Trinity and San Jacinto and Galveston Bay
Basin and Bay Expert Science Team

DRAFT
Work Plan Report

Draft Submission to the Trinity and San Jacinto Rivers and Galveston Bay Basin and Bay Area Stakeholder Committee

December 1, 2010

Trinity and San Jacinto and Galveston Bay Basin and Bay Expert Science Team

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December 2010

Danny Vance, Chairman,
Trinity and San Jacinto Rivers and Galveston Bay
Basin and Bay Stakeholder Committee

Mr. Vance:

For your consideration, the Trinity and San Jacinto and Galveston Bay Basin and Bay Expert Science Team (Trinity-San Jacinto BBEST) hereby submits its draft report pursuant to the charge under Senate Bill 3 (80^{th} R, 2007) regarding the development of a work plan to facilitate the adaptive management of the environmental flow standards adopted for the Trinity and San Jacinto River Basins and the Galveston Bay system. The Trinity-San Jacinto BBEST members have reached consensus on the presentation of the recommendations submitted in this document.

Respectfully submitted,

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William H. Espey, Jr., Chairman

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PREAMBLE

The Trinity-San Jacinto Basin and Bay Expert Science Team (T-SJ BBEST) presents the following *Draft Work plan* to the Trinity and San Jacinto Rivers and Galveston Bay Basin and Bay Area Stakeholder Committee (T-SJ BBASC). This document is the culmination of several months of effort on the part of the Trinity-San Jacinto BBEST to provide a draft work plan for the T-SJ BBASC's consideration to facilitate the adaptive management of the environmental flow standards adopted for the Trinity and San Jacinto basins and Galveston Bay system.

The efforts documented within this draft report represent a significant step forward in the Texas environmental flows process, addressing the charge to the T-SJ BBASC and T-SJ BBEST by attempting to identify a process to validate and refine environmental flow standards, analyses, recommendations, and strategies in the Trinity and San Jacinto River Basins and the Trinity-San Jacinto Estuary. The Trinity-San Jacinto BBEST members have dedicated themselves to providing within this document an identification of specific efforts and objectives, along with supporting rationale, that will lay the necessary groundwork for the continued validation and refinement of flows necessary to protect a sound ecologic environment. It is anticipated that the Trinity-San Jacinto BBASC will exercise its collective judgment on the proposed process proffered herein to further balance environmental flows with the needs of the people of Texas in the Trinity and San Jacinto River Basins and the Galveston Bay area (Trinity-San Jacinto Estuary).

Senate Bill 3 Charge

Senate Bill 3, passed in 2007 by the 80th Texas Legislature, established a stakeholder-based process for including consideration of environmental flow needs in new water rights permits. Stakeholders for the Trinity and San Jacinto basins created a multidisciplinary team of scientists (i.e. the Trinity-San Jacinto BBEST) to recommend environmental flow regimes for the Trinity River, the San Jacinto River, and Galveston Bay. The responsibility of the BBEST is described in Article 1 of SB 3.

> *"(m) Each basin and bay expert science team shall develop environmental flow analyses and a recommended environmental flow regime for the river basin and bay system for which the team is established through a collaborative process designed to achieve a consensus. In developing the analyses and recommendations, the science team must consider all reasonably available science, without regard to the need for the water for other uses, and the science team's recommendations must be based solely on the best science available."*

SB 3 defines environmental flow analysis and environmental flow regime as:

> *"(15) 'Environmental flow analysis' means the application of a scientifically derived process for predicting the response of an ecosystem to changes in instream flows or freshwater inflows."*
>
> *"(16) 'Environmental flow regime' means a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."*

Article 1 of SB 3 also outlines how the environmental flow regime will be considered by the TCEQ in establishment of environmental flow standards. This clearly indicates the environmental flow regimes submitted to the TCEQ are but one of several considerations that form the basis of environmental flow standards presently under development by the TCEQ.

> "(b) In adopting environmental flow standards for a river basin and bay system under Subsection (a)(1), the commission shall consider:
>
> > (1) the definition of the geographical extent of the river basin and bay system adopted by the advisory group under Section 11.02362(a) and the definition and designation of the river basin by the board under Section 16.051(c);
> > (2) the schedule established by the advisory group under Section 11.02362(d) or (e) for the adoption of environmental flow standards for the river basin and bay system, if applicable;
> > (3) the environmental flow analyses and the recommended environmental flow regime developed by the applicable basin and bay expert science team under Section 11.02362(m);
> > (4) the recommendations developed by the applicable basin and bay area stakeholders committee under Section 11.02362(o) regarding environmental flow standards and strategies to meet the flow standards;
> > (5) any comments submitted by the advisory group to the commission under Section 11.02362(q);
> > (6) the specific characteristics of the river basin and bay system;
> > (7) economic factors;
> > (8) the human and other competing water needs in the river basin and bay system;
> > (9) all reasonably available scientific information, including any scientific information provided by the science advisory committee; and
> > (10) any other appropriate information."

SB 3 recognizes there is a degree of uncertainty in the environmental flow regime that will be described and environmental flow standards that will be created. The legislation addresses that uncertainty by containing provisions for a continuing adaptive management process, a key component of SB 3, that can be applied to refine initially identified flow regimes as information (science) that confirms ecological – flow relationships required to support a sound ecological condition becomes available. SB 3, enacted through the Texas Water Code, identifies specific mandates for the development of a work plan to facilitate the adaptive management of the environmental flow standards, as follows:

> *Section 11.02362 (p) In recognition of the importance of adaptive management, after submitting its recommendations regarding environmental flow standards and strategies to meet the environmental flow standards to the commission, each basin and bay area stakeholders committee, **with the assistance of the pertinent basin and bay expert science team**, shall prepare and submit for approval by the advisory group a work plan. The work plan must:*
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> 1. *establish a periodic review of the basin and bay environmental flow analyses and environmental flow regime recommendations, environmental flow standards, and strategies, to occur at least once every 10 years;*
> 2. *prescribe specific monitoring, studies, and activities; and*
> 3. *establish a schedule for continuing the validation or refinement of the basin and bay environmental flow analyses and environmental flow regime recommendations, the environmental flow standards adopted by the commission, and the strategies to achieve those standards.*
>
> *Section 11. 1471 (f) An environmental flow standard or environmental flow set-aside adopted under Subsection (a) may be altered by the commission in a rulemaking process undertaken in accordance with a schedule established by the commission. In establishing a schedule, the commission shall consider the applicable work plan approved by the advisory group under Section 11.02362 (p).*

In its role providing guidance to the SB 3 process, the SAC has endeavored to provide a guidance document regarding the development of such a work plan (SAC 2009). SAC, 2009 notes the work plan is essentially the backbone of the adaptive management process, suggesting it must provide a procedure for identifying what further study or clarification is required. Secondly, it must, "have funding and resources to address those issues." Lastly, it must provide a "mechanism to support some level of change in the standards and/or implementation strategies."

This draft work plan has been designed as a strategic document, containing a reasonably detailed plan that is considered to be achievable and understandable, relying on existing programs and data where possible in an effort to recognize the economic realities present at this time. SAC 2009 further notes that the implementation of this work plan will require utilizing, "various sources of data on streamflow, hydrometeorology, concentrations of key constituents in the water, and developed metrics," identified as indicative of ecosystem health. It is important that if existing data are to be utilized, they must be fully documented and sustained over a period sufficient to capture the range of natural variability. This work plan attempts to identify, where possible, existing long-term monitoring programs from which data are available for possible inclusion, as well as data collection efforts necessary to validate and/or refine indicator responses to the flow regime. Ultimately, while the utilization of existing resources is an important approach to successfully funding the work plan efforts, such resources will likely be insufficient. SB 3 remains unclear if it is the responsibility of the BBASC or BBEST to identify specific means of funding the efforts identified in the work plan.

This report describes the objectives of studies, monitoring, and data collection efforts the T-SJ BBEST believes will be sufficient to ultimately achieve the above described SB 3 mandates, recognizing that detailed scopes of work are beyond the scope of this effort. Incorporated within this document is the rationale for the necessity of such information and the objectives such collection efforts and analyses are anticipated to achieve, attempting to demonstrate the necessary magnitude of information required for the assessment of a sound ecological environment and its relation to freshwater inflows in an organized context.

It is the understanding of the T-SJ BBEST that the work plan must set forth a process to address essentially two concurrent topics: the validation of the standards set forth by rule from the Texas Commission on Environmental Quality (TCEQ) and the refinement of these standards, recommendations, strategies for their achievement, and their supporting analyses. Ascribing to the SAC 2009 guidance, the immediate technical goal of the work plan is to fill in data gaps and assist in the eventual development of a cause-and-effect relationship of some measure(s) of ecosystem health to representations of environmental flows.

Process

SB 3 is not clear on the specific role the T-SJ BBASC and T-SJ BBEST are to play in executing the work prescribed in the work plan. However, as noted in SAC 2009, "the five year term of their respective appointments suggests that they are to play a continuing role in the SB 3 adaptive management process. At a minimum, the BBASC and BBEST appear uniquely positioned to provide coordination and oversight of the work to be undertaken." It is anticipated that such will be the case with the T-SJ BBASC and T-SJ BBEST, whereas both will operate in an oversight or review capacity, with implementation of the workplan handled by agencies and/or contractors. T-SJ BBEST members might individually participate in that capacity.

It is required that a work plan include a periodic review of the basin and bay environmental flow analyses and environmental flow regime recommendations, environmental flow standards and strategies. This process must occur at least once every 10 years, although more frequent analyses are not excluded. A more reasonable benchmark is a 4 year review cycle for evaluation of new data and research that may have been collected that could be deemed sufficient to alter the original recommendations and resultant standards.

It is proposed that the adaptive management process for the environmental flows remain similar to that which has been employed to date, and scheduled in such a way as to be consistent with the five (5) year regional water planning process. In a 5-year cycle, the BBEST would have a period (12-months, similar to the schedule of the first round of BBEST efforts) to assess and review the present state of available science and judge, by consensus, if the available science is sufficient to warrant a modification to the existing environmental flow standards. If the BBEST determines that a modification is warranted, a new recommendation would be proffered to the EFAG, BBASC, and TCEQ, ascribing to the original mandates set forth for the BBEST by SB 3. The BBASC would then perform a similar process of assessing these environmental flow recommendations, balancing them with human needs, formulating and evaluating possible strategies, and submitting a consensus recommendation to the EFAG and TCEQ; again, similar to the process employed during the first round of SB 3 efforts. This effort would be strongly coordinated with efforts of the applicable regional water planning groups, in order to provide efficient utilization of available information both to and from the regional water planning efforts.

The technical aspects of the process set forth by the work plan can essentially be described as follows:

- i) Identify data gaps
- ii) Consider geographic distribution
- iii) Identify objectives of studies and how they might be utilized in an environmental flow context
- iv) Evaluate existing programs for their utility
- v) Specify near-term studies or surveys
- vi) Specify long-term monitoring or studies
- vii) Specify if a model exists which might be validated or that a model needs to be developed

For instream and estuarine considerations, the above process will be applied to each of the ecological components recognized as important by the T-SJ BBEST in Chapters 2 and 3 of this document, respectively. Chapter 4 then summarizes how such efforts might be integrated. The following recommendations are proffered, including specific monitoring, studies and activities which will support the future validation and refinement of the original environmental flow analyses, regime recommendations, adopted flow standards and strategies to achieve those standards.

