Professional Peer Review of

Evaluation of the Proposed Edwards Aquifer Recovery Implementation Program Drought of Record Minimum Flow Regimes in the Comal and San Marcos River Systems

Final Hardy Report to the Edwards Aquifer Recover Implementation Program

Prepared for:
Edwards Aquifer Recovery Implementation Program
Attention: Dr. Robert Gulley

Review Prepared by:
Annear Associates, LLC
Cheyenne, Wyoming

Introduction

This review was conducted under contract with Texas A&M University and per the authority and direction of its Program Manager, Mr. Robert Gulley. As provided by contract, a review team of highly qualified environmental flow professionals was assembled (Appendix A) and assigned the charge of providing an objective scientific analysis of the contents of the *Final Hardy Report to the Edwards Aquifer Recover Implementation Program* (Final Hardy Report). In keeping with the guidelines we were provided, the review team's comments were strictly limited to facts, assumptions, and conclusions contained in the Final Hardy Report. At the time when the review was conducted, review team members were unaware of specific program details or recovery time lines. As a consequence, comments in this report are provided in a context that the flow levels studied in the Final Hardy Report might apply to both short (one or two years) and long-term (permanent) conditions.

Understanding how ecosystems function, let alone modeling how various components will respond to natural or anthropogenic inputs and then managing them for intended outcomes necessarily incurs relatively high degrees of uncertainty. The longer the chronological horizon of interest, the greater the degree of uncertainty. Modeling such as was conducted by the Final Hardy Report is essential to manage uncertainty, and the degree of effort invested by the authors of that report is impressive.

However, the review team members agreed that there are several other factors, not included in the study, that could affect the report's outcomes and conclusions, especially over a longer term. Many of those factors can take several years or decades to become evident, thus the basis for the cautionary, adaptive perspective we provide. Ecosystem function (and true species recovery) is a reflection of pattern and process over long periods and static, threshold flow standards typically cannot sustain these processes and the organisms that have evolved in association with them.

Within these sideboards, the conclusions presented in the Final Hardy Report are valid on a short-term basis (one or more consecutive years). However with each successive year, the potential for efficacy decreases largely due to generally unpredictable, and sometimes unidentified, environmental factors. For the target organisms and the habitats in which they live to achieve recovery and persist over the long-term, additional information is needed to understand, anticipate, and manage these factors as much as possible. We trust that the interpretations, opinions, and suggestions we have provided in this peer review are a constructive and helpful tool to help shape that future work and advance recovery efforts.

Overarching Comments

The San Marcos and Comal river systems and associated human and natural communities represent a complex, linked ecosystem. Over time both river systems have adjusted to a number of new controlling variables (e.g., increased water use, impervious cover, introduction of non-natives, increased recreation, and other factors).

Overall, there are no serious flaws or errors in the Final Hardy Report as related to short-term management considerations for recovery of the target species. However, there are significant omissions, as discussed below that may compromise the validity of the findings on a long-term basis. Assumptions of the approach are well documented and are reasonable given present understanding of aquatic ecosystems. The tools and methods of analysis employed, with respect to habitat modeling, are appropriately used and based on best available information. The acknowledgement of data gaps and uncertainties is commendable. Aquatic ecosystems are very complex and even though considerable effort has been expended to understand the Comal and San Marcos River systems, much is still unknown and developing a functionally complete comprehension of the system is a high standard to achieve. Studies such as this are intended to minimize or manage uncertainty – not eliminate it. Within this constraint, appropriate knowledge gaps were identified and addressed by suggested monitoring and adaptive management recommendations.

The Final Hardy Report focuses on the potential effects of degraded habitat in a relatively short period of time (a single drought year). Though long-term drought may not have been experienced in recent history, prospects for an extended drought (possibly associated with the effects of global climate change) are real and possibly increasing. If the flow criteria analyzed in the report are intended to be institutionalized for a long period of time or in perpetuity, analysis of the cumulative effects of longer term drought periods on ecosystem processes would be appropriate.

The application of the models to produce flow-habitat relationships and temperature time-series outputs are accepted practice. The models used were all appropriate and appear to have been properly calibrated or adapted for use in this study. The report identifies many of the readily apparent potential threats to these populations and habitats. Accepted methodological approaches were used to analyze the relationships between critical environmental attributes (habitat suitability and temperature) and flow levels. Most of the important limitations to the scientific analyses and assumptions upon which data interpretations were based were clearly articulated, which strengthens the conclusions and recommendations provided in the report.

The overall approach of using simulated model outputs in combination with observed and empirical data is to be commended. Combining the physical habitat modeling with the temperature modeling represents the state-of-the-art for carrying out these types of studies. The temperature modeling was improved by using recent (2009) empirical data along with the vegetation distribution using historical vegetation mapping results.

Intensive sampling, model calibration, and 2-D simulations of habitat were completed for both systems. Considerable detail is presented, including vegetation cover maps, habitat suitability, and reach maps illustrating ranges of hydraulic habitat suitability over a range of flows for selected species. These analyses were well done. Interfacing field data gathered by wading and by boat and with topographic data from LiDAR represents the state-of-the-art and allows for simulations of flow over the entire flow range from low flow onto the flood plain. Illustrations and information tables were clear and useful. Apparently no simulations of seasonal habitat periodicity or inter-annual habitat suitability were developed. However, it appears that all information necessary for such simulations was available.

The conclusion "that the flow regimes being considered by EARIP will provide adequate protection for aquatic resources given the underlying assumptions and the mitigation measures proposed by the EARIP have been successfully implemented" is supported for survival population levels by the data presented under apparently average climatic conditions. However, recovery after such stressful conditions cannot be assured by evidence presented thus far and should be the focus of rigorous adaptive management. Only after critical analyses comparing the proposed regimes over different seasons and under differing conditions of water supply and climate can the conclusion that the same "minimum flow regimes" applied to all years would provide adequate protection and recovery. Applying one set of "minimum flow regimes" to future years should be considered an interim measure pending more study of the system dynamics, human impacts, and biological detail.

It appears the current report was constrained somewhat by the scope of the work. To obtain a better understanding of the probability of persistence faced by the organisms studied, additional information and analyses would be helpful. Our review team previously made recommendations relative to this needed information. See the team's previous report dated 5/10/2010 where we recommended, "Full characterization of the system hydrology: past, present, and potential including all elements: magnitude, duration, frequency, timing, and rate of change is necessary. Establishing water year categories through 1) development of annual flow duration curves, 2) delineating water year strata (e.g. dry, normal, wet), 3) classifying each water year of the period of record into a specific stratum, and 4) then using that classification in a time series analysis to develop adaptive water management strategies would help refine recommendations. Additionally, hydrologic data should be stratified for water quality analysis according to cool, normal, and hot climatic conditions."

In particular, there appear to be considerable threats posed by secondary impact mechanisms – some of which were mentioned but most of which it appears were not directly studied. Additional work is needed to address issues such as the threats posed by non-native fishes and parasites and prospects for aquatic vegetation collapse at low flows. Though vegetation disturbance associated with human recreation is logically suspected of inhibiting recovery of TWR in the San Marcos River, it is unclear if the level of impact has been directly studied or quantified. Threats posed by these and other sources at low flows may be as great as or greater than the availability of WUA and physical habitat in which organisms may live.

The report provides an appropriate level of technical documentation on the modeling approaches and evaluation of the proposed minimum flow regime targets adopted by the EARIP for a similar instance as the drought of record. We note the presumption that a drought will mirror a previous one in climatic intensity or with the same combination of factors (water quality parameters same as in 1950's, watershed conditions similar (e.g., impervious cover), connectivity constraints similar, biotic interactions similar (e.g., invasive species threats the same), demand for water and recreational demand the same, etc), does not seem probable. These facts underscore the need to look at more than WUA and physical habitat.

The analyses in the Hardy Report also focused on the potential effects of known threats that exist now or have existed in the past. A thorough assessment of future risk might look to identify potential effects of factors that appear likely to exist or increase in the future. Such factors would include the prospects for considerably more recreational use of the San Marcos River than currently occurs. Studies might also be done of potential effects of contaminated groundwater entering the systems studied here through the numerous springs that feed these environments. Clearly, it is impossible to minimize or eliminate all uncertainty associated with managing for the long-term persistence of endangered species and the reality is that for all the potential risks we can identify today, there are others that are impossible to foresee. The recommendations section of the Final Hardy Report offered appropriate suggestions for future study that should be considered to help minimize risks of persistence associated with Texas Wild Rice (TWR) and Fountain darters.

The report also limited its analysis to the lowest recorded flows of record. Because an even more severe or extended drought is possible, it would be useful to analyze lower flows for both short and longer periods. Such information would help managers deal with future pressures to allow restriction of flows to even lower levels if and when such public pressures develop. Given the rate of population growth in this part of the U.S. and state, such a scenario seems likely.

As will be discussed below under *Specific Comments*, improvements to the physical habitat modeling could have been realized through model validation (hydraulic and habitat) and time-series analysis (hydrology, suitable habitat, and temperature). Demonstrating changes to habitat through time during both the assumed drought of record and for the entire period of record would have provided better context. Also, providing additional benchmarks, such as comparing the suggested minimum flows of the Edwards Aquifer Recovery Implementation Program (EARIP) to both the historical and naturalized flows would have been beneficial. Such analyses could be particularly informative by examining the period from the late1980's to present when intensive biological monitoring has been ongoing. Comparisons between the phenology of biological species and hydrology/habitat variability over this time period should be part of any future studies.

The results contained here suggest that higher absolute minimum flows might be appropriate. Setting such conservative standards now could make it more socially acceptable to achieve needed (higher) flow levels than trying to increase the presently proposed minimum flow levels in the future if the need for such protective flows was documented. A time series analysis that looked at a series of repeated droughts over a more extended period would help clarify potential effects.

While the title of the report is, "Evaluation of the Proposed Edwards Aquifer Recovery Implementation Program", it appears the report simply demonstrates that the proposed minimum flows provide sufficient habitat (quantity and quality) for short-term survival of selected species and life stages. A true evaluation of the recovery prospects requires comparative analyses as suggested in our specific comments to meet the stated objective of recovery and long-term persistence of the species. As such, we suggest the title be modified to more accurately reflect the relatively narrow scope of the studies presented therein.

The report should address in some way all of the technical components (hydrology and hydraulics, biology, geomorphology and physical processes, water quality, connectivity) emphasized by the 2001 National Research Council review of "The Science of Instream Flows: A review of the Texas Instream Flow Program". Without some discussion of each of the components, by default the report leads to the assumption that hydraulic habitat and water temperature are the primary limiting factors in these river systems. While this may be true, the report should provide a discussion and present logical arguments as to why the other components are not limiting during recent historical times or would not be important during a narrow window of time in the future. Particular attention to seasonality and periodicity of flow events since the late 1980's when intensive monitoring started would be enlightening. In addition, evidence should be presented on the potential low dissolved oxygen levels during low flow events when combined with extremes in high ambient air temperatures. The modeling capability presented would certainly support such analyses.

