PEER REVIEW OF THE EDWARDS AQUIFER RECOVERY IMPLEMENTATION PROGRAM'S SCIENCE SUBCOMMITTEE RECOMMENDATIONS AND THE HARDY STUDY

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Executive Summary

Review team comments were based on ecological principles advocated by the Instream Flow Council (IFC) that rivers are characterized by the unique combination of hydrology, geomorphology, biology, water quality, and connectivity components and processes (Annear et al. 2004 and Locke et al. 2008). The overall approach, analyses and conclusions contained in both reports took great strides to begin to address these elements.

The Subcommittee was given a difficult and complex assignment and did a thorough job of data assimilation, analysis, evaluation, and recommendation development using widely accepted scientific methods. The "j charges" report clearly addresses the two tasks the Subcommittee was asked to perform. The flow recommendations are based on the best available science and are presented in a form that is widely used within the scientific and water management community. The general approach taken for arriving at recommendations (i.e. consideration of monitoring data, model output, hydrologic records, and professional judgement) is acceptable and exemplifies the proper way to approach such a complex study. The review team recommends that further investigation into seasonal needs of the listed species and their life stages be carried out with a focus on future management actions related to preserving, or restoring seasonal and water year variability.

Given the recommendations from Task 1, Task 2 was accomplished in a logical and thorough manner using an approach that is both scientifically valid and defensible. The options considered a broad range of water use and management scenarios. Results provide guidance for meeting the flow levels and stages recommended in Task 1. The review team supports the flow and stage triggers as described in this report and recommends they be implemented on an interim basis pending future model improvement and ongoing research.

Overarching Comments

Report Strengths

Overall these two reports represent a relatively sophisticated approach to dealing with a complex and contentious situation that exceeds the level of analysis and consideration of the majority of similar studies in North America today. This is one of the few programs where there is such a strong commitment to the recovery and expansion of endangered species. Though there are additional things that could have been done, we found these reports to be valid, defensible, science-based presentations of what is known regarding the physical habitat-flow relationships of the primary target species (fountain darter, Texas wild rice, Comal Springs riffle beetle) in the San Marcos and Comal Rivers. As such, the reports present a solid basis for describing these aquatic ecosystems and are a valuable contribution to the Science Subcommittee and recovery effort.

The interim recommendations in the reports provide reasonable information to ensure that the species will not become extinct. However, it is the opinion of the review team that they do not provide enough information to ensure full protection and expansion of the species' populations. For example, elements like watershed inputs to surface and ground water quality, as well as recreation contributions to sedimentation, turbidity, physical disturbance, and associated impacts to aquatic vegetation, need additional research leading to management. The information in these reports represents a good starting point from which to design additional studies and analyses to further refine the existing recommendations. Additional study leading to improved triggers and other appropriate management procedures as recommended in the document would resolve more of the uncertainty associated with species recovery and expansion. In the review committee's opinion, this is one of the few studies where there is this level of commitment to management of the long-term survival of the species.

We fully endorse the technical analysis and output of the flow dependent characteristics of physical habitat for target aquatic species within the Comal and San Marcos Rivers. Developing influence diagrams for the three target species provided a valuable tool to understand both intrinsic and extrinsic factors that affect the target species. Providing the historical information along with the updated modeling based on new information (temperature and dissolved oxygen) and physical habitat for Texas wild rice, Comal Springs riffle beetle, and fountain darters, demonstrates improvement to the science. Using group workshops to seek consensus appears to have been an effective strategy and is to be commended. Carrying out model validation to predict locations of animals against observed locations of animals is considered "best practice". The tools and methods of analysis employed, with respect to fish habitat, are appropriately used based on best available information. The modeling was improved by using empirical data such as vegetation distribution based on historical vegetation mapping results. Additionally, considering other factors such as non-native species of plants and animals, parasites, recreation, anthropogenic impacts due to watershed development, and inclusion of genetic analysis where appropriate (e.g., to explain population patterns in riffle beetle), shows a depth of investigation that is not commonly seen in other studies of this type. Recognizing the importance of developing a water management solution that reflects principles of the natural flow paradigm was appropriate; however this goal was only partially addressed by the recommendations.

The review committee finds no serious flaws or errors in the team's methodology, findings, and recommendations. Assumptions of the approach are well documented and are reasonable given today's understanding of aquatic ecosystems. The tools and methods of analysis employed, with respect to habitat modeling, are appropriately used based on best available information. We believe the report addressed the stated goal (focus of the work) and provided information necessary to begin to address targeted elements within the Edwards Aquifer Authority Act.

As noted above, the development of influence diagrams was a good way to recognize the many possible factors and pathways that comprise habitat for and affect the distribution and abundance of the target organisms. The more useful influence diagrams are those that reflect multiple pathways and inter-relationships among the various elements (as opposed to those that reflect independent, direct effects) because they realistically convey the complex interactions of real-world ecological processes. Though the reports do a good job of exploring the relationships between a relatively few selected environmental variables, these diagrams clearly show that recommendations could be improved by considering more factors, and their interactions, than have been addressed to date.

Balancing the needs of a multitude of species-specific requirements is a common issue in making one overall flow regime recommendation. The process undertaken by the team of taking the higher flow requirement for any particular species in each case, and then to assume this requirement would not negatively impact the other species or overall ecosystem integrity is a common approach used in many other studies. Subsequent monitoring to test this assumption is appropriate. These two approaches are consistent with current thinking, understanding of flowing aquatic ecosystems, and ecological theory.

The commitment to monitoring is an excellent approach to ensuring the long-term survival of the endangered species of the Comal and San Marcos springs and associated aquatic communities.

Guidance for the Final Report

There are only so many things that can be included in any study and it is unrealistic to think that this or any study could look at everything. Those involved in these reports recognize that fact either intuitively or explicitly. However there are additional elements that should be addressed and integrated for subsequent analyses.

Additional strength could be provided to support and enhance this study through more direct integration of other elements within the influence diagrams. The influence diagram frameworks need to be further refined and formalized based on the comments and reviews received from experts.

Though species survival and abundance is a function of the interaction of many variables, hydrology drives the system. Conceptually, the prospects for species recovery could be enhanced by more thoroughly integrating recommendations with the major elements that influence flow in the springs. Time series analysis, matching the physical habitat modeling with the hydrologic record and ultimately producing habitat duration curves, would help identify bottlenecks and important thresholds and is standard procedure for physical habitat modeling.

For continuity all analyses should be based on the same underlying description of the system hydrology. How the flow is partitioned among the different springs and routed through the system is not only critical for obtaining realistic representations of the hydrology but is the primary driver of the water quality and physical habitat models.

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.

The ten additional research needs identified on page 90 of the "j charges" report are appropriate. Inclusion of this information and complete hydrologic analysis are features we look for in any significant flow-oriented study to provide all study teams with a common fundamental basis for their work. We found the level of hydrologic analysis lacking in both the Hardy report in which we find no mention of hydrology as well as the "j charges" report where consideration of natural vs. historic vs. existing hydrologic processes were not addressed as directly as they could have been considering that hydrologic alteration is one of the key factors that is involved with the status of the target species. The various computer runs in the appendix of the "j charges" report were good but the team felt more could have been gleaned from the analysis by at least contrasting each run with run #2 for each system (no pumping).

The review team was unclear what additional studies are to be included in this process, but note several places in the "j charges" report that led us to believe additional work was under way to further refine the recommendations in this report. For example page 63, paragraph 3, last sentence speaks of additional work to refine existing models and obtain more accurate estimates of flow needs. The section titled *Further Studies* on page 66 led us to believe that additional effort was underway or imminent to address the call for additional understanding outlined in that report and modify the recommendations in the "j charges" report. It is unclear how much of this work could be done by what we inferred was a final report, if indeed an additional formal report is part of this process. Attention to the Subcommittee's recommendations noted above provides a critical basis for all future work; providing an accepted, common hydrologic database. This common database should be completed for the existing gages and for all points of ecological interest using an appropriate water routing model to":

- Examine intra-annual flow variability. Each water year class hydrologic data should be partitioned to further define the range of variability by month or season and,
- Stratify the hydrologic record by water year (e.g. dry, normal, and wet) as a basis for future collaborative management of the resource where all parties involved in managing water and wildlife resources work together better. Each water year should subsequently be assigned to one of these classes of water availability.

Once the hydrology time series is completed, this becomes the primary input to conduct water quality (including temperature) and physical habitat modeling through time and space. Thermal criteria should be used to develop seasonal flow criteria. Physical habitat analyses start with the need for converting hydrologic time series data to habitat time series and the presentation of habitat duration plots representing the total system as well as specific reaches. In Figure 45 of the technical assessment report by Hardy, the flow/habitat relation is curvilinear. Typical for this kind of relation any time series analyses and duration plots for system hydrology and physical habitat would be quite different. In these cases (really all cases) it is important to translate the hydrology time series into physical habitat time series and subsequent summations and duration plots. When searching for potentially limiting habitat events this conversion is necessary.

Figure 46 of Hardy (2009) is an excellent way of presenting model results with actual field observations and should become standard practice in complex systems with high water use and where maintenance or recovery of aquatic species is the goal. With system wide analyses driven by time series, illustrations of the distribution of highly suitable physical habitats by season and year can be produced. With this information the investigating team can start teasing out potential limiting events (and duration) that influence species' life stage development and population response. Once these life stages and the timing and duration of limiting events are understood management schemes can focus on control of water diversions and pumping to maintain areas and timing of highly suitable physical habitat conditions at appropriate seasons and places (even improving the extent and duration of suitable conditions if recovery or restoration is the goal).

Excellent first steps are presented in this report illustrating model use. Following suitable physical habitat time series study and identification of potential limiting events the most appropriate comparison of field observations on species distribution would be with those simulated conditions and areas shown to be most favourable during critical life stage events. For wild rice, good correlations with actual field observed distributions would be very unlikely at the discharge and quality conditions found at the time of field observation. Rather it is likely that past events and duration have greater influence on the observed distribution. One would expect a much greater correspondence with areas experiencing repeated and sustained highly suitable conditions. This can only be illustrated via time series simulations.

