantially different e-flow requirements, and because two (Big Sandy and Cedar Ridge) are on-channel reservoirs located on streams from which they directly impound their water supplies and the other (Allens Creek) involves a major diversion of river water (Brazos River) into an off-channel reservoir.

5.1 Description of Test Cases

It is important to note that the specific project features and capacities used for representation of the test case reservoirs in the e-flow impact analyses presented herein may not agree with the latest plans or permits for these projects, and they have been assumed solely for purposes of this assessment. In addition, the results of this analysis are not intended to represent a finding of water availability for these projects. Similarly, the various e-flow prescriptions used in these analyses are not purported herein to be those that would be protective of a sound ecological environment nor are they considered herein to be necessarily appropriate for adoption as final e-flow standards. They are merely used here for demonstrative purposes.

Key features describing the three projects selected as test cases for the analyses are summarized in the following table.

Table 1 Principal Features of Test Cases for Analyzing E-Flow Impacts

Project Feature	Big Sandy Reservoir	Allens Creek Reservoir	Cedar Ridge Reservoir
River Basin	Sabine	Brazos	Brazos
Stream on Which Reservoir Located	Big Sandy Creek	Allens Creek	Clear Fork Brazos River
Stream from Which Diversions Made	Big Sandy Creek	Brazos River	Clear Fork Brazos River
Maximum Conservation Storage Capacity (ac-ft)	79,179	145,533	310,383
Maximum Conservation Pool Surface Area (ac)	4,950	7,003	6,190

Of the three, only Allens Creek Reservoir is authorized under an existing water rights permit, and it has not been constructed. The authorized diversion from Allens Creek Reservoir is 99,500 acre-feet/year, which purportedly was the firm annual yield of the project when it was permitted with the TWDB's Consensus Planning Criteria imposed on the project's Brazos River diversions for environmental flow purposes. Big Sandy Reservoir is not a planned project at this time. Cedar Ridge Reservoir is a recommended water management strategy and has been identified as a site of unique value for the construction of a reservoir in the 2011 Brazos G Regional Water Plan.

For each of the test cases, the effects of several different e-flow prescriptions were analyzed to assess their impacts on the firm annual yield of their associated reservoirs. These e-flow prescriptions included variations of multi-tiered e-flow regimes similar in structure to those recommended by the BBESTs and uniform monthly e-flow requirements derived using the TWDB's Consensus Planning Criteria and the Lyons Method. Variations of the multi-tiered e-flow regimes included: (1) subsistence and base flows only; (2) subsistence and base flows and high-flow pulses; and (3) for one test case (Big Sandy Reservoir), subsistence and base flows, high-flow pulses, and overbank flows. The numerical values of the different components of these e-flow prescriptions and other descriptive parameters for the high-flow pulses and overbank flows are summarized in Tables 2, 3 and 4 for Big Sandy Reservoir, Allens Creek Reservoir, and Cedar Ridge Reservoir, respectively.

As noted on the tables, the multi-tiered e-flow regimes with high-flow pulses originate from different sources. For Big Sandy Reservoir, the e-flow recommendation from the Sabine-Neches BBEST for Big Sandy Creek at the Sandy Creek streamflow gage, which is located immediately downstream from the proposed site for Big Sandy Reservoir, has been used. For Allens Creek Reservoir, the e-flow requirements for the Brazos River at Richmond as stipulated in the current draft permit for the Brazos River Authority's (BRA) pending application for a System Operations permit have been assumed to be applicable to the project's diversion point on the Brazos River near the mouth of Allens Creek (approximately 20 miles upstream from Richmond). For purposes of analyzing Cedar Ridge Reservoir, a new multi-tiered e-flow prescription had to be developed using the HEFR program with default parameters. To determine the e-flow regime, a drainage area ratio of 1.2506 was applied to translate the measured daily flows at a USGS gage located on the Clear Fork of the Brazos River near Nugent, which is approximately 30 miles upstream, to the Cedar Ridge Reservoir site. HEFR was then applied to the adjusted daily streamflows.

Depending on the test case being analyzed, different approaches have been used for defining the hydrologic conditions that are required for applying the base-flow and high-flow pulse components of the e-flow regime prescriptions. For Big Sandy Reservoir in the Sabine basin, the set of defined hydrologic conditions (dry-average-wet) developed by the Sabine-Neches BBEST based on the combined storage in several selected reservoirs within the basin as simulated with the Run 3 version of the Sabine WAM was used. For Allens Creek Reservoir in the Brazos basin, monthly values of the combined storage of the BRA system of reservoirs as simulated with the Run 3 version of the Brazos WAM for the 1940-1997 period were analyzed to define hydrologic conditions (dry-average-wet) based on the criteria stipulated in §E.3 of the pending draft permit for BRA's System Operations authorization (<60% full, subsistence condition; >60% full and < 74% full, dry condition; >74% and <96% full, average condition; and >96% full, wet condition). Results from this analysis were used for all of the applications of the different methods to Allens Creek Reservoir to designate hydrologic conditions for purposes of implementing the base-flow and high-flow components of the e-flow regime. For Cedar Ridge

Table 2 E-Flow Prescriptions Analyzed for Big Sandy Reservoir

Sabine-Neches BBEST

MONTH	BASE & SUBSISTENCE FLOWS				WET HIGH-FLOW PULSE				AVERAGE HIGH-FLOW PULSE				DRY HIGH-FLOW PULSE			
	Wet Base Flow (cfs)	Avg Base Flow (cfs)	Dry Base Flow (cfs)	Subsist-ence Flow (cfs)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)
Jan	163	106	66	20	1	942	16	14,544	2	358	10	5,932	0	0	0	0
Feb	163	106	66	20	1	942	16	14,544	2	358	10	5,932	0	0	0	0
Mar	163	106	66	20	1	942	16	14,544	2	358	10	5,932	0	0	0	0
Apr	111	51	30	9	1	950	19	12,852	2	313	13	5,062	1	313	13	5,062
May	111	51	30	9	1	950	19	12,852	2	313	13	5,062	1	313	13	5,062
June	111	51	30	9	1	950	19	12,852	2	313	13	5,062	1	313	13	5,062
Jul	26	18	14	8	1	132	11	2,054	2	50	6	671	1	50	6	671
Aug	26	18	14	8	1	132	11	2,054	2	50	6	671	1	50	6	671
Sept	26	18	14	8	1	132	11	2,054	2	50	6	671	1	50	6	671
Oct	63	36	20	8	1	367	14	6,055	2	130	9	2,189	0	0	0	0
Nov	63	36	20	8	1	367	14	6,055	2	130	9	2,189	0	0	0	0
Dec	63	36	20	8	1	367	14	6,055	2	130	9	2,189	0	0	0	0

Note: Shading indicates designated seasons for e-flow purposes.