Instream Flows

The draft environmental flow standards for the Trinity and San Jacinto Rivers include specific recommendations characterizing the flow regime at seasonal time steps. These environmental flow standards have been established at specific "measurement" points, as dubbed by TCEQ in the proposed rules, located at USGS gage sites within the Trinity and San Jacinto Rivers. These measurement points include the West Fork of the Trinity River (Gage 08049500); Trinity River at Dallas (Gage 08057000); Trinity River at Oakwood (Gage 08065000); Trinity River near Romayor (Gage 08066500); East Fork San Jacinto River near Cleveland (Gage 08070000); and the West Fork San Jacinto River near Conroe (Gage 08068000). Three flow components have been used for classification of flow levels at these gage sites. These include subsistence, base and pulse flows. In addition, pulse flows values have been defined in terms of peak flow triggers, volumes and duration.

This chapter is organized into five categories: Study Area Development, Hydrology, Hydraulics/Habitat/Geomorphology, Freshwater Ecology, and Water Quality. It is acknowledged that while each of these components broadly represent the various aspects of the study of instream flows and their relation to the environment, it is likely that assessments and analyses of each category will likely overlap, and may be better prosecuted in an coordinated manner. This overlap is explicitly recognized in the section on hydraulics, habitat, and geomorphology, as suggested efforts assessing these categories are inextricably linked. Each category details the establishment of a baseline data set utilizing existing and/or planned data development efforts based on assessments of data gaps. Existing programs are evaluated for their utility, and objectives of studies are identified in the context of how they might be useful in an environmental flow context. Near-term studies and/or surveys are specified, along with longer-term monitoring efforts or studies. It is important to note the geographic distribution of these monitoring efforts, studies, and surveys is considered an integral part of this process.

The following information needs and associated recommended monitoring or research will extend the knowledge base necessary to support validation and refinement of the original environmental flow analyses. The majority of the recommendations are derived from data gaps and information needs first identified in chapter 4 of the *BBEST. 2009. Environmental Flow Recommendations Report*. That chapter includes a list of issues from Richter et al. (2006) in regards to information needs for the application of adaptive management tasks. These recommendations are based on the assumption that existing agency environmental monitoring programs will continue within the basin at the same recent historical frequency. Recommended monitoring and research is therefore intended to supplement and build upon this existing monitoring framework.

Ultimately, the overall goal for the Trinity and San Jacinto basins is a naturally functioning and sustainable ecosystem that supports a balance of ecological benefits and economic and recreational uses. Objectives for each of the multiple disciplines, including hydrology, biology, physical processes, water quality, and connectivity have been developed, with an overriding initial aim to determine the natural, historic, and current conditions of each where possible. Preliminary indicators can be selected, with the Work plan identifying opportunities for their assessment and reconsideration as the science is developed. The culmination of these coordinated study efforts will be the characterization of the flow-habitat and flow-ecological relationships within the Trinity and San Jacinto River basins and their fluvial ecosystems. Results will provide a means of assessing the biological and physical responses to various flow regimes. A comprehensive methodology is presented from existing studies and field-gathered data that is anticipated to provide the predictive capabilities necessary to evaluate the ecological significance of the full range of flows (from low, to moderate, to high throughout the annual hydrologic cycle) on the riverine ecosystems of the Trinity and San Jacinto basins.

Validation and Refinement

A significant component of the SB 3 mandate for the Work plan is the validation and refinement of the flow standards as science is developed. "Validation," in this context, represents activities and analyses designed to evaluate the effectiveness of flow regimes in context of variability of parameters needed to create and test the flow regime. This includes testing the cause-effect relationship between flow and ecological response. "Refinement" suggests that as science is developed, a determination might be made at some future point that enough significant information has been developed to warrant modification of the flow standards and to offer improvements in the characterization of the flow regime necessary for protecting a sound ecological environment. It is anticipated that such studies would be heavily coordinated with the objectives and output from SB 2 TIFP efforts.

The description of the technical studies is divided into two main sections: an overview of the existing information and proposed studies (including how the proposed activities address specific objectives and indicators). A broad description of data collection methods, data analysis and modeling, and multidisciplinary coordination is also provided. It is the characterization of the objectives of these efforts which is perhaps most important. While detailed specifics of data collection processes and methodologies of analyses are beyond the scope of the development of this work plan, these objectives, and their supporting rationale, should be the principal focus as future efforts attempt to address the relations of flow to a sound ecological environment.

Study Areas

Although the 6 gage measurement points identified by the TCEQ define the environmental flow standards, study areas do not necessarily have to be located adjacent to these sites. A tiered process is proposed in order to facilitate the planning of study activities, focusing on Segments, Reaches, and Sites. These specific divisions of the basin will be referred to as "Study Segments," "Study Reaches," and "Study Sites." The more general terms "segment," "reach," and "site" will be used to refer to general lengths of river or stream. While broader studies may be conducted across an entire Segment, other studies will likely be conducted at particular Study Sites. Localized studies may have a single purpose or may address multiple indicators and involve multiple disciplines (e.g., hydraulic and habitat modeling site). Study sites should be identified in cooperation with the Stakeholder group and the SB2 efforts following the process described below. Details like the specific length of each site will be determined in the field and be dependant upon availability, distribution and abundance of habitat types, as well as upon availability of study resources.

A three-tier evaluation to identify Study Sites is proposed to capture the variability present in both basins, including upstream downstream gradients, reach level complexity, and tributaries. Tier 1 evaluation will be at a high-level, based primarily on basin geology, valley shape, and Texas ecoregions, resulting in the designation of large-scale Study Segments for both the Trinity and San Jacinto Rivers. Depending on monitoring resources, these Segments should be located in a variety of locations to better characterize the variety of conditions and biological resources that exist in the basin. These Segments will be further divided into potential Study Reaches based primarily on major hydrological and geomorphological features and conditions.

The Tier 2 evaluation will be more detailed, focusing on specific parameters relative to the hydrology, biology, physical processes, and water quality supported within those Reaches. Tributaries should be selected in a manner that will take into account unique features, in addition to physical attributes and location within the watershed (e.g. river mile, drainage area). At least one survey at two tributaries should be conducted at each flow level (subsistence, base and pulse) during the next 4 years. This detailed evaluation will determine which activities are recommended within the proposed Study Reaches.

The Tier 3 evaluation will examine in finer detail shorter stretches of the rivers (Study Sites) that would represent the Reach in general and be of a practical size for the resources available. It is not economically feasible to conduct intensive study activities such as hydraulic modeling or riparian assessment for entire Study Reaches. Therefore, the selection of representative Study Sites offers a means of efficiently characterizing the system.

This effort should be considered a high priority task that can be accomplished within 1-4 years of the initiation of Work Plan efforts, using a process similar to defining the base ecological condition.

Mapping of unique features.

BBEST needs to develop a process to identify special environmental areas (oxbows, conservation areas, riparian wetlands) using off the shelf data for targeting future studies. Some of these areas provide unique services (e.g. rearing areas for fish in oxbows) to the river ecosystem. The relationship of the flow regime to the exact functioning and services provided by these features needs to be further defined to insure these services are being preserved. The initial phase of mapping could be done within the next 2 years. The detailed surveys on site will require additional resources and will likely extend beyond the next 4 years.

Hydrology

The focus of this hydrologic/hydraulic component of the work plan is to provide an overview of available information, an assessment of current and natural conditions, and a description of the proposed technical studies. A three-tiered approach has been suggested for study site considerations. The objectives for data collection efforts and analyses are discussed, anticipating multidisciplinary coordination amongst the various categories included in this work plan for the assessment of instream flows.

Summarization of Existing Data

USGS gage data and flow trends at representative gages

The U.S. Geological Survey (USGS) has maintained a network of streamflow gages in the Trinity and San Jacinto river basins as far back as the late 1800's. Presently, 124 streamflow gages are currently (2010) maintained within the Trintity and SanJacinto River basins, including 17 streamflow gages on the Trinity River and 7 on the San Jacinto. Some historical data are available from additional stream gages that are no longer being maintained in the basins. Published data from all of these gages are readily available online, and are summarized below:

Table 1. Current and Historical USGS stream gages in the Trinity and San Jacinto Rivers

Number	USGS Gage ID	USGS Gage Name	Drainage Area	Period of Record	
				Begin	End
1	8042800	W Fk Trinity Rv nr Jacksboro, TX	683	3/1/1956	10/5/2010
2	8044000	Big Sandy Ck nr Bridgeport, TX	333	10/9/1936	10/6/2010
3	8044500	W Fk Trinity Rv nr Boyd, TX	1725	1/20/1947	10/4/2010
4	8044800	Walnut Ck at Reno, TX	75.6	4/14/1992	10/6/2010
5	8045550	WFk TrinityRv at White Settlement Rd,Fort Worth,TX	2068	4/17/2009	10/14/2010
6	8045850	Clear Fk Trinity Rv nr Weatherford, TX	121	6/1/1987	4/18/2010
7	8045995	Clear Fork Trinity Rv at Kelly Rd nr Aledo, TX		7/28/2010	10/5/2010
8	8047000	Clear Fk Trinity Rv nr Benbrook, TX	431	7/9/1947	10/5/2010
9	8047050	Marys Ck at Benbrook, TX	54	5/14/1998	10/14/2010
10	8047500	Clear Fk Trinity Rv at Ft Worth, TX	518	3/17/1924	10/6/2010
11	8048000	W Fk Trinity Rv at Ft Worth, TX	2615	8/21/1920	10/15/2010
12	8048543	W Fk Trinity Rv at Beach St, Ft Worth, TX	2685	10/22/1986	10/15/2010
13	8048970	Village Ck at Everman, TX	84.5	10/23/1989	10/12/2010
14	8049500	W Fk Trinity Rv at Grand Prairie, TX	3065	3/20/1925	10/21/2010
15	8049580	Mountain Ck nr Venus, TX	25.5	10/22/1985	10/7/2010
16	8049700	Walnut Ck nr Mansfield, TX	62.8	9/30/1960	10/12/2010
17	8050100	Mountain Ck at Grand Prairie, TX	298	10/24/1986	10/7/2010
18	8050400	Elm Fk Trinity Rv at Gainesville, TX	174	8/29/1985	10/14/2010
19	8050800	Timber Ck nr Collinsville, TX	38.8	10/21/1985	10/12/2010
20	8050840	Range Ck nr Collinsville, TX	29.2	12/14/1992	10/12/2010
21	8051135	Elm Fk Trinity Rv at Greenbelt nr Pilot Point, TX	694	10/13/2004	10/6/2010
22	8051500	Clear Ck nr Sanger, TX	295	10/23/1986	10/6/2010
23	8052700	Little Elm Ck nr Aubrey, TX	75.5	10/23/1985	10/4/2010
24	8052745	Doe Br at US Hwy 380 nr Prosper, TX	38.5	10/12/2004	10/6/2010
25	8052780	Hickory Ck at Denton, TX	129	4/23/1985	10/4/2010
26	8053000	Elm Fk Trinity Rv nr Lewisville, TX	1673	10/9/1986	10/5/2010
27	8053009	Indian Ck at FM 2281, Carrollton, TX	13.7	3/8/2007	10/7/2010
28	8053500	Denton Ck nr Justin, TX	400	11/16/1984	10/4/2010
29	8055000	Denton Ck nr Grapevine, TX	705	10/24/1984	10/25/2010
30	8055500	Elm Fk Trinity Rv nr Carrollton, TX	2459	5/12/1972	10/5/2010
31	8055560	Elm Fk Trinity Rv at Spur 348, Irving, TX	2537	5/24/2007	10/6/2010
32	8056500	Turtle Ck at Dallas, TX	7.98	12/17/1951	10/7/2010
33	8057000	Trinity Rv at Dallas, TX	6106	1/22/1982	10/1/2010
34	8057200	White Rk Ck at Greenville Ave, Dallas, TX	66.4	7/18/1961	10/6/2010
35	8057410	Trinity Rv bl Dallas, TX	6278	11/16/1956	10/1/2010
36	8057445	Prairie Ck at US Hwy 175, Dallas, TX	9.03	11/4/1975	10/4/2010
37	8059000	E Fk Trinity Rv nr McKinney, TX	190	8/22/1949	10/15/2010
38	8059350	Indian Ck at SH 78 nr Farmersville, TX	104	6/14/2007	11/8/2010
39	8059400	Sister Grove Ck nr Blue Ridge, TX	83.1	7/9/1975	10/9/2009
40	8061540	Rowlett Ck nr Sachse, TX	120	3/12/1968	10/6/2010
41	8061551	E Fk Trinity Rv blw Lk Ray Hubbard nr Forney, TX	1071	10/7/2008	10/5/2010
42	8061750	E Fk Trinity Rv nr Forney, TX	1118	1/17/1973	10/5/2010
43	8062000	E Fk Trinity Rv nr Crandall, TX	1256	9/13/1982	10/4/2010
44	8062500	Trinity Rv nr Rosser, TX	8147	3/2/1987	10/5/2010
45	8062700	Trinity Rv at Trinidad, TX	8538	10/17/1984	10/6/2010
46	8062800	Cedar Ck nr Kemp, TX	189	10/7/1986	10/4/2010
47	8062895	Kings Ck at SH 34 nr Kaufman, TX	224	3/12/2009	10/5/2010
48	8063048	White Rk Ck at FM 308 nr Irene, TX	65.8	10/16/2007	11/2/2010
49	8063100	Richland Ck nr Dawson, TX	333	10/19/1984	10/7/2010
50	8063590	Waxahachie Ck at Waxahachie, TX	60.4	7/23/2008	10/8/2010