As noted throughout the report, expansion of life history information would benefit the understanding of flow requirements. Integrating existing knowledge of the timing of life history events, particularly for the fountain darter and Texas wild rice, with hydrologic and habitat time series would lead to better understanding of these endangered species' flow needs and seasonally appropriate decision making. Differences between "old HSC" and "new HSC" curves are quite dramatic and illustrate the significant changes in suitable physical habitat area that may occur between 40 cfs and 150 cfs. To maintain or enhance conditions for the darter populations through time series analyses of past habitat conditions the analyst can determine **when** (seasons and years) and **where** (reaches having highly suitable as well as stable conditions with longer duration at critical times) physical habitat conditions occurred that had the potential for supporting healthy populations. From a management perspective the important question often becomes: "can those conditions be maintained or even improved with similar timing and distributions in the future?" The converse is equally true for identifying conditions of most unsuitable physical habitat conditions. Can the timing and duration of unsuitable events be reduced? Fine tuning HSC curves to these species' distribution plots is the preferred way for calibrating and verifying suitable physical habitat mode output.

The report goes to considerable detail to calibrate and verify the water quality model. This is laudable and represents standard practice in this discipline. However, similar verification for the hydrodynamic modeling is not given. Verification is essential as the velocity distribution predictions are critical inputs to the physical habitat simulations. Proper calibration and verification must be standard practice for stream physical habitat analyses. See National Research Council (2008) for a thorough discussion of formulating and applying models in ecosystem management.

As the influence diagrams clearly indicate, the abundance and distribution of organisms are driven by the interaction of a large suite of factors. Though scientists strive to define these inter-relationships, the fact is that there are no widely accepted models today that are capable of integrating more than a limited number of variables into a single model. In recent years, however, there has been some effort devoted to performing Bayesian Probability Assessments that are structured somewhat like the influence diagrams shown in Hardy's 2009 report. Though such models can require very large data sets, they can also be performed on a conceptual basis relying on consensus-developed assumptions (probabilities) about relationships between and among identified environmental elements. Conducting Bayesian analysis with consensus-developed probabilities is essentially a formalized approach of using professional judgment to make decisions about how systems operate.

Regardless of the specific method(s) used, professional judgment is the fundamental basis for all modeling and is necessary to integrate information across a variety of disciplines that is derived from models. Even a formal acknowledgment of the absence of data, when accompanied by reasonable assumptions, will advance understanding and serve as the basis for refinement of ecosystem needs. This kind of integration requires open communication across disciplines, which appears to be well established with the EARIP.

It appears that the hydrology analyses driving the Physical Habitat and Water Quality modeling as well as the Hydrology analyses central to the Expert Science Subcommitee for the Edwards Aquifer Recovery Implementation Program were developed separately. Because each discipline tends to work independently, the notion of being forced to agree on a common description and model representation of the system hydrology before the different analytical analyses are conducted, remains a central issue for more holistic views of river systems. Programs where there is a lack of a common description of the hydrology through time and space become the primary excuse for not conducting time series analyses of water quality and physical habitat followed by the identification of potential bottlenecks to species' life stage development and population viability. This is unfortunate because these types of analyses of spatial distribution and timing can provide a basis for identifying critical limiting events as constraints to healthy life stage development for aquatic species.

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. 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. Again, hydrologic time series analysis and full characterization described above is a fundamental step towards time-sensitive forecasting and proactive water management of this system.

Future Work and Synthesis

A positive indication from the reports is that the Edwards Aquifer Recovery Implementation Program committed to continued monitoring, data collection, and modeling to advance understanding for planning and management of the system. This suggests movement toward Adaptive Management, which is critical for a system of this complexity. We are unsure how much additional work can be conducted prior to a final report, if such subsequent document is underway or planned, and recommendations and whether some of the recommendations we feel need to be addressed can actually be incorporated. However, to the extent that additional work is possible we offer the following discussion and suggestions:

- Global climate models provide an indication of the magnitude of change for each group of hydrologic descriptors (magnitude, duration, frequency, timing, and rate of change) and can provide the basis for sensitivity analysis and refinement of water management decision making. The hydrologic time series analysis suggested above provides the foundation for incorporating climate change information with appropriate sensitivity analysis into management models; where expected changes to each water year type are characterized and used to indicate the range of conditions that may be faced.

- The legal and institutional mandate of the Edwards Aquifer Authority provides a clear legal and institutional basis for additional studies that appear to allow for changes to the water management plan, *"if it is later revealed that significant impacts are not captured in the model results. . ."* When coupled with additional water quality and physical habitat data, future system modeling efforts can provide valuable support for an adaptive management approach. Important first steps toward a viable Adaptive Management Program are presented in both the "Hardy" and the "j charges" reports. As long as the stakeholders and management agree to periodic (2-5 year) updates of the data bases along with repeated model runs, the program should reach a common understanding of limiting conditions and consensus on what would be necessary to protect or even enhance system conditions allowing recovery of the target endangered species. However, agreeing on actual implementation measures to achieve protection or recovery may be practically difficult or politically unacceptable.

- Monitoring and the means to adapt the future findings are appropriate and critical to meeting the overall goal of this effort. We emphasize that good science can lead to common understanding and agreement on the conditions that are controlling the biological response of species and populations of concern. Disagreements may well arise over management measures and the political will to implement control over water use. An adaptive management program, of which monitoring is a critical piece, should move away from disagreements over the science and help focus discussion toward understanding potentials for protection by preventing further degradation (or even enhancing) by addressing the limiting system conditions found to be critical for maintaining viable species populations.

- One potential stressor on endangered species that should be addressed is the spread of aquatic invasives, such as zebra mussels.

Peer Review Team Comments For: Technical Assessments in Support of the Edwards Aquifer Science Committee "j Charge" Flow Regime Evaluation for the Comal and San Marcos River Systems. (Hardy Report)

Influence Diagrams for Target Species

P. 4; The Subcommittee is to be commended for conducting a series of workshops involving a multidisciplinary team of biologists to develop influence diagrams. We also commend the Subcommittee for keeping a meticulous record of the conversations. One of the most overlooked tasks in carrying out these types of studies is to "document your logic". This step was critical for identifying the key issues and the creation of influence diagrams was effective for displaying the complexity of all factors and how existing knowledge could help guide them in the modeling.

P. 4 -13; A recurring comment applicable to all species regarding the diagrams is the importance of "connectivity". Fragmentation of river systems and the resultant loss of genetic diversity and increased potential for extinction is a well recognized aspect of meta-population ecology and research. These systems are physically and thermally fragmented and physical barriers are plotted in the diagrams as a part of the "big picture" for each species except fountain darters. References here and elsewhere to "connectivity" are unclear as to which of the 4 aspects is involved (longitudinal, lateral, vertical or temporal). This issue may be dealt with in future studies but it would be helpful to discuss the applicability of each of these aspects. Figure 8 and the few other references we found in the report discuss connectivity primarily as it relates to dispersal of the organism of interest; but it would be good to relate the role of connectivity to other important environmental variables such as (seasonal) thermal barriers, sediment import/export, nutrients, and energetic materials.

P. 8, Figure 6; This is a good illustration of the relationships affecting water quantity and quality that is applicable for all species and an important determinant for these systems.

P. 11, Figure 10 (and others); Channelization and urban encroachment are also influencing factors that should be included.

P. 11; A better understanding of the overall habitat processes could be achieved by providing more information as to why or how flooding and drought are considered. Depending on the situation, these hydrologic processes can have both positive and negative influences. Per the natural flow paradigm, intra- and inter-annual flow variability are key drivers for most organisms and their habitat.

P. 14; It is noted that a flood in 1998 altered the channel geometry and greatly affected the vegetation of the San Marcos River. Analysis of subsequent cross sectional data was judged that "the channel changes could potentially impact modeling results enough to warrant remapping of channel topographies". Later in the report analyses illustrate a scale change in the flow/physical habitat relations but little change in the overall shape of the relation. However, the scale is very important when conducting time series analyses. As the program progresses it would be important to periodically update the data base by resurveying the topography when significant channel change has occurred. As a way of determining when significant channel change is evident we recommend that the river be geomorphically stratified and permanently monumented cross sections be established and periodically surveyed within each strata.

Remapping the distribution of vegetation over time is likewise important. As the time series is put together, the different channel topographies and vegetation distributions would be entered into the data base at appropriate intervals to represent the channel for specific time periods in the series.

P 17; Most 2-dimensional models do a reasonably good job of simulating velocities under the range of flow conditions noted but one important component that should be addressed is how they model edge effects. Because many species are associated with the edge of rivers, an accounting should be provided for how the RMA2 model deals with edge effects. This is another reason the review team emphasizes the need to calibrate and verify velocity distributions using empirical data.

P. 18; It is not clear how the partitioning among springs from Brune (1981) compare with the hydrology analyses discussed in this report. It is very important that the same description of the system hydrology, including partitioning among spring flows and routing water through the system, be used for all water quality and physical habitat analyses as the WUA results and conclusions are based on this assumption.

P. 23; Each vegetation species was assigned a unique hydraulic roughness except Texas wild rice, for valid reasons. Recognizing the sensitivity of Texas wild rice to velocity, it is important that these data be estimated based on at least some empirical data over a range of flows and seasons to verify modeled velocity distributions.

P. 25; 1st paragraph; The resultant velocities from the 2-D model are still modeled values, not "actual values," whether they are adjusted by the velocity ratio or not, emphasizing again the need for verification of velocity predictions.

Water Quality and Temperature Modeling

P. 25; The modeling exercise using maximum dissolved oxygen values would likely have been more meaningful had minimum or daily average values been used. Also, since an optimum temperature range was defined for fountain darters, it would appear that modeling diel temperature values might also be insightful, especially if seasonal analysis were to be undertaken.

P. 29; The basis for the assumption at the bottom of Table 6 about the level of spring flow in the upper portion of Landa Lake is unclear. This reinforces the need for a common descriptor of how water is routed through the system.

P. 30; Dissolved oxygen levels are typically lowest just before daylight as a function of extended respiration of aquatic plants and periphyton over night. The influence of other limiting factors such as BOD would be reflected then too so it would not be necessary to factor out specific causes of low DO. It is not necessary to track diel DO levels but if the study only focuses on one time of day it should be tied to daybreak, which at least in theory could be a potential bottleneck. The report does not say what time of day DO relates to, which raises some question about whether the number presented is truly a limiting factor.

P. 30; Given the urban setting and relative lack of apparent riparia to absorb runoff contaminants, dissolved oxygen modeling should be performed with the effect of ammonia, nitrate oxidation, sediment oxygen demand, phytoplanktonic algae/macrophytes, and associated respiration, growth, nutrient effects, and BOD. This lack represents a key area of future integration tying the watershed, water quality, and usable habitat of the endangered species.

