FROM: Franklin T. Heitmuller, Member – Texas Environmental Flows Science Advisory Committee

SUBJECT: MEMORANDUM—Incorporation of sediment transport estimates and models into flow recommendations of the basin and bay expert science teams and stakeholder committees

DATE: September 16, 2008

Texas Senate Bill 3 mandates that locally based basin and bay expert science teams (BBESTs), with consultations and support from the Environmental Flows Science Advisory Committee (SAC) and basin and bay area stakeholder committees, "develop environmental flow analyses and a recommended flow regime" that "maintain(s) the viability of the state's streams, rivers , and bay and estuary systems" using " reasonably available science." Within this overarching objective, Senate Bill 3 devotes considerable attention to balancing demands on water resources among competing interests and securing environmental flows through the acquisition of water rights, whether existing or unappropriated, among other organizational aspects of the program.

With much focus on the acquisition of water rights, permitting guidelines, and balancing water demands, naturally the first priority for scientific inquiry is low-flow hydrology. Specifically, what proven methods exist to determine minimum standards for coupled streamflow and water quality? To address this immediate priority, a report reviewing desktop methods to establish environmental flows in Texas rivers was submitted to the Texas Commission on Environmental Quality in 2008, which primarily focuses on minimum-flow techniques, including the Lyons Method. Further, considerable attention was given to the topic of minimum-flow techniques at the SAC meeting in September 2008. However important minimum flows are to the viability of rivers and estuaries, subsistence and base flows are only two components of an instream flow regime, the others being high-flow pulses and overbank flows. The 2008 desktop methods report evaluated selected software tools, including the oft-mentioned Indicators of Hydrologic Change (IHA) program, but did not specifically recommend a desktop technique for establishing high-flow pulses or overbank flows.

Prescribing high and overbank flows is one problem, but addressing the very important process of sediment transport is another. As flows increase from base flow to high-pulse flows to overbank floods, rates of sediment transport at the channel bed and in the water column greatly increase. The transport of sediment is as important to the complexity and structural diversity of rivers, riparian zones, deltas, and estuaries as the conveyance of water itself. The balance between the force of water and the resistance of sediment sculpts the many fluvial patterns and shapes that provide habitats and conditions to which aquatic and riparian species uniquely adapt over time. If only flows are considered, without the associated sediment, then an incomplete assessment of the state's rivers and bays reduces the likelihood of rehabilitation. A worst-case scenario might involve high-pulse flow releases that increase rates of river-channel degradation.

The importance of sediment transport and river channel morphology has been highlighted by instream flow activities associated with Texas Senate Bill 2. Also, in a National Research Council review of the Texas Instream Flow Program (TIFP) (2005), it was stated that the section considering physical processes and sediment transport required "significant augmentation" to relate them to the hydrologic regime, and that a "thin, single set of analytical approaches" would not be sufficient to "address the range or complexity of physical processes." In response to these comments, the state agencies responsible for the TIFP further addressed physical processes and sediment transport in the revised technical overview document (TOD) of the TIFP (2008), which contains the following statements:

- "Geomorphic studies will assess the active channel processes responsible for developing physical habitats."
- "Agencies will develop sediment budgets…"
- "…geomorphic studies need to be tailored to the specific sub-basin being investigated"
- "…the lack of geomorphic data for Texas' rivers is problematic."
- "…a monitoring program that collects geomorphic data for major rivers will be required."

The TOD goes on to recommend specific lines of inquiry to address these problems and achieve program goals.

BBESTs are responsible for flow recommendations required by Senate Bill 3. It is thus within their purview to consider reasonably available scientific methods to account for sediment transport to bay and estuary systems. The imminent deadlines for which the BBESTs must provide flow-regime recommendations exclude the possibility of making present-day sediment-load measurements and analyses for the short-term requirements. However, estimates or predictions of sediment transport for various flows would serve as a benchmark from which to assess programmatic goals, and adaptive management practices could include consideration of sediment transport data as they become available. Measurable objectives that link sediment transport to healthy rivers and floodplains include achieving optimized: (1) channel-bed elevations and rates of bank erosion, (2) instream geomorphic unit structure and function, including composition and adjustment frequency of pool-riffle sequences and other units (see Brierley and Fryirs, 2005), (3) turbidity, and (4) floodplain accretion rates. Measureable objectives that link sediment transport to healthy estuaries include achieving optimized: (1) rates of deltaic accretion, (2) rates of estuarine shoreline erosion, and (3) turbidity. Achieving these objectives would promote healthy aquatic and riparian habitats, thereby providing native species with the abiotic conditions to which they have successfully adapted. It is also likely that the ratio of generalist species to specialized species would tend toward a more natural balance.