Consensus Planning Criteria

MONTH	Median Flow (cfs)	25th Percentile Flow (cfs)	7Q2 Flow (cfs)
Jan	148	82	12
Feb	180	122	12
Mar	202	129	12
Apr	161	91	12
May	127	64	12
June	57	32	12
Jul	24	17	12
Aug	20	13	12
Sept	24	17	12
Oct	38	23	12
Nov	77	47	12
Dec	143	72	12

Lyons Method

MONTH	Monthly Flow (cfs)
Jan	57
Feb	71
Mar	119
Apr	92
May	82
June	43
Jul	19
Aug	13
Sept	16
Oct	12
Nov	24
Dec	49

Sabine-Neches BBEST

OVERBANK FLOW			
Freq. (# per 2 years)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703
1	2,930	30	35,703

Table 3 E-Flow Prescriptions Analyzed for Allens Creek Reservoir

Draft Brazos River Authority SysOps Permit for Brazos River at Richmond

MONTH	BASE & SUBSISTENCE FLOWS				WET HIGH-FLOW PULSE				AVERAGE HIGH-FLOW PULSE				DRY HIGH-FLOW PULSE			
	Wet Base Flow (cfs)	Avg Base Flow (cfs)	Dry Base Flow (cfs)	Subsist-ence Flow (cfs)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)
Jan	2,955	1,630	885	743	1	19,500	16	297,550	1	9,670	8	90,288	1	3,748	5	36,266
Feb	2,955	1,630	885	743	1	19,500	16	297,550	1	9,670	8	90,288	1	3,748	5	36,266
Mar	3,670	2,030	1,170	743	1	19,150	13	270,154	1	10,200	7	101,405	1	5,640	5	44,668
Apr	3,670	2,030	1,170	743	1	19,150	13	270,154	1	10,200	7	101,405	1	5,640	5	44,668
May	3,670	2,030	1,170	743	1	19,150	13	270,154	1	10,200	7	101,405	1	5,640	5	44,668
June	2,635	1,450	930	743	1	15,300	12	166,116	1	8,830	7	77,177	1	4,880	4	38,181
Jul	2,635	1,450	930	743	1	15,300	12	166,116	1	8,830	7	77,177	1	4,880	4	38,181
Aug	2,635	1,450	930	743	1	15,300	12	166,116	1	8,830	7	77,177	1	4,880	4	38,181
Sept	2,038	1,150	760	743	1	13,175	11	146,866	1	7,730	7	56,162	1	2,500	4	22,458
Oct	2,038	1,150	760	743	1	13,175	11	146,866	1	7,730	7	56,162	1	2,500	4	22,458
Nov	2,038	1,150	760	743	1	13,175	11	146,866	1	7,730	7	56,162	1	2,500	4	22,458
Dec	2,955	1,630	885	743	1	19,500	16	297,550	1	9,670	8	90,288	1	3,748	5	36,266

Note: Shading indicates designated seasons for e-flow purposes.

Consensus Planning Criteria

MONTH	Median Flow (cfs)	25th Percentile Flow (cfs)	7Q2 Flow (cfs)
Jan	2,566	964	734
Feb	4,315	1,773	734
Mar	3,241	1,343	734
Apr	4,601	1,835	734
May	9,059	3,159	734
June	5,576	2,596	734
Jul	2,515	1,139	734
Aug	1,379	734	734
Sept	2,293	1,104	734
Oct	2,224	1,098	734
Nov	2,437	1,100	734
Dec	3,048	1,055	734

Lyons Method

MONTH	Monthly Flow (cfs)
Jan	1,320
Feb	1,792
Mar	2,400
Apr	2,628
May	5,229
June	3,780
Jul	1,509
Aug	903
Sept	984
Oct	734
Nov	842
Dec	1,184

Table 4 E-Flow Prescriptions Analyzed for Cedar Ridge Reservoir

Example HEFR Application

MONTH	BASE & SUBSISTENCE FLOWS				WET HIGH-FLOW PULSE				AVERAGE HIGH-FLOW PULSE				DRY HIGH-FLOW PULSE			
	Wet Base Flow (cfs)	Avg Base Flow (cfs)	Dry Base Flow (cfs)	Subsistence Flow (cfs)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)	Freq. (# per season)	Peak Flow (cfs)	Pulse Duration (days)	Pulse Volume (acft)
Jan	18.0	12.0	7.0	0.7	1	36	4	643	1	36	4	643	1	36	4	643
Feb	18.0	12.0	7.0	0.7	1	36	4	643	1	36	4	643	1	36	4	643
Mar	18.0	11.0	5.0	0.7	1	593	7	3,160	1	593	7	3,160	1	593	7	3,160
Apr	18.0	11.0	5.0	0.7	1	593	7	3,160	1	593	7	3,160	1	593	7	3,160
May	18.0	11.0	5.0	0.7	1	593	7	3,160	1	593	7	3,160	1	593	7	3,160
June	14.0	7.8	3.5	0.7	1	823	7	4,385	1	823	7	4,385	1	823	7	4,385
Jul	14.0	7.8	3.5	0.7	1	823	7	4,385	1	823	7	4,385	1	823	7	4,385
Aug	14.0	7.8	3.5	0.7	1	823	7	4,385	1	823	7	4,385	1	823	7	4,385
Sept	18.0	9.8	4.6	0.7	1	517	7	3,437	1	517	7	3,437	1	517	7	3,437
Oct	18.0	9.8	4.6	0.7	1	517	7	3,437	1	517	7	3,437	1	517	7	3,437
Nov	18.0	9.8	4.6	0.7	1	517	7	3,437	1	517	7	3,437	1	517	7	3,437
Dec	18.0	12.0	7.0	0.7	1	36	4	643	1	36	4	643	1	36	4	643

Note: Shading indicates designated seasons for e-flow purposes.