Continued monitoring and an adaptive management approach is necessary if the resilience of this system is to be maintained. Hydrology is a critical aspect linking the ecology and human systems. As such attention to flow regimes and habitat dynamics is critical for additional research, not only to establish specific habitat relationships but to establish and track habitat and population responses over time to ensure not only short-term survival but species recovery.

Specific Comments on Final Hardy Report

Page 1, Introduction

The report introduction states that it will focus evaluations on the "minimum flow regime targets adopted by the Edwards Aquifer Recovery Implementation Program during a similar instance as the drought of record". The report should clearly state the goals, objectives, and questions addressed within this report and specifically mention the time period over which the recommended flow levels will be in force. For example, "...the proposed minimum flow regime targets adopted by the Edwards Aquifer Recovery Implementation Program..." mentioned here and throughout the report, needs a concise definition, in terms of hydrology. It would be beneficial to provide a brief discussion on the minimum flow targets and the rationale for how they were derived. If this information is provided elsewhere in this text or other documents, it should be referenced here.

An excellent point is made that: *"These flow regimes cannot be sustained indefinitely (i.e., beyond the time period associated with the drought of record) without irreparable harm to the resources and/or placing these aquatic resources at unacceptable levels of risk."* This points out the need for a hydrology time series analysis to define when the drought of record (DOR) is happening versus times when flows are higher. An important piece of the recovery plan would include setting criteria indicating flows have moved into a DOR triggering implementation of the proposed minimum flow(s). The flow values used for minimums (6 months at one number, 6 months at another slightly higher number) are not flow regimes, simply two minimum flow standards, which may allow for short-term survival but not for recovery and long-term persistence of the species in question.

A quotation of the charge made to the report authors by the EARIP should be included. The report presumes that a drought will mirror a previous one in climatic intensity and with the same combination of factors (water quality parameters same as in 1950's, watershed conditions similar (e.g., impervious cover), connectivity constraints similar, biotic interactions similar (e.g., invasive species threats the same), demand for water and recreational demand the same, etc). This does not seem probable and may compromise the long-term validity of the technical analysis provided here.

The report stresses that the flow regimes modeled were specifically chosen to ensure short-term survival of the aquatic resources in the San Marcos and Comal river systems, to ultimately ensure "recovery potential". This caveat is important and is stressed in the report. Focusing on only solitary drought events is informative at a basic level but limits managers' ability to understand potential risks to survival of target organisms during extended drought periods. Given that the Edwards Aquifer Recovery Program is aimed at "recovery " and the Texas Water Plan emphasizes comprehensive instream flow studies (See Table 3-1, Sample Questions to Guide Technical Evaluations, in NRC, 2001 The Science of Instream Flows A Review of the Texas Instream Flow Program), a broader approach integrating longer term hydrologic characteristics could have been taken. The drought cycle is a part of the overall hydrologic condition. To ensure flow regimes will provide for the long-term protection, enhancement, and recovery (where necessary) of the aquatic resources within these rivers would necessitate analysis of the habitat conditions *after* the drought cycle as well. What is important to establish is the dynamics of species survival; what conditions are necessary to restore viability, what conditions constitute a threshold? Additional hydrologic analysis (e.g., scenarios bracketing past drought flows with even more extreme events or variations) would increase the view of system behavior and the breadth of potential impacts examined. Comprehensive investigations of the variation in hydrology and water quality as well as simulated habitat variability to search for potential associations with events of high stress and conditions necessary for population recovery would be appropriate study elements for both short and long-term periods.

Page 1, Background

This section presents some basic historical flow information for both the Comal and San Marcos Rivers. Clearly there have been considerable seasonal and inter-annual variations in water flow in both systems, but the extent of this variation is not well developed. Emphasis is placed on the flow during the extreme drought periods of the 1950's. No discussion is given (pro or con) of the need to develop simulations approximating the physical habitat and water quality conditions during that period for comparison with more recent years when intensive biological monitoring has taken place. Other factors that should be included, and are at least by inference, are the need for connectivity (for organisms to escape potentially lethal habitats and re-colonize depleted areas following drought) and geomorphology (or the need to minimize or avoid fluvial geomorphic processes/bedload transport in parts of the study area) during low flow periods.

Page 2, Background - Comal River

Hydrologic information (for the Comal and San Marcos rivers) is an important element in understanding the drought flow condition and relevance of flow recommendations; however this information appears lacking in the report. A table showing the minimum, maximum, and average flow at defined points or gages on both of the streams should be included.

Clearly there is a flow level below the proposed minimum threshold at which endangered species in this system are extirpated. It would be helpful if this analysis could identify the approximate flow level at which this might occur to, at a minimum, emphasize the fine line that may exist between the proposed flow regime and the "extirpation" flow level. Such information may help the EARIP understand the need to possibly increase the minimum flow they have proposed in order to minimize the risk of permanently losing these species.

The document states, "*During the drought of record…*". This would be a good place to clearly provide criteria upon which a DOR would be based. We are unable to find the definition for the acronym "EAA". This should be provided.

Spring flows ceased for 144 consecutive days in 1956; fell below 60 cfs for more than 100 days, and also fell below 40 cfs for over 40 days. The low mean daily flow was 26 cfs; other low flows were observed in 1989 (62 cfs), 1990 (46 cfs), and 1996 (83 cfs). Comal riffle beetles and fountain darter were apparently extirpated during this drought period. Clearly, the low flow period in 1956 was substantially lower than low flows experienced subsequently. The report states that low flows after the 1956 period did not extirpate riffle beetles, fountain darter, drypoid beetles, or the Peck's cave amphipod. This is apparently the rationale for the proposed low flow thresholds of 30 cfs for no more than 6 months with increased pulse flows to 80 cfs for the following 6 months. These proposed low flow recommendations appear to have been developed before habitat studies were done. The rationale and process for the derivation of the low flow regimes in most studies is based on hydrologic modeling or another process. As a premise for this low flow study, the basis upon which thresholds were developed should be provided in the report. Without this specific documentation, it is difficult to ascertain the real risk associated with these flow regime proposals, even qualitatively.

Page 2, Background - San Marcos River

As noted above for the Comal River, more complete hydrologic information should be provided. Criteria upon which a DOR would be based should be provided.

The lowest recorded discharge was 46 cfs in August 1956, which also had the lowest monthly average flow recorded (54cfs). Mean monthly discharges between 1955 and 1956 were between 54 and 77 cfs. Importantly, no quantitative data exist for the response of the target aquatic resources over this extended low flow period. Since the 1980's, Texas Wild Rice has sustained populations during all subsequent low flow years, even in the face of impacts from recreation, high flow scour events, and non-native species. Viable populations have been maintained during the extended low flow period in 2009. Low flows examined by the Hardy study were set for 45 cfs for no more than 6 consecutive months, with pulse flows increased to 80 cfs during the following 6 months. Without explanation for the basis of these low flows, we have the same concerns we identified for the Comal River noted above.

Page 2-4, Background - EARIP Drought of Record Low Flow Regimes

Again, it is not clear how the DOR is defined in terms of a flow value. Figure 1 is apparently showing the DOR begins sometime around the flow corresponding to January 1, 1947 and ends sometime around 1959. Is this the defined time period for the DOR? Does this mean when flows in the San Marcos River drop to 175 cfs this is the trigger for a DOR? As noted previously, there should be a section in the report that deals with hydrology and specifically there needs to be more discussion on what constitutes a DOR in terms of flow values.

Page 4, Methods

The methodological approach described in this section is very thorough and informative. The level of detail contained in these studies is exceptional and appears to facilitate the kind of analyses that are needed to effectively understand the consequences of different flow regimes. Intensive sampling, model calibration, and 2-D simulations of habitat were completed for both systems. Considerable detail is presented, including vegetation cover maps, habitat suitability, and reach maps illustrating ranges of hydraulic habitat suitability over a range of flows for selected species. These analyses were well done. Interfacing field data gathered by wading and by boat and with topographic data from LiDAR represents the state-of-the-art and allows for simulations of flow over the entire flow range from low flow onto the flood plain. Illustrations and information tables were clear and useful. Apparently no simulations of seasonal habitat periodicity or inter-annual habitat suitability were developed. However, it appears that all information necessary for such simulations was available.

Page 4, Methods - Vegetation Mapping

Mapping techniques to create vegetation polygons with dominant and subdominant species and joining with hydrodynamic modeling grids to assign roughness values and vegetation class attributes are an excellent application of the science.

Page 6, Methods - Topographic data reduction and computational mesh generation. Combining topographic maps, LiDAR, and in-channel shots is standard, thorough modeling practice. The 2nd sentence under this topic reads like LiDAR was used within the wetted channel (standard LiDAR does not penetrate through the water surface), but is resolved in the following sentence with the use of in-channel bed topography. It is common when LiDAR data and field data obtained using survey gear are combined to find inconsistencies in the elevations where data sets overlap. If there were inconsistencies in this study, then the manner in which they were resolved should be reported. Figure 4 shows the process of going from raw data points to contour map to good effect.

Page 7-9, Methods - Hydraulic Modeling

This is standard, thorough 2-D modeling practice. Figure 5 shows close match between observed and predicted water surface elevation (WSE). Table 1 shows a thorough and complete data set. The roughness values listed here all appear reasonable and within expected ranges for each vegetation or substrate type.

Page 9, Methods – Habitat Suitability Criteria (HSC)

The HSC curves for TWR, two non-natives aquatic vegetation species, and darters reflect recent research (Saunders et al. 2001, BioWest 2010a&b) and integrate additional information (empirical observations of darter depth utilization). Modifying the suitable depth criteria for darters as described here is appropriate and a credit to the authors to confirm the need for this.

The HSC curves were adopted from other studies and were well documented. No evidence is presented in this report of any testing of the adopted HSC curves as to their efficacy in describing species distribution at various simulated flows. For studies evaluating endangered species and proposed instream flows for implementation within critical water supply settings such as the Edwards Aquifer verification/validation, demonstration of habitat simulation agreement with species observations is called for (see National Research Council, 2008. Hydrology, Ecology, and Fishes of the Klamath River Basin). If such verification/validation was done by the original authors of the HSC curves then reference to the fact should be included. Academic aquatic scientists and ecosystem modelers have become quite critical of instream flow studies in recent years due to the lack of proper calibration and verification of model use in stream systems. These scientists point out that model calibration and verification/validation has become established practice in water quality modeling for over three decades and is of equal importance for hydraulic and suitability aspects of riverine habitat modeling.

When very low velocity levels (0-1fps) are within the optimum suitability range for some target species, verification of velocity data sets for simulated high flows would lend a high degree of credibility to the simulated velocity distributions produced by 2-D hydrodynamic modeling.