Table 1 (cont'd). Current and Historical USGS stream gages in the Trinity and San Jacinto Rivers

Number	USGS Gage ID	USGS Gage Name	Drainage Area	Period of Record	
				Begin	**End**
51	8063800	Waxahachie Ck nr Bardwell, TX	178	10/15/1984	10/8/2010
52	8064100	Chambers Ck nr Rice, TX	807	10/16/1984	10/7/2010
53	8064700	Tehuacana Ck nr Streetman, TX	142	10/30/1985	10/6/2010
54	8065000	Trinity Rv nr Oakwood, TX	12833	10/17/1923	10/20/2010
55	8065200	Upper Keechi Ck nr Oakwood, TX	150	4/23/1962	10/19/2010
56	8065350	Trinity Rv nr Crockett, TX	13911	3/31/1964	10/20/2010
57	8065800	Bedias Ck nr Madisonville, TX	321	7/9/1962	10/11/2010
58	8066000	Trinity Rv at Riverside, TX	15589	--	--
59	8066170	Kickapoo Ck nr Onalaska, TX	57	12/10/1965	10/13/2010
60	8066200	Long King Ck at Livingston, TX	141	6/11/1962	10/13/2010
61	8066250	Trinity Rv nr Goodrich, TX	16844	12/17/1965	10/6/2010
62	8066300	Menard Ck nr Rye, TX	152	8/21/1950	10/5/2010
63	8066500	Trinity Rv at Romayor, TX	17186	5/3/1924	10/6/2010
64	8067000	Trinity Rv at Liberty, TX	17468	1/8/1931	2/19/2010
65	8067070	CWA Canal nr Dayton, TX		2/10/1981	10/6/2010
66	8067525	Goose Ck at Baytown, TX	15.8	2/11/1985	10/26/2010
67	8067548	W Fk San Jacinto Rv nr Huntsville, TX	84.9	2/9/2009	10/11/2010
68	8067650	W Fk San Jacinto Rv bl Lk Conroe nr Conroe, TX	451	10/5/1972	9/20/2010
69	8068000	W Fk San Jacinto Rv nr Conroe, TX	828	5/7/1924	9/20/2010
70	8068090	W Fk San Jacinto Rv abv Lk Houston nr Porter, TX	962	2/3/1984	9/17/2010
71	8068275	Spring Ck nr Tomball, TX	186	4/5/2000	9/15/2010
72	8068325	Willow Ck nr Tomball, TX	41	9/7/1984	10/27/2010
73	8068390	Bear Br at Research Blvd, The Woodlands, TX	15.4	10/17/1994	9/17/2010
74	8068400	Panther Br at Gosling Rd, The Woodlands, TX	25.9	3/19/1974	9/20/2010
75	8068450	Panther Br nr Spring, TX	34.5	4/30/1972	9/15/2010
76	8068500	Spring Ck nr Spring, TX	409	10/18/1994	10/27/2010
77	8068700	Cypress Ck at Sharp Rd nr Hockley, TX	80.7	6/9/1975	3/25/2008
78	8068720	Cypress Ck at Katy-Hockley Rd nr Hockley, TX	110	6/10/1975	7/8/2010
79	8068740	Cypress Ck at House-Hahl Rd nr Cypress, TX	131	6/10/1975	10/5/2010
80	8068780	Little Cypress Ck nr Cypress, TX	41	5/14/1982	9/24/2010
81	8068800	Cypress Ck at Grant Rd nr Cypress, TX	214	5/14/1982	10/4/2010
82	8068900	Cypress Ck at Stuebner-Airline Rd nr Westfield, TX	248	5/15/1982	9/8/2010
83	8069000	Cypress Ck nr Westfield, TX	285	7/2/1944	10/4/2010
84	8069500	W Fk San Jacinto Rv nr Humble, TX	1741	10/23/1928	7/29/1954
85	8070000	E Fk San Jacinto Rv nr Cleveland, TX	325	4/26/1939	10/29/2010
86	8070200	E Fk San Jacinto Rv nr New Caney, TX	388	7/8/1952	10/26/2010
87	8070500	Caney Ck nr Splendora, TX	105	1/8/1944	11/3/2010
88	8071000	Peach Ck at Splendora, TX	117	4/28/1999	11/3/2010
89	8071280	Luce Bayou abv Lk Houston nr Huffman, TX	218	2/2/1984	10/26/2010
90	8072050	San Jacinto Rv nr Sheldon, TX	2879	5/19/1989	10/18/2006
91	8072300	Buffalo Bayou nr Katy, TX	63.3	7/13/1977	10/18/2010
92	8072350	Buffalo Bayou nr Fulshear, TX	81.7	3/24/1986	3/24/1986
93	8072600	Buffalo Bayou at State Hwy 6 nr Addicks, TX		9/23/2010	10/7/2010
94	8072700	S Mayde Ck nr Addicks, TX	32.3	6/12/1973	10/17/2000
95	8072730	Bear Ck nr Barker, TX	21.5	7/12/1977	10/26/2010
96	8072760	Langham Ck at W Little York Rd nr Addicks, TX	24.6	7/12/1977	10/25/2010
97	8072800	Langham Ck nr Addicks, TX	48.9	6/12/1973	10/16/2000
98	8073500	Buffalo Bayou nr Addicks, TX	277	11/7/1979	10/6/2010
99	8073600	Buffalo Bayou at W Belt Dr, Houston, TX	290	7/28/1971	10/6/2010
100	8073700	Buffalo Bayou at Piney Point, TX	299	12/26/1912	10/6/2010

Table 1 (cont'd). Current and Historical USGS stream gages in the Trinity and San Jacinto Rivers

				Period of Record	
Number	USGS Gage ID	USGS Gage Name	Drainage Area	Begin	End
101	8074000	Buffalo Bayou at Houston, TX	336	1/31/1980	4/28/2009
102	8074020	Whiteoak Bayou at Alabonson Rd, Houston, TX	34.5	8/7/1984	10/28/2010
103	8074150	Cole Ck at Deihl Rd, Houston, TX	7.5	4/17/1964	10/22/2009
104	8074250	Brickhouse Gully at Costa Rica St, Houston, TX	11.4	9/2/1964	7/8/2010
105	8074500	Whiteoak Bayou at Houston, TX	95.1	11/5/1979	10/20/2010
106	8074540	Little Whiteoak Bayou at Trimble St, Houston, TX	18.1	12/13/1979	7/8/2010
107	8074598	Whiteoak Bayou at Main St, Houston, TX	127	5/5/1993	6/21/1993
108	8074760	Brays Bayou at Alief, TX	15	2/11/1977	10/28/2010
109	8074800	Keegans Bayou at Roark Rd nr Houston, TX	12.7	8/18/1964	7/2/2010
110	8074810	Brays Bayou at Gessner Dr, Houston, TX	52.5	4/7/1977	10/27/2010
111	8075000	Brays Bayou at Houston, TX	94.9	10/29/1979	10/21/2010
112	8075110	Brays Bayou at MLK Jr Blvd, Houston, TX	135	10/16/2006	9/21/2010
113	8075400	Sims Bayou at Hiram Clarke St, Houston, TX	20.2	8/19/1964	10/27/2010
114	8075500	Sims Bayou at Houston, TX	63	11/7/1952	9/7/2010
115	8075605	Berry Bayou at Nevada St, Houston, TX	4.95	5/31/2006	10/22/2010
116	8075730	Vince Bayou at Pasadena, TX	8.26	5/5/1971	11/10/2010
117	8075763	Hunting Bayou at Hoffman St, Houston, TX	7.21	10/16/2006	10/20/2010
118	8075770	Hunting Bayou at IH 610, Houston, TX	16.1	4/17/1964	10/20/2010
119	8075780	Greens Bayou at Cutten Rd nr Houston, TX	8.65	10/28/1964	7/8/2010
120	8075900	Greens Bayou nr US Hwy 75 nr Houston, TX	36.6	8/12/1965	11/1/2010
121	8076000	Greens Bayou nr Houston, TX	68.7	10/24/1979	10/21/2010
122	8076180	Garners Bayou nr Humble, TX	31	1/22/1919	10/21/2010
123	8076500	Halls Bayou at Houston, TX	28.7	11/4/1952	10/25/2010
124	8076700	Greens Bayou at Ley Rd, Houston, TX	182	11/28/1962	7/3/2010

Previous assessments performed by the T-SJ BBEST suggest that base flow conditions in the Trinity basin have increased dramatically over time. These changes are likely due to a number of factors, including changes in precipitation, urban growth, interbasin transfers, and return flows.

The relationships between flow components and various ecological processes in the Trinity and San Jacinto river basin ultimately need to be developed in order to facilitate the future refinement of flow standards as science is developed. The presently hypothesized characteristics of these flow components are presented in Table 2 below.

Table 2. Flow component table and associated characteristics

Component	Hydrology
Subsistence flows Infrequent, low flows (typically during summer)	Return flows (such as wastewater discharge) make up a large portion of flow
Base flows Average flow conditions absent the effects of rainfall derived events, including variability	Elevated over time, may be due to increased return flows and interbasin transfers in the Trinity Varies by season and year
High flow pulses In-channel, short duration, high flows from rainfall derived events	Increased development in the basin (increasing impervious cover) may have increased the magnitude and frequency of these events
Overbank flows Infrequent, high flows that exceed the channel	Occur due to natural climate, geography, and geology of the river basin

Objectives

The objective for the characterization and analysis of hydrology is the development of a flow regime that sustains ecological processes throughout the system. This can be broken down into three constituent parts:

1. Determination of the components of the flow regime and their characteristics that support study objectives of the aforementioned disciplines;
2. Determining the natural variability of flow component characteristics; and,
3. Evaluating water losses and gains throughout the system.