P. 30-31; The presentation of calibration and verification data for the water quality modeling as illustrated in Fig.23 represents the long established practice among water quality experts. This must also be included for the hydrodynamic (hydraulics) models. Also noted here is reference to modeling DO. Later in the report emphasis is placed on needing to know if DO depletions may occur during the night time. These water quality models are useful for such analyses of diel predictions by season and climatic condition.

P. 31; Inclusion of twenty one segments of 100 feet in length, each similar reaches is an example of strong technical work.

Habitat Suitability Curves

P. 35; This paragraph represents a strength of this work and approach: the scientific community were apparently actively engaged in the collection or review of the information used. The HSC for wild rice were based on work by Saunders et al. (2001); Hardy et al. (1998) established the basic sampling protocols for HSC for fountain darters; there was additional data available on vegetation use (by darters) but not useable because of vagaries in vegetation coding schemes. According to the report, this issue is being addressed through ongoing vegetation mapping that will allow incorporation of the long-term data for fountain darter vegetation suitability curves. In addition, the annual monitoring data collaboratively collected by TPWD and USFWS for Texas wild rice (TWR) were used to evaluate the existing TWR HSC and based on that review, were not modified.

P. 35; Here and other places in the report identify the importance of aquatic vegetation as habitat features for darters. Habitat modeling for these vegetation types should also be continued for future analyses.

P. 36; Normalizing the HSC curves, and resultant habitat versus flow curves is a very common and accepted practice. The amount of data considered is comprehensive relative to many similar types of studies. The combination of modeling data with empirical data which is then thoroughly discussed with all stakeholders represents an excellent way to develop HSC curves.

P. 36, 37; From the report: this beetle occurs in gravel substrate and shallow riffles in spring runs and upwelling spring orifices. They may, like many Elmid species, require 6 months to 3 years to complete a life cycle, and usable water depth is 1 to 4 inches. These life history pieces, along with the 1950's drought experience, suggest that the species can survive low flow conditions, but also may be susceptible to water quality changes (contaminants) or sediment influxes. The final paragraph on this page, discussing decreased genetic variability as strong evidence for isolation coincides with meta-population ecology and, again, points to the importance of additional emphasis to address connectivity in this system (from watershed to groundwater recharge and surface water runoff to spring to channel and downstream). The rationale for depths, given what little is known, is logical and acceptable. All of this argues for additional, basic research into the life history and habitat requirements of this species.

P. 37, top 2 paragraphs; If flowing water is important for survival of beetles, clarification is needed to explain why velocity (even if described by a binary function) was not also used for habitat modeling.

P. 37, 4th paragraph; If sufficient information been gathered over the years to develop a relationship between Texas wild rice presence or abundance and turbidity it should be incorporated into the habitat modeling analysis for wild rice. Nutrient availability is known to be an important factor in growth for other species of wild rice. The importance of this factor for Texas wild rice should be studied for use in future decision making.

P. 37; It is admittedly a challenge to determine the relative efficacy of the two sets of suitability curves presented here, but it seems the USFWS-USU curves may do a more conservative job of reflecting flow needs for this species. The TPW curves give the appearance of being more precise however it is unclear what the various HSC steps are based on other than perhaps an effort to narrow the range of suitable flows (for depth) or give more weight to lower flows (based on velocities). However verification of model outputs with actual stands of wild rice will determine the appropriate HSC for this species (see Figure 45).

Current understanding clearly suggests that protecting this species should also address turbidity in a quantitative manner. Criteria of some sort are needed to manage flow, recreational activities, or runoff in the watershed to maintain turbidity below some defined level. Development of these criteria will require additional studies to establish the relationship(s) between these variables.

Also, as noted above, there is no recognition of the need for different flows at different times of year for different life history needs. The relative merit of extremely high flows could possibly be deduced by an explanation of re-colonization processes following the 1989 flood. Delineation of water year strata as recommended by the review team for full description of the hydrology, coupled with life cycle periodicity of Texas wild rice would provide information on the intra- and inter-annual habitat requirements for recovery of this species.

P. 39, Figure 27; The extension of optimum water velocity (SI = 1.0) leftward to 0.25 ft/s does not seem to be supported by the 1996 and 1933 observations discussed in the text. Further explanation for this curve modification is needed.

P. 40 -43; The science utilized for HSC modeling of this species is thorough. This species appears to prefer medium to shallow pool depths and we would expect to see a relationship that favors relatively low discharge as affecting depths and velocities. In fact it seems that fountain darter habitat is affected primarily by low flow effects on temperature or on vegetation, which the analysis picks up. Technical team multivariate analysis of habitat associations with depth, velocity, vegetation type, and height of vegetation (likely surrogates for cover) confirm the direction of the analysis, and illustrate the advisability of revised modeling. This section does make the point that this species may spawn at all times of year but it is unclear if flow needs for various life stages vary during the year or if spawning is more prevalent at some times of year or seasons, or is keyed to flow pulses of some sort.

P. 42, Figure 29; This figure does not indicate whether this HSC curve is for mean velocity or velocity near stream bed. Since both were used in the analysis, they should both be shown.

Physical Habitat Modeling

P. 44; The assumption that vegetation/substrate characteristics did not change as a function of flow rate seems counter to the analysis. We know the bed changed, e.g, after floods and upstream watershed activity. The 'dam removed' option at Cape's Dam showed as much. For the case of the TWR, the point is made that low and high flows are associated with disturbance, either from recreation or the flood flows and sediment scour. With the extensive data monitoring that is currently being done on TWR beds, it would seem data could be collected to reflect the situation better. See comments under P. 14 above.

P. 44; Assigning vegetation type and associated roughness values to each node is acceptable and an appropriate way to assess habitat suitability at nodes.

Physical Habitat Modeling

P. 45; There is apparently a typo for the binary equation used for this macroinvertebrate. According to P. 37, second paragraph, beetles used water greater than 0.02 ft not less than.

Modeling Results and Discussion

P. 46, 47, 48; The report provides no guidance or goal for how much of this segment should be protected. If the goal is to keep temperatures below critical levels over just half the area, then 50 cfs may meet that standard. However, if the goal is to identify the flow that will keep temperatures below critical levels at all times and throughout the entire segment, then a higher flow would seem more appropriate. From previous pages, 78 degrees represents approximately the 0.5 suitability point, and 80 degrees the 0.2 suitability point. Given that almost a mile of stream is brought to 78 degrees or 0.5 suitability at a flow rate of 100 cfs, it appears that this is the point at which degradation becomes significant rather than 60 or 30 cfs.

The statement on P. 47 regarding water temperatures for the main stem is more clear: "*A general warming trend is noticeable for all flow rates but its magnitude is minimized at larger total flow rates of 150 to 300 cfs.*" According to Figure 33, "minimized" means over a mile of stream – the approximate length that is 78 degrees or slightly above at 150 cfs total flow rate. The report notes the large number of control structures and their influence on water temperature – an important point related to overall system connectivity. The review team feels that this information may not have been given sufficient consideration in the "j charges" report, and should be.

Additionally, if water temperature varies seasonally, the influence of such variations on physical habitat quality and availability should be included. For example the higher temperatures predicted for most flows in Landa Lake would negatively impact reproduction of fountain darters. Previous comments were made that this species has been found to reproduce at all times of year. Considering that highest temperatures such as those modeled here only occur during late summer or early fall, it would be helpful to know the proportion of contribution to the population that might be affected by reducing seasonal recruitment. Detailed time series analysis and knowledge of variation in recruitment would quantify potential impacts.

P. 48, 49, 50; Diel fluctuations in DO would be expected and it is good to see the reference to unpublished data from vegetation beds in Landa Lake and discussion, albeit brief, of potential effects of BOD and respiration. Plants typically respire at a fairly constant rate however they only produce oxygen when stimulated by daylight. So it is logical that evidence of high production of DO during the day would be countered by high respiration at night. Decay of plant material is a secondary means of oxygen depletion but certainly not the only one. Additional DO data that reflect concentrations at their lowest level (at sunrise) would seem appropriate to include in the model, especially in consideration of the unpublished data referenced here. The opinion that DO doesn't appear limiting (so was not used in the analysis) is probably reasonable for present conditions but additional analysis may show otherwise for low flows and is needed to resolve this uncertainty.

It is unclear what concentrations of DO would be limiting, but some standard should be identified and further explored. These effects would be greatest in heavily vegetated pools and less of an issue in flowing portions where reaeration occurs. It is likely this pattern would change throughout the year.

The role of control structures on maintaining DO through reaeration seems apparent. If system connectivity issues are addressed through channel restoration, these reaeration benefits must be kept in mind (e.g., through incorporation of built 'natural riffle' structures).

P. 50-52; The additional simulation runs based on criteria developed from collection data on riffle beetles in the main spring is a good follow-up idea. The sampling design employed is robust. The results reinforce the conclusions that the greatest rate of habitat decline is around 100-150 cfs. Discussion dealing with the question of 'why are the beetles still here if they are so affected by low flows, and what do the results indicate (directionally)," is comprehensive and direct. There are two approaches discussed. One is a flow versus wetted surface area; the other is based on criteria developed from data in the main spring runs as an alternative to the surface area analysis. The review team could not determine which approach carried more weight in this analysis.

P. 52-59; Fountain darter habitat is strongly constrained by temperature not physical habitat; highest WUA under the modeling for max daily temps in Comal River occurred at a flow of 150 cfs. Revised HSC increased the amount of WUA realized over the Bartsch et al. HSC (Table 11). The discussion of caveats relative to the modeled split flows (into the old channel and new channel) and results and updated modeling currently underway, was confusing. If the channel changes that were not reflected in the current analysis include topography and vegetation (caveat 1) and they show a strong physical habitat association with flow and darter habitat as well, the statement that thermal effects are more limiting than the amount of physical habitat will have to be withdrawn. If the use of a spring orifice temperature as a boundary condition (caveat 2) is important, would it affect the conclusion(s) as well?

One statement indicates that this thermal effect results in potentially reduced larval survival. Here is one of the few times the report emphasizes life stage events. As the program matures, such attention to the timing and duration of potentially limiting life stage events on species of interest should become routine practice. Time series of maximum daily water temperature distributions through the system by season (under simulated ambient air conditions representing hot, normal, and cool years) would be most informative.