Page 15 -19, Methods - Physical Habitat Quantity and Quality, *Non-native vegetation Control*

Analysis of habitat for TWR and *Hydrilla verticullata* and *Hygrophila polysperma* allowed for an effective examination of non-native vegetation control areas. The basic approach for control was to, 1) remove non-native plants from existing optimal TWR stands and 2) remove non-native vegetation within a 2-meter buffer of occupied optimal TWR stands but additionally constrained by TWR having a greater suitability than the modeled non-native species.

These approaches seem reasonable given the data that exists. One caveat comes from Liebig's "law of the minimum" that states it doesn't matter how much habitat is provided, if that is not the limiting factor for the TWR plants in those areas (see http://en.wikipedia.org/wiki/Liebig's_law_of_the_minimum). There are always limits, and layers of limits; i.e., remove one limitation, and the next one becomes important. Any physical entity with multiple inputs and outputs is surrounded by layers of limits (Meadows 2008). However, what is often confounding is that the limits may shift – in other words, limits to the TWR may shift in response to stand size or some other dynamic factor. None of this argues against the approach taken, but merely expresses caution about expectations of results of the non-native vegetation control efforts. Lastly, the areal significance of *Colocasia esculenta* may suggest some further research for this species, especially if the habitat-guided control efforts for other plant species are even moderately successful.

Explanation of the analysis and accompanying graphics (Figures 10-12) were informative. As with any major field project (potentially removing over 25,000 m^2 of non-native vegetation qualifies as 'major'), converting the plans to implementation will be key. Applicability of the data, particularly under approach 2), where data accuracy is a critical element of a 'correct' decision, will likely require exploratory pilot efforts to work through field decisions before attempting targeted control work on a large scale.

Page 15, Methods - Physical Habitat Quantity and Quality, *Fountain Darters – Riverine Sections*

When carrying out flow-habitat modeling, there are several ways the HSC data can be used with the hydraulic data. In this instance the authors chose to use the geometric mean approach. This is a commonly used calculation method but it would be beneficial to provide the rationale for using this approach over other approaches. Validation of habitat model output by comparing suitable and unsuitable habitats with empirical data illustrating fish distributions would lend credibility to both the HSC and geometric mean composite suitability computations.

Habitat metrics can be expressed in a number of ways. For example, relating WUA as a percentage of the maximum observed WUA at each simulated flow would allow readers to better relate the WUA at each flow to the maximum that can be expected at a study site over the entire range of flows simulated. This may or may not change the overall conclusions of this report but would allow readers to better gauge the relative merits of the proposed minimum flow levels to other flow levels. Presenting the information as percent of total surface areas is, however, acceptable. It would be beneficial to provide the rationale for choosing this metric.

Page 15, Methods - Physical Habitat Quantity and Quality, *Fountain Darters – Lake Sections*

It is appropriate to recognize the limitations of applying flow-habitat models in lake environments and the need to use another approach, such as wetted area and depth, as used in the report. Relying on reservoir water quality models in lake systems is also commonly used.

A minor point, but use of the term "optimal" here and throughout the text is misleading and suggestive that all aspects of "habitat" have been captured. The term "habitat" can be very broad and encompassing. As a consequence, a more technically correct term might be "maximum observed suitable habitat." This change does not affect the validity of any interpretations or analyses, but would simply relate the attribute(s) being described more precisely.

Conducting analyses based on determination of WUA is widely accepted and used in virtually all instream flow studies. However, it is important to note that the relationship between the amount of WUA and numbers of target organisms is variable and imprecise between different rivers, segments, and species. The amount of WUA provides a good indication of the relative suitability of physical habitat for an organism and one would generally expect organisms to fare better and possibly expand in response to more WUA; but there is no guarantee of such outcome or steady state relationship between this factor and numbers of organisms. This is largely due to the fact that "habitat", as noted above, is comprised of a large universe of dynamic factors and processes that influence organisms. Certainly maximizing physical habitat (WUA) is a desired goal. Analyses based on the amount of WUA can help reduce or manage uncertainty, but such studies do not eliminate it or guarantee a particular outcome. It is axiomatic that physical habitat modeling is necessary but is not sufficient to provide a complete understanding of the species' ecology.

Page 16, Methods – Physical Habitat Quantity and Quality, *Texas Wild Rice – Theoretical Optimal and Suboptimal Area*

As noted above it would be beneficial to provide the rationale for using the geometric mean of the component depth over other approaches.

Overall, the approach described here is exceptional and should provide an appropriate and useful analysis.

Pages 17-19, Methods – Physical Habitat Quantity and Quality, *Non-native vegetation*

It is unclear if non-native vegetation density is constant year round or between years. Additional information about the abundance and distribution of non-native vegetation on an intra- and inter-annual basis would strengthen conclusions about the adequacy of the target flows for ensuring persistence of TWR. It would also be useful to include information on the growth and spread of these plants and TWR. This information would allow the reader more understanding of the feasibility of and need for physically controlling these plants as a way to facilitate the long-term persistence of TWR. The basic strategy and logic presented in the text is reasonable, though it is unclear why a 2 meter buffer is of greater utility than another size of buffer. Is this driven by the size of polygons used in modeling or a known life history feature of TWR or the non-native vegetation species? Clarification of these questions is needed.

The described approach for identifying most suitable areas for non-native vegetation removal and TWR expansion is a judicious and appropriate strategy that has merit over blanket removal of non-native vegetation.

Page 20, Methods - Temperature modeling

A glaring omission from this section is any discussion of the potential effects of global climate change on probabilities of achieving thermal or hydrologic conditions described in this report. Given the uncertainties associated with the effects of global climate change in both the short and long-term, a credible discussion of the probability associated with future annual thermal patterns and precipitation characteristics is warranted. At a minimum, the report should acknowledge the elevated uncertainties that may be experienced in the short (decadal) and longer terms.

Another missing component that should be included here or in an expanded water quality section would be the potential role of other water quality considerations, both surface and ground water inputs over both the short and long-term. At the low flow levels proposed by the EARIP, even small changes in some pollutants that could enter these systems from either surface or ground water could significantly affect the persistence of the organisms studied here. The potential impact should at least be acknowledged in the final report. Future studies and monitoring should more specifically address this issue.

The last sentence of this paragraph notes that adverse thermal conditions should not exceed 6 months, but this seems based more on professional judgment than data analysis. Professional judgment is highly acceptable in many situations; however this is where a time-series analysis would be possible and beneficial.

Water quality was restricted to water temperatures. Given the sophistication of the study otherwise, it is surprising that other constituents were not addressed, especially dissolved oxygen. Average monthly and even daily time steps for this parameter are not sufficient when looking at the potential dynamics of plant stands, associated fish species (fountain darter), and sediment oxygen demand. Extreme oxygen deficits are possible at these low flows and can cause imperceptible mortalities to fishes, especially small, young life stages.

Thermal death criteria for specific life stages for all species should be provided.

Page 21, Methods – Temperature Modeling, Comal water temperature modeling, *Model Structure*

The QUAL2E model used was calibrated by the senior author and published and has been in use since. It incorporates headwater (7) and point load locations (44) to represent various springs in the system. As such it represents an established tool with adequate testing and refinement.

Page 21, Methods – Temperature Modeling, Comal water temperature modeling, *Assumed spring flows for Comal headwater and point loads*

The revision of flow rates for specific springs as a function of total Comal River discharge incorporated 8 years of field monitoring by EAA and work of Guyton Associates (2004), who analyzed historical water levels and spring flows for the 1948 to 2001 period. Assumptions and adjustments adopted within the report, based on the additional information from these sources, seem reasonable.

It is unclear why 74.51 F was used as the constant temperature on page 24 and why this level of precision (hundredth of a degree) was appropriate. Additional clarification is needed.

Page 24, Methods – Temperature Modeling, Comal water temperature modeling, *Assumed flow splits for Old and New Channel*

Table 12 - Showing the historic flow splits along with the preferred flow splits would be informative. The rationale for splitting the flows for the simulated model runs seems appropriate given the information provided. However, it would be informative to understand the historical flows in terms of differences from the flow splits being used for modeling.

Page 27, Methods – Temperature Modeling, Comal water temperature modeling, *Climate Data and Model Calibration*

Air temperatures for the 1956 meteorological year would enhance the utility of Figure 16, to show the relative similarity and differences between modeled air and water temperatures and the air temperatures occurring during the historic low flow year. Old Channel simulations (Figure

18) seemed to represent the critical excursions into or past the larval threshold differently than New Channel across from Landa Park Office (Figure 19) or the Landa Lake near Spring Island (Figure 20). There were at least 7 observed temperature readings in the Old Channel that were higher than the threshold and simulations; at least 4 of these occurred where the simulation did not reach past the threshold and the observed values did. In the New Channel, the simulations exceeded the observed values and 18 times exceeded the threshold when the observed values did not. At Landa Lake the observed high values generally exceeded the simulations but did not reach above the larval threshold temperature. The under-estimates are a concern, particularly in the Old Channel, which appears to be a critical habitat area. Additional discussion explaining these dynamics and related consequences would be helpful.

The water temperature modeling in this report relies heavily on the previous application and calibration of the QUAL2E model reported in 2009 (recalibrated from Bartsch et al. 2000). However, significant changes in the hydrology of the system have been included in this report. Therefore some discussion of recalibration of the QUAL2E model in this new setting seems appropriate. Was the model recalibrated to better fit the empirical data or simply used with new hydrology? In Figure 18, simulated high temperatures do not seem to provide a good fit to empirical data in Landa Lake.

On page 28, the report references a USGS gage on the Comal River, but the gage location is not provided here, nor is it apparent on any figures provided to this point. As noted previously, it would be helpful to include more information on and from any and all gages on the Comal River (and San Marcos).

Page 30, Methods – Temperature Modeling, *San Marcos water temperature modeling, <u>Model Structure</u>*

Significant changes in the hydrology of the system have been discussed in this report. Therefore discussion of recalibration of the QUAL2E model in this new setting seems appropriate. Again, was the model recalibrated to better fit the empirical data or simply used with new hydrology? An even poorer fit (both maximum and minimum) for the San Marcos Thompson Island is illustrated in Figure 28. If recalibration was done and this is the best fit that could be made considering the other sites for simulations then discussion to that effect would be appropriate. Time series simulations of water temperatures over the period of intensive biological monitoring would be informative. Recalibration should be done given the new hydrology. Time series using the recalibrated model would require additional partitioning of years and seasons of the record into periods of dry, normal/average, and wet hydrology and hot, normal/average, and cool air temperature conditions. Much of this information is apparently available from stream gage and airport weather records.