Initial Hydrologic Indicators for Baseline Establishment

The indicators selected to evaluate flow regime components are frequency, timing, duration, rate of change, and magnitude of overbanking, high pulse, base, and subsistence flows. Natural variability will be based upon the above indicators from the older portions of gage records; whereas, current variability will be limited to the last 20 to 25 years of flow records. Indicators for water losses and gains are strictly the difference in the amount of water entering and leaving specific sections of the river channel. The development and establishment of such information will work towards the establishment of a baseline upon which analyses from other disciplines will be performed.

Table 3. Hydrologic Indicators

Indicators		
Category	*Indicator*	*Explanation*
Flow regime components	Overbank flows (frequency, timing, duration, rate of change, and magnitude)	Infrequent, high magnitude flow events that enter the floodplain * Maintenance of riparian areas * Transport of sediment and nutrients * Allow fish and other biota to utilize floodplain habitat during and after floods * Riparian and floodplain connectivity to the river channel * The National Weather Service provides flood impact summaries for most USGS streamflow gage sites, based on water surface elevation or "stage." These summaries provide an estimate of negative impacts of overbank flows.
	High pulse flows (frequency, timing, duration, rate of change, and magnitude)	Short duration, high magnitude, within channel, rainfall derived flow events * Maintain physical habitat features along the river channel * Provide longitudinal connectivity along the river corridor for many species (e.g. migratory fish) * Provide lateral connectivity (e.g., connections to oxbow lakes)
	Base flows (frequency, timing, duration, rate of change, and magnitude)	Range of average or "normal" flow conditions * Provide instream habitat quantity and quality needed to maintain the diversity of biological communities * Maintain water quality conditions * Recharge groundwater * Provides for recreational or other uses
	Subsistence flows (frequency, timing, duration, rate of change, and magnitude)	Low flows maintained during times of very dry conditions * Maintain water quality standards * Prevent increased loss of aquatic organisms
Natural variability	Natural	Determination of the natural variability of the above indicators, based on the older portions of gage records, presumably less impacted by human activity. The exact time period may vary by gage site.
	Current	Variability of the above indicators based on the last 20-25 years of gage records.
Losses/gains	Gain or loss in section of river	Difference in the amount of water entering and leaving a specific section of the river channel. Sources of gains include inflow from tributaries, alluvial and deeper aquifers, and discharges to the river. Sources of losses include evaporation, evapo-transpiration from riparian areas, diversions, and recharge of alluvial and deeper aquifers. Indicator may be influenced by shallow groundwater surface elevation and hydraulic head of deeper aquifers where present.

Flow Regime Component Characterization

The Trinity River and San Jacinto River ecosystems have evolved in response to the inter- and intra-annual variability in flow that includes cycles of overbank flows, high flow pulses and subsistence flows with intervening periods of base flows. This variability in the cycling of flow is typically referred to as the flow regime. An evaluation of the flow regime will address several of the hydrological indicators including natural variability, current variability, and gain or loss in river flow. A number of long-term flow gaging stations exist in the basin (Table 1 shown previously) allowing characterization of flow variability, i.e., how the flow regime changes spatially (moving downstream towards the coast and from tributary to mainstem) and temporally (comparing early periods to later periods). Although not readily available via the web-based USGS National Water Information System database, additional channel and flow datasets are avilable in the historical hard copy files of all the gages in each basins. This historical data recovery can yield the following datasets:

- average velocity,
- channel cross-section,
- channel control description,
- two-demensional velocity field (doppler flow measurements at moderate to high flow), and
- single to 2 point velocity fields at base to low-flow.

These types of data will provide additional site specific information on temporal changes in channel morphology, corresponding changes in the velocity vector field, and provide a valuable overlay to historical biologic and water-quality overlays. Questions to be addressed include:

- To what extent have the low, high pulse, and flood flows in the river changed over time in response to human influences?
- Have extreme low flows become more frequent or extreme?
- How do hydrographs from recent years compare to predevelopment hydrographs?
- What are the primary human influences on the flow regime, and where do these impacts occur?
- Do certain human impacts appear to dominate over other human influences?
- What types of water development activities are planned for the future, and how might those developments influence river flows?
- How important are ground water contributions to base flows?
- What is the nature of hydraulic connections between river stage and alluvial water table levels?
- How might these connections be altered by future water developments?

Regional Water Planning and Water Availability Modeling efforts have gone a long way towards the development of such information. Studies under these programs should be explored and utilized to bring such information forward for consideration.

Natural variability

Natural variability includes typical fluctuations in base flow, limited periods of very low or subsistence flow, and high flows including within-channel pulse events and overbank flow events. Since the time of the earliest flow records (late 1800's), a significant increase in base flow is exhibited at all gages as a result of factors such as increased wastewater return flows and interbasin transfers. The long period of record allows comparisons between early periods that may represent a more natural condition to later periods reflecting current land use, water usage, and other conditions affected by human's use of water and the landscape.

Statistics derived from a hydrologic evaluation will be used to characterize the flow record and evaluate ranges for the four main instream flow components: subsistence flow, base flow, high flow pulses, and overbank flow. Pre-existing flow analysis tools may be used to evaluate these components (e.g., Indicators of Hydrological Assessment [IHA], Hydrology-based Environmental Flow Regime [HEFR], Texas Hydrological Analysis Tools [TxHAT]) or alternatively, standard statistical methods may be used including non-parametric statistics (e.g., 5th percentile flow). Quantitative values for ecological flow components have already been derived within the T-SJ basin during the first phase of the BBEST process through the prosecution of MBFIT and HEFR analyses. Any statistical characterization of flows will be complementary to field studies and physical assessments that identify flow levels beneficial to the existing natural ecologies of the Trinity and San Jacinto River basins.

Temporal variations which would be assessed include long-term, decadal variations in hydroclimatology, as well as intra-annual variations in monthly streamflows. Analyses should attempt to address the relation between instantaneous and daily flows, including what information is gained/lost from their assessment. Spatial variations include assessments of the variation in hydrologic patterns from a measured location, and to what extent measurements at a site represent its upstream watershed. Flow duration curves should be prepared for undeveloped and developed conditions at all relevant stream gauges.

Losses / gains

Where the interaction of surface water and groundwater in adjacent aquifers is thought to be substantial, an evaluation of the flow between the surface and groundwater is proposed. The relevance of this interaction, in relation to the overall base flow of the stream reach would be be assessed in order to further clarify objectives related to groundwater/ surface water interactions and thier percentage as a source or sink of flow in the stream reach.

Near-term:

- 3-Tier process for establishment of study areas
- Characterization of flow regime components

Mid-term:

- High-flow pulse and overbank assessment
- Loss/gain

Long-term

- Continued flow regime component characterization

Hydraulics/Habitat/Geomorphology

There is a need to establish predictive relationships between key habitat variables (e.g. depth, velocity, substrate, cover) and flow levels. These variables are known to influence the distribution of stream and river biota. In addition to the statistical analysis of the flow record at existing gages, site-specific field studies should focus on development of two-dimensional (2D) hydraulic and habitat models. A 2D hydraulic model provides simulated flow conditions for a given stretch of river (habitat study site). The simulated flow conditions are then run through a GIS-based physical habitat model to predict habitat conditions within that habitat study site. For each simulated flow, the spatial availability of suitable habitat can then be queried using habitat suitability criteria for habitat guilds and key species. For each guild and key species, streamflow to habitat relationships are developed. The general process of hydraulic modeling in support of habitat modeling is described in sections 6.2, 7.3, and 10.2 of TIFP 2008.

Predictive physical habitat models (e.g. PHABSIM) have been developed using these variables and previously developed individual species preferences for these variables. The end product is a predictive model that relates weighted usable area (WUA) versus flow. As noted these data are used with indicator species/metric preferences to develop these models. These preferences can be established by studies in the basin or by using off the shelf literature values derived from other studies with that indicator in similar river systems.

With the advent of high technology applications that use side scan sonar (SSS), acoustic Doppler current profiling (ADCP) that is geo-referenced it is now possible to physically map (depth, habitat, flow, velocity) over large areas including representative reaches selected for biological studies. Recent technology developed by Dr. Thom Hardy that processes these types of data can be used to directly calculate WUA for some indicator species. Automated and/or geo-referenced photography can also be used to visually document changing conditions in physical habitat at various flow levels and/or over broad areas of the watershed with minimal effort. This information when linked with a more detailed topographic and hydrological mapping effort, can provide a very comprehensive assessment of changing conditions associated with fluctuating flow levels.

This task should be considered a high priority and capable of being accomplished within the next 4 years. The photographic monitoring system could be deployed and utilized within a 1 year period.

Data Gaps

- **As noted previously, there is a significant data gap regarding the availability of cross sections and matrix of water velocities within cross sections at sites other than USGS flow gages** – Some available now but more needed in order to identify representative short reaches for more intensive work and monitoring. Applies to both rivers and the coastal basins. Cross section needs to go up to cut bank. Need stage and velocities at various discharge levels. Consider acoustic Doppler along with other methods.
- **Riffle/pool/run locations and measurements at various flow levels** – Some available now but more needed in both river basins and the coastal basins.
- **Bottom structure identification and mapping** – Consider side-scan sonar along with other methods.
- **Sinuosity** – Analysis of aerial and satellite imagery. Considerable imagery is available but analysis is needed.
- **Sediment loads and transport** – Recent work sponsored by TWDB on lower Trinity needs to be complemented by additional work in both river basins and in the coastal basins. There are some periods of suspended sediment data several decades old, but very little recent. There is no bed-load data.
- **Channel stability** – Analysis of historical sequences of aerial images and also historical sequences of USGS cross sections. Data available but analysis needed. Also, ground-level geo-referenced photographs of the river and banks should be taken at regular or event driven intervals.
- **Bed and bank substrate characterization** with respect to habitat and erosion.
- **Cross-sections and slopes of lower reaches of tributaries, sloughs, oxbows, etc. inundated by backwater from high stages downstream.**
- **Topography and habitat in floodplains** – Adequate precision to determine inundated/wetted areas.
- **Acquisition and analysis of historical data** – Literature review and archiving of surveys, maps, and related information to determine original conditions and changes that have occurred.
- **Long reach surveys** needed to determine the variability of conditions and to enable selection of representative short reaches for intensive work

and long-term monitoring. Some of the above types of data can be collected during the surveys. Some are done on Trinity but more needed there, plus San Jacinto and coastal streams.

For the study of the Trinity and San Jacinto basins, 2D hydraulic and habitat models will be developed to evaluate changes in microhabitat across a range of flow rates. This analysis will specifically aid the development of subsistence and base flow components and will therefore focus on flow rates from about the median to the 10^{th}-percentile flow. The locations of the hydraulic and habitat modeling will be identified subsequent to the tiered evaluation of study locations. Potential questions such studies might attempt to address include:

(1) Has any hydraulic modeling been performed for the river? Has any flood hazard mapping been undertaken?
(2) How well are relationships between river stages (water elevations) and river flow levels understood?
(3) How well are relationships between river flow and the distribution of velocities and depths in the river channel understood?
(4) Is there longitudinal (upstream to downstream) connectivity in flow or are there major discontinuities (i.e. diversion dams), and if so where?
(5) Has the lateral connectivity between the river and its floodplain been altered in any way?

Potential approaches to be identified as broad study objectives for Hydraulic studies suggested in the Work plan:

(6) Develop river stage-discharge relationships (e.g., at flow monitoring stations or from hydraulics models).
(7) Plot the relationship between flow and estimated percent floodplain inundated at representative river transects (e.g., at stream gauges or from aerial photos).
(8) Develop flow depth and velocity estimates across river transects (e.g., at stream gauges or using hydraulics models).