Total sediment transport in rivers is separated into two components, suspended load and bedload. Suspended load is important for natural floodplain deposition processes and maintenance of deltaic and estuarine wetland environments. The best available information for suspended sediment load of Texas rivers is contained in a series of reports by the Texas Water Development Board and predecessor agencies (Stout and others, 1961; Adey and Cook, 1964; Cook, 1967; Cook, 1970; Mirabal, 1974; Dougherty, 1979). These reports summarize monthly suspended sediment concentrations and loads, and monthly streamflows, for various gaging stations in Texas over various periods of record.

Bedload transport is responsible for instream habitat complexity and maintenance, as well as deltaic accretion (formation). The amount of bedload transported by a river also determines its channel geometry and ability to recover from natural or anthropogenic disturbances, including floods and upstream impoundments. Unlike suspended load, bedload has not been historically monitored in Texas rivers; therefore an evaluation of bedload transport likely would require the application of a model(s). Bedload models, usually based on hydraulic principles, are notoriously inaccurate (Gomez and Church, 1989), uncertain (Gomez and Phillips, 1999), and applicable to rivers that exhibit steady-state equilibrium, but offer the most rapid approach to estimate transport. The various formulas for estimating bedload transport commonly require values for bed-material particle size, channel slope (energy gradient), flow depth, among other measureable or estimated factors. Common bedload transport equations include Meyer-Peter and Müller (1948), Einstein (1950), Ackers and White (1973), Bagnold (1980), Parker and others (1982), and Gomez (2006), among others. One investigator has recently recommended the Einstein (1950) approach for low-gradient sand-bed channels (Dennis Evans, U.S. Geological Survey, personal communication, 2008) although others recommend excess stream power approaches (Gomez and Church, 1989) modeled after Bagnold (1980). If changes in channel-bed elevation over time are known, then another method to estimate bedload transport is Exner's equation (see equation 1 in Paola and Voller [2005]). The following sources provide useful bedload transport model equations and explanations: (1) Gomez and Church (1989), (2) Stevens and Yang (1989), and (3) Robert (2003).

Although BBEST deadlines are incompatible with the time and effort required for sediment load measurements and analyses, a sediment-load monitoring program could be initiated at key gaging stations in Texas, including those near the coastal outlets of rivers, but above the apexes of deltas. Measures of suspended load and bedload quantify the sediment delivered to bays and estuaries and permit comparison among the river systems. Simultaneous collection of streamflow and sediment load over time allows quantification of the "effective discharge", or the flow that is responsible for the cumulative majority of sediment transport over time (Biedenharn and others, 2000), which is a useful indicator for determining high-flow pulses. Further, sediment budget models developed for "naturalized" watershed conditions could be compared with actual measurements, thereby providing a base from which outcomes can be measured. Caution is in order regarding measurements of sediment load, as they are known to be highly variable over space and time. Rather than associating point values of sediment load with streamflow, a range of expected loads would be a more appropriate. Applicable techniques and equipment to measure sediment load are in Edwards and Glysson (1999).

<u>Summary of Comments</u>

- Appraisals of instream and estuarine ecological viability would greatly benefit from a preliminary association of streamflow with estimates of total sediment load (suspended load and bedload). Estimates of total sediment load for various flows provide a measure from which programmatic objectives can be assessed. Adaptive management strategies could be used to adjust target objectives for total sediment load as techniques are improved or more data become available.

- The most readily available data from which to estimate suspended load in coastal Texas rivers are historical measurements at gaging stations, which are contained in reports by the TWDB and predecessor agencies.
- Bedload measurements for various flows in coastal Texas rivers are not available. The most readily available science from which to estimate bedload transport rates involves the application of bedload models. These models, although problematic for rivers not in steady-state equilibrium, could provide baseline estimates of bedload to which actual measurements could be compared.
- A suspended load and bedload monitoring program would be worthwhile for key streamflow-gaging stations in Texas. Simultaneous streamflow and sediment load measurements over time could be used to determine the effective discharge and duration of effective flows for present-day, post-regulation conditions. Caution is in order regarding sediment load measurements, as they are known to be highly variable over space and time.

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