P. 60 and 61; Figure 43 does not highlight habitat relations for darters between reaches.

P. 62; There is agreement with the concern for potential depressed DO levels during night time respiration at low flows, in highly vegetated areas, likely at high temperatures, (typical of drought time). This is a very reasonable recommendation given that systems that have abundant vegetation experience large diel fluctuations in DO as the daytime water temperature approaches that of the air temperature. It should be addressed in on-going modeling efforts.

Texas wild rice habitat shows a consistent upward trend with increasing discharge, except in areas with backwater affects and other velocity limitations. The report does a good job of walking through the data results, step by step. The note under State Hatchery A, concerning flow rates near the historic mean having velocities still in range for wild rice are an argument for their existence and persistence there. The summary for this section is clear and reasonable.

P. 63; Texas wild rice in Spring Lake clearly has declined since original accounts which suggests that it may be more limited by factors such as water quality than quantity. It seems apparent that something has changed. If the management goal is to do more than just protect remaining stocks of organisms (e.g. to actually restore or increase stocks to some established level), then it seems that more effort is needed to understand why this shift in abundance has occurred.

P. 65; The absence of this endangered species from a particular section may not be reason to omit that section from consideration or study. If restoration of habitat and populations is a goal of this study, additional studies may be needed to better understand why this species is no longer in its historic range and then take steps to correct that problem. If however, the river is so constrained by factors such as urbanization and flow depletion that simply cannot be altered, then it would be important to acknowledge such constraints.

P. 66; From the discussion it appears the argument is made that below 30 cfs Texas wild rice is associated with modeled suitabilities below 0.5; and above 65 cfs, Texas wild rice occupied cells with suitabilities greater than 0.50. It is stated, *"This appears to be a systematic bias in the modeling results at lower flows that should be examined in more detail . . ."* The review team agrees, it would be highly recommended to invest more effort to understand why this occurs. The review team agrees with the last sentence that the number of simulated flows should be increased to enhance resolution of flow-habitat relationships.

P. 67-68; Figures 45 and 46 are useful to illustrate the value of physical habitat modeling through time and space. See our comments above at the bottom of page 5 and top of page 6 on these figures and the role of time series analyses.

P. 68, Figure 46; The scale of the figure is such that it is difficult to see if the red dot occupies a low or high suitability cell. A statistical analysis of presence/absence would improve verification.

P. 70; The summary comments are reasonable, however, the review team agrees there should be more simulations to refine the curve in the lower flow range. More mention of some seasonally adjusted flow recommendations vs. a single number for this and other species would be helpful. One other factor that is not addressed (and causes all such studies some difficulty) is the matter of understanding whether less high quality habitat has the same value and more lower quality habitat (since each condition can in theory generate an identical WUA score). This phenomenon could explain some of the reason why rice is found where it is in Figure 46.

P. 71-75; Use of the MODFLOW-NR for Task 2 is state-of-the-art for groundwater modeling. As a finite-difference model, the grid node points and boundary conditions are of key interest relative to the strength of the data being used to specify values of transmissivity and storativity. Specifying the boundary conditions, whether of known head or flux, is mandatory for solving the groundwater-flow equation(s). In some cases, the boundary conditions will be mixed, with some portions of the aquifer having known head and some portions having known flux. GIS layers can be used to specify cell parameters, layers (e.g., conductivity at depth). These conditions may vary over time as well, as a function of aquifer stage and the specifics of conduits to and from other formations, requiring (or allowing for) even more layers, cells, and cell parameters. This can become exceedingly complex, in reality, and to model. And, even when current computing can handle it, *the question is: has the complexity increased the level of groundwater understanding?* (see Bredehoeft, J. 2010. Models and Model Analysis. Ground Water 48(3):328). Good decisions are based on complete understanding – of what we know, and just as importantly, what we don't.

For these reasons, additional information specifying the uncertainty surrounding the estimates of springs flows from the aquifer modeling effort is an important area of further disclosure. Because the spring flows are an expression of the state of the aquifer, a thorough description of baseline hydrology is imperative. Full characterization of the system hydrology: past, present, and potential, including all elements of characterization: magnitude, duration, frequency, timing, and rate of change would improve the report and ultimate acceptance of management prescriptions derived from it. Confronting the degree that these elements have been altered, as well as the likely watershed changes (e.g., trends in population growth, i.e. impervious cover has been correlated to population size/density), effects on aquifer recharge rate and other hydrologic effects (e.g., climate change) that will influence the hydrology further are important areas of further discovery and delivery.

P. 74-76; The use of empirical data to confirm the predictive modeling outputs is excellent. However, the team was not completely clear on why the two analyses were not combined or only one was presented. Along with the results from the Bartsch et al. (2000) simulations, the updated simulation results are also being presented and include the updated HSC and channel topography changes but are caveated by noting that they rely on original temperature simulation results. This issue is addressed in a subsequent section – top of page 83, which firmly establishes that, based on both these simulations, HSC and channel changes can shift the relationship of habitat to flow. While providing both simulations and analysis could be viewed as an example of thoroughness, since this is a basic premise of physical habitat modeling, it also may be considered extraneous and is certainly confusing, if only momentarily.

Table 14 shows that total WUA declines slightly from 135 to 170 cfs. However this is due to a trend in 6 of the 8 sites, which make up less than 32% of the total WUA. According to Table 14, two sites, Spring Lake and Rio Vista, comprise 69% of the total WUA at 135cfs and 70% of the total WUA at 170 cfs. The importance of these two sites for fountain darter habitat is not clear in the text, which would seem to contradict the numbers in Table 14.

The results for Mill Race section and discussion are insightful and bring up an interesting issue: the hydrilla which predominates vegetation at this site is non-native, but a preferred vegetation type for native fountain darters (suitability 0.6, tied for 9th place in a list of 22 species, see Figure 30). Inferring from the influence diagrams (Figure 8 – TWR; Figures 9, 10, 12, FD), invasive plants may negatively impact Texas wild rice (hence the call for plant restoration), but be benign or even beneficial to the Fountain Darters. The principles guiding management of this situation are complex but extremely important, in light of the charge to protect the system.

P. 78, Figure 51; It is not clear why the No Dam alternative was so low, in terms of WUA, especially given the prevalence of backwater effects decreasing available habitat in all the other applicable sections. Interpretations and data presentation appear acceptable. Providing increased resolution in modeling between 35 and 100 cfs is an excellent suggestion.

P. 82, Figure 55; See our comments at the bottom of page 6 and top of page 7 regarding the differences between "old HSC" and "new HSC". Overall this is a good section that further establishes the 65 cfs cutoff.

Other Native Aquatic Species

P. 83, 84; The text provided is useful background when enough is known about the species to draw firm conclusions. For many of the species covered, this was not the case. Exceptions included the Texas blind salamanders, which even though subterranean, are dependent on watershed-level protection of the ground water, particularly in terms of contaminants.

P. 83 – 84; If predictive models are not developed for spring-dwelling species then, the assumption that maintaining flow regimes for surface dwelling species likewise protects spring dwelling species appears reasonable. However, it appears San Marcos salamanders would be affected by any watershed land or water use that increases fine sediment loading, not just recreation. The proposed monitoring should test this assumption.

Non-native Species

P. 84-87; This is a good, albeit light, discussion of non-native species and potential impacts on native flora and fauna. Collectively, inclusion of this section is a powerful argument for maintaining a natural regime; many of the non-native species thrive in low flow conditions, or concentrated impacts occur under low flows (e.g., competition, predation). Active vegetation management, formally managing for inter-annual hydrologic variability, and restoring system connectivity may well be the best long-term approaches to managing the suite of invasives already present to levels that do not exacerbate negative interactions with the native species. The number and breadth of introduced/exotic species already in these systems (7 introduced/exotic, 18 native in Comal River; 9 introduced/exotic, 19 native in Sam Marcos River), represent an ominous threat to the remaining biota if a 'perfect storm' of degrading spring conditions is allowed to occur. Ground water contamination from within the watershed, sediment- or contaminant-laden runoff, drought and hot weather, excessive pumping, and unmanaged low-flow recreation represent a few of the potential "storm elements" that should be considered when managing the system and 'buffering' for the unforeseen.

Recreation

P. 88; This section is well-grounded and raises a couple of key points. It seems quite likely that human use in and adjacent to the springs and streams is a potentially significant issue that should be dealt with more specifically and managed more directly. Increased human population level is one thing that has definitely changed since 1933 and elicited a variety of changes. Though these are spring systems, the issue of disturbed silt and silt deposition on vegetation suggests that a varied flow regime, to the extent possible, would provide benefits to these systems. This matter also raises again the question of seasonality of impacts. If, for example, fountain darter spawning is more prevalent at a certain time or times of year, then recreation and watershed management could focus on those periods.

P. 89; These recommendations are all pertinent and if followed should lead to improved understanding of system limitations and species distributions and trends over time. This report represents a good beginning for building a collaborative understanding of the ecology of the system.

Peer Review Team Comments For: Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer. ("j Charges" Report)

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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.

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.

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.

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.

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 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.

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.

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.

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.

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.

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".

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

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.

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.

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.

San Marcos Spring Analysis and Assumptions

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

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.

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.

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

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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.

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.

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.

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.

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.

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.

References

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Reviewer Qualifications

Thomas C. 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. He has led 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. 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 serves as team chairman. From 1992 to 1994 he chaired the instream flow technical subcommittee for the Colorado River Endangered Fishes Recovery Program. Mr. Annear is a co-founder 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 the project leader for 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. He has written over 150 scientific reports, numerous publications and popular articles on river management; been an invited speaker at international symposia; and helped address instream flow issues on a variety of projects in the U. S. and Canada. Mr. Annear has a bachelor's degree in fisheries and wildlife management from Iowa State University and a master's degree in aquatic ecology from Utah State University.

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 MN 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 MN 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. Mr. Chisholm earned a B.S. degree in water resources and fisheries science from the University of Wisconsin/Stevens Point (1980) and a M.S. in Zoology (fisheries science) from the University of Wyoming (1985).