Such efforts' objectives should be the characterization of existing habitat conditions across a range of flow rates. Specific habitat types will be characterized based upon habitat utilization data recorded in the Trinity and San Jacinto basins relevant to the aquatic organisms present in the areas. The collection of the biological and habitat data is described elsewhere in the Work plan. Identifying breakpoints or sharp changes in habitat availability provides insight into flow rates relevant to river ecology. Relevant flow ranges identified by the habitat modeling will be compared to the frequency of those flows exhibited in historical and current flow records. Instream flow guidelines for achievement of particular flows may be recommended on the basis of both physical habitat requirements and upon historical frequency of occurrence. Other analyses, including development of a habitat time series, may be conducted to consider both habitat and flow frequency.

Development of hydraulic and habitat models is one of the more resource intensive tasks involved in a typical instream flow study. Model development represents a multistage, multi-disciplinary process that includes (1) biological data collection to characterize relevant habitat, (2) physical data collection to characterize the river channel, (3) data processing to integrate points into a cohesive map of the river system, (4) hydraulic model development, calibration and validation, (5) habitat model development, including the integration of habitat utilization data, (6) analysis of habitat model results and, finally, (7) evaluation of results leading to development of flow guidelines.

To characterize velocity and depth patterns at a level suitable for use in microhabitat, the model developed at each habitat Study Site needs input data at a sufficiently high resolution. In particular, detailed maps of bathymetry (elevation of the channel bed) and substrate (materials comprising the channel bed) are required as well as water surface elevation data. At the same time, flow rate, depth and velocity should be collected.

Topography, water surface elevation and discharge

At each model Study Site, complete channel and near-channel floodplain Digital Terrain Models (DTMs) should be created using a combination of survey-grade GPS equipment and conventional surveying equipment coupled with hydro-acoustic depth/velocity sounding data. Survey data will be reviewed for completeness (missing data, holes in the topography, etc.) on a daily basis using ArcView software, and supplementary topographic surveying will be conducted to ensure complete coverage of the identified intensive Study Sites.

Once the model Study Sites are established, low-altitude, high-resolution color aerial photography will be flown at each of the modeling Study Sites at relatively low flows. Aerial photography will be used to the degree practicable to fill in potential gaps in difficult to survey areas for the completion of a DTM to characterize the channel in both the 2D hydraulic and habitat models. Color aerial photography could also be used to assist in substrate mapping, riparian mapping, water's edge description, mesohabitat mapping, and woody debris assessment.

Calibration data for hydraulic modeling consists of a stage-discharge relationship at the upstream and downstream end of each Study Site. Water surface elevations will also be measured throughout the Site at various discharges, along with accordant water surface elevations in order to adequately characterize changes in edge of water and water surface slope throughout the Site. Data to validate the accuracy of the 2D hydraulic model results should be collected during these various flow conditions and should consist of the length and width of any large recirculation zones in addition to velocity data. Velocity data consisting of average column velocity and direction should be collected as well.

Model calibration, validation and sensitivity analysis

Calibration is the process whereby a model's input parameters are tuned to maximize measures of model performance using measured field data. To assess the ability of the model to predict real-world conditions, the model is then validated against the additional field data using the calibrated ("tuned") parameter values. Substrate roughness and eddy viscosity are two calibration parameters commonly used in this process. Each time stage-discharge data for the development of rating curves is collected (each Site at a minimum of 3 flows), additional depth/velocity point measurements for calibration should be collected.

The 2D hydraulic model will be calibrated to at least three measured water surfaces (high, medium, and low flow) by adjusting substrate roughness and eddy viscosity parameters. To adjust substrate roughness, substrate maps at each Study Site should include an estimated hydraulic roughness height based on the size of the largest particle in each substrate category. All subsequent hydraulics modeling of the various flows for habitat modeling should be completed using calibrated channel roughness heights and viscosity parameter adjustments. A range of flows should be modeled at each Study Site. This flow range covers the majority of median monthly flows in the historical range including temporary pulse flow events, but not including flood flow conditions. The focus of this range is in-channel aquatic habitat conditions.

Uncertainty in environmental models exists and can, to some degree, be characterized. A riverine model uses generalized parameters to describe and simulate the physical characteristics of the river. These generalized parameters have uncertainty bounds associated with them, which leads to model uncertainty. Calibration of a hydraulic model aids in reducing but not totally eliminating model uncertainty. The sensitivity of hydraulic model results to changes in calibrated parameters should be investigated. If the model is found to be highly sensitive to a parameter, efforts should be made to reduce the parameter uncertainty through further data analysis, calibration and/or acquisition of additional data.

High flow pulse and overbank assessment

Using HEC-RAS models and high-resolution LiDAR topography, extent of inundation should be evaluated along the length of the river for a series of high flow pulses or small floods. This analysis will be valuable in assessing the hydrologic indictors of overbanking and high flow pulses. Differences in interval between inundation events should be evaluated spatially along the length of the river to identify breakpoints or to identify areas where frequent inundation has significant ecological impact.

The range of flows to be evaluated will have recurrence intervals ranging from less than two per season (high pulse flows) to 10 years (overbank flows). Given the small magnitude of some of these flows, i.e., much lower magnitude than typically analyzed for flood studies (e.g., 100-year flood), the in-channel bathymetry will become an important factor. Detailed cross-sectional information may need to be developed for select reaches of the river where it is not currently known. This information may be developed from a combination of new survey data and statistical relationships that result in synthetic in-channel cross-sections.

Validation

- From the on-site data, quantify key geomorphic parameters and calculate how they correlate to actual flows and to the TCEQ-adopted flows.
- Determine the range and variability of key geomorphic parameters including physical habitats, velocities, etc. with respect to flow.
- Selection of short study reaches need to be shown to be thoroughly representative of longer reaches in which they occur. Selection must be based on biologic, water quality, and hydrologic considerations along with geomorphologic factors.

Refinement

- Intensive study and monitoring of selected short reaches should demonstrate the actual ecologic responses to flow. Then the recommended flows and associated frequencies and ranges can be adjusted.

Near Term/Long Term Actions

Near Term (0-5 year)

- Conduct surveys on long reaches that cover the TCEQ-adopted flow sites, collecting the types of field data indicated in *Data Gaps* above.
- Analyze imagery indicated in *Data Gaps* on the same reaches.
- Select representative short study site(s) within each long reach for intensive work and long-term monitoring. Selection must include consideration of all four areas – hydrology, biology, water quality, and geomorphology.
- Prioritize the short reaches and begin intensive site-specific work to detail the flows at which key ecological functions occur.

- Begin long-term monitoring of key parameters at the short reaches once the initial intensive work is done.
- Before the end of five years, review all work and recommend retention or amendment of TCEQ's flow standards.

Long Term (0-10 years)

- Adapt work plan to any amendments TCEQ makes to the flow standards.
- Perform intensive work in any short reaches where it has not yet been done and begin long term monitoring at those locations.
- Continue long-term monitoring already begun.
- Repeat the refinement step of reviewing results and by the end of five years recommending retention or amendment of flow standards.

Ecology

Analyses and Establishment of baseline ecological conditions

Prior to initiating any analysis of new or existing data there is a need to define the baseline ecological condition for the mainstem river and tributaries of the Trinity and San Jacinto River. As noted previously, current measurement points are limited to six gage locations and therefore do not reflect overall basin conditions. However, due to the large drainage area and complex mixture of land use and demographics the establishment of baseline conditions is not a trivial task. The definition of baseline conditions should include expected/desired fish community, macrophyte community, mussel community, and riparian community. As a result, various indicator metrics (e.g. species, guilds, traits) must be selected. The definition should also include the expected flow regime, water quality, sediment budget, and habitat conditions that would support these communities. The baseline description would be expected to differ to some extent between locations due to upstream-downstream differences in rainfall, water quality, land use, and geology. The baseline condition would be the agreed upon condition which future data would be compared to in order to evaluate whether the ecosystem was changing in unexpected ways, and if those unexpected changes were established as being related to changes in the flow regime. In addition to describing the baseline ecological condition, "alert" conditions should be identified that would indicate possible exceedances of the normal range of baseline conditions and which could trigger consideration of changes in the environmental flow regime or environmental flow standards.

This task should be completed within 6 months of the approval of the work plan. BBEST members are encouraged to develop proposals which will be submitted to the BBEST prior to a BBEST meeting that will be convened to identify baseline values. Proposals will be one page or less and standard in format to facilitate review and discussion at the BBEST meeting. When defined, the baseline condition should include key assumptions. The baseline values should be viewed as tentative initially and will be modified as appropriate as additional data are collected and/or analyses conducted. The BBEST members recognize that rivers are complex and will take extreme care to ensure baseline values can be related to instream flows.

Priority: High. Needs to be accomplished immediately and can be done within relatively short time but is considered a continuous process as new information is acquired.

Objectives

There is a need to assemble information and/or conduct various inter-related studies, the objective of which is the establishment of the relationship of critical habitat and fish community structure at various flows, and how this relates to the entire river ecosystem. It is highly recommended that the response of indicator biota and associated water quality and physical attributes (including riparian zone communities) to various components of the flow regime be monitored at these representative study sites. These are described below.

Identification of Indicator Metrics & Species

One of the primary tasks that need to be accomplished is the selection of key indicator species or metrics of interest. This task should be accomplished while defining the baseline ecological condition. However, additional indicators can be added as new information is generated within the study area or in the literature from studies in Texas Rivers or similar ecosystems. Sources of information to accomplish this task are other SB3 studies conducted in adjacent river basins, the Trinity and San Jacinto River Overlay documents, and scientific literature compiled from similar rivers systems. This task should be accomplished within 6 months at the BBEST meeting using a process similar to defining the base ecological condition.

Identify a typical and accessible, riffle, run sequences within representative reaches or other locations and conduct low flow subsistence monitoring of water quality, habitat and biota. This would be used to characterize flow water quality biota relationships during subsistence flows.

It is recommended that manual and automated water quality monitoring of representative reaches and other locations as appropriate be conducted at subsistence flows to characterize the diel patterns in critical parameters such as dissolved oxygen and temperature. Automated meters should be placed in a pool (preferably at the downstream end) that could be accessed relatively easily. The meter should be equipped with state of the art temperature, pH, conductivity, optical DO probes, in situ chlorophyll, and turbidity probes and be capable of collecting data at a minimum interval of 30 minutes. This meter would be able to document water quality conditions under the range of flows that occur.

In addition to water quality it is recommended that concurrent physical habitat and biological surveys (fish, mussels, macrophytes, habitat availability, and riparian vegetation) be conducted when flow has dropped to, or below, subsistence flow. This survey would be conducted once in each year in which flows dropped to subsistence flow. The survey would be conducted on both mainstem and tributary representative reaches. Survey protocols should ascribe to those used in the Texas Instream Flow Program (TIFP). In addition to evaluating habitat and water quality and biota, particular emphasis should be placed on determining if longitudinal connectivity existed throughout the study reach. The primary purpose of conducting these subsistence flow surveys is to evaluate the relationship of flow to critical water quality parameters such as dissolved oxygen and temperature and indicator response. The installation and operation of automated monitoring for water quality is possible with minimal effort and should be considered a short term high priority task that could be accomplished within 4 years if suitable hydrology occurred (subsistence flows).

Biological surveys may take longer and/or require additional resources. However, this should also be considered a short-term task and could be completed within 4 years if hydrological conditions are suitable. If feasible it is highly recommended that automated water quality meters be installed and maintained at existing gage sites and selected representative reaches to provide background data over the entire flow regime, in addition to subsistence flows.

Conduct a synoptic survey on each of the selected river reaches and tributaries under baseflow conditions.