Page 30, Methods – Temperature Modeling, *San Marcos water temperature modeling, <u>Assumed spring flows for San Marcos headwater and point loads</u>*

There is a lack of quantitative data on individual spring flow discharges to assign specific flow rates over the range of San Marcos discharges. This mandated that individual spring flows within Spring Lake were treated as a single incremental flow and this is a straightforward treatment of the constraint posed. From Table 13: only two of the 6 headwater (1) and point load (5) discharges for the San Marcos River are assumed to vary as total discharge decreases over the range of flows studied (130-45 cfs): Spring Lake Headwater and Incremental inflow Reach 1, for reasons noted above Interpretation of results should refer back to this limitation. This uncertainty may limit the precision of the conclusions.

The QUAL2E model is widely used and appears to have been properly calibrated and run for this study. Another model that might be considered and could offer significant benefits for other determinations discussed later in this report is the QUAL2K model (see http://www.epa.gov/athens/wwqtsc/html/qual2k.html). This model is a modernization of the former model but offers some expanded modeling features that include, among other things, use of unequally spaced reaches; simulation of attached bottom algae, light extinction as a function of algae, detritus, and inorganic solids; and simulation of pathogen removal as a function of temperature, light, and settling. Use of QUAL2K would likely not change the recommendations provided in this report but could help the authors or others address elements such as pathogen management and vegetation survival under low flow conditions in future reports.

Page 33 Methods – Temperature Modeling, *San Marcos water temperature modeling, Assumed spring flows for San Marcos headwater and point loads*

As noted above, descriptive information about the San Marcos River gage as well as more detailed hydrologic information from the gage would be helpful.

Pages 36-67, Results and Discussion

The habitat modeling results provided for the San Marcos River are impressive and thorough. Quantification of additional areas for TWR with removal of two non-native species shows the peak gain occurs at 100 cfs. Analysis of optimal and suboptimal habitat as the foundation for expansion of TWR into stable areas of unoccupied optimal habitat is a proactive application of science in an adaptive management framework. The 2-D mapped areas of TWR physical habitat provide a visual basis for relating the results and also necessary information for actually planning field operations. The report also provides quantitative information on the potential gain in TWR habitat through removal of two non-native plants, which comprise 2 of the 3 most common and abundant non-native plants documented. A conservative approach is proposed and seems prudent. The only caveat to this is obvious: proceed slowly, (spatially more isolated, smaller plots) making sure that the removal of non-native species, particularly within TWR stands, did not set up unintended conditions which exacerbate the invasive characteristics of the targeted plants. Documentation of conditions before, during, and after removal are paramount for later diagnostic efforts should something go awry.

The highest predicted suitable habitat generally occurs somewhat away from the stream margins both at 45 and 80 cfs. These results suggest that potentially high quality areas in these regions currently not occupied by TWR should be considered for planting or priorities for non-native vegetation removal as discussed below.

Another potential explanation, one that does not necessarily negate the report recommendation, is that there is another limiting factor in these areas, other than the measured habitat. For example, the distributions of the TWR may reflect unique hydraulic conditions (e.g., inside of bends), which are a function of channel shape and the helical flows of water, sediment, and nutrients.

Another explanation of the distribution of TWR could relate to the overall regime of flows; that this current distribution of TWR is an expression of longer term prevailing conditions, and that the stand itself modifies habitat when provided a range of flows within which to exist. Time series analysis of the habitat for this species would help establish the basis for comparison of flow regimes (hydrologic time series wed with HSC curves) and an estimate of the impact on habitat conditions for any particular arrangement of flows. It would also allow diagnostic analysis of notable population events, especially when coupled with a wider array of potentially impacting factors (e.g., outbreaks of invasive species, extreme temperature events, recreation activities, sediment, nutrients, etc.). While the report is clearly addressing its stated charge, 'evaluation of the proposed minimum flow regime targets during a similar instance as the drought of record', documentation of the habitat resulting from the entire hydrologic regime, and any subsequent modifications of flows, are not provided. Adaptive management, so clearly called for and which was initiated by this substantial effort, would benefit from formal analysis of the target populations of interest and the flow/habitat time series which supports them. Gaps in understanding these systems would become clearer as well.

Page 37, Results and Discussion – San Marcos Physical Habitat Modeling, *Texas Wild Rice, <u>Simulated TWR Optimal versus Suboptimal Physical Habitat</u>*

Analyzing WUA data as a function of maximum WUA instead of as a function of stream surface area appears as if it would show a greater rate of change at the low flow range of interest. This presentation of the data likely would not change the overall conclusion but could strengthen it.

The word "strongly" is subjective and probably not appropriate; however, the overall conclusion that TWR may expand into areas of unoccupied suitable areas that remain suitable over a wide range of flows is a reasonable conclusion. It is unclear if expansion would occur in a short-term or longer term.

Page 40, Results and Discussion – San Marcos Physical Habitat Modeling, *Texas Wild Rice <u>Simulated TWR Optimal versus Suboptimal Physical Habitat</u>*

The headers for Table 15 are unclear. It appears the second column should have "simulated" added to the header and in the third column, "2009 mapped" should be added to the header. The same correction appears needed for Figure 35.

Page 42, Results and Discussion – San Marcos Physical Habitat Modeling, *Texas Wild Rice <u>Potential TWR expansion with removal of H. verticillata and H. polysperma</u>*

Use of the word "strongly" is subjective and unsupported. There is no information in simulations in this report that relate to the long-term persistence of TWR under any conditions, though a time series analysis of physical habitat and temperature would be helpful.

The conclusion of both providing adequate flows and removal of non-native vegetation is compelling. However, long-term monitoring is needed to confirm the indication that proactive planting and non-native vegetation removal would lead to long-term persistence of TWR. Other mechanisms may be at work influencing the growth and abundance of these organisms other than WUA as evidenced by the fact that the non-natives encroached on TWR in the past and could do so again. Though the assumption that non-native vegetation removal has a "high" potential for increasing TWR abundance, there are no data in the report that relate to this probability. This does not change the basic conclusion brought forth here that this activity may have merit and should be explored by managers. The prospects for TWR expansion are probably not an absolute, but may vary from year to year due to a variety of different environmental conditions. As such, lack of expansion in one year might not necessarily preclude success in a subsequent year and vice versa. Modeling alone is likely insufficient to resolve the potential value of this strategy.

Pages 43-47, Results and Discussion – San Marcos Physical Habitat Modeling, *Fountain Darters - Simulated Fountain Darter Physical Habitat*

The results illustrate the value of the habitat modeling represented in this report. Potential changes of vegetation resulting from flow regime changes were not specifically included, but the results show the spatial influence of depth and velocity over the range of discharges. The sophistication of modeling analysis is evident: after providing the information indicating relatively small reductions of darter habitat between the examined flow ranges (45-80 cfs) the authors the necessity to implement adequate control measures to protect the vegetation community, to reduce potential secondary impacts on darters.

The last paragraph of this section of the report makes the appropriate point that the proposed flow regimes seem likely to provide enough WUA/habitat to ensure persistence of TWR and that other measures to control secondary impacts such as those associated with recreation and non-native fishes are equally or more important elements in a recovery program. The following section of this report addresses potential effects associated with temperature at low flow, but there may be other water quality issues to monitor and manage as well. Such impacts could conceivably arise from surface or ground water and their impacts would be greater at lower flow. If these potential secondary impacts have not yet been identified or managed, they should be the subject of future consideration and study.

Page 45, Results and Discussion – San Marcos Physical Habitat Modeling, *Fountain Darters, Simulated Fountain Darter Physical Habitat*

We agree with the conclusion that "*the combined suitability of darter habitat shows incremental increases as the discharge increases and that the spatial mosaic remains relatively constant.*" However, we do not follow the logic that it "*...is in part related to integration of vegetation in the calculation of the combined suitability which remains fixed over all ranges of simulated discharges.*" Unless the coding of the mesh is changed at each independent run of the model for each discharge, the vegetation, or substrate coding, is always constant in these models. We can't tell what actual velocities were measured at the flows of interest from the report, but suggest that if habitat remains relatively constant over a range of modeled discharges, then it is likely the velocity HSC curve is relatively constant at these low flows (see Figure 9). A sensitivity analysis can be run where vegetation is included as input to the model and then do another run of the model with the vegetation component removed. Results should be somewhat similar with the only difference being the scale on the Y axis (habitat units). The statement that "*Potential changes in vegetation as a function of flow regime within the San Marcos River were not considered in these analyses*" provides needed explanation of what was done.

It is reasonable to exclude Spring Lake from the WUA analysis since the modeled output in lakes is typically insensitive to changes in flow rate.

Whenever WUA curves show a monotypic increase in habitat relative to discharge, there should be a discussion presented to explain the shape of the WUA curve. It would be beneficial to know what the natural (no human alteration to the flow) range of discharge is for these reaches of the river. Is it reasonable to expect maximum habitat occurs at flows greater than 250 cfs? These animals evolved in the natural range of flows since the last ice age and it would helpful to know if flows greater than 250 cfs are overbank flows, or rarely occur, etc. The known biology of the animal and the shape of the WUA should be discussed.

Pages 47 to 51, Results and Discussion – San Marcos Physical Habitat Modeling, *Fountain Darters*, *Implications of Temperature on Fountain Darters*

The temperature discussion is excellent. The detailed discussion refines the habitat suitability for fountain darters in various areas of this spring and addresses or explains the recent findings of other research. Conclusions related to the decreased viability of habitat for reproduction and recruitment in the river below Rio Vista are provided and have important implications during drought.

The graphical data presented generally support the conclusion that the flow regime being considered in the San Marcos River will provide adequate habitat quantity and quality necessary to provide protection for this species during similar instances as the drought of record. However, comparisons made with assumptions of differing climatic conditions would be valuable (e.g. dry water year and hot climate year, etc.). These comparative analyses including potential effects on dissolved oxygen are needed as well as simulations over seasons and years (short and long-term) to evaluate recovery after critical droughts.

It is widely recognized that temperature modeling of natural systems based on laboratory data is problematic but it is the standard practice. It is also common to have some observed data where temperatures exceed thresholds and the animals persist. However, given the intent is to protect species from extirpation, it is a good approach to use consistent metrics and apply a measure of precaution. There are inherent errors in models and since this exercise was designed to stay above a "thermal death" line, erring on the side of caution is warranted.

The horizontal lines in Figures 41 to 45 should have a label of "increased larval mortalities" on the graphs or supporting text in the figure caption. On page 50, reference to reaches 1 and 5 do not appear to be the subject of data presented in Figure 42. Also on page 50, the statement that ambient air temperature in the spring of 2009 was about 75F may be correct but there is no citation or other data to indicate where this number came from or whether it is the correct value to reference.

Page 51, Results and Discussion – Comal River

Physical habitat modeling again is well done and illustrated with detailed habitat maps and graphs. The general conclusion is that sufficient darter habitat will be maintained on at least a short-term basis. Many caveats are given and emphasis directed toward the need to control non-native species, ensure flow through the old channel, and protect vegetation. Indeed, survival of some, if not most, organisms during potential drought conditions similar to the 1950's appears likely under the proposed 'minimum flow regimes". Recovery following such stressful events is not demonstrated and generates uncertainty when combined with potential water quality conditions.