Consensus Planning Criteria

MONTH	Median Flow (cfs)	25th Percentile Flow (cfs)	7Q2 Flow (cfs)
Jan	15.7	6.5	0.7
Feb	19.1	8.3	0.7
Mar	20.1	9.5	0.7
Apr	23.7	7.6	0.7
May	44.0	9.2	0.7
June	40.4	12.4	0.7
Jul	12.3	1.4	0.7
Aug	8.2	0.9	0.7
Sept	15.0	0.7	0.7
Oct	16.4	3.6	0.7
Nov	12.2	2.1	0.7
Dec	9.6	4.5	0.7

Lyons Method

MONTH	Monthly Flow (cfs)
Jan	4.8
Feb	5.2
Mar	7.8
Apr	7.2
May	14.4
June	12.6
Jul	5.1
Aug	4.1
Sept	6.6
Oct	4.8
Nov	4.8
Dec	4.8

Reservoir in the upper Brazos basin, a frequency analysis was performed on the monthly storage in Possum Kingdom Reservoir generated from the Brazos WAM Run 3, and specific Possum Kingdom storage values with exceedence frequencies corresponding to the compliance guidelines for the three levels of base flow (low-medium-high) calculated from the HEFR program were determined (see Table 5 below). These storage values were then used as triggers to define when the different hydrologic conditions (low-medium-high) were in effect for each season in the application of the e-flow prescriptions for Cedar Ridge Reservoir. While it is recognized that storage in Possum Kingdom Reservoir potentially would be impacted by the proposed Cedar Ridge Reservoir since the Possum Kingdom water right is being subordinated to the proposed upstream project by agreement among owners and that the defined hydrologic conditions might change accordingly, this approach nonetheless was used as a matter of convenience for the sole purpose of these analyses. As noted in Section 2.2, it is recognized that the use of Possum Kingdom storage for defining hydrologic triggers for the different hydrologic conditions may result in some underestimation of the requirements for base-flow pass-throughs as the magnitude of daily flows increases from dry to wet conditions, which in turn could preclude full achievement of the compliance guidelines.

Table 5 Compliance Guidelines and Associated Possum Kingdom Reservoir Storage Used for Defining Hydrologic Conditions for Cedar Ridge Reservoir

COMPLIANCE GUIDELINES (FREQUENCIES) BY SEASON AND STATE					
Hydrologic State		Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Subsistence	0	100.0%	100.0%	100.0%	100.0%
Low	1	76.3%	80.2%	73.5%	74.6%
Meduim	2	58.3%	66.0%	61.7%	60.8%
High	3	39.4%	51.7%	51.2%	46.5%

POSSUM KINGDOM STORAGE TRIGGERS BY SEASON AND STATE					
Hydrologic State		Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Low	1	632,251	620,396	644,560	640,291
Meduim	2	684,747	665,798	676,992	679,813
High	3	716,033	695,961	696,609	706,267

5.2 Analysis Methods for Evaluating E-Flow Impacts

As noted previously, there are several methods that have been employed pursuant to the SB-3 process for evaluating the impacts of e-flow prescriptions on proposed water supply projects. These different methods have been applied, to varying degrees, to assess the impacts of the e-flow prescriptions described in the previous section on the firm annual yields of the three reservoir test cases. General descriptions of the different analysis methods follow. The basic procedures employed in each of these methods for determining e-flow pass-through quantities and reservoir yields are summarized in Table 6 below. As indicated, in each of the methods, the e-flow pass-throughs are determined based on either monthly WAM regulated flows (Row 1), which are then used as monthly instream flow requirements in a WAM simulation (Row 2), or daily flows derived from monthly WAM regulated flows (Row 3), which are then summed and used as monthly instream flow requirements in a WAM simulation. The firm annual yields of the test case reservoirs are determined either through the monthly WAM simulations (Row 5) or with the reservoir operation routine in the daily HDR Spreadsheet program (Row 6).

Table 6 Basic Features of E-Flow Impact Analysis Methods

ANALYSIS ACTIVITY	METHODS FOR EVALUATING E-FLOW IMPACTS				
	1 HDR-1 Spreadsheet	2 HDR-2 Spreadsheet + WAM	3 TWDB Methodology + WAM	4 AECOM Spreadsheet + WAM	5 Kennedy Monthly WAM
<u>Determination of E-Flow Pass-Throughs</u>					
(1) Monthly E-Flow Pass-Throughs Calculated from Monthly WAM Regulated Flows	No	No	No	Yes	Yes
(2) Monthly E-Flow Pass-Throughs Used as Monthly Instream Flow Requirements in WAM	No	No	No	Yes	Yes
(3) Daily E-Flow Pass-Throughs Calculated from Monthly WAM Regulated Flows	Yes	Yes	Yes	No	No
(4) Daily E-Flow Pass-Throughs Summed to Monthly Values for Use as Instream Flow Requirements in WAM	No	Yes	Yes	No	No
<u>Determination of Firm Annual Yield of Reservoirs</u>					
(5) Based on Monthly WAM Simulations	No	Yes	Yes	Yes	Yes
(6) Based on Daily Spreadsheet Analyses	Yes	No	No	No	No

5.2.1 HDR-1 Spreadsheet

This Excel spreadsheet was developed by HDR Engineering specifically for evaluating the impacts of multi-tiered e-flow prescriptions similar to those developed by the BBESTs pursuant to the requirements of SB-3 on the yield of a single reservoir. <u>The operation of only a single reservoir subject to only a single multi-tiered e-flow regime can be simulated with one execution of the spreadsheet.</u> The spreadsheet performs an analysis of the daily inflows to the reservoir to determine actual e-flow pass-through requirements based on a specified e-flow prescription, and then it applies these daily e-flow pass-through requirements in a daily reservoir operations simulation to determine the firm annual yield of the reservoir, taking into account net evaporation losses from the reservoir and other requirements for inflow pass-throughs to satisfy downstream senior water rights. Application of this method to assess the impacts of different e-flow prescriptions on reservoir yield follows the 10-step procedure outlined in Section 4.2 above (see pages 20-22), and, as noted, it requires input to the spreadsheet for the daily inflows to the reservoir being simulated and for the daily pass-throughs for satisfying the demands of downstream senior water rights. These inputs normally are derived from the monthly regulated and unappropriated (available) flows simulated with a WAM at the location of the reservoir being analyzed, after being distributed to daily values based on appropriate and applicable historical streamflows as measured at a gage, or other sets of daily flow patterns.

As presently structured, the HDR Spreadsheet is capable of determining the e-flow pass-through requirements for a multi-tiered e-flow prescription consisting of subsistence and base flows and three levels of high-flow pulses (low-medium-high or dry-average-wet specifications), with seasonally varying parameters for each pulse. Overbank requirements with annual frequencies are not represented in the existing spreadsheet. Subsistence and base-flow requirements are checked directly against daily reservoir inflows to determine allowable flow quantities available for impoundment or diversion. Specified seasonal hydrologic conditions, determined external to the spreadsheet, are used to establish the appropriate base flow and/or high-flow pulse in effect at any given time during the simulation.