This survey would involve documenting the location, size, and condition of key habitat features including riffles, runs, pools, tributaries, backwaters, sloughs, macrophytes, riparian zone, etc. In addition, combined biological surveys of fish and mussels should be conducted to determine or fine-tune species preference models. This should be coordinated with physical habitat assessments (e.g. cross-sectional or 2D profiles of depth, velocity, cover, and substrate) to support development and support of physical habitat models (e.g. WUA vs. flow). Such a study is necessary at several mainstem and tributary reaches to evaluate the response of indictor metrics to and suitability of the current flow regime. This should be conducted at least once during a 4 year period.

Conduct coordinated surveys during higher flow pulses to evaluate connectivity with adjacent riparian habitat, floodplain and/or oxbows and response of fish communities.

Coordinated surveys involving on-the-ground physical surveys and the analysis of existing GIS vegetation layers and resources should be conducted once a year during the first 4 years at each representative reach. Survey protocols would follow those used in the Texas Instream Flow Program. Sampling emphasis would be on measuring lateral connectivity, both hydrologically and biologically. The GIS analysis would utilize overlays of inundated areas and vegetation community layers to quickly assess the influence of higher flow pulses and their function as they relate to maintaining the riparian zone (e.g. percentage of plant community inundated). This approach has been used on the Sabine River and Cypress River. When overbank flows occur, biological surveys of fish, and riparian vegetation should occur to document increased levels of connectivity. These data are necessary to evaluate the benefits of pulse and overbank flows on instream, riparian and floodplain. If highly accurate (<1 ft) topographic models are not electronically available (e.g. GIS), LIDAR technology should be used to produce sufficient topographic models at the appropriate accuracy and precision to characterize the topography within the floodplain and facilitate development of gage elevation versus inundated area predictions. There are known gaps in electronically available elevation models at the required accuracy in sections of the Trinity River and possibly the upper San Jacinto River. In addition, it may be useful to evaluate the response of indicator fish migration and subsequent larval fish abundance during and after seasonal pulses to evaluate the suitability and influence of these flows on spawning and recruitment. These studies should be conducted at least once during the next 4 years. However, some like the spawning/larval fish surveys would likely require a longer period of time (5-7 years).

<u>Conduct basin wide baseline surveys of (state listed species) mussels and related studies</u>

Information on the distribution, relative abundance, habitat needs, and spawning requirements of mussels are largely lacking in both watersheds. Some of these species are currently listed as threatened by the State of Texas. Basin wide surveys (e.g. diving, benthic sampling) should be conducted during base and subsistence flow levels to evaluate their distribution and habitat preferences and response to flow regimes. In addition, there is a critical need to identify the spawning requirements for mussels (i.e. glochidia vs. host specificity vs. critical habitat/flow requirements). These relationships that affect an organism indirectly by influencing their host have been documented for other species and are difficult to evaluate without detailed information on both species. Unfortunately this will require numerous special studies including field surveys and laboratory studies. Comprehensive field surveys should be conducted at least once during the 4 year period.

<u>Establishment of Long term riparian monitoring sites.</u>

BBEST recommends that a comprehensive monitoring program be established at the representative reaches and other locations as needed to refine and produce a more predictive relationship between flows in both rivers and their influence on plant community dynamics and composition. This would represent a long term goal.

Water Quality

Data Gaps

- Additional dissolved oxygen data to provide sufficient information, for stream segments associated with each recommended gage, to confirm compliance with low flow stream standard criteria. (Note: For locations where calibrated and verified water quality models available, modeling results may be used.)

- Additional dissolved oxygen data to provide sufficient information, for stream segments associated with each recommended gage, to assess dissolved oxygen conditions that occur at moderate to high flow conditions.

- Additional nutrient data (nitrogen and phosphorus) to provide sufficient information to establish relationships between flow and nutrient concentrations and between flow and nutrient loads.

- Data for dissolved oxygen and other selected parameters collected during the rising limb and falling limb of wet weather flow events.

- Quality characterization of river sediments to determine the quality conditions and to identify specific parameters of concern relative to ecological conditions.

- Additional temperature data to provide sufficient information, for stream segments associated with each recommended gage, to confirm compliance with stream standards and to assess temperature at low flow conditions.

Validations

- Confirm using existing data and data collected as described above; compliance with stream standards and/or other criteria to protect ecological conditions.

- Perform mathematical model runs to confirm compliance with stream standards and/or other criteria to protect the ecological conditions.

- Perform analytical analyses to determine impact of flow-related conditions (i.e., higher nutrient load) on downstream reservoir.

- Perform analytical analyses to assess the probable introduction of constituents (i.e., nutrients, toxics) into the water column from sediment material.

- Perform analytic analyses to assess the variability of water quality conditions (dissolved oxygen, temperature, conductivity, nitrogen, phosphorus, and other selected parameters) during moderate to high flow events and between moderate to high flow events.

- Perform analytical analyses to assess the probability of moderate to high flow events resulting in water quality conditions detrimental (i.e., "black rise" conditions experienced during 1980s) to ecological conditions.

Refinement

- Utilizing data gathered and analytical assessments as described here and elsewhere in the report, determine if refinement is necessary to the recommended flow regime values.

- Utilizing data gathered and analytical assessments as described in this and other sections of the report, assess if adjustment is necessary to the recommended gages for which flow regimes should be established.

Near-Term/Long-Term Actions

New-Term Actions

- Coordinate data gathering and special studies with work plan being developed for Senate Bill 2.

- Gather water quality data and sediment characteristic data within the segments related to Gages TR near Oakwood (Note: within SB 2 segment for TR), TR at Romayer, SJR near Cleveland, and WFSJR near Conroe.

- Gather Trinity River channel physical data for segments related to Gages TR near Oakwood (Note: within SB 2 segment for TR), TR at Romayer, SJR near Cleveland, and WFSJR near Conroe.

- Analyze data and develop findings and conclusions regarding the relationship between water quality data and the proposed flow regimes.

- Develop long-term action plan to gather data and perform analyses of water quality conditions for river segments associated with other proposed gages.

Long-Term Actions

- Gather water quality data and sediment characterization data within the segments related to selected other proposed gages.

- Gather Trinity River channel physical data for segments related to selected other proposed gages.

- Analyze data and develop findings and conclusions regarding the relationship between water quality data and the proposed flow regimes.

- Develop analytical tools and/or mathematical models to be used in assessing moderate to high flow water quality conditions.

- Develop/adapt eutrophication mathematical model to Lake Livingston.

References

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Richter, B.D., A.T. Warner, J.Meyer and K. Lutz. 2006. A collaborative and adaptive process for developing environmental flow recommendations. River Research and Applications 22:297-318.

http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GW Reports/R369_InstreamFlows.pdf

Estuary

Salinity/Hydrology (Trungale)

The terms short, mid and long term are more reflective of the level of effort necessary to arrive at a conclusive answer to the problem, than of the time to conduct such undertakings. Clearly the long term question of the importance of salinity to estuarine health is underway.

Short Term

While shortcomings of the flow-salinity-ecology conceptual model have been recognized by all of the BBEST members (Regime p.130, Conditional rejection of recommendation based on this model), most BBEST members appear to recognize some promise in this approach particularly in light of the absence of data for the preferred conceptual model: flow-nutrient-productivity. The salinity zonation model was adopted for analysis of three species, two "with early life history stages that were more sensitive than adults, e.g. seed germination in *Vallisneria* and larval survival in *Rangia cuneata*. The same logic resulted in a focus, not on the abundance of oysters, but on the level of parasitism in the oysters." However a significant portion of the BBEST found that "while the salinity-zonation approach holds a potentially viable method, the salinity-zonation approach as utilized in Chapter 3 has many limitations that unfortunately do not allow for the identification of freshwater inflow requirements that can be shown to be necessary to support a sound ecological environment for Galveston Bay in its entirety."

The work plan as it relates to the flow-salinity-ecology conceptual model should attempt to address these limitations and potentially others. It will be important to recognize that this model will at best provide part of the answer. While salinity has traditionally been considered "the quintessential estuarine parameter" (SAC 2009), its importance has recently been called into question by several BBEST members. The recommendations for this part of the work plan are intended to address some of the specific limitations of the salinity zonation analysis until such time as missing data might be collected and an alternative or ideally, supplementary hypotheses related to relationships between nutrients and productivity might be formalized and tested.

Identified limitations to the salinity zonation approach

Data Gaps

(i) Competing needs for multiple species.
The TSJ B&E subcommittee initially selected seven indicator organisms, however the report only presented salinity zonation analysis results for the three immobile organisms and the flow recommendations for spring, summer and fall were derived exclusively from the analysis of these three species.

The work plan should:

a) Evaluate the effect of the appropriate flow recommendations on salinity zones for additional indicators starting with, but perhaps not limited to, those initially identified by the TSJ B&E subcommittee.
b) Test the conclusion that these indicators (either the three immobile species or an expanded list) are appropriate for representing the health of Galveston Bay.
c) Recognizing that estuarine species have broad tolerances for salinity ranges, if a set of indicators responsive to salinity cannot be identified "as representing a healthy Galveston Bay ecosystem in its entirety" this should be explicitly stated and some attempt to quantify the relative benefit of preferred salinity zones to overall estuarine health might be attempted.
d) There is a need to evaluate the response of various estuarine indicators throughout their range in the estuary including tidal streams and bayous. These areas are currently not sampled. Therefore, the lack of correlation between individual and community metrics obtained from TPWD biological data and freshwater inflow and related variables (e.g. salinity, nutrients) may reflect the bias associated with only sampling open bay areas.
e) Consider the addition of new species which were previously not recognized during the BBEST process.
f) Documentation of the specific sources utilized to select how specific salinity niche parameters for particular life stages were obtained.

The work plan should compile this documentation.

Analysis issues

(i) Frequencies of occurrence of proposed freshwater inflows
The BBEST report includes some confusing and perhaps erroneous analysis of historical flow frequencies related to the period of record used in the various analyses. The work plan should correct and clarify these.

(ii) Geographic factors related to flows and salinity zone areas.
Logistic regressions were developed to predict the salinity zonation response to freshwater inflows at specific sites (Trinity and San Jacinto Rivers) and on composite inflows (Coastal streams excluding Trinity and San Jacinto, and the total Galveston inflow). For some of the salinity zones, the contribution from multiple sources likely has a significant effect on the salinity response and this effect has not been evaluated in the current analysis (see discussion of coastal streams and bayous above). The work plan should propose conducting multivariate analysis to determine the effect of inflows from different sources on the salinity zones for indicators selected.

(iii) Full range of flows including magnitude-frequency-duration and seasonality
The initial salinity zonation analysis results in recommendations for three seasons (Spring, Summer, Fall but not Winter) with a single magnitude, periodicity, annual occurrence (long term) and recommended annual frequency. Most BBEST members as well as the SAC in their comments on the BBEST report

contend that this does not represent a regime as envisioned by the SB3 legislation.

The work plan should either

a) Expand the current analysis to evaluate a broader range encompassing a full flow regime, or
b) Propose an alternative or complementary approach to address other components of a freshwater inflow regime.

Evaluation of the annual freshwater inflow targets developed by Region H, endorsed by the conditional group and adopted by TCEQ (though not specifically as a permit requirement)

The work plan should employ the WAMs to simulate future conditions to determine if these frequencies are achieved. Supplemental selected future flow conditions could be simulated within the existing TxBlend model to evaluate their effect on the salinity zones for indicator species.

Mid Term

Evaluation of Salinity Circulation model.

Questions have been raised for several years, including within the current BBEST effort, as to the ability of the current 2-dimensional hydrodynamic model (TxBLEND) to adequately predict salinity. This problem is particularly relevant in the upper part of Trinity Bay where the model error is greatest. The TWDB has produced a model verification report documenting this model error and has initiated a pilot project to develop an alternative (3D) model, though this effort brings additional challenges.