Page 51, Results and Discussion – Comal River – *Fountain Darters*, *Simulated Fountain Darter Physical Habitat in Landa Lake*

We agree that entire populations of darters (adults and juveniles) probably would not be eliminated at the temperatures shown, especially if temperatures return to favorable levels during the lifetime of these fish. If favorable temperatures do not return for several years, resident populations may disappear though re-colonization would likely occur from upstream refugia. Recreation-related impacts and other secondary impacts (e.g. invasive species) could be severe at this time and could threaten long-term recovery. Again, this is another case where time series analysis of historic conditions and simulated worst case future conditions (that might be more severe than historic conditions), would provide important information.

Non-native fishes are a relatively new factor that may change the prospects for long-term persistence of fountain darters and the comments made here about their potential effects are valid. Other "new" or evolving factors that may change persistence prospects for darters should be identified as well. Control or removal of non-native fishes (and snails) can at least temporarily reduce pressure on small fishes like darters, but will likely require permanent monitoring and removal by humans. True recovery of endangered species should be such that species can persist on their own over time without the need for continued, regular intervention by humans. Thus non-native species removal should strive for total removal although this is a difficult goal. The uncertainties associated with this management practice speak strongly to the need to maintain the most WUA (and flow) possible to prevent non-native fishes, snails, and parasites from gaining a key advantage in terms of numbers and impacts. In consideration of the potential cascading effects of secondary impacts like these (especially on a long-term basis but also over the short and mid-term), the assessment provided by this report may be overly optimistic. Long-term monitoring and responsive action are warranted to document trends if and when they occur and enhance recovery prospects.

The second to last sentence in this section (page 58) states that "sufficient darter habitat will be maintained" but it is unclear what level of population existence is expected. It would be helpful if the authors indicated whether "sufficient habitat" relates to minimal persistence, maintaining robust populations, or some other level of abundance.

Pages 58-63, Results and Discussion – Comal River – *Fountain Darters, Implications of Temperature on Fountain Darters*

The graphical data presented generally support the conclusion that the flow levels being considered in the San Marcos River will provide adequate habitat quantity and quality necessary to provide protection for this species during similar instances as the drought of record on a short-term basis. However, comparisons made with assumptions of differing climatic conditions would be valuable (e.g., dry water year and hot climate year). These comparative analyses including potential effects of dissolved oxygen are needed as well as simulations over seasons and years to evaluate recovery after critical droughts.

Temperature modeling at 30 cfs illustrates conditions that exceeded both darter larval mortality and cessation of viable egg production thresholds in Landa Lake. At 80 cfs a few hours in late afternoon still exceed larval mortality and viable egg production threshold levels. Uncertainty about the possibility for incomplete mixing of the water column raises questions about the reliability of the QUAL2E simulations and leads the authors to believe the model over-states the thermal impacts ("likely results in an 'over-stating' of the thermal impacts in Lower Landa Lake."). This uncertainty calls for additional analyses incorporating dissolved oxygen in the water quality model simulations. This need is reinforced by reference to Figure 56 showing "that the lower extant of Landa Lake is primarily dominated by mud sediments which can have a high potential for oxygen demand under the right conditions." The cause for previous extirpations of Comal Springs riffle beetles is not known.

The horizontal line in Figures 50 to 54 should have a label of "larval mortality threshold" or text in the figure caption.

The discussion at the top of page 63 reflects an appropriate use of professional judgment.

Figure 55 shows that the river goes through a golf course, which may have or create water quality issues associated with the addition of nutrients (e.g., nitrogen, phosphorous) on an instantaneous or chronic basis. This situation provides just one example of the potential risk of water quality impacts from a variety of inputs that need to be explicitly addressed in future studies.

Pages 64, Results and Discussion – Comal River – *Implications of Flow Regime on Vegetation Dynamics*

The discussion related to all factors that can influence the aquatic ecosystem of Landa Lake is thorough and comprehensive *"...directed research on...flow regimes...residence time...velocity fields, on aquatic plant dynamics needs to be undertaken early in the adaptive management process to better inform the adequacy of the flow regimes being contemplated by the EARIP."* It is evident the tools used to date are only a subset of the effort that is required to understand the unique and complex ecosystem of Landa Lake.

Overall, this section characterizes the strength of this report, which is clearly detailed modeling and thorough examination of related factors affecting the results. Specific areas of uncertainty are noted in the report that illustrate this point:

1) Uncertainties related to vegetation response to sustained low flow regimes within Landa Lake and the fact that this represents a potentially significant unknown. The vibrancy of the current vegetation stands over the past decade is related as a positive signal for the resilience of the aquatic plant community;
2) Sediment oxygen demand within Landa Lake and uncertainties related to sediment accumulation and potential impact on the aquatic plant community. The short review of literature in this area is provided to explain this concern and is relevant and insightful;
3) A discussion of vegetation dynamics in shallow lakes, relating the complexity of interactions between dissolved inorganic carbon, periphyton, macroinvertebrates, and fish. The authors conclude, and we agree, that control of non-native species to positively impact the native aquatic vegetation in this system needs to be effective and that directed research on the implications of flow regimes on aquatic plant dynamics needs to be undertaken early as part of an adaptive management process.

The discussion on page 64 is good and adds a measure of accountability to managers to consider a potentially significant threat. Though the information needed to quantify potential effects of low flows on the survival of aquatic plants in general was apparently beyond the scope of this study, the authors make an excellent case for further developing and analyzing this potential threat.

A strong case for pursuing a conservative approach to setting long-term minimum flow levels is made. While analyses in this report suggest that WUA for target species may be acceptable on a short-term basis, the reality is that secondary factors that were not analyzed may pose a risk to the persistence of endangered species. The summary paragraph at the bottom of this page (paragraph 5) is precisely on the mark.

Page 67, Results and Discussion – Comal Springs riffle beetle

The statement, *"Our review of the water quality data do not indicate any demonstrable shift in water temperature or quality that would suggest that at these lower flow rates, impacts from water quality would be expected."* is technically correct, but what is not mentioned is that the effects of other water quality factors (pollutants) would be magnified at low flows and could have a negative effect if they were introduced. In addition to pollutants, there are likely negative consequences due potential diel swings of dissolved oxygen.

The discussion following the results shows no discernable impact to the riffle beetle. According to the report, empirical evidence of their persistence over the past two decades is evidence the proposed minimum flows provide for habitat necessary for protection of these species. Concerns expressed are: the implicit expectation of persistence of current water quality conditions, stability in water quality, stability in the surrounding watershed conditions and land use. While evidence supporting these concerns is not provided, we suggest this is not likely the case, even over the past two decades.

Pages 67- 68, Summary

The flow-habitat modeling, the temperature modeling, and the vegetation mapping are state-of-the-art (with the noted exception of a time series analysis). However, the authors very logically and correctly state there is much that is still unknown, particularly in Landa Lake with respect to dissolved oxygen and temperature regimes. While the authors conclude that the proposed flow minimums should result in the (short-term) survival of the species, there were no evaluations consisting of comparisons among alternative flow regimes. The authors appropriately caveat this conclusion stating *"...these flow regimes are not sustainable on a long term basis..."* The recommended minimums are specific to maintaining adequate habitat conditions for short-term survival of the target species during conditions similar to the drought of record. We agree these flow regimes will likely provide adequate protection for the aquatic resources but only if the underlying assumptions and proposed mitigation measures are successfully implemented.

One of the stated uncertainties is related to vegetation dynamics in Landa Lake. Other uncertainties include the degree to which the hydrodynamic velocity fields may permit cooler water to make it downstream to the old channel culvert system, and whether or not parasite and non-native fish control would be successful. The authors also note the impact of the proposed low flow regime on vegetation stand viability is unknown and this may dynamically impact darters and other species that strongly associate with the vegetation. The call for careful expansion of pilot control efforts for snails and undertaking an aggressive non-native fish program is important given the significance of this resource and the relatively small (tenuous) spatial scale of its existence. This underscores the need for systematic documentation of the population responses to flow regimes, control of non-natives, water quality parameters in addition to temperature, impacts of recreation, and small scale studies of vegetation die-offs.

To establish the theoretical and practical basis for adaptive management, sensitivity analysis of the proposed minimum flows through time series for both hydrology and habitat analyses should be undertaken not only for short-term survival during a drought of record, but of equal importance, conditions for long term recovery.

Given these uncertainties, it is problematic to then suggest *"...that darter populations will persist at reasonable numbers both within Landa Lake and upper reaches of the old channel with the* *flow regime magnitudes currently being considered."* The level of uncertainty and what is known about populations of darters make it difficult to suggest persistence in perpetuity under these conditions. Clearly on-going monitoring is essential to address the uncertainties.

It is stated, *"We further reiterate the importance that these opinions assume all other mitigation measures are successfully implemented and would include non-native (fish) control, etc."* It should also be stated that given the uncertainties regarding dissolved oxygen (diel) and thermal connectivity, scientifically credible monitoring (designed to address hypotheses) is absolutely essential to address factors such as ecosystem parameters that were not included in this report, the uncertainties associated with the assumptions of the recommended mitigation measures, and the predicted outcomes of the models that were applied.

Within the San Marcos River, addressing the uncertainty related to successful recreation control for target TWR stands and removal of non-native vegetation represent substantial areas of negative feedback, in both the human and natural systems. A formal adaptive management plan, strategically stepping through modeling, research action, monitoring, and adjustment would be appropriate for all aspects of managing this system.

Pages 69-70, Recommendations

The recommendations given are certainly important. In addition, attention to additional water quality components and research on variable flow regimes and climatic conditions necessary for population recovery after the stresses brought on by critical drought conditions should be an integral component of adaptive management.

The specific recommendations follow from the results and discussion provided within the report and addressing them would generate a better understanding of the systems covered. Further, they would begin to provide information to allow a proactive approach to management – before a crisis mode is reached. For example, it seems prudent to begin implementation of recreation measures and testing the procedures, spatially, institutionally, and socially before extreme drought conditions are reached.

Use of the report results to guide direct management control activities is a logical outcome given the detail and refinement in the report and is laudable. The discussion and recommendation for future research related to vegetation dynamics and control of non-native species and control of flows in the old versus new channels is an appropriate focus of future study as part of the adaptive management strategy. However, expansion of the scale of perspective to TWR, fountain darter, and riffle beetle through time series analysis would further augment proactive management activities, further the understanding of target population dynamics, and allow science (habitat/ecology) based comparison and refinement of the low flow regime proposals. These efforts are absolutely essential in view of the uncertainty of using only flow-habitat and temperature models and the gaps in knowledge that were identified by the authors.

References

Meadows, D. H. 2008. Thinking in systems: a primer. Chelsea Green Publishing Company, White River Junction, Vermont, USA.