For determining the occurrence of a qualifying high-flow pulse event based on the specified daily reservoir inflows, the HDR Spreadsheet assumes that a qualifying pulse event begins on the first day that the actual flow exceeds the prescribed peak flow requirement of the particular high-flow pulse that is in effect for the current season and hydrologic condition. Daily flows up to the magnitude of the peak flow prescription then are passed on subsequent days until either the volume prescription or the duration prescription of the effective high-flow pulse is satisfied[5]. Passage of the appropriate subsistence or base e-flow prescription then resumes. In the spreadsheet, the need for passing or not passing high-flow events in the daily inflow record is determined by season for each of the prescribed high-flow pulses by accounting for the passage of previous high-flow events relative to the prescribed attainment frequency requirements.

A modified version of the HDR Spreadsheet also has been developed for purposes of these reservoir yield impact analyses to allow e-flow prescriptions based on the TWDB Consensus Planning Criteria (CPC) and the Lyons Method to be implemented on a daily basis in the spreadsheet calculations. For the application of these methods, only daily streamflows in excess of these e-flow requirements are allowed to be impounded in the reservoir, unless additional flows have to be passed downstream to satisfy senior water rights. For the CPC e-flow prescriptions, the hydrologic state, which defines the particular e-flow value in effect (dry-average-wet) at any given time, was determined on a daily basis using reservoir storage for Big Sandy Reservoir and Cedar Creek Reservoir since both of these reservoirs are located on streams from which they impound their supplies. The daily Brazos River flow at the location where diversions are made into Allens Creek Reservoir was used to determine the hydrologic state for the CPC e-flow prescriptions imposed on diversions into the reservoir since the Brazos River is the primary source of supply for the project.

5.2.2 HDR-2 Spreadsheet Plus WAM

This method utilizes the HDR Spreadsheet described above to determine daily e-flow pass-throughs for a specific e-flow prescription at a particular stream location, which may or may not be at the site of a proposed reservoir or water supply project. These daily e-flow pass-throughs then are summed to monthly values, which are subsequently used in a monthly WAM simulation as instream flow requirements that can be imposed on proposed reservoirs or water supply projects. Application of this method to assess the impacts of different e-flow prescriptions on reservoir yield follows the 13-step procedure outlined in Section 4.2 above (see pages 17-19). This method requires input to the spreadsheet for the daily flows at the location where the e-flow prescription is being applied. These inputs normally are derived from the monthly regulated flows simulated with a WAM at the location of the e-flow prescription, after being distributed to

5 It should be noted that the approach used in the HDR Spreadsheet whereby a qualifying high-flow event is assumed to begin on the first day that the flow exceeds the prescribed peak flow amount produces what is likely an unnatural discontinuity in the resulting daily flow hydrograph. This occurs because, in the spreadsheet, the peak flow that is required to be passed on the initial day of a qualifying high-flow event is immediately preceded by a day with its flow equal to the currently-effective base flow amount (assuming any flow greater than that amount is diverted or impounded). Typically there could be one or two days of ascending flows prior to the peak-flow day on mainstem river segments that would also qualify as part of the high-flow event, but are excluded with the approach used in the HDR Spreadsheet. While this approach does introduce some inconsistency in the transition from a base-flow condition to a high-flow pulse or overbank flow event, and vice versa, it probably doesn't make much difference in the overall accounting of the occurrence of the different high-flow events or in their likely ability to support certain ecological functions.

daily values based on appropriate and applicable historical streamflows as measured at a gage on a nearby stream with similar hydrologic characteristics.

The HDR Spreadsheet can be applied separately to determine e-flow pass-throughs at several different locations within a river basin, all of which can then be input to a WAM as instream flow requirements at the several locations. If several proposed reservoirs or water supply projects are being analyzed with the WAM, they would all be subject to these instream flow requirements at the multiple locations, assuming that all of the proposed reservoirs and water supply projects were specified as being junior in priority to the instream flow requirements.

5.2.3 TWDB Spreadsheet Plus WAM

Pursuant to developing information for the Trinity-San Jacinto BBASC regarding the impacts of the Trinity-San Jacinto BBEST's e-flow recommendations on proposed water supply strategies in the basins, the TWDB developed a methodology for determining e-flow pass-throughs at locations where the BBEST's e-flow recommendations were available. The TWDB's methodology is based on analyzing daily streamflows derived from the monthly regulated flows simulated with a WAM (without any proposed reservoirs or water supply projects accounted for) at the locations of the available e-flow recommendations. These daily e-flow pass-through requirements are then summed to monthly values and input to the WAM(s) as instream flow requirements at their respective locations. The effect of the e-flow requirements on water availability for proposed projects can be evaluated through operation of the WAM. This general procedure is the same as the 13-step procedure outlined in Section 4.2 above (see pages 17-19).

The approach for determining e-flow pass-throughs at a particular stream location as used by the TWDB is similar to that incorporated into the HDR Spreadsheet, except for the method used to identify high-flow pulses and overbank flows. The TWDB uses the Indicators of Hydrologic Alteration (IHA) program to separate the daily regulated flows derived from WAM monthly flows into various flow categories, including base flows, high-flow pulses, small floods, and large floods. The output from the IHA program then is further analyzed to determine which high-flow pulses and flood events identified by IHA satisfy the criteria for the specific high-flow pulse and overbank e-flow components included in an e-flow regime prescription. Using the IHA program for delineating high-flow pulses and overbank flow events is consistent with how the Trinity-San Jacinto BBEST performed these analyses when developing its recommendations, but this approach is not considered to be practicable when applying an actual e-flow prescription to a real water supply project; hence, it is not considered appropriate for performing analyses of recommended or proposed e-flow regimes to evaluate to their potential impacts on proposed projects. The procedure used in the HDR Spreadsheets where a high-flow event is triggered when the flow on a given day exceeds the peak flow value of a high-flow component of a prescribed e-flow regime provides a more workable and practicable approach for implementing an actual e-flow prescription for a real water supply project.