The work plan should clearly articulate the model uncertainty and quantify the effect of this uncertainty on the final recommendations. The model should be corrected if possible (perhaps by recalibrating to improve predictions for specific areas) or the BBEST should recommend support for the development of a more accurate model should that be necessary.

Long Term

Evaluate whether salinity is an important parameter for estuarine health and attempt to quantify the relative importance of other factors (nutrients, sediments) associated with freshwater inflow.

Nutrients/Sediments (McFarlane)

The nutrient dynamics within Galveston Bay have recently been summarized (Pinckney 2006). The dynamic nature of nutrient distributions in this estuary reflects a balance between river discharge, benthic regeneration, and seasonal water temperature. Biotic responses by phytoplankton to nutrient inputs are rapid, on time scales of one day. Estuarine phytoplankton biomass quickly increases, taking advantage of higher nutrient concentrations. During periods of low river discharge, benthic flux is responsible for sustaining phytoplankton production. The Trinity River is the primary source of freshwater and new nutrient inputs to the bay, but the assimilative capacity of Lake Livingston has a major impact on the nutrients reaching the bay (Jensen et al. 1991). Phytoplankton blooms were associated with periods of moderate to high river discharge. High river discharge events resulted in high concentrations of nitrite and nitrate in the bays. The pattern for overall dissolved inorganic nitrogen followed freshwater inflow, and was also correlated with phytoplankton biomass in the bay, indicating a tight coupling between inorganic nitrogen inputs and phytoplankton responses.

Warnken & Santschi (2009) have described the flux of nitrogen in the lower Trinity River. The concentration of suspended particulate material correlated well with river discharge although the variance increased at high flow. The concentration of nitrate was less correlated with river discharge.

The U.S. Geological Survey has recently conducted a preliminary study of two high flow events at Wallisville that demonstrated differences in nutrient delivery to Galveston Bay (Lee, M.T. 2010. A preliminary evaluation of Trinity River sediment and nutrient loads into Galveston Bay, Texas, during two periods of high flow. U.S. Geological Survey, unpublished manuscript). Suspended sediment concentration, total nitrogen and phosphorus are associated with turbidity, suggesting that the nutrients were attached to the suspended sediments. Suspended sediment quickly peaked and steadily declined while discharge remained essentially constant for high flow originating downstream from Lake Livingston. During another event, suspended sediment steadily increased with increasing flow released from Lake Livingston. The increase in total nitrogen paralleled the increase in discharge, but phosphorus did not increase in a similar manner.

Nutrients are essential in fueling phytoplankton productivity which in turn fuels production at higher trophic levels. However, the correlations are tenuous because of the lack of available data which considers multiple trophic levels. More difficult is the time scales associated with different end members at each trophic level which increases from days at the base of the trophic pyramid to years at the top. Efforts are underway at TPWD to address this issue which involves compiling available data into an Ecopath model. This is a study in progress which may ultimately help address the linkages between nutrient inputs and productivity associated with important producers (fish).

Additionally, with returned flows increasing on the San Jacinto side of Galveston Bay in coming decades, the nutrient inputs from this river, and the nutrient forms, will play an important role in determining nutrient budgets. It is likely that there will be more ammonium and urea relative to nitrate and nitrite as a result of the kind of flows which will move down the San Jacinto, which are very distinct from those which will flow down the Trinity River.

Data Gaps

The studies described above do not provide sufficient data to statistically model the relationships between nutrient loadings and components of a flow regime. Studies need to be designed and promoted by the BBEST to obtain the data necessary for statistical modeling. The best temporal scale for estimating loading rates is the frequency at which loading events occur to the system. For Galveston Bay, major nitrogen loading events are directly related to Trinity River discharge. Discharge is a function of meteorological conditions, which are unpredictable at time scales greater than two weeks. Water samples for the determination of nutrient concentrations should be collected at shorter frequencies to obtain accurate and reliable loading estimates and associated flow rates. The BBEST will deliberate on the problems associated with sampling to support a statistical model of flow and nutrient loadings and develop recommendations for monitoring projects.

Validation

Nitrogen is the limiting factor to bay productivity, and nitrate is the dominant form of nitrogen entering the bay. But nitrate does not correlate well with river discharge, and nitrate concentration appears to vary with the sub-watershed of origin, so it may be difficult to validate the relationship between freshwater inflow and bay productivity. The BBEST will evaluate the data obtained from monitoring projects designed to develop a flow – nutrient model and make recommendations on validation of any indicators based on nutrient flow relationships.

Refinement

If one or more indicators are developed based on a nutrient – flow relationship, further studies will be considered and recommended by the BBEST to refine such indicators.

Near/Long Term

Near term studies will be elaborated and recommended to collect data on the relationship between flow and nutrient loadings from the rivers to the bay. Once data sets have been collected, long term studies will be needed to assess the robustness and predictability of the statistical relationships between nutrient loadings and flow patterns.

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Jensen, P., S. Valentine, M.T. Garrett Jr., and Z. Ahmad. 1991. Nitrogen loads to Galveston Bay. Proceedings Galveston Bay Characterization Workshop Feb 21-23, 1991 GBNEP-6. GBNEP, Galveston, TX

Pinckney, J.L. 2006. System-scale nutrient fluctuations in Galveston Bay, Texas (USA). p.141-164 *in* Functioning of microphytobenthos in estuaries. Royal Netherlands Academy of Arts and Sciences.

Warnken, K.W., and P.H. Santschi. 2009. Sediment and trace metal delivery from the Trinity River watershed to Galveston Bay and the Gulf of Mexico. Estuaries and Coasts 32:158-172.

Estuarine Ecology Section (Buzan)

Input from: Jim Lester, Bob MacFarlane, Woody Woodrow, George Guillen, Antonietta Quigg, David Buzan

Texas Parks and Wildlife Department has conducted monitoring of the biological community of Galveston Bay for many years. Since the 1970's they have conducted fisheries independent monitoring using standard sampling gear and have produced a very extensive database that can be used to assess the ecological health of the estuary. Other agencies including Texas Commission on Environmental Quality and the Texas Water Development Board have produced monitoring data of direct relevance to the condition of the biological community. Given the history and experience of these agencies and other organizations, monitoring and research identified in the final work plan should be coordinated with organizations working in the area and is not intended to substitute for current monitoring and research efforts.

Due to the shortage of historical biological data predating the experience of BBEST participants, the group concluded that it was appropriate to declare current ecological conditions in the bay to meet the criterion of a "sound ecological environment." This determination is equivalent to stating that future changes in the ecology of the bay will be assessed against current conditions. However, exactly when and how to set a baseline was not decided and requires additional study. At any particular time, some biological parameters are increasing, some decreasing and some stable. A "sound ecological environment" does not translate to a stable, unvarying environment. Thus it will be important to establish what a baseline set of conditions will be and how an assessment of change will be conducted.

i) Draft baseline values for the estuary which will be used to evaluate whether changes in freshwater inflow are affecting estuarine health.
   (1) BBEST members develop proposals to be submitted to the BBEST prior to a BBEST meeting. Proposals will be one page or less and standard in format to facilitate review and discussion at the BBEST meeting.

(2) BBEST will identify baseline values.
   (a) Key assumptions
      (i) Baseline values will be draft and modified as appropriate when future data are collected and/or analysis conducted.
      (ii) Estuarine systems are complex and extreme care will be made to ensure baseline values can be related to freshwater inflow effects.
(3) Baseline values will be identified 6 months after work plan approval.
   (a) Possible examples: normal range of area of *Vallisneria* bed, acceptable range of reproductive index of *Rangia*, acceptable range of frequency of oyster parasitism in defined parts of the bay

ii) Identify data collection, analysis and research needed to evaluate and refine the recommendations of the BBEST for freshwater inflows to Galveston Bay.

iii) BBEST members develop proposals which will be submitted to the BBEST prior to a BBEST meeting. Proposals will be one page or less and standard in format to facilitate review and discussion at the BBEST meeting. Proposals will outline future recommended analysis, data collection, research needed to evaluate the process for determining freshwater inflow regimes and to evaluate the freshwater inflow recommendations.

iv) Process for identifying environmental flow regime for the estuary
   (1) Possible examples include: Reevaluate the process for determining the relationships between salinity and *Vallisneria*, *Rangia* reproduction, and/or oyster parasitism

v) BBEST will identify analysis, data collection, research needed.
   (1) Possible examples include: Additional monitoring of phytoplankton, zooplankton, and benthos and their relationships to flow; monitoring of biological communities in tidal streams (upstream of areas traditionally sampled by TPWD); analysis of brittle star occurrence in TPWD data, analysis of seagrass occurrence; relationship between rainfall runoff to coastal watersheds (ex. Houston bayous) and freshwater inflow to the bays, etc.

d) BBEST will communicate needs for analysis, data collection, and research needs to organizations that may be able to do the recommended work and/or provide funding to others to do the work.

e) Identify data collection, analysis and research needed to validate or refine the freshwater inflow standards set by TCEQ. There may not be a process to evaluate the November 2010 proposed standards since they do not have seasonal components and they do not have an expected frequency. For certain parts of the ecosystem, critical relationships between seasonality of flow and ecological health are expected.

f) Identify data collection, analysis and research needed to develop strategies to meet standards set by TCEQ. The process described above could be used to develop concepts for projects.

g) Short term objectives will be to set the parameters of indicator baselines and to determine how best to evaluate changes from a “sound ecological environment." Long term objectives will be focused on development of data and analyses that will permit improved recommendations on indicators of freshwater inflow effects and on characteristics of an environmental flow regime more protective of a "sound ecological environment."

h) BBEST will meet twice per year to provide update on progress in analysis, data collection, and research, and revise baseline values and/or recommendations as necessary.
i) BBEST will compare available information to baseline values 4 years after implementation of the work plan. The purpose will be to evaluate whether estuarine health has been or is being affected by changes in freshwater inflow. At this time, the BBEST will identify a long-term schedule for work plan review.

Benthics/Oysters (McFarlane)

The BBEST has selected three benthic indicators of estuarine ecological health related to freshwater inflow: the germination and survival of *Vallisneria*; the parasite load and level of predation on the eastern oyster (*Crassostrea virginica*); and the reproduction of a clam, the Atlantic rangia (*Rangia cuneata*). Both oyster and clam have planktonic larvae that are widely distributed, but once they settle they become sessile and move very little (the clam) or not at all (the oyster). Both molluscan species, when abundant, are important suspension feeders, filtering particles from the water, the oyster while above the bottom (epifauna) and the clam while buried beneath the surface (infauna), thus improving water quality. The oyster has an additional advantage in being an important commercial species.

The eastern oyster is broadly tolerant of salinity conditions and can be found almost everywhere in the Galveston Bay ecosystem. However, in higher salinity waters it suffers greater deleterious effects from a predatory snail, the oyster drill (*Stramonita haemastoma*), and a microscopic protozoan parasite, Dermo (*Perkinsus marinus*). Oysters seem to prosper best in waters of 10 to 20 psu salinity. The Atlantic Rangia has a more restricted distribution. It prospers in 5 to 15 psu salinity waters (Patillo et al. 1997).

Several recent publications have reported different interpretations of the data on oyster abundance and freshwater inflow (Turner 2006 and Buzan et al. 2009). The relationship reported by Turner (2006) between mean annual inflow and landings or salinity and landings showed no correlation. Buzan et al. (2009) provided an alternative analysis that described a relationship between freshwater inflow and oyster abundance. This disagreement relates to oyster abundance and not to levels of parasitism and predation on which the proposed indicator is based.