APPENXIX A

Review Team Members

Thomas C. Annear, Project Leader. Mr. Annear is the water management and instream flow program coordinator for the Wyoming Game and Fish Department. He has worked for the department since 1981 and helped develop and implement their instream flow program from its inception. He has directed or assisted with studies that led to filing over 100 instream flow water rights and conducted or coordinated aquatic impact assessments for every major water development project in the state since 1983. From 1992 to 1994 he chaired the instream flow technical subcommittee for the Colorado River Endangered Fishes Recovery Program. In 2003 he helped form an inter-divisional water rights management team to address water rights issues associated with the acquisition, disposal, and management of Game and Fish commission lands and has served continuously as team chairman. Mr. Annear assembled and chaired a steering committee in 1996 that led to formation of the Instream Flow Council (IFC), served as that organization's first president, and is an active member of the Executive Committee. He was project manager and senior author of the IFC book *Instream Flows for Riverine Resource Stewardship* (2002 and a revised edition in 2004), is a co-author of the IFC book *Integrated Approaches to Riverine Resource Stewardship: Case Studies, Science, Law, People, and Policy* (2008), and was project leader for the IFC's International Instream Flow Program Initiative (2009) that assessed the status and effectiveness of state and provincial fish and wildlife agency instream flow programs in the U.S. and Canada and opportunities for improvement. He has written over 150 scientific reports, numerous publications and popular articles on river management; been an invited speaker at national and international symposia; and helped address instream flow issues on a variety of projects in the U.S., Canada, and Europe.

Ian M. Chisholm is the Supervisor of the Minnesota Department of Natural Resources' Stream Habitat Program. He has developed the program since its inception in 1989, shortly after he began work for the MN DNR's Division of Ecological Resources. The primary focus of this team of eleven scientists is to understand river and stream systems, increase the appreciation and understanding of ecosystems, and promote the use of science in decisions affecting natural ecosystems. He has worked with instream flow issues since 1983 and has been an active founding member of the Instream Flow Council since 1995. Mr. Chisholm chaired the science subcommittee that produced the IFC's book, *Instream Flows for Riverine Resource Stewardship*. Current research and work includes: creating, developing and delivering a GIS-based watershed assessment tool for Minnesota's major watersheds; developing a calibrated and validated erosion index for Minnesota rivers; conducting a watershed-wide (HUC 8 scale) assessment of river stability and sediment supply; continuing to develop and maintain a HSC library for Minnesota fishes, now covering 102 species and 257 species life-stages (162,500 individual fish observations); maintaining long-term biological monitoring sites on five (5) rivers, first sampled in 1987; administering a stream restoration priority list for capital bonding funding; conducting review and comments on FERC-licensed hydropower projects for the Minnesota DNR's divisions of Fish and Wildlife and Ecological Resources; surveying, designing and supervising stream restoration projects (over 100 completed statewide) following a natural channel design approach; and, providing training and materials on river systems, including 4 week-long courses on fluvial geomorphology.

Dr. Clair B. Stalnaker has been a key player in the instream flow arena for over 30 years – in research, method development and implementation, and policy. He organized and served as leader of the Cooperative Instream Flow Service Group (and various subsequent titles) under the U. S. Fish and Wildlife Service and Geological Survey. This program brought together an interagency group of multidisciplinary scientists for the purpose of advancing state-of-the-art science and elevating the field of instream flow management to national and international prominence. The primary focus of this group was toward a more holistic view of river science addressing the major components of instream flow management, namely hydrology, geomorphology, water quality, and aquatic biology and promoting instream flow regimes (incorporating intra- and inter-annual variability) rather than "minimum flows". He retired as a senior scientist with the U.S.G.S. where he was chief of the River Systems Management Section, Midcontinent Ecological Science Center, Fort Collins Colorado. He earlier served as Assistant Professor, Fisheries and Wildlife Science (1966 to 1976) and as Adjunct Professor in the Department of Civil Engineering at Utah State University and more recently as Adjunct Professor in the Departments of Earth Resources and Fisheries and Wildlife at Colorado State University. He has served on national and international technical advisory committees and task forces and authored numerous publications focusing on the instream flow aspects of water allocation and river management. He served on the Water Science and Technology Board of the National Research Council committee report on "Water Transfers in the West: Efficiency, Equity, and the Environment" and the National Research Council, Board on Environmental Studies and Toxicology report on "Hydrology, Ecology, and Fishes of the Klamath River Basin". He is an Honorary Life Member of the Instream Flow Council and was awarded the Instream Flow Council's Lifetime Achievement Award in 2008. Since 2004 he has served as a member of the Science Advisory Board for the Trinity River Restoration Program, California.

Allan Locke has worked as a fish habitat protection biologist in Ontario and Alberta over the past 30 years. His work has encompassed the fields of fish habitat restoration, habitat protection, conservation biology, river, wetland and lake ecology and most recently, instream flow needs. In 1981, Allan joined the Alberta Fish and Wildlife Division as the Provincial Aquatic Habitat Protection Biologist. His responsibilities were to develop fisheries habitat protection guidelines with the intent to provide industry, governments, resource managers, and the public with an understanding of fisheries concerns regarding specific land use activities. Gaining knowledge and experience in the science of instream flow needs, Mr. Locke went on to develop a provincial program to address the important issue of protecting Alberta's rivers and creeks with respect to water use. In 1998, Mr. Locke succeeded in getting Alberta to become a founding member of the Instream Flow Council. From 1998 to 2000, he served on the Instream Flow Council Executive Committee as the first Director of Region 5 (Canadian Provinces). From 2004 to 2006, he was president of the Instream Flow Council. As a member of the Instream Flow Council, Allan volunteered his time as a co-author on the Council's first book, *Instream Flows for Riverine Resource Stewardship* and the second revised edition. Mr. Locke was the project manager and senior author for the Council's third book, *Integrated Approaches to Riverine Resource Stewardship: Case Studies, Science, Law, People, and Policy.*

July 13, 2010

Dr. Robert Gulley, Program Director
Edwards Aquifer Recovery Implementation Program

Delivered via email

Re: Responses to comments on our j-charge report

Dear Dr. Gulley:

Attached are the Expert Science Subcommittee's responses to the comments by Annear Associates, LLC on our j-charge report "Analysis of species requirements in relation to spring discharge rates and associated withdrawal reductions and stages for critical period management of the Edwards Aquifer". The subcommittee met on May 17, 2010, to respond to the comments and exchanged emails over the past few weeks to finalize our responses after receiving clarifications from Annear Associates, LLC on several comments.

Please let me know if you have any questions or comments.

Sincerely,

Robert E. Mace, Ph.D., P.G.
Chair, Edwards Aquifer Area Expert Science Subcommittee

Responses of the Edwards Aquifer Area Expert Science Subcommittee to the Peer Review Team Comments on "Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer" aka the "j-Charge" Report

Responses to the overarching comments:

"The review team agrees that pumping reductions to meet these trigger criteria is a positive interim strategy. However, this is a reactive approach and is bound to be difficult to implement in a way that maintains and enhances the species and habitat conditions in the springs."

- ***To clarify, the Expert Science Subcommittee was tasked with providing triggers and associated pumping reductions in response to species requirement, but we did not call for pumping reductions. The Steering Committee will ultimately be making those recommendations. The critical period management approach could be described as reactive rather than proactive, but note that it is not expected to be the entire solution to the problem.***

Responses to comments on: Task 1 Analyze species requirements in relation to spring discharge rates

P. 3 – The flow criteria in the table do not make any distinction as to time of year. In most other aquatic systems, different flow rates or levels at different times of year are needed to maintain or restore aquatic species.

- ***In comparison to in-stream flow analysis for rivers, seasonal variations in these spring systems are minor.***

P. 4; It is legitimate to assume that adequate flows for surface dwelling aquatic organisms will likely address needs of aquifer-dwelling species. This is intuitive because the species are "pool" species that key on lentic habitats more characteristic of aquifer conditions even if they exist in flowing portions of the aquifer. The list of environmental attributes should also include longitudinal and vertical connectivity. Longitudinal connectivity refers to connectivity processes over space within the existing channel (and springs) of a water body. Vertical connectivity is a reference to the manner in which a surface water is connected to ground water. Connectivity is multi-faceted and can relate to the ability of organisms to actively or passively move up or downstream or through gravel from groundwater to channel bed, as affected by the presence of barriers or features that impede (or facilitate) their movements. Barriers to the movement of biota can include physical, thermal, or chemical obstructions. Impervious cover over a landscape can constitute a barrier for vertical connectivity, impeding water and nutrient flow from the surface to groundwater. Connectivity can also relate to non-biotic elements such as water quality elements (pollutants or sediment) and geomorphic processes (bed load transport). It is clear that the authors of the "j charges" report recognize the importance of this diverse concept, but we felt that because of its importance in affecting the distribution and abundance of the endangered species, it would be effective to specifically mention and address this key ecosystem attribute. Connectivity can be a key driver in determining the distribution and colonization of species throughout a system and directly affect their ability to re-populate areas that may have become temporarily unusable.

- ***As long as flow is sustained, we are assuming connectivity of the habitat of the subsurface species is maintained at each spring system. Additionally, we recommended that lower flows occur over a much shorter time period than historically experienced during the drought of record. As such, we are assuming that habitat connectivity for the Comal Springs Riffle Beetle would be maintained at a level suitable to meet the stated goal of survival and recovery.***

Approach

P. 6; The "workgroup" approach described at the top of this page, as well as the "subcommittee" approach used to develop this report, are strengths of the approach taken to develop the spring flow recommendations and indicative of the application of the best available science.

- ***We agree.***

P. 6-10; This list of monitoring reports and programs is unique and provides this study with much more information upon which to analyze model outputs and apply professional judgment than exists for the great majority of other flow studies. The wealth of information described on pages 6 - 11 further attests to the best available science being applied.

- ***Thank you.***

Natural Flow Theory

P. 11; It is a reasonable assertion to suggest that a recommendation to restore the natural flow regime would be impractical. These species have survived, to some degree for the last 150 years in altered flows, so it is imperative that this entire period of record be used for describing hydrologic variability and making flow recommendations.

- ***To clarify, "150 years" generally refers to human alterations over time in the spring ecosystems. Continuous gage data only goes back to the 1930s for Comal Springs and to the 1950s for San Marcos Springs.***

P. 11, last paragraph; A conservative strategy should be no less than the lowest observed flow especially considering that these species are endangered for the very reason that such low flows are part of the reason for their classification. A more appropriate conservative strategy would be to pick some higher flow with less duration than was observed historically. The complexity of stream ecosystems makes setting an absolute low number very difficult but those closer to the river and issues doubtless have a sense of a proper range based on their professional judgment.

- ***We agree.***

Professional Judgment

P. 12. This approach, including use of professional judgment, represents the state of the art / science for these type of studies. There are no models that provide precise answers without the application of some degree of interpretation and professional judgment. The team is to be commended for clearly articulating the process and the very real fact that professional judgement must be used.