5.2.4 AECOM Spreadsheet Plus WAM

The procedures involved in applying the AECOM Spreadsheet Plus WAM approach are similar to those described in Section 5.2.2 above for the HDR Spreadsheet Plus WAM method, except that monthly, instead of daily, regulated flows from the WAM are used directly to determine the e-flow pass-throughs at a particular stream location. In this spreadsheet, monthly regulated flow volumes from the WAM are compared to the equivalent monthly volumes of the different e-flow components comprising an e-flow regime to determine the monthly pass-through volumes. As with the HDR Spreadsheet, the AECOM Spreadsheet can be applied to determine e-flow pass-through requirements at multiple locations where e-flow prescriptions are available within a basin. These monthly pass-through volumes then are input to the WAM as instream flow requirements at their respective locations, and the WAM, with proposed reservoirs and water supply projects incorporated, then can be operated to determine available water supplies or reservoir yield subject to satisfying all of these e-flow requirements.

One point to note with regard to the AECOM analysis method is that when the prescribed volume of a high-flow pulse is exceeded by the WAM flow volume for a particular month and the month is declared to qualify as a high-flow pulse event, the effective daily base-flow for that month is applied to the balance of the days outside the prescribed duration of the high-flow pulse event. The volume equivalent of these daily base-flow quantities then is added to the high-flow pulse volume to establish the total e-flow pass-through volume for the month. It is likely that simply comparing the required high-flow pulse volume to the monthly WAM flow volume to determine if a high-flow pulse prescription is satisfied results in the identification of more qualified pulses than would otherwise be identified based on the full definition of a qualified high-flow pulse, i.e., that the prescribed peak flow, volume, and duration criteria are all satisfied. An alternative approach would be to use the sum of the high-flow pulse volume and the remaining days' base-flow volume as the trigger for determining months with qualified pulses. This would tend to limit the number of qualified pulses, possibly to a level more consistent with what the actual pulse definition would produce.

It should be noted that the application of the AECOM Spreadsheet in the Sabine basin uses WAM Run 3 storage in the Big Sandy Reservoir for the assignment of hydrologic conditions while other approaches described herein use WAM Run 3 total reservoir storage in the Sabine basin. Hence, the results from the AECOM approach may differ somewhat from those derived with the Kennedy WAM approach described below, even though their general computational procedures using monthly flows for determining e-flow requirements are equivalent.

5.2.5 Kennedy Monthly E-Flow WAM

Kirk Kennedy has added the necessary coding into the data files for a monthly WAM that determines directly during a simulation the required pass-through quantities for all of the flow components of a multi-tiered e-flow regime, i.e., subsistence flow, three levels of base flow varying by season, three levels of high-flow pulses varying by season, and an overbank flow. Special accounting also is coded to implement and track the required attainment frequencies for the high-flow pulse and overbank flow criteria. Of course, all of these determinations are based on monthly flow quantities as simulated with the WAM, as translated from the daily or event flows stipulated for a particular e-flow prescription. In this respect, this approach as incorporated into the monthly WAM is similar to that used by AECOM. The fundamental difference, of course, is that all of the calculations and determinations are made internal to the WAM simulation, which simplifies the overall e-flow representation process and greatly facilitates the water availability analysis of multiple water supply projects subject to multiple e-flow prescriptions. In this regard, this monthly WAM approach is substantially superior to all of the other methods for analyzing the effects of e-flow prescriptions on water supply projects. Application of this method to assess the impacts of different e-flow prescriptions on reservoir yield follows the 8-step procedure outlined in Section 4.1 above (see pages 16-17).

As with the AECOM approach, the current version of the Kennedy Monthly E-Flow WAM compares the prescribed volume of a high-flow pulse to the WAM flow volume for a particular month to determine if the month qualifies as a high-flow pulse event, and if so, then adds the effective daily base-flow volume for the balance of the days of the month outside the prescribed duration of the high-flow pulse event to establish the total e-flow pass-through volume. Again, this likely results in more qualified pulses being identified than would be otherwise using daily flows and applying the full definition of a qualified high-flow pulse, i.e., peak flow, volume and duration, and use of an alternative procedure such as that described above for the AECOM approach may be more appropriate. Modifications to the WAM code to address this issue currently are being considered.

5.3 Test Case Results Using Different Analysis Methods

The five different methods described above for evaluating the impacts of prescribed e-flow regimes on the ability of proposed water supply projects to produce a firm yield have been analyzed through applications to the three test cases. The results of these analyses are summarized in Table 7 for those specific e-flow prescriptions that were considered for each case. For comparative purposes, yields also have been determined using e-flow prescriptions based on the TWDB's Consensus Planning Criteria and/or the Lyons Method. Also shown for each test case reservoir is its firm yield with no e-flow pass-throughs imposed.

Differences in the firm yield values without e-flow requirements engaged (Rows 1, 7 & 12) for the HDR-1 Spreadsheet method in Column 1 and those for the other methods in Columns 2-5 are attributable solely to using a daily time step for the yield analyses (HDR Spreadsheet) versus using a monthly time step (WAM simulations). As indicated for these test cases, the differences in yield are really fairly small compared to the yield magnitudes (maximum of 1.4%) and well within the accuracy of the input data. This is not surprising for Big Sandy Reservoir and Cedar Ridge Reservoir since these are both impounding all of their respective inflows to the extent they have storage capacity, but it is somewhat surprising for Allens Creek Reservoir since its yield is primarily dependent on the quantities of flow that can be diverted from the Brazos River with a maximum diversion rate of 2,200 cfs. Certainly, these diversion amounts could vary depending on whether a daily or monthly time step is used.

As expected, the effect of including high-flow pulses in an e-flow regime (Rows 3, 9 & 14) requires more flow to be passed downstream for environmental purposes and, consequently, produces less firm yield for the reservoirs than when only the subsistence and base flow regime requirements are engaged (Rows 2, 8 & 13). The exception is Allens Creek Reservoir where no high-flow pulses were identified during the critical drought period for the reservoir with the HDR Spreadsheet methods (Columns 1 & 2, Rows 8 & 9) based on the daily regulated flows. Additionally, in the HDR-2 Spreadsheet Plus WAM method (Column 2), the monthly magnitudes of the e-flow regime requirements, either with or without the high-flow pulses engaged for the Allens Creek Reservoir diversions from the Brazos River, were always less than the monthly pass-through requirements for downstream senior water rights in the Brazos WAM;

Table 7 Summary of Firm Annual Yields for Reservoir Test Cases Using Different E-Flow Impact Analysis Methods Applied to Different E-Flow Prescriptions