Need inclusion of Vallisneria

Data Gaps

A great deal of data exists for eastern oysters in Galveston Bay. Fishery-dependent data can be found in a series of Texas Parks and Wildlife Dept. Coastal Fisheries Management Date Series reports ("Trends in Texas Commercial Fishery Landings, 1972-20xx") issued at irregular intervals. Fishery-independent data collected by the extensive Coastal Fisheries monitoring program are found in a similar series of TPWD MDS reports ("Trends in Relative Abundance and Size of Selected Finfishes and Shellfishes along the Texas coast: November 1975 – December 20xx"). The fishery-independent data for Galveston Bay are also available online from the Galveston Bay Estuary Program (http://ttrendstat.harc.edu/Fisheries/webform1.aspx). Data on the extent of Dermo infections from 1999 to date is available at a website, http://www.oystersentinel.org.

(1) Predation on oysters is not currently monitored. The predatory snail is not routinely collected in the sampling gear due to its size. BBEST will consider how best to monitor for the predator and the level of predation in selected areas of Galveston Bay.
(2) Current sampling of Dermo infections is informative, but based on a methodology may be difficult to replicate. TPWD is working with molecular techniques to evaluate a technique of genetic fingerprinting for detection of parasitism. BBEST should consider this and other monitoring methodologies for developing better data on the relationship between parasite frequency and load in oysters.

Less information is available for Atlantic rangia in the Galveston Bay ecosystem. Rangia are most frequently captured in oyster dredges, but the oyster dredges are not deployed to sample prime habitat for rangia. Thus the quantitative data that exist for rangia are not considered to be reliable.

Oyster dredge data are only semi-quantitative and used to calculate CPUE, expressed as number per hour. This is only an index of abundance. The most useful metric is an estimate of density, the number of organisms or events per unit of area. The most reliable method for estimating density would deploy a sampling frame of known dimension and remove all target organisms within the frame.

(3) Studies are underway in Galveston Bay to obtain data on the reproductive condition of Rangia, the abundance of Rangia larvae and the river flow levels at the time of sampling. BBEST should stay informed of this and other studies of Rangia reproduction to determine whether suitable data is being collected to fill this data gap.
(4) BBEST will deliberate on the suitability and efficacy of other indicators of benthic ecological health related to freshwater inflow. One suggestion has been made of the horse oyster (Ostrea equestris) as a high-salinity biological indicator. Suggestions of additional monitoring to obtain data to assess proposed benthic indicators should be provided to the relevant agencies.

Validation

Validation of predation and parasitism frequencies will be challenging for eastern oysters. The existing Galveston Bay fishery independent data demonstrate a significant declining trend for oysters in Trinity Bay, Upper and Lower Galveston Bay, East Bay. The cause(s) of these declining trends is/are unknown. Oysters in West Bay and Christmas Bay have not declined. BBEST will consider the relationship between this trend and the use of oyster parasitism and predation as an indicator. If appropriate, studies will be recommended to determine the stability and suitability of the indicators. Studies of the reproductive condition of Rangia, the abundance of larvae and the level of river inflow in the area of the bay with high Rangia abundance should be conducted.

The very fact that the eastern oyster, an important indicator and keystone species, has been undergoing a long-term decline over the greater part of the Galveston Bay ecosystem also calls into question the judgment that Galveston Bay is currently a sound environment.

Refinement

It is premature to envision how monitoring of eastern oyster and Atlantic rangia populations in the Galveston Bay ecosystem will lead to refinement of the environmental flow regime. The proposed environmental flow standard for Galveston Bay is not sufficiently specified to allow a determination of when it is violated. Thus one cannot test environmental impacts of failing to meet the standard.

Near/Long Term

For the near term, it is essential that the current data collection pertaining to the eastern oyster be maintained, and quantitative data collection for Atlantic rangia be initiated. Specific monitoring programs designed to assess reproduction of Rangia and parasite and predator impacts on oysters should be initiated or expanded. Further efforts to determine the cause of the current oyster decline should be initiated.

Over the long term, BBEST will coordinate with the resource management agencies to design and implement a program of monitoring of the benthic community that incorporates multiple correlates of freshwater inflow.

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Integration

Table 4. Integration Matrix

Component	Category	**Item**	**Near-Term**	**Mid-Term**	**Long-Term**
Instream		3-Tier study area development	x		
		Mapping of unique features	x		
	Hydrology	Flow regime component characterization	x		
		High flow pulse and overbank assessment		x	
		Loss/gain		x	
		Continued flow regime component characterization			x
	Hydraulics/ Habitat/ Geomorphology	Surveys of long reaches covering TCEQ-adopted flow sites	x		
		Imagery analyses	x		
		Prioritization of intensive study sites	x		
		Intensive site-specific studies of high priority sites	x		
		Initiate long-term monitoring of key parameters at study sites (subsequent to intensive study)	x		
		Intensive site-specific studies of lower priority sites			x
		Continued long-term monitoring			x
	Ecology	Analyses and establishment of baseline ecological conditions	x		
		Identification of Indicator Metrics & Species	x		

Component	Category	**Item**	**Near-Term**	**Mid-Term**	**Long-Term**
		Identification of typical riffle-run sequences, conduct low flow subsistence monitoring, biological surveys	x (if suitable hydrology occurs)		
		Synoptic survey of selected rivers under baseflow conditions	x (at least once during 4-year period)		
		Coordinated surveys during high flow pulses	x (at least once during 4-year period)	x (spawning/larval fish surveys)	
		Basin-wide baseline surveys of (state listed species) mussels and related studies	x (at least once during 4-year period)		
		Establishment of long-term riparian monitoring sites			x
	Water Quality	Coordinate data gathering and special studies with work plan being developed for Senate Bill 2.	x		

Component	Category	**Item**	**Near-Term**	**Mid-Term**	**Long-Term**
		Gather water quality data and sediment characteristic data within the segments related to Gages TR near Oakwood (Note: within SB 2 segment for TR), TR at Romayer, SJR near Cleveland, and WFSJR near Conroe.	x		
		Gather Trinity River channel physical data for segments related to Gages TR near Oakwood (Note: within SB 2 segment for TR), TR at Romayer, SJR near Cleveland, and WFSJR near Conroe.	x		
		Analyze data and develop findings and conclusions regarding the relationship between water quality data and the proposed flow regimes.	x		
		Develop long-term action plan to gather data and perform analyses of water quality conditions for river segments associated with other proposed gages.	x		
		Gather water quality data and sediment characterization data within the segments related to selected other proposed gages.			x
		Gather Trinity River channel physical data for segments related to selected other proposed gages.			x
		Analyze data and develop findings and conclusions regarding the relationship between water quality data and the proposed flow regimes.			x

Component	Category	**Item**	**Near-Term**	**Mid-Term**	**Long-Term**
		Develop analytical tools and/or mathematical models to be used in assessing moderate to high flow water quality conditions.			x
		Develop/adapt eutrophication mathematical model to Lake Livingston.			x
Estuary	Salinity	Evaluate the effect of the appropriate flow recommendations on salinity zones for additional indicators starting with, but perhaps not limited to, those initially identified by the TSJ B&E subcommittee.	x		
		Test the conclusion that these indicators (either the three immobile species or an expanded list) are appropriate for representing the health of Galveston Bay.	x		
		Recognizing that estuarine species have broad tolerances for salinity ranges, if a set of indicators responsive to salinity cannot be identified "as representing a healthy Galveston Bay ecosystem in its entirety" this should be explicitly stated and some attempt to quantify the relative benefit of preferred salinity zones to overall estuarine health might be attempted.	x		

Component	Category	Item	Near-Term	Mid-Term	Long-Term
		Evaluate the response of various estuarine indicators throughout their range in the estuary including tidal streams and bayous. These areas are currently not sampled. Therefore, the lack of correlation between individual and community metrics obtained from TPWD biological data and freshwater inflow and related variables (e.g. salinity, nutrients) may reflect the bias associated with only sampling open bay areas.	x		
		Consider the addition of new species which were previously not recognized during the BBEST process.	x		
		Documentation of the specific sources utilized to select how specific salinity niche parameters for particular life stages were obtained.	x		
		Analyze frequencies of occurrence of proposed freshwater inflows	x		
		Analyze geographic factors related to flows and salinity zone areas	x		
		Expand current analysis to evaluate broader range encompassing a full flow regime, or propose alternative or complementary approach to address other components of freshwater inflow regime	x		
		Evaluate annual freshwater inflow targets (WAM, TxBLEND)	x		

Component	Category	**Item**	**Near-Term**	**Mid-Term**	**Long-Term**
		Evaluate salinity circulation model		x	
		Evaluate whether salinity is an important parameter for estuarine health, quantify relative importance of other factors (nutrients, sediments) associated with freshwater inflow			x
	Nutrients/Sediments	BBEST design and promote studies to obtain the data necessary for statistical modeling	x		
		Nutrient concentration water sampling at frequencies shorter than two weeks	x		x
		BBEST develop recommendations for monitoring projects.	x		
		BBEST evaluate data obtained from monitoring projects designed to develop flow-nutrient model and make recommendations on validation of any indicators based on nutrient- flow relationships		x	
		BBEST consider and recommend further studies to refine indicators developed based on a nutrient-flow relationship		x	x
	Estuarine Ecology	BBEST draft proposals for development of baseline values for the estuary which will be used to evaluate whether changes in freshwater inflow are affecting estuarine health.	x		

Component	Category	**Item**	**Near-Term**	**Mid-Term**	**Long-Term**
		BBEST draft proposals to identify data collection, analysis and research needed to evaluate and refine the recommendations of the BBEST for freshwater inflows to Galveston Bay.	x		
		Process for identifying environmental flow regime for the estuary (could include: reevaluation of the process for determining the relationships between salinity and *Vallisneria, Rangia* reproduction, and/or oyster parasitism	x		
		BBEST identify analysis, data collection, research needed. Possible examples include: Additional monitoring of phytoplankton, zooplankton, and benthos and their relationships to flow; monitoring of biological communities in tidal streams (upstream of areas traditionally sampled by TPWD); analysis of brittle star occurrence in TPWD data, analysis of seagrass occurrence; relationship between rainfall runoff to coastal watersheds (ex. Houston bayous) and freshwater inflow to the bays, etc.	x		
		BBEST will communicate needs for analysis, data collection, and research needs to organizations.	x		
		Set the parameters of indicator baselines	x		
		Determine how best to evaluate changes from a "sound ecological environment"	x		
		Development of data and analyses that will permit improved recommendations			x

Component	Category	Item	Near-Term	Mid-Term	Long-Term
		Identify data collection, analysis and research needed to validate or refine the freshwater inflow standards. For certain parts of the ecosystem, critical relationships between seasonality of flow and ecological health are expected.			x
		Identify data collection, analysis and research needed to develop strategies to meet standards set by TCEQ.			x
		BBEST will meet twice per year to provide progress updates	x		
		BBEST will compare available information to baseline values 4 years after implementation of the work plan.		x	
	Benthics/Oysters	BBEST deliberate on the suitability and efficacy of other indicators of benthic ecological health. Suggest additional monitoring to assess proposed benthic indicators.	x		
		Initiate quantitative data collection for Atlantic rangia	x		
		Initiate or expand monitoring programs designed to assess reproduction of Rangia and parasite and predator impacts on oysters.	x		
		Initiate efforts to determine the cause of the current oyster decline	x		

Component	Category	**Item**	**Near-Term**	**Mid-Term**	**Long-Term**
		BBEST will coordinate with resource management agencies to design and implement a program of monitoring benthic community that incorporates multiple correlates of freshwater inflow			x