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, Allan 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.*

Dr. Thomas A. Wesche has over 35 years experience as an Aquatic Habitat Biologist and Hydrologist. Dr. Wesche has been a leader in the areas of fish habitat evaluation and monitoring, instream flow analysis, habitat improvement, stream, riparian and watershed restoration, and channel maintenance/flushing flow determination. He has authored over 300 professional reports, research papers, and book chapters on these subjects and has designed, implemented and monitored numerous fish habitat restoration programs. Dr. Wesche has served as a technical expert for salmonid habitat assessment and restoration on two large Natural Resource Damage Assessments, the Couer d'Alene River basin of northern Idaho and the Clark Fork River of western Montana. Dr. Wesche also developed and instructed a week-long training course for the Bureau of Land Management National Training Center entitled "Aquatic Habitat Restoration and Enhancement" for a number of years. He currently serves as a member of the San Juan River Recovery Program's Biology Committee and has been active in the Middle Rio Grande Endangered Species Act Collaborative Program for many years. He routinely deals with passage issues for salmonid and non-salmonid fish species, including the design and implementation of bypass channels around major diversion structures. Dr. Wesche is presently involved in the development of the Stream Management Plan for Grand County, Colorado, the development of a site specific selenium standard for a confidential client, the restoration of Flat Creek through Jackson, Wyoming, and the Laramie River Restoration Project through Laramie, Wyoming.

Annear Comments on J Charges report

Over-arching comments

- Influence diagrams are important and show complexity of ecosystems and the limitations of modeling them. There are no existing models that integrate all of these factors. The best way to address influence diagrams is to model those elements for which reasonable models exist and make professional judgments about how the other elements factor in. Even this approach is limited and omits some important factors.
- Review team comments were founded on ecological principles espoused by the IFC that rivers are characterized by the unique combination of hydrology, geomorphology, biology, water quality and connectivity. In general, the "J" charges did address most of these elements, with the exception of connectivity, though they didn't specifically separate them out in this format.
- One important factor that received too little consideration was physical and hydrologic connectivity as related to movement, distribution, and recolonization of species in both systems. The duration, timing and role of connectivity should be considered. Still, this environmental element would likely not change the flow recommendations but might help with management of the springs and streams within the specified flow regimes.
- Recommendations aren't really a flow regime; they're just flow triggers that aren't tied to seasons or address historic intra- and inter-annual flow patterns. Being springs, this pattern is less than a snow-melt driven river (for example) but some acknowledgment of hydrologic pattern and process (even if it's a minimalistic pattern) should probably be considered.
- There is little mention of life history duration. How long does it take each organism to complete its life cycle? How does Texas wild rice expand or become established? How long do fountain darters live (so how often can it skip a period of reproduction)?
- One point worth clarification is that comments about thermal maxima as a function of low flows appear as if they should just relate to the warmest periods in late summer. Thermal criteria should be adjusted seasonally to develop seasonal flow limits in fall, winter, and spring when air temperature is cooler.
- Another point that needs more emphasis is that while the endangered species may have survived the 1950's drought (except fountain darters in Comal Springs), that fact does not suggest that such a low flow could or should be prescribed on a permanent or regular basis. Trained scientists can easily comprehend this fact but casual readers may not intuitively understand that higher flows are needed at most other times in order for species to persist over the long term.
- One of the more important elements that was not studied as it affects any of the endangered species was in-channel recreation. Indeed a defensible argument would appear reasonable to maintain high flows primarily to limit recreation in sensitive areas of both streams.
- One potentially significant oversight in the report is the lack of direction for the frequency and duration of when the average 6 month and minimum monthly flows would be allowed. The authors need to provide more guidance than to say these levels would hopefully only be reached on "rare" occasions. The frequency of these low flow levels needs to be tied in closely with information about life history requirements and cycles of all the endangered species.
- Though some species such as Ramshorn snails do not presently appear to be negatively affecting endangered species or their habitat, the potential certainly exists that such may not always be the case. Monitoring populations of aquatic invasive species alone will not ensure

protection or enhancement of habitat for fountain darters. If these species really do pose a threat they should not only be monitored but strategies and efforts to control their populations should be identified and adopted. This is true for the latest wave of aquatic invasive species such as zebra mussels. In addition to focusing on flow issues, managers should develop and implement protective strategies to prevent introduction of this and other non-native aquatic species immediately.

- In brief, recommendations are based on best available science. There is a relatively high level of professional judgment involved in selecting the precise numbers for each level of protection and it would seem a case could be made for slightly higher or lower numbers by a casual observer. Professional judgment is a valid and often superior scientific tool that can and should be used in situations where detailed models do not provide clear threshold recommendations. Computer models often give the illusion of precision but most address only a limited range of inputs and bear their own degree of error that is often overlooked. Professional judgment in combination with extensive empirical data, used properly, is an appropriate way for senior scientists with many years of experience to consider multiple inputs and formulate comprehensive conclusions and recommendations. While the review team could identify other possible flow levels, the great body of knowledge and study that have been done for this system compels us to defer to the authors of the report. Again, their recommendations are certainly not out of line with the range of possible flows that appear needed to achieve the recovery of these species. I find no fault with the authors' contention that they have used the best available science or that the flows are either inflated or too conservative..
- The hydrology analysis and determination of triggers is valid and defensible although additional study might refine that analysis somewhat. It seems unlikely that triggers and conclusions would change greatly, however, considering the level of pumping that currently occurs and the trend to increase that level as population increases.

P vi, paragraph 2 – The subcommittee chose to address our charges within the context of ***a flow regime*** *for the protection of all listed species as well as the* ***integrity of each ecosystem****. 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. This by definition means that conditions cannot go beyond thresholds necessary for survival of any of the listed species.*

These criteria are appropriate and necessary when dealing with endangered species.

P vii, 1st full paragraph, last sent. - One thing is clear, long-term monitoring is essential and further study and research specifically during critical low-flow periods (or simulated critical low flows) are needed to accurately determine the potential impacts to the species.

Monitoring and the means to adapt to future findings is appropriate and critical to meeting the overall goal of this effort – recovery of the species.

p. viii - We believe further study is needed to (1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on recharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the management module, and (10) refine model calibration between San Marcos and Barton springs.

These recommendations are all appropriate and necessary. Modeling to date has reduced uncertainty but has not eliminated it.

Introduction, Task 1, p. 3 – Flow criteria don't make any distinction to time of year. Are all times of year of equal importance to target species? In most cases different flows at different times of year are appropriate.

P. 4 Interpretation of the task – good to couch study in these 3 terms. Though an ecosystem issue, it's ok to focus on the main driver (hydrology) and also look for flow regime vs. minimum flow.

P. 4 Interpretation of the task, par 1 – it's 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.

P. 4 Interpretation of the task, last par – the list of environmental attributes should also include longitudinal and vertical connectivity. Connectivity can be a key driver in distribution and colonization of species throughout a system and be a driver in the ability to re-populate areas that may have become temporarily unusable causing the temporary loss of individuals.

P. 5 First full paragraph – logic behind various flows needed to ensure recovery of species is sound and appropriate. A single minimum flow rarely maintains any species let alone leads to its recovery or expansion.

Pp 6-10 - This list of monitoring is unique and affords this study with much more information upon which to analyze model outputs and apply professional judgment than exists for the great majority of instream flow studies in the U.S. and other countries.

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 probably 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 may have some sense of a proper range based on professional judgment.

P 12 Professional Judgment – In spite of the critiques directed at professional judgment by some, this tool can be highly effective and should not be minimized in terms of its relevance and accuracy for identifying what's going on in some situations and how organisms respond to particular flows and flow regimes.

P. 13 Flow Regime – 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 can overlook this potential serious bottleneck. Instantaneous flows of prescribed duration would seemingly be a better tool.

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-to-back periods of these conditions but it would be good to clarify what they think allowable limits might be.

The authors' logic about natural precipitation events providing for higher flow pulses may be acceptable however the report might recognize or address the potential for additional water development in the region that might capture additional surface flow – or make recommendations that would limit future developments.

The issue of seasonality should be more specifically addressed – at least acknowledge what natural seasonal variability was prior to development to support the statement that the specified strategy will approximate those conditions.

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 to at least consider.

P. 15 Comal Springs analysis and assumptions – the fact that fountain darters had to be reintroduced here from San Marcos spring clearly indicates that connectivity is perhaps just as important a habitat consideration as other riverine elements such as flow, water quality, vegetation, etc. Connectivity may not be needed on a continuous basis but probably should be managed for on a regular basis in most if not all years.

P. 17, first full paragraph, last sentence – how is "habitat" defined in terms of reduction at 150 cfs?

P. 17, last paragraph – If vegetation the only feature that limits habitat for and populations of fountain darters in the Old Channel, it might suggest that the flow would have a different benefit or value to fountain darters if vegetation communities were managed to encourage return of native species.

P. 18, paragraph 4 – This account suggests a tolerance for a relatively high amount of habitat for this endangered species (between 60% and 75%). Given the status of this organism and the stated goal of the study to not tolerate any reduction in habitat for any endangered species, this level of flow seems too low and inconsistent with stated goals.

P. 20 last paragraph – Discussion about the reduction in parasite prevalence following flood events suggests that such events are important and should be included in recommendations in spite of the conflicting statements and observations that Texas wild rice populations may be impacted by such high flows and not recover very quickly. 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.

P. 22, first two complete sentences – simply monitoring Ramshorn snails will not ensure protection or enhancement of habitat for fountain darters. If this species really does pose a threat it should not only be monitored but strategies and efforts to control their populations should be identified and adopted.

P 22, first full paragraph – these observations can be correct but in other systems, high flow events tend to mobilize pollutants to the detriment of riverine organisms. It's unclear what this paragraph is suggesting other than a statement of the obvious. If water quality degradation is an issue it would seem that specific mechanisms should be included here and potential strategies proposed to deal with those threats.

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.

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 and quite likely correct. However, it would not be prudent to prescribe or allow those conditions any more frequently than they occur naturally. Prescribed drought is never an acceptable condition for perpetuating aquatic organisms. The recommendations provided by Hardy seem most defensible and acceptable for this species.

P. 25 Comal Springs dryopid beetle – comments about the habitat needs and flows needed to perpetuate this organism seem logical and defensible. Additional data collection would be helpful to affirm these observations.

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 but 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.

P. 26 Historical Discharge – While 1927 – 2009 represents the complete record it probably does not reflect well on the historic discharge level. A better gage of historic discharges would be to look at average flows during every decadal interval during this period to identify significant, persistent trends and better appreciate how existing flow relate to historic flows. Documentation of low flow periods over this interval is, however helpful to appreciate the kinds of temporary low flows that have occurred and approximate effect on the endangered species.

P 26 – 30 Comal Springs flow regime recommendations – Overall these recommendations seem reasonable and have a basis in observed trends and modeling. However, the selection of target flows relies largely on professional judgment, which is not a bad thing. Models are developed and used to relieve uncertainty and should not necessarily be relied on solely as the basis for a recommendation. None of the models or studies done for Comal Springs were of a sort to provide a single flow or flow regime output. Given the characteristics of these species, the many confounding factors and available scientific tools, it would be difficult to make more precise recommendations. Those presented here are reasonable and will achieve the objectives of the charge.