RESERVOIR TEST CASE AND ASSUMED E-FLOW PRESCRIPTION	FIRM ANNUAL YIELD (acre-feet/year)				
	(1) HDR-1 Spreadsheet	(2) HDR-2 Spreadsheet + WAM	(3) TWDB Methodology + WAM	(4) AECOM Spreadsheet + WAM	(5) Kennedy Monthly WAM
Big Sandy Reservoir *					
(1) No E-Flow Requirements Engaged	43,450	44,060	44,060	44,060	44,060
(2) S-N BBEST Subsistence and Base E-Flows Engaged	33,750	35,050	35,050	32,110	34,730
(3) S-N BBEST Subsistence, Base and Pulse E-Flows Engaged	30,400	31,610	35,050	29,070	30,770
(4) S-N BBEST Subsistence, Base, Pulse and Overbank E-Flows Engaged	n/a	n/a	n/a	29,070	30,770
(5) Consensus Planning Criteria E-Flows Engaged	34,200	n/a	n/a	n/a	n/a
(6) Lyons Method E-Flows Engaged	28,100	n/a	n/a	n/a	n/a
Allens Creek Reservoir *					
(7) No E-Flow Requirements Engaged	106,200	105,960	n/a	n/a	105,960
(8) BRA SysOps Richmond Subsistence and Base E-Flows Engaged	94,700	105,960	n/a	n/a	91,760
(9) BRA SysOps Richmond Subsistence, Base and Pulse E-Flows Engaged	94,700	105,960	n/a	n/a	88,270
(10) Consensus Planning Criteria E-Flows Engaged	98,000	n/a	n/a	n/a	103,730
(11) Lyons Method E-Flows Engaged	86,300	n/a	n/a	n/a	n/a
Cedar Ridge Reservoir *					
(12) No E-Flow Requirements Engaged	45,300	45,340	n/a	n/a	45,340
(13) HEFR Example Subsistence and Base E-Flows Engaged	43,050	43,160	n/a	n/a	42,270
(14) HEFR Example Subsistence, Base and Pulse E-Flows Engaged	37,050	37,190	n/a	n/a	34,930
(15) Consensus Planning Criteria E-Flows Engaged	43,700	n/a	n/a	n/a	n/a
(16) Lyons Method E-Flows Engaged	42,950	n/a	n/a	n/a	41,970

* Note that conditions assumed for representation of these reservoirs may not agree with latest plans or permits, but are assumed solely for purposes of these analyses.

hence, the firm yields of Allens Creek Reservoir from the WAM with the e-flow regime requirements engaged (Rows 8 & 9) are the same as the yield with no e-flow requirements imposed on the river diversions (Row 7). The Kennedy Monthly E-Flow WAM, however, does indicate the occurrence of qualified high-flow pulses during the critical drought period for Allens Creek Reservoir since the firm yield with the high-flow pulses engaged (Column 5, Row 9) is less than the yield without the pulses engaged (Column 5, Row 8). The fact that qualified high-flow pulses were identified during the critical drought period for Allens Creek Reservoir with the Kennedy Monthly E-Flow WAM but not with the daily-flow HDR Spreadsheets is the result of the different triggers used in the two approaches for identifying high-flow pulses. The Kennedy Monthly E-Flow WAM compares the prescribed pulse volume to the monthly regulated flow volumes from the WAM, whereas the HDR Spreadsheets check the prescribed peak flow rate for the pulse against the mean daily flows for the Brazos River as derived from the monthly regulated flows from the WAM.

In general, based on the results from the HDR-1 Spreadsheet daily analysis method (Column 1), the firm yields of the three reservoirs with the TWDB Consensus Planning Criteria engaged (Rows 5, 10 & 15) are somewhat greater than the yields with the multi-tiered e-flow regime requirements imposed (Rows 3, 9 & 14). For Big Sandy Reservoir and Allens Creek Reservoir, the firm yields of the reservoirs with the Lyons Method e-flow requirements engaged (Rows 6 & 11) are somewhat lower than the yields with the multi-tiered e-flow regime requirements imposed (Rows 3 & 9), whereas the firm yield of Cedar Ridge Reservoir with the Lyons Method e-flows engaged (Row 16) is somewhat higher than the yield with the multi-tiered e-flow regime requirements imposed (Rows 14).

There are two main points to note with regard to the results presented in Table 7. First, for the on-channel reservoir test cases, Big Sandy Reservoir and Cedar Ridge Reservoir, all of the methods analyzed, with the exception of the TWDB Methodology Plus WAM approach, produce generally similar yield values with the multi-tiered e-flow regimes engaged, and they demonstrate similar increases in yield without the high-flow pulses included as part of the e-flow regime versus with the high-flow pulses included. Second, for the off-channel Allens Creek Reservoir, yield results from the HDR Spreadsheet methods and the Kennedy Monthly E-Flow WAM with the multi-tiered e-flow regimes engaged differ somewhat primarily because of the effects of quantifying the e-flow pass-throughs using daily flows in the HDR Spreadsheets and monthly flows in the Kennedy Monthly E-Flow WAM. Using daily flows should be more accurate and consistent with actual flow conditions.

6.0 OBSERVATIONS AND RECOMMENDATIONS

Based on the investigations described herein, particularly the assessment of the different methods available for evaluating the impacts of different e-flow regimes on proposed water supply projects and the results of applying these methods to selected reservoir test cases, the following observations and recommendations are offered for consideration by the BBASCs and the TCEQ in their endeavor to develop e-flow recommendations and standards:

6.1 Observations

1) E-flow recommendations considered important for supporting a sound ecological environment can include several different levels of flow components, namely subsistence and base flows, high-flow pulses and overbank flows, and it is important that each of these recommended e-flow components be effectively represented by season and for defined hydrologic conditions when evaluating potential impacts on proposed water supply projects.

2) The measure of compliance for the different flow components of a multi-tiered e-flow regime is based on a comparison of the frequency at which the different flow components are satisfied and the compliance guidelines (frequencies of occurrence) that are stipulated in the underlying e-flow recommendation; hence, these compliance guidelines should be factored into any analysis of multi-tiered e-flow regimes and their impacts on proposed water supply projects.

3) The extent to which flows from a WAM simulation (either Run 3, Run 8 or Run 9 without or with proposed water supply projects in operation) comply with the prescribed attainment frequencies of one or more e-flow regimes at their respective locations is important information that should be useful to BBASCs and the TCEQ in their deliberations to balance water for environmental flow purposes with other needs for available water supplies.