- ***Thank you.***

Analysis Assumptions and Recommendations

P. 12 – 13; The approach of using metrics defining thresholds for loss of habitat and an instantaneous threshold below which no water should be taken is consistent with similar studies throughout North America. The review team had difficulty understanding how seasonal and inter-annual adjustments would be made and when these adjustments would be implemented in a real time operational sense. There is no evidence, such as a time series analysis of any hydrologic period or periods against which these criteria have been overlain or plotted to show how these metrics will support necessary intra- and inter-annual variability.

- ***Once developed, critical period management for the aquifer is in place all the time in this system which addresses the need for seasonal and inter-annual adjustments. We agree that a time-series analysis will be valuable for the habitat conservation plan and/or the final critical period management plan.***

P. 13; The report notes, *"...the frequency and duration of these extreme events are of critical importance and, if extended beyond the natural tendency of the system, can be detrimental to the resident ecological community."* The assumption being made here that the variability of the flow record of the past 150 years is a reasonable representation of the longer term record may not be reasonable given the declining nature of the endangered species in this system.

- ***We agree; that's why we considered other factors other than historical hydrology.***

P. 13; The use of average statistics is risky. While the various time intervals have merit in terms of maintaining flow regime characteristics, most species are affected by instantaneous low or high flows. The use of average statistics can mask potentially serious bottlenecks associated with short-term low (or high) flows.

- ***We agree.***

The allowed or expected frequency of the minimum 6 month average flow and 1 month minimum average is unclear. Certainly the authors do not anticipate back-to-back periods of these conditions but it would be good to clarify what they think allowable limits might be.

- ***We agree; an analysis of these values in the context of a habitat conservation plan will need to be done.***

The authors' logic about natural precipitation events providing for higher flow pulses may be acceptable however future studies should address the potential for additional water development in the region that might capture additional surface flow and alter spring flows. In addition, future reports should offer recommendations about how much additional water development is allowable within various parts of the watershed.

- ***We concur.***

The issue of seasonality should be more specifically addressed – the report should at least acknowledge the level of natural seasonal variability that existed prior to development to support the statement that the specified strategy will approximate those conditions. This was a major point of discussion in the review team's overall comments.

- ***See our response to the comment for Task 1, page 3.***

P. 14; The report notes, *"...high flow pulses are very important . . . in both . . . ecosystems to flush the system, remove vegetation mats, move sediment, and occasionally scour out vegetation . . . We evaluated high flow pulses within the context of each of the threatened and endangered species and made the determination that as these events are driven by precipitation, they would occur naturally."* The team is to be commended for not just focussing on the average to low flow range but including the higher flow ranges as well. Many studies overlook this very important aspect of river ecology. We caution, however, that a simple assumption that pulses will occur naturally is not a means of ensuring these events will occur. An additional, higher statistic than those listed is needed to address this flow level.

- ***We believe that this would be difficult to achieve in an aquifer system; a karst aquifer responds differently than a riverine environment.***

P. 14, last paragraph; The process of analysis omits mention of historic / natural conditions and appears to use existing conditions as a starting point. This approach accepts the existing condition as the default standard which seems like a tenuous perspective given the fact that the species have become endangered under these conditions and return to flow patterns and processes closer to historic levels would seem necessary.

- ***These species are endangered because of geographic isolation and risk associated with drought and pumping; therefore, using existing conditions in the absence of historical biological data is a reasonable starting point.***

P. 14; A seasonality component is necessary and should be included.

- ***See our response to the comment for Task 1, page 3.***

Comal Springs Analysis and Assumptions

P. 15; The fact that fountain darters had to be reintroduced here from San Marcos Spring clearly indicates that connectivity is important. Connectivity to habitat that could sustain them under drought conditions (thermal refugia) was a function of water flow from the spring, which was affected by pumping. Since being reintroduced, the fountain darters have flourished. In terms of zoogeography, we assume that the same fish species in a region were distributed through hydrologic connections that may or may not be apparent today. In essence, the reintroduction established a population by (artificial) connection to a fountain darter refuge (San Marcos Springs). We make the point that insuring conditions that allowed habitat refugia, and the connectivity to them, to exist within the springs, would go a long way towards ensuring fountain darter persistence. Meaningful, or full, recovery should involve the ability of organisms to re-colonize any areas of suitable, historic habitat without human intervention.

- ***The flows recommended at Comal Springs were established to prevent the need for reintroduction (human intervention) of fountain darters from San Marcos as was required following the drought of record.***

P. 18, paragraph 4; Given the status of this organism and the expressed goal as stated on page vii, paragraph 3 of this report that says "*Our interpretation of a protective flow regime is one that will ensure the "survival and recovery of the species in the wild". To accomplish this goal, the subcommittee determined that the recommended flow regime must sustain an overall trend of maintaining or increasing the populations of the threatened and endangered species*", acceptance of up to a 40% reduction in habitat seems too high.

- ***The important component of this reduction is that it will only be temporary in nature. A temporary reduction (1 month or 6 month average) that occurs infrequently is not considered to contradict our goal.***

P. 20 last paragraph; Discussion about the reduction in parasite prevalence following flood events suggests that such events are important. Flow management strategies to address this issue should be included in recommendations regardless of potential conflicts with any other endangered species. Because the range of flows during studies of cercarial abundance were relatively limited (no more than 441 cfs) it is unclear if higher pulses of flows would indeed have the speculated effect of reducing their numbers.

- ***We agree.***

P. 21, last paragraph; Simply monitoring Ramshorn snails will not ensure protection or enhancement of habitat for fountain darters. If this species really does pose a threat, their populations should not only be monitored, but strategies and efforts to control their abundance and distribution should be identified and adopted.

- ***We agree.***

P 22, second full paragraph; This discussion of potential effects associated with recreation suggests that some level of habitat degradation is acceptable in Comal Springs, which is a questionable position when dealing with recovery of endangered species. In many cases like this there is zero tolerance for takings unless specific levels are identified and justified in recovery plans.

- ***Because of the current condition of endangered species in the Comal Springs system, some level of habitat degradation over short periods of time will not contradict our goal of an overall trend of maintaining or increasing populations.***

P. 25 first two paragraphs re: Comal Springs Riffle Beetle; These observations about the ability of this organism to survive natural drought periods are logical. However, it would not be prudent to prescribe or allow those conditions any more frequently than they occur naturally. Sometimes when water managers accept or recommend an instream flow level that is substantially lower than existing flows (or is based on the lowest flow on record), the result is in essence the same as a prescribed drought. Managers should be careful not to indicate an acceptance of low flows that approximate historic low flow levels on the basis that organisms have survived those conditions in the past.

- ***We agree, and thus the rationale behind us using multiple approaches (not just historic hydrology) in the development of our recommendations.***

We appreciate that the Science Subcommittee is sensitive to this fact and offer encouragement to implement flow regimes that exceed drought levels. Prescribed drought is never an acceptable condition for perpetuating aquatic organisms. The recommendations provided by Hardy (2009) seem defensible and acceptable for this species.

- ***We agree.***

P. 25, Comal Springs dryopid beetle; Comments about the habitat and flows needed to perpetuate this organism are logical and defensible. Additional data collection would be helpful to affirm these observations.

- ***We agree.***

P. 26, Peck's Cave Amphipod; It is not uncommon for invertebrates like this and the beetles to experience wide swings in population numbers within or between years. Flow is probably only one of the drivers behind these swings. Water quality is likely also involved. It is unclear to this point in the report how or if water quality in spring flow is affected by surface management practices in the Edwards Aquifer drainage area. If there are input areas of concern these should be identified.

- ***We agree that water quality needs to be addressed in the HCP.***

Comal Springs Flow Regime Recommendations

P 26-27, Figure 5; Final recommendations deviate from the long-term average, 6 month minimum, and 1 month minimum statistics. The process details resulting in the recommendations of 225, 75, and 30 cfs are not completely clear and undoubtedly relied on professional judgement. We support professional judgment but descriptions of the logic and decisions that led to these changes must be documented more thoroughly. We can envision how these recommendations could be used as reactive strategies but it is unclear how these recommendations could be used to pro-actively manage the system. This issue is addressed in more detail under the review team's comments for Task 2.

- ***Best professional judgment was used to interpret the information in Figure 5 and develop the recommendations. The development of an habitat conservation plan and/or a critical period management plan is a proactive approach to managing the system.***

No biological rationale is given for allowing the absolute minimum to go down to 5cfs except for the implication that this flow is greater than 0 cfs. In the absence of additional information or discussion about the basis for this prescription, this flow level does not support the goal for survival and increasing populations of the fountain darter in Comal Springs.

- ***We agree; we used 5 cubic feet per second to simply ensure that a monthly (~30-day) mean flow did not allow springs to stop flowing. We expect that any flow at 5 cubic feet per second would be momentary. A monthly mean flow was used to accommodate the stress periods in the aquifer model.***

There are many unknowns that could affect the actual achievement of species recovery and this is an excellent example where continued monitoring and study is warranted. Monitoring alone is not enough as water managers should also put in place authority and financing to implement emergency protective actions if future study shows it necessary. Of course, criteria should be developed to define the meaning of "necessary".

- ***We agree.***

P. 28, 2nd paragraph; the goal should be not just be "survival", but "recovery".

- ***Our goal was to support an overall trend to maintain or increase populations instead of survival.***

P 29, Next to last paragraph; "*. . . we have elected to recommend flows higher than the historically observed low flow statistics at Comal Springs because of the extirpation of the fountain darter following the 1950' drought . . .*" This statement is in contrast with the information on page 28 regarding the selected absolute minimum of 5cfs discussed above. Additional discussion is needed to clarify this apparent discrepancy.

- ***Comal Springs stopped flowing for 144 consecutive days; therefore, 5 cubic feet per second is higher than historically observed values.***

P. 30; As stated previously, it is interesting the Subcommittee made the decision not to incorporate a margin of safety. The EARIP should ensure the legal and institutional capacity allows for changes that may be necessary in the future if it is determined that flow regimes need to be more conservative.

- ***This comment is directed to the EARIP.***

P 30, 2nd paragraph; The recommendation for monitoring should not be just for study at critical low flow periods, but for other flow levels as well so that suitable comparisons can be made and conclusions drawn.

- ***We agree.***

San Marcos Spring Analysis and Assumptions

P 32, 3rd paragraph; Future studies should document the level of recreation use between years.

- ***We agree.***

P. 34, 2nd paragraph; The review team agrees that consideration should be given first to monitoring data, then to model results. This is a strength of the approach used.

- ***Thank you.***

P. 35, paragraph 1; SNTEMP is a useful tool for assessing thermal dynamics in streams and is generally known to be relatively insensitive to air temperature. More influential drivers are shading and groundwater inputs. It is important to include the most accurate data possible for all sensitive drivers.