Figure 5 – It is hard to tell precisely how each of these flow levels is determined or what the basis is (for example) for a "minimum 6 month average flow". One point worth clarification is that comments about thermal maxima or response to lower flows relate to just the warmest periods in late summer. Thermal criteria should be adjusted seasonally and probably not used to develop seasonal limits in fall, winter and spring.

The recommendations do not provide a particular flow regime as the section heading suggests, though probably would maintain some semblance of a natural flow regime by allowing natural flows above the defined limits. However if depletions are allowed that reduce spring flows to the specified levels, the present formula would not seemingly afford maintenance of a flow regime. Considering that most of the endangered species are essentially pool species, some individuals of which have ventured to lotic habitats suggests that lower flows would be acceptable as long as water temperatures achieve seasonal objectives. The recommendations could do a better job of using temperature as a way to secure a flow regime since maximum temperatures are only observed at a limited time during the year. As a consequence higher flow may be needed during late summer to attenuate temperatures and lower long-term average and even 6-month average flows might be acceptable at other times of year.

One thing that this section is lacking and should provide is a recommendation for the frequency and duration of recommended flows. This could be based on life history requirements (such allowing a low flow condition no more often than once in every life history cycle of the organism with the longest period between recruitment periods).

It is not surprising that 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".

P. 35, paragraph 1 – SNTEMP is a useful tool for assessing thermal dynamics in streams as is generally known to be relatively insensitive to air temperature. More influential drivers are shading and groundwater inputs. It's important to use the most accurate data possible but especially important to have good data for these major drivers.

P. 35, Table 4 – It is important to specify what minimum spring flow is either in the table or text preceding the table.

P. 41, top par. - 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 seem appropriate to develop recommendations that relate to this trend and construction of additional flood retention dams in the future.

P. 55 – this discussion provides some additional indication of the need to consider connectivity of habitats and time series analyses when analyzing or setting flow recommendations.

P. 56, 1st paragraph – these statements provide 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 primary and useful tool to set a flow regime recommendation on this basis.

P 56. San Marcos gambusia – the assumptions in this section are scientifically valid.

P. 56 Texas blind salamander – the assumptions in this section are scientifically valid.

P. 57-58 San Marcos salamander – the assumptions in this section are scientifically valid.

P. 59 Comal Springs riffle beetle – the assumptions in this section are scientifically valid.

P. 59 Historical flows at San Marcos Springs – the observations here are appropriate. Given the changes to the system, it would seem improper to support low flows at historic levels as to their ability to maintain the endangered species. Duration and seasonality are concerns that would need to be addressed.

P. 60 San Marcos Springs flow regime recommendations, last paragraph – the general strategy here is valid however use of average flow as a criteria suggests that periodic, instantaneous lower flows would be acceptable, which could cause problems with species survival. It is also a concern that the report does not identify criteria for what "rarely" means in terms of the frequency of lower flow levels.

P. 62-65 and Table 11. - The recommendations presented here seem justified in terms of meeting the overall goals described for the project and report. There is a relatively high level of professional judgment involved in selecting the precise numbers for each level of protection and it would seem a case could be made for slightly higher or lower numbers by a casual observer. Professional judgment is a valid and often superior scientific tool that can and should be used in situations where detailed models do not provide clear threshold recommendations. Computer models often give the illusion of precision but most address only a limited range of inputs and bear their own degree of error that is often overlooked. Professional judgment in combination with extensive empirical data, used properly, is an appropriate way for senior scientists with many years of experience to consider multiple inputs and formulate comprehensive conclusions and recommendations. While the review team could identify other possible flow levels, the great body of knowledge and study that have been done for this system compels us to defer to the authors of the report. Again, their recommendations are certainly not out of line with the range of possible flows that appear needed to achieve the recovery of these species. I find no fault with the authors' contention that they have used the best available science or that the flows are either inflated or too conservative.

Task 2: Analyze withdrawal reductions and stages for critical period management

This section overall appears to be thorough and well based. Assuming the groundwater model is reasonably accurate, the authors of this section have developed most of the data needed and done a credible job if interpreting model outputs.

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 unlikely that specific studies are needed of the effects of higher than average flows, except perhaps for Texas wild rice.

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 may 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 (perhaps with the exception of predicting the likelihood of the return of a 1950's-level drought) are all appropriate and would doubtless help develop a better understanding of how to manage pumping processes over time from the aquifer.

Annear comments on Hardy Report

Over-arching observations:

- Most of the influence diagrams are good ways to recognize the many possible factors at play in terms of affecting habitat for and the abundance of the species studied in this report. The more useful influence diagrams are those that reflect multiple pathways and inter-relationships among the various elements because they realistically convey the difficulty of modeling ecological processes. Though these do a good job of identifying potentially significant variables. This study invests most of its direct focus on a relatively narrow range of elements of physical habitat and water quality (temperature). There are no models today that are capable of integrating more than a limited number of variables into a single model. The models used here are widely accepted and appropriate.
- WUA is commonly referred to as "habitat" which is a bit of a misnomer because WUA is a reflection of the combined suitability of only 3 or 4 elements from the entire suite of environmental elements that combine to create this attribute. This is a common practice in modeling with physical habitat models and does not change any of the observations; however, it would be better to refer to or think of these values as physical habitat so as to not minimize the many other important factors that combine to form habitat in its whole.
- There seems to be a lack of effort to integrate connectivity issues (longitudinal and temporal) though there is recognition of vertical connectivity for those organisms that survive low flow (drought) periods by residing in spring upwelling areas and gravels.
- Results reflect instantaneous WUA which is standard but a time series analysis that addresses life history elements and flow availability during the year might help find and assess the potential effect of habitat bottlenecks on these species.
- The report doesn't state goals or objectives for amount of the amount of habitat that should be occupied or is acceptable. Nor is there a goal for desired genetic diversity. These aren't critical elements but would help the reader understand whether or how well various flow levels achieve desired goals.
- This report is not clear as to whether the goal of managing habitat is to just protect species or restore them.
- In many instances, the report simply notes facts such as a lack of vegetation creates low WUA for darters, but offers no additional information about whether vegetation restoration can or should be done as a species recovery strategy.
- The observance that beetles survive periodic perturbations by burrowing into gravels leads one to think that watershed management and prevention of allowing fine sedimentary materials to enter the stream may be as important as managing water quantity. Clearly, complete integration of water quality (chemical constituents, sediment, temperature, and DO) and quantity is critical to this analysis.
- It is also unclear if one species has a higher priority over others or what strategy will be employed to select the most beneficial flow(s)

Fountain Darters

P 10. References here and elsewhere to "connectivity" are unclear as to which of the 4 aspects is involved (longitudinal, lateral, vertical or temporal). This may be dealt with later in modeling but it would be helpful to discuss the applicability of each of these aspects. The influence diagram on this page also indicates that connectivity only relates to dispersal of the organism of interest but it would be good to relate the role of connectivity to other important environmental variables such as sediment import/export, nutrients, energetic materials, etc.

Multiple places – modeling of depth, velocity and substrate can provide analysis of relatively static conditions but to provide an accurate assessment of the role of flow regimes, it's important to develop information about habitat processes at least for those elements that vary over time. These include water quality functions, sediment import/export rates (and effects on channel conditions), and connectivity patterns over time.

P. 11. A better understanding of the overall habitat processes could be achieved by providing some information as to why or how flooding and drought are considered. Are these positive or negative influences? Per the natural flow paradigm, intra- and inter-annual flow variability are key drivers for most organisms and their habitat and more discussion of the timing, magnitude, duration, frequency and rate of change of flow patterns would be helpful – especially comparing those characteristics over decadal periods (or some other specified blocks of time).

P. 13 The above observations would likely improve the general understanding of relationships' effect on fountain darters but overall, the physical habitat characterization was done using industry accepted techniques and is superior in scope and consideration to most other studies like this.

Hydrodynamic Modeling - *Physical Characterization*

P. 14 The issue raised at the end of paragraph 3 is a vexing one. Specifically noting that vegetation development has higher potential for affecting habitat than channel characteristics suggests that the report should invest more effort to quantify this situation.

Water Surface Elevation Modeling - Comal River

P 17. Most 2-dimensional models do a reasonably good job of simulating velocities under the range of flow conditions noted but one important component that should be addressed is how they model edge effects. Because many species are associated with the edge of rivers, an accounting should be provided for how the RMA2 model deals with edge effects. This doesn't make this model a wrong choice but could affect its relative accuracy for quantifying habitat availability and suitability considering that boundary layer habitats such as the margins of streams often contain a relatively large portion of the useable area, especially for fish.

Using HEC-RAS to set computational boundaries is standard protocol for this kind of model.

P 18. Without looking at the Brune report, it appears that this critical element of quantifying flow may be too imprecise. Considering the importance of decisions based on these studies, one would expect a more precise determination of flow from the various spring inputs.

Vertical Velocity Distributions in Vegetation

P 24. Developing vegetation-specific roughness factors is appropriate and would help improve the accuracy of hydraulic modeling and quantification of physical habitat availability (WUA). These roughness values all look to be within an appropriate range.

Boundary Conditions

P. 29. The assumption at the bottom of Table 6 about the level of spring flow in the upper portion of Landa Lake is unclear. Though assumptions are often necessary, it would be good to see the basis of this one by showing the observed velocities and temperatures from the summer of 1996.

Model Calibration and Verification

P. 30. Flow volume isn't presented here but it isn't needed to follow diurnal changes in temperatures. This is a seemingly good correlation but it would be helpful to repeat the analysis at more than one flow.

Dissolved oxygen levels are typically lowest just before daylight as a function of extended respiration of aquatic plants and periphyton over night. The influence of other limiting factors such as BOD would be reflected then too so it would not be necessary to factor out specific causes of low DO. It's probably not necessary to track dirunal dissolved oxygen levels but if the study only focuses on one time of day it should be tied to daybreak, which at least in theory would be a potential bottleneck especially during times of year when water temperatures are warmest. The report doesn't say what time of day DO relates to, which raises some question about whether the number presented is truly a limiting factor.

Comal Springs Riffle Beetle

P. 36. No mention is made of this species' reproductive periodicity and it is unclear if different flow requirements at different times of year (depth, velocity, flow rate) are appropriate. The report should at least acknowledge uncertainty about this element if there are no data to support a seasonally varied recommendation.