4) The matrix of an e-flow recommendation can include different levels of flow requirements for the base-flow and high-flow pulse components corresponding to different hydrologic conditions, often referred to as low-medium-high or dry-average-wet conditions. Proper application of these flow components requires that there be a specific mechanism for defining the hydrologic condition of a particular water body or flow system in order to know at all times which of the three levels of flow requirements currently is in effect. Ideally, if such hydrologic conditions are to be included as part of an e-flow matrix, the BBEST should develop an appropriate mechanism for defining these conditions.

5) Using the frequency of occurrence of a hydrologic indicator (e.g., upstream reservoir storage, antecedent streamflow, etc.) as the basis for establishing triggers to define when certain hydrologic conditions (i.e., low-medium-high or dry-average-wet) and their associated base-flow requirements are in effect does not necessarily ensure that the desired achievement guidelines will be satisfied. Typically, with this approach, as the flow magnitudes for the different base-flow recommendations increase, there is less likelihood that the achievement guidelines will be fully satisfied. The degree to which such deviations may occur can be evaluated as part of the analysis of applying an e-flow recommendation, or set of recommendations, to proposed water supply projects. To minimize such deviations, where seasonal attainment frequencies are explicitly defined for base flows as

part of a particular e-flow recommendation, an iterative approach to developing hydrologic triggers designed to more closely satisfy the desired attainment goals might be necessary.

6) It may be reasonable in many cases to use the annual average of all of the seasonal base-flow compliance guidelines for a particular hydrologic condition as the frequency basis for establishing the trigger (related to upstream reservoir storage, antecedent streamflow, or some other hydrologic parameter) for when the hydrologic condition is in effect. This results in a single trigger for each hydrologic condition rather than multiple triggers for the different seasons. Using this simplification depends, of course, on the relative magnitudes of the individual seasonal compliance guidelines for each hydrologic condition. Still, assuming that the deviation among these seasonal compliance guidelines is not more than about 15 or 20 percent, the degree of accuracy lost relative to the level of complication required to implement the more complex system of seasonally-varying hydrologic triggers for a real e-flow regime application may not be that significant.

7) While the definition and use of hydrologic conditions are essential and integral to the application of the base-flow components, they may or may not be necessary for implementing high-flow pulses depending on how a particular e-flow recommendation is designed to function. If the decision as to whether a particular current high-flow event has to be passed downstream is to be based solely on whether the attainment frequency for the currently effective high-flow pulse has been satisfied considering historical daily flows, then there is no need to develop hydrologic condition assignments for the different high-flow pulse components. However, if the e-flow regime as designed by a BBEST associates each of the different high-flow pulse components for a particular season with a specific hydrologic condition, then there must be some mechanism for determining hydrologic condition at all times, and ideally, each BBEST should develop the appropriate mechanism for its respective basin.

8) The hydrologic indicators determined for the different base-flow components of an e-flow regime often are used to also define the hydrologic conditions for high-flow pulses, but this is more of a matter of convenience rather than an accurate reflection of the conditions under which the high-flow pulse events actually occur. Aside from using the base-flow hydrologic triggers for defining high-flow pulse hydrologic conditions, using the approach whereby the decision as to whether a particular high-flow event has to be passed downstream is based solely on whether the attainment frequency for the currently effective high-flow pulse has been satisfied by the historical daily flows is considered the most reasonable and straightforward for implementing the high-flow pulse components of an e-flow regime. This, of course, avoids having to undertake a complicated investigation to attempt to define meaningful high-flow pulse hydrologic triggers for designating different hydrologic conditions.

9) The HDR Spreadsheet, HDR Spreadsheet Plus WAM, and TWDB Spreadsheet Plus WAM methods are the only currently existing approaches for evaluating the impacts of multi-tiered e-flow regimes on water supply projects that use daily streamflows to identify and quantify the individual e-flow components.

10) The AECOM Spreadsheet Plus WAM method and the Kennedy Monthly E-Flow WAM both account for the e-flow requirements of multi-tiered e-flow regimes using monthly flow volumes.

11) Using daily flows to identify and quantify e-flow pass-through requirements in accordance with a prescribed multi-tiered e-flow regime should provide more accurate representations of the e-flow components and should be more consistent with actual streamflow variations than using monthly flows.

12) With regard to identifying and quantifying pass-through volumes for high-flow pulses and overbank flows using daily flows, the HDR Spreadsheet procedure can provide useful results and is probably adequate in most cases for e-flow evaluation purposes.

13) Using the peak-flow day as the day for defining the beginning of a qualifying high-flow pulse event and continuing the high-flow event for either the remaining days of the prescribed e-flow duration or until the prescribed e-flow volume is satisfied (the HDR Spreadsheet procedure) likely precludes certain qualifying flow-days prior to the peak-flow day from being included in the pulse accounting. Typically there could be one or two days of ascending flows prior to the peak-flow day on mainstem river segments that also would qualify as part of a high-flow event, and therefore would have to be passed downstream as part of the high-flow event. Otherwise, only base flows would have to be passed downstream. While this approach does introduce some inconsistency in the transition from a base-flow condition to a high-flow pulse or overbank flow event, and vice versa, this probably doesn't make much difference in the overall accounting of the occurrence of the different high-flow events or in their likely ability to support certain ecological functions.

14) The application of hydrograph separation programs (IHA or BFI) similar to the approach used by the TWDB for identifying qualifying high-flow pulse and overbank flow events should provide information that is more consistent with the procedures employed in developing the underlying e-flow regime prescriptions; however, the level of precision gained in terms of identifying all of the qualifying high-flow events may not be that significant compared to the results from the simpler and more straightforward spreadsheet methods, and certainly, the application of hydrograph separation programs is a less workable and practicable approach for identifying qualifying high-flow events for real project applications of actual e-flow recommendations.

15) For the on-channel reservoir test cases, Big Sandy Reservoir and Cedar Ridge Reservoir, the HDR Spreadsheet methods, the AECOM Plus WAM approach, and the Kennedy Monthly E-Flow WAM produce generally similar yield values with the multi-tiered e-flow regimes engaged, and they demonstrate similar increases in yield without the high-flow pulses included as part of the e-flow regime versus with the high-flow pulses included.

16) For the off-channel test case, Allens Creek Reservoir, yield results from the HDR Spreadsheet methods and the Kennedy Monthly E-Flow WAM with the multi-tiered e-flow regimes engaged differ somewhat primarily because of the effects of quantifying the e-flow pass-throughs using daily flows in the HDR Spreadsheets and monthly flows in the Kennedy Monthly E-Flow WAM.