- ***We agree.***

P. 36, 1st paragraph; A short explanation of how Saunders et al. determined "importance in the ecosystem" would be helpful.

- ***Our interpretation is that it was based on the native vegetation's abundance in the ecosystem.***

Page 39-40, Figure 9; The Subcommittee should use a finer scale of flow increments between 30 and 80 cfs to see if there is a discernable inflection or change in the slope of the curve over this range of flows.

- ***We agree.***

P. 41, line 5; Reference to the effect of flood retention dams on fluvial geomorphic processes (siltation) is an important factor. Hydrologic events that have led to this condition are just as important as those processes that perpetuate vegetative growth and physical habitat for endangered species. It would be appropriate to develop recommendations that relate to this trend and construction of additional flood retention dams in the future.

- ***We agree.***

P. 48-50; It is obvious that recreational use of the river is having an impact on wild rice and other aquatic vegetation. Studies to quantify these effects at different times of year are needed to incorporate in development of flow regime recommendations. Based on the outcome of these studies, specific management measures may need to be developed.

- ***We agree.***

P. 50, 1st paragraph and P. 51; Data are not provided to determine whether the differences between years and seasons are statistically significant. Also, if there is a natural late-season die-back of Texas wild rice that might contribute to seasonal changes, this aspect of the species' life history should be described.

- ***See earlier comment. Note that there is no late season die-back of Texas wild rice.***

P. 53, 3rd paragraph; The percent reductions in WUA do not appear to be substantial given the changes in flow, especially given the inherent measurement error in both flow measurement and hydraulic modeling. Our reference to "substantial" relates to numeric changes and the relatively small change in WUA with change in flow. We appreciate that WUA is only a relative indicator of physical habitat suitability and the relationship between that metric and organism abundance is unique for each stream or system. As a consequence, even a small change in WUA in some streams could result in a relatively large impact (or benefit) for some species. In light of this fact, additional discussion would help explain why the relationship between flow and WUA may or may not be an important consideration as opposed to simply another piece of evidence.

- ***We acknowledge that in certain instances there were only slight changes in WUA relative to changes in flow. As such, additional approaches, including professional judgment, were used for decision making to supplement the WUA assessment.***

P. 55; If the WUA estimates are credible, over time one would reasonably expect the plants to become established in more than 9 and 17% of the habitat. A time-series analysis would be helpful here to further investigate this linkage.

- ***There are other species already occupying (and competing for) potential habitat.***

P. 55; This discussion provides additional indication of the need to consider connectivity of habitats and time series analyses when analyzing or setting flow recommendations. In this instance, we affirm that in addition to longitudinal, vertical, and lateral connectivity, it is important to also consider the temporal aspect of this attribute per time series analysis. The importance of addressing and managing for appropriate intra- and inter-annual connectivity patterns and processes is well established and can be a major driver for many aquatic organisms.

- ***We agree that a time series analysis should be conducted during the alternatives analysis for the habitat conservation plan.***

P. 56, 1st paragraph; These statements provide a compelling basis for placing an emphasis on the human component of biotic effects as it relates to habitat needs for the endangered species. Not many instream flow studies rely on this kind of criteria but it seems clear that human-caused degradation is a significant driver here. Professional judgment would be a useful tool to set a flow regime recommendation on this basis.

- ***We agree.***

Pp 56-59; The assumptions in this section are scientifically valid.

- ***We agree.***

Historical Flows at San Marcos Springs

P. 60; It is not clear what is meant by "*rarely be experienced*". Perhaps the long term average flow target of 140 cfs could be presented graphically so that the frequency and duration for an appropriate time step, say monthly or whatever best suits the assemblage of flora and fauna, can be seen to better illustrate the point.

- ***Flows are presented in Appendix G. Figure 27 shows how often the 1 month and 6 month targets are exceeded. The phrase "rarely be experienced" will need to be addressed in the habitat conservation plan; it wasn't necessary with the critical period management plan.***

P. 60, 4th paragraph; The goal should be recovery as well as survival. In the last paragraph, the WUA-flow relations developed by Hardy (2009) for fountain darter do not support the claim made in the 2nd sentence about the 140 cfs flow. More detail regarding the professional judgment that went into this recommendation would be helpful.

- ***See comment above on recovery/survival. Professional judgment was used to balance the needs of all endangered species, not just the fountain darter. We believe the report adequately documents the professional judgment used.***

P. 61; The review team notes that the overall strategies used by the Subcommittee for recommending flows is to pick statistical values as the flow limit and then use habitat modeling and other information to justify the highest value without going above the statistic. This is an acceptable strategy but it does not appear that this protocol was consistently followed. The review team thinks the present recommendations are acceptable interim guidelines but additional information is needed to explain the deviations.

- ***We disagree that this was the main strategy used. We used data, modeling, natural flow, and professional judgment at varying degrees depending on what information was available.***

P. 62, Table 11; As suggested above, more detail regarding professional judgment would be helpful to explain how specific recommendations were derived. Results presented by Hardy (2009) and Saunders et al. (2000) by themselves do not appear to be supportive of the 140 cfs recommendation for the Long-term Average flow prescription.

- ***Based on the occupied area of Texas wild rice and professional judgment, we made adjustments to balance the needs of all species.***

The Subcommittee chose to exceed the historically observed flow statistics at San Marcos because of uncertainty associated with stochastic events that might significantly impact species. Of particular note is the 1-month average minimum of 60cfs with an absolute minimum of 52 cfs. This contrasts with the low flow recommendation for the Comal Springs where the lowest flow reached since reintroduction of the darter has been 26cfs.

- ***See previous comment.***

P. 64; Additional rationale is needed to explain why this calculation was used, as opposed to other methods to set the 1-day minimum flow.

- ***See both previous comments.***

P. 65- 66; As with our previous comments, it is clear the Subcommittee thoroughly discussed this issue and it is clear they chose not to factor in a safety margin in view of the uncertainty. And to reiterate, it is not known if the legal and institutional setting will allow for changes to the water management plan if it is later revealed that impacts are occurring and the flow needs to be increased. Ultimately, this is a decision about how the Subcommittee wants to manage risk.

- ***This comment is really directed to the EARIP.***

P. 66-68; The Subcommittee's recommendations for future study are certainly appropriate for developing a better understanding of the system and should be pursued. Increased sedimentation and recreational pressure are confounding issues that need to be specifically addressed during future study of the San Marcos Springs.

- ***We agree.***

Response to comments on: Task 2 Analyze withdrawal reductions and stages for critical period management

P 69-74; The MODFLOW-NR represents the state-of-the-art and is appropriate for evaluating Task 1 minimum flows and stages. Accounting for groundwater and surface water is a very complex undertaking and the Subcommittee outlined very clearly how this was done in the context of evaluating a number of flow alternatives. The Subcommittee is to be commended for addressing this complexity in a comprehensive and reasonable fashion. The review team found that conducting the 40-odd runs was a useful exercise that illustrated how the present management model can be used in meeting Task 1 flow recommendations.

- ***We concur. Thank you for the acknowledgment.***

P. 75; The report clearly shows the Subcommittee attempted to address the very uncertain topic of climate change. If the climate models show the possibility of decreased flows in the future, the Subcommittee could create simulation runs representing a range of possible flow conditions and examine the effect on flow recommendations. Addressing climate change when making flow recommendations presents an enormous challenge and is not unique to this basin. We suggest the Subcommittee consider looking at a number of climate change models and once they agree to one that predicts less water in the future, they could calculate the return intervals for whatever time period is most appropriate.

- ***We are assuming that there is a margin of error in the analysis and that this is an adaptive management process which will be updated in the future when more information is available. We also recognize in the recommendations for future work that global climate modeling can be used to look at effects of climate in the future.***

P. 79; The sensitivity analysis is a good scientific tool for examining possible scenarios.

- ***We concur. Thank you for the acknowledgment.***

P. 81-84, Table 13 and Figures 22 to 24; The various pumping scenarios and how the various runs do or do not meet Task 1 flow recommendations are logically presented. Figure 24 is particularly informative as it shows how the operating criteria would influence flow statistics.

- ***We concur. Thank you for the acknowledgment.***

P. 85; The recommendations would reduce pumping only during Stage I. It is unfortunate that changes in other stages could not be evaluated due to lack of time, though this is understandable given the manner in which Task 2 was conducted. We agree that additional evaluations are needed, especially for Stages II and III.

- ***We agree that additional evaluation needs to be done.***

P. 89; These "real time" operational issues should be addressed in the next phase. These operational issues however, are valid and we agree with the Subcommitte's assessment. We assume that real time operational issues will be addressed including possible adjustment by forecasting, water year, and season.

- ***We agree as we mentioned in the recommendations that the management module needs to be refined to better represent the aquifer management especially at the large potential cutbacks.***

P. 89, last paragraph; Comments about the need to understand the effects of rapid flow fluctuations may be warranted as all of the endangered species appear to have an affinity for stable conditions of a spring flow environment. It would seem that Texas wild rice is the species that would benefit most from specific studies of the effects of higher than average flows.

- ***We concur that Texas wild rice would benefit from studies of the effects of higher than average flows.***

P. 90; Further studies; computer models all have limits and the current analysis is no exception. There are many unknowns in how this system really works and how pumping at various levels from a variety of locations really affects spring flow. In fact, the relationship between groundwater level, pumping, and spring flow likely exhibit naturally dynamic characteristics associated with a variety of factors that are beyond the ability of managers to accurately measure. That said, most of the additional studies mentioned in this section are all appropriate and would help develop a better understanding of how to manage pumping processes over time. These recommendations are well thought out and appear to be consistent with modern scientific opinion regarding the use of modeling in water planning and management as is discussed by the National Research Council (2008).

Specific recommendations for the next generation of water quality and physical habitat modeling and guidance for addressing seasonal and inter-annual variability through improvements in modeling and time series analyses are outlined in our review of the Hardy 2009 report. The continued integration of these modeling efforts as improved by ongoing and future monitoring would provide a firm foundation for producing conservation plans in support of the Endangered Species Act. Depending on how these studies are conducted and the legal and institutional constructs within which they occur, we perceive a very good opportunity to refine flow regime recommendations using a scientifically based adaptive management approach. We acknowledge that this kind of approach is probably not yet in place, but we suggest that such a program, if properly designed and implemented, could be effective.

- ***We concur.***

P 94; There appears to be a critical shortcoming between how the water consumption licences are administered and what it means to flows in the system. The recommendation that ". . . .*the Edwards Aquifer Authority . . . consider modification of its rules to provide for more immediate responses to critical period management triggers."* is reasonable and needed.

- ***We concur.***

Appendix G.

The utility of the graphs of scenario runs would be greatly improved by plotting a reference condition (for example Run 2) with each run. This would provide a direct comparison of the magnitude and pattern of change each scenario relative to a common base line.

- ***We don't feel that there is a consensus reference case to show on the plots.***