Texas Wild Rice

P. 37 It is admittedly a challenge to determine the relative efficacy of the two sets of suitability curves presented here, but it seems the USFWS-USU curves may do a better and more conservative job of reflecting flow needs for this species. The TPW curves give the appearance of being more precise however it's unclear what the various steps are based on other than perhaps an effort to narrow the range of suitable flows (for depth) or give more weight to lower flows (based on velocities). It is hard to tell if this is an appropriate and acceptable strategy based on the information in the report.

Current understanding clearly suggests that protecting this species should also address turbidity in some quantitative way. This element isn't necessarily tied to flow but some reference is needed about managing flow, recreational activities, or runoff in the watershed to maintain turbidity below some defined level.

Also, as noted above, there is no recognition of the need for different flows at different times of year for different life history needs. Are higher flows needed at times of year for dispersal of seeds or vegetative parts? Are lower flows needed at times of year for seed germination or sprouting? The relative merit of extremely high flows could possibly be deduced by an explanation of re-colonization processes following the 1989 flood.

Fountain Darters

P. 40 Suitability curve development and the justification for modifications is reasonable and an appropriate improvement over previous studies. One matter that should be clarified is whether velocity criteria pertain to mean column velocities or nose velocities. I presume the latter measurement location is what is referenced. There is a comment at the bottom of page 44 that velocity criteria may in fact relate to mean column velocities. Regardless, this point is not clear in the report and is an important consideration because darters typically associate with boundary layers.

This section does make the point that this species may spawn at all times of year but it is unclear if flow needs for various life stages varies during the year or if spawning is more prevalent at some times of year or seasons – or is keyed to flow pulses.

Physical Habitat Modeling

P. 44 Assigning vegetation type instead of roughness values to each node is acceptable and an appropriate way to assess habitat suitability at nodes. Evaluating water velocities at 6 inches above the bottom boundary layer only partly addresses the fact that fountain darters seek low or zero velocity stations associated with boundary layers but this strategy does provide a better indication of suitability than mean column velocities.

Comal Springs Riffle Beetle Habitat Equation

P. 45 This equation appears to be written backwards per discussion later that says a suitability of "1" was used for all areas greater than 0.02 ft. Information about this species' habitat preferences on page 37 indicate that most individuals are found in flowing areas where depth is between 1 and 4 inches (0.08 to 0.33 ft) even though some organisms are found in deeper water. Assigning a simple binary system as proposed in the report captures this fact, though it's unclear why the lower limit of 0.02 feet was chosen except to reflect that the organism can be found anywhere there is water that is within the technical limit of measurement. Habitat preference information also indicates the species requires at least some flowing water, so suitability would appear to be more accurately defined as the interface of these areas within some defined limits of velocity, probably low. A binary system for velocity could be used as well (flowing vs. non-flowing nodes).

Texas Wild Rice Habitat Equation

P. 45 This approach for determining suitability is industry standard and acceptable. A similar equation should be used for riffle beetles. The results of these calculations will rely on which set of suitability criteria are used. The model could also be run with a value for turbidity included in a manner similar to how temperature is treated for fountain darters because of comments previously that water clarity is an important factor. Reference should be made as to whether flow needs are different for different times of year based on life history needs of the species.

Fountain Darter Habitat Equation

P. 45 This approach is acceptable. As noted, the choice of suitability criteria to use in this equation is the primary factor that will affect the overall relationship between flow rate and suitability. Reference should be made as to whether flow needs are different for different times of year based on life history needs of the species.

Comal – Temperature

P. 46 The last sentence in the first paragraph seems at odds with the data and actually suggests that 50 cfs will only maintain suitable temperatures as far as perhaps mile 2.1. The report provides no guidance or goal for how much of this segment should be protected. If the goal is to keep temperatures below critical levels over just half the area, then 50 cfs may meet that standard. However, if the goal is to identify the flow that will keep temperatures below critical levels at all times and throughout the segment, then a higher flow would be more appropriate.

P. 47 The last paragraph on this page notes that the higher temperatures predicted for most flows in Landa Lake would negatively impact reproduction of fountain darters. Previous comments were made that this species has been found to reproduce at all times of year. Considering that highest temperatures such as those modeled here only occur during late summer or early fall, it would be helpful to know the proportion of contribution to the population that might be affected by reducing recruitment at this time. If most spawning occurs at other times this impact may be relatively less. Even if recruitment occurs equally throughout the year, this loss of recruitment may be tolerable in terms of persistence of the species. Again, it seems appropriate to indicate the goal of temperature management and whether managers want to remain below critical levels throughout the system at all times of year or if some other standard has been identified.

Dissolved Oxygen

P. 48 Diurnal fluctuations in DO would be expected and it is good to see the reference to unpublished data from vegetation beds in Landa Lake and discussion, albeit brief, of potential effects of BOD and respiration. Plants typically respire at a fairly constant rate however they only produce oxygen when stimulated by daylight. So it is logical that evidence of high production of DO during the day would be countered by high respiration at night. Decay of plant material is a secondary means of oxygen depletion but certainly not the only one and probably accounts for less effect than respiration.

Additional DO data that reflect concentrations at their lowest level (daylight) would seem appropriate to include in the model, especially in light of the unpublished data referenced here. The opinion that DO doesn't appear limiting (so was not used in the analysis) is probably reasonable for present conditions but additional analysis may show otherwise at low flows and warmer temperatures.

It is unclear what concentrations of DO would be limiting (as suggested in the report) but some standard should be identified. These effects would be greatest in the springs and less of an issue in flowing portions due to the potential for re-aeration in flowing water. It is likely that this pattern would change throughout the year as a function of water temperature and perhaps average wind speed.

Comal Springs Riffle Beetle

P. 50-52 This analysis and interpretation seems reasonable. While organisms appear to have survived extreme low flow conditions it would be irresponsible to prescribe those conditions on a permanent basis. Periodic disturbance or perturbations such as floods or drought play an important role in the long-term persistence of most aquatic organisms.

Physical Habitat Using Maximum Daily Temperatures

P 54-59 This analysis appears reasonable but should be noted that it applies only to times of year when temperatures are greatest and probably do not relate to other times of year – especially winter and spring.

San Marcos

Dissolved Oxygen

P 62 – observations about oxygen concentrations reflects appropriate awareness by the study team and offers insight that this will be more fully addressed in subsequent studies.

Texas Wild Rice - *System-Wide Physical Habitat*

Spring Lake

Texas wild rice in Spring Lake clearly has declined since original accounts, which suggests that it may be more limited by factors such as water quality than quantity. It is unclear if velocity distributions have changed but it would be helpful to provide more information about physical habitat changes since the 1930's. Is velocity different today? Has the lake filled in? Is substrate different? Or is there some other factor associated with increased human presence in this area that is likely to blame. It is possible that effects could be associated with some seasonal flow factor as well such as timing, duration, frequency (of flow change), magnitude, rate of change. If the management goal is to do more than just protect remaining stocks of organisms (e.g. to actually restore them to some established level), then more effort is needed to understand why this shift in abundance has occurred.

All other study sections – as expected there is variation in the relationship between flow and habitat suitability at each segment, so there is not one best flow that takes care of a longer stretch of stream. It is also not surprising that velocity is a major driver in the river considering that it appears the natural channel was shaped by historic flows to pass relatively high volumes of water. Flows below 100 cfs appear as if they fill the channel increasingly less at lower flow rates.

Revised Upper San Marcos Physical Habitat Modeling

P. 65 The absence of this species from a particular section may not be reason to omit that section from consideration or study. If restoration of habitat and populations is a goal of this study, additional studies may be needed to better understand why this species is no longer in its historic range and then take steps to correct that problem. If however, the river is so constrained by factors such as urbanization and flow depletion that simply cannot be altered, then it would be important to acknowledge such constraints at the very outset of the study.

Comparing WUA changes on a non-standardized basis between segments may be misleading to some readers but it is important to focus on trends instead of actual square feet of usable area. Displaying the combined WUA as a percentage is a preferred way to assess the relative merits of different flows and does reflect the trends of individual sections of stream.

Texas Wild Rice Physical Habitat Summary

P. 70 The summary comments are reasonable and additional, finer-scale increments would provide more information. I'd like to see more mention of some seasonally adjusted flow recommendations vs. a single number for this and other species. One other thing that is not addressed (and causes all such studies some difficulty) is the matter of understanding whether less high quality habitat has the same value as more lower quality habitat (since each condition can in theory generate an identical WUA score). This phenomenon could explain some of the reason why rice is found where it is in figure 46.

Fountain Darter – *System-Wide Physical Habitat*

P 74-76 It remains a concern that references to seasonal needs or the role of a dynamic hydrograph for a variety of purposes is not mentioned. Likewise, it is unclear if vegetation management isn't an important management strategy both in areas where it currently exists at acceptable levels as well as in areas where it appears to be absent. Perhaps flow conditions or channel substrates are affecting vegetative growth but additional discussion or analysis would be helpful.

Upper San Marcos Physical Habitat

P. 76 – 81 Interpretations and data presentation appear acceptable. While it may be possible that WUA for some or all sections may be higher between 65 and 100 cfs, it seems unlikely that it would be significantly different such that one might reach a different conclusion than presented here.

Fountain Darter Physical Habitat Summary

P 83. The basic conclusion made in this section appears well grounded in the available science. However it is unclear how much precision is needed for managers in order to formulate water management recommendations.

Other Native Aquatic Species

San Marcos Gambusia (Gambusia georgei)

The assumption that acceptable flows for one fish may be adequate for another is difficult when both are actually in existence; however this statement is more risky when one fish has not been seen or studied. Clearly if this fish is still in existence it will have a better chance of survival in water at any level than in a dry channel. However the fact that it has apparently gone extinct under the past hydrologic and water management pattern suggests that those conditions were not favorable. It would be more appropriate to not speculate what the flow needs are of this fish and limit discussion to known facts – of which there are few relative to its habitat needs.

Texas blind salamanders *(Eurycea rathbuni)*

The reference to maintaining acceptable levels of water quality is a key for all species and should be a concern to water managers. The report is on solid ground to state that maintaining flow in the aquifer is key for this species – and the others that are the focus of this study.