17) The application of the HDR Spreadsheet Plus WAM method to evaluate the impacts of multi-tiered e-flow regimes at several locations on proposed water supply projects within a basin provides a reasonably accurate representation of the e-flow requirements since it utilizes daily streamflows to identify and quantity the prescribed e-flow components, and the associated WAM simulation with corresponding instream flow requirements provides useful and meaningful water availability results within the context of this analysis for the projects considered.

18) The application of the Kennedy Monthly E-Flow WAM is the most straightforward approach for evaluating the impacts of multi-tiered e-flow regimes at several locations on proposed water supply projects within a basin, and it also provides meaningful water availability results for the projects considered that can be useful in analyzing the relative effects of different e-flow prescriptions, even with the simulated e-flow requirements based on monthly flow volumes. This method is also consistent with the approach TCEQ uses when evaluating water availability for water rights permit applications.

19) The AECOM Spreadsheet Plus WAM method utilizes monthly flows to identify and quantify e-flow requirements; therefore, its utility is similar to the Kennedy Monthly E-Flow WAM, except that it is more cumbersome to apply in that separate spreadsheet analyses have to be performed to identify and quantify the e-flow requirements for input to the WAM simulation.

20) The TWDB Spreadsheet Plus WAM method may provide the most accurate representation of the e-flow requirements for a given e-flow regime prescription based on daily flow analyses, but it also requires more effort to implement because it involves application of the IHA hydrograph separation program to identify qualifying high-flow pulse and overbank flow events.

21) It is important to note that when processing WAM-simulated flows outside of an actual WAM simulation to determine e-flow pass-through requirements such as is required for applying the HDR Spreadsheet Plus WAM, TWDB Spreadsheet Plus WAM, and AECOM Spreadsheet Plus WAM methods, the conditions and assumptions included in the underlying WAM simulation are embedded in the simulated flows and, therefore, are reflected in the e-flow pass-through requirements as well. These cannot be changed without a re-simulation of the WAM with different conditions and assumptions specified. Changes in WAMs as a result of permitting actions or updates to the flow sequences occasionally are made, and would need to be addressed with regard to e-flow requirements if deemed significant. This issue is avoided with the direct application of a WAM that represents both the e-flow prescriptions and new water supply projects in the same simulation, but, again, at the present time this type of WAM application is limited to considering only monthly flows for representing and quantifying the different components of a recommended e-flow regime.

6.2 Recommendations

1) For evaluating the extent to which simulated flows from a monthly WAM simulation (either Run 3, Run 8 or Run 9 without or with proposed water supply projects) comply with the prescribed attainment frequencies of one or more e-flow regimes, it is recommended that the monthly WAM flows be distributed to daily values, that the resulting compliance frequencies be calculated over the duration of the WAM simulation period, and that these frequencies be compared with the required attainment frequencies.

2) The HDR Spreadsheet approach for identifying qualified high-flow pulses and overbank flow events using WAM-simulated flows translated to daily values, (i.e., initiating a high-flow event when the mean daily flow exceeds the peak flow requirement and continuing the high-flow event until either the prescribed duration or volume is satisfied) is recommended as being appropriate and acceptable for analyzing e-flow regime compliance. With regard to real project applications of actual e-flow prescriptions, this

method is considered to provide a more workable and practicable approach than applying a hydrograph separation program (IHA or BFI).

3) The HDR Spreadsheet Plus WAM method (HDR-2, see Section 5.2.2) is recommended as the primary tool for evaluating the impacts of multi-tiered e-flow regimes on proposed water supply projects, recognizing that the use of daily flows in the HDR Spreadsheet produces more accurate representations of the e-flow requirements for a particular e-flow prescription than using monthly flow. However, the Kennedy Monthly E-Flow WAM (see Section 5.2.5) also is recommended as an acceptable approach for performing these types of e-flow analyses based on the results from the test cases examined herein, and it is recognized as the superior method with regard to effectively representing both water availability, consistent with the way in which TCEQ would evaluate a permit application, and e-flow requirements in the same analysis.

4) For analyzing the impacts of a single proposed water supply project on downstream flows relative to a prescribed e-flow regime, it is recommended that the HDR Spreadsheet method (HDR-1, see Section 5.2.1) also be applied, with these results compared to those produced with the HDR Spreadsheet Plus WAM method or the Kennedy Monthly E-Flow WAM. Using the HDR Spreadsheet method tends to minimize inaccuracies associated with applying historical daily flow patterns to distribute monthly flows to daily values as would be required for the WAM flows produced with either the HDR Spreadsheet Plus WAM method or the Kennedy Monthly E-Flow WAM in order to effectively evaluate compliance with the prescribed e-flow regime.

5) When processing WAM-simulated flows outside of an actual WAM simulation to determine e-flow pass-through requirements such as is required for applying the HDR Spreadsheet Plus WAM method, it is recommended that the conditions and assumptions included in the underlying WAM simulation, which are also reflected in the derived e-flow pass-through requirements, be thoroughly documented and posted as part of the resulting e-flow instream flow stipulations incorporated into any subsequent WAM. This will allow any changes in the WAM due to future permitting actions or updates to the flow sequences to be evaluated with regard to their potential effects on the accuracy of the calculated instream flow requirements.

6) As development proceeds with incorporating new features of the WRAP program into WAM applications that will improve the coding and efficiency of representing multi-tiered e-flow regime components and their frequency requirements, it is anticipated and recommended that these new versions of the WAMs, when fully tested and validated, will supersede the Kennedy Monthly E-Flow WAM approach.

7) It is recommended that modifications be made to the HDR Spreadsheet to enhance its procedure for identifying high-flow pulse events and to also include an overbank event. A procedure to "look forward" one or two days in the daily flow record to determine the possible occurrence of an upcoming high-flow event similar to the way a water rights holder might look upstream for the same purpose should be considered in order to include one or two days of qualifying high flows prior to the peak-flow day and thereby eliminate the discontinuity that is currently embedded in the spreadsheet going from a base-flow day to the peak-flow day. Alternatively, consideration should be given to including in a high-flow event all of the daily flows with magnitudes greater than a specified base flow value that occur on either side time wise of the peak-flow day. Finally, there also needs to be a

procedure coded into the spreadsheet that will allow decoupling of the requirements for passing high-flow pulses and overbank flows from the prescribed hydrologic conditions that are used to implement base flows. Decisions as to whether or not these qualifying high-flow events should be passed downstream then would be made on the basis of whether or not the prescribed attainment frequencies for such events had been satisfied based on previous daily flows during a season or a year or several years.

7.0 REFERENCES

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