Non-native Species

It is generally accepted and certainly logical that predation on all species tends to increase as their spatial area decreases and especially as cover (vegetation) declines. There is little doubt that one of the best strategies to minimize negative impacts associated with non-native predators is to maintain physical habitat, vegetation, and habitat diversity. The fact that fountain darters remain in this system along with non-native predators at this time is an indication of their ability to co-exist. It is unclear if they might exist at higher densities in the absence of predators. Fountain darters are likely spatially segregated from most predators by virtue of their affinity for low velocity habitats near the bottom of the springs and streams whereas most predators often inhabit areas higher in the water column.

Recreation

P. 88 This section is well-grounded and raises several key points. It is quite likely that human use in and adjacent to the springs and streams is a significant issue that should be dealt with more specifically and managed more directly. Increased human population level is one thing that has definitely changed since 1933 and elicited a variety of changes in the quantity and quality of spring flow as well as physical habitat disturbance. Though these are spring systems, the issue of disturbed silt and silt deposition on vegetation suggests that a varied flow regime, to the extent possible, would provide benefits to these systems by helping transport sedimentary materials through the system. This matter also raises again the question of seasonality of impacts. If, for example, fountain darter spawning is more prevalent at a certain time or times of year, then recreation and watershed management could focus on those periods.

A Review of

"Technical Assessments in Support of the Edwards Aquifer Science Committee "J Charge" Flow Regime Evaluation for the Comal and San Marcos River Systems

December 29, 2009 Draft

Prepared for

The Edwards Aquifer Recovery Implementation Program

by

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Prepared by:

Ian Chisholm

Stated Goal

"The focus of this report is to provide technical analysis in support to the Expert Science Subcommitte of the Edwards Aquifer Recovery Implementation Program to evaluate flow regimes for each river system required under Senate Bill 3 "J" charges." (page 1, second paragraph).

Summary

Overall, I support the science and findings contained within this report. I believe the report addressed the stated goal (focus of the work) and provided information necessary to begin to address targeted elements within the Edwards Aquifer Authority Act.

The reviewed document represents work that is technically strong, fairly wide in scope, with conclusions that are consistent with the study results and current literature and science. It introduces a (peer-derived) overarching framework to ground and place the current work in proper context and help inform additional efforts and input. The report provides necessary information to effectively address species requirements in relation to spring discharge rates and water withdrawal reductions and stages of the Edwards Aquifer. All of these aspects of the report are to be commended.

Specific examples of the technical strengths include: physical characterization of the study area, 2D modeling, and incorporation of vegetation dependant hydraulic roughness, review and update of HSC with more current data, temperature modeling, and inclusion of genetic analysis where appropriate (e.g., to explain population patterns in riffle beetle).

The scope of the work is evidenced by the peer-reviewed influence diagrams, modeling of habitat requirements for a plant, an insect, and a fish (2 kingdoms and 3 phyla), derivation and coordination of the habitat suitability curves and analysis, system-wide temperature modeling and calibration, and integrated treatment of water quality, biology, and elements of geomorphology and connectivity.

As with any endeavour, there is room for improvement, and the report is replete with acknowledgement of that fact throughout. Additional strength could be provided to support and enhance this study through more direct integration of the current study with other elements within the influence diagrams. The influence diagram frameworks need to be further refined and formalized, based on the comments and reviews received from experts. Additional suggestions follow, below.

- Conceptually, the report could be improved by integrating more thoroughly with the hydrology feeding the springs. Hydrology drives the system. Time series analysis, matching the physical habitat modeling with the hydrologic record and ultimately producing habitat duration curves, would help to further identify bottlenecks, and important thresholds and is standard procedure for physical habitat modeling.
- Full characterization of the system hydrology: past, present, and potential, including all elements: magnitude duration, frequency, timing, and rate of change would also improve the report. To what degree have these elements been altered and what are the likely watershed changes and hydrologic effects (e.g., climate change) that will influence the hydrology further? Because this is such an important aspect, I have to believe it was specifically not part of the assigned tasks of this report.
- Related to additional hydrologic analysis and greater integration with the influence diagrams: more specific geomorphic analysis including channel morphology, dams and channel use (e.g., recreation) and their influence (hydraulic and sediment) on sediment transport and habitat, and the relationship of the current hydrology to the maintenance and construction of habitat. To what extent have the dams, the loss of riparia, and hydrology (e.g., watershed runoff, changing recharge rates, and pumping) influenced habitat and population patterns?
- Expansion of the habitat modeling to include a (habitat) guild representative for each habitat type found in the springs would ensure that habitat connections between target species and key life stages (analysis assumes all life stages of each target species are represented by one set of curves) or food organisms would not be overlooked and possibly severed.
- Additional attention to the loss of species diversity that seems to be evident in both springs. While diversity indices are strongly related to sampling

effort (space and time) up to the asymptote, the tables provided in the report warrant further investigation. Has diversity dropped 28% in the Comal River and 46% in the San Marcos River between 2001 and 2007? The report alludes to introduced species as a factor. Introduced species (invasives) are typically favoured over natives as habitat is artificially disturbed and generalized. Does the presence of dams (fragmenting and pooling river segments) and watershed changes represent the underlying cause? What factors are at play?

- Expansion of the water quality elements to include chemicals and elements common to urban stormwater runoff. Specific modeling of stormwater/water quality inputs and effects requires matching hydrology and WQ elements. For example, salt runoff during winter months when flows are typically lower may represent a negative associative impact (effect of salt is diluted under higher runoff flows and is higher when flows are low), while the impact (scouring vegetation, filling in habitat) of additional sediment inputs may increase with higher runoff volumes.

Specific Comments:

Page 4 -13. Influence Diagrams for Target Species

A recurring comment (applicable to all species) regarding the diagrams is the importance of "connectivity". Fragmentation of river systems and resultant loss of genetic diversity and increased potential for extinction is well recognized aspect of meta-population ecology and research (see Hanski 1999, for example). These systems are dammed and connectivity is plotted in the diagrams as a part of the "big picture" for each species except fountain darters. Given the disappearance of the fountain darter from the Comal Springs system following the 1956 drought, and subsequent re-planting from San Marcos, how has this aspect been overlooked? Are these dams fully passable by this species, during the range of flows? Temperature "disconnects" habitat as well, in the extreme.

Also, Figure 6 (page 8) is applicable to all species: the relationship of the watershed to runoff and groundwater and surface water (spring flows) and its quantity and quality, and the potential human interaction points (pumping, overland flow, point and non-point pollution) is a constant and important determinant for these systems.

The importance of watershed influences is underscored on page 14, where the report notes that sedimentation is occurring within the channel and has been associated with channel topography changes, brought about by construction activities in the Sessom Creek watershed. Apparently the modeling and analysis has accounted for the channel changes, but not the changes in aquatic vegetation, which has a higher associative potential for suitable darter habitat. Further address of this or explanation is warranted; the relationship between watershed activities, hydrology, and sediment is an ultimate driver of the long-term health of the endangered species and this system.

Page 18. Further establishing the hydrologic partitioning may be important, or at least that the partitioning is constant at the range of studied flows, as the WUA results and conclusions are based on this assumption.

Page 22. The caveat concerning the channel and modeling in the Cape's Dam section: hypothetical results due to heavy sedimentation should be noted as such in the appropriate tables later in the report.

Page 23. Each species was assigned a unique hydraulic roughness *except* Texas wild rice (key species of interest), for valid reasons. But velocity is a key variable for wild rice habitat and hydraulic roughness a mediator of velocity. What is the estimated value used and how sensitive is resultant WUA to this value?

Page 25. Water Quality and Temperature Modeling

The modeling and calibration of water quality models with additional data seems strong. Fountain darter habitat modeling assumed worst case scenario for temperature (hottest 48 hours), in line with a precautionary approach and establishing that the model is calibrated for the extremes, which likely most impact the species.

Page 30. Given the urban setting and relative lack of apparent riparia to absorb runoff contaminants, dissolved oxygen modeling should be performed with the effect of ammonia, nitrate oxidation, sediment oxygen demand, phytoplanktonic algae/macrophytes, and associated respiration, growth, nutrient effects and BOD. As noted by the author, this lack represents a key area of future integration tying the watershed , water quality, and ultimate habitat of the endangered species.

Page 31. Figure 23. Graph shows match of modeled and observed flows: modeled flows were very close to slightly lower than observed on the higher temperatures (above 78 degrees F) and higher on the lower high temperatures (at or below 78 degrees F). Throughout the simulated period (48 hours) the model nailed the diel swing.

San Marcos River ; Twenty one segments of 100 feet in length, each similar reaches – an example of strong technical work.

Page 35. Habitat Suitability Curves (HSC) This paragraph represents a strength of this work and approach: the scientific community were actively involved in the collection or review of the information used. The HSC for wild rice were based on work by Saunders et al. (2001); Hardy et al. (1998) established the basic sampling protocols for HSC for fountain darters; there was additional data available on vegetation use (by darters) but not useable because of vagaries in vegetation coding schemes. According to the report, this issue is being addressed through ongoing vegetation mapping that will allow incorporation of the long-term data for fountain darter vegetation suitability curves. In addition, the annual monitoring data collaboratively collected by TPWD and USFWS for Texas wild rice (TWR) were used to evaluate the existing TWR HSC and based on that review, were not modified.

Page 36, 37. Comal Springs Beetle

From the report: this beetle occurs in gravel substrate and shallow riffles in spring runs and upwelling spring orifices. They may, like many Elmid species, require 6 months to 3 years to complete a life cycle, and usable water depth is 1 to 4 inches. These life history pieces, along with the 1950's drought experience, suggest that the species can survive low flow conditions, but also may be susceptible to water quality changes (contaminants) or sediment influxes. The final paragraph on this page, discussing decreased genetic variability as strong evidence for isolation coincides with metapopulation ecology and, again, points to the importance of additional emphasis towards connectivity in this system (from watershed to groundwater recharge and surface water runoff to spring to channel and downstream). The rationale for depths, given what little is known, is logical and acceptable. Note: all surface area with depth greater than 0.02 feet was considered usable.

Page 37, 38, 39 Texas Wild Rice (TWR)

TWR is apparently the riffle species of this analysis, preferring shallower and faster water. In addition, TWR occurs at sites with high water clarity, is susceptible to disturbance, and is adversely affected by shade. These latter data were not available for this analysis but would be areas to refine the modeling further. Again, the relationship between watershed conditions (e.g., activity and stormwater management), riparia, spring flows, recreational activity management schemes and TWR habitat would seem to be fruitful from a long-term management perspective.

Page 40 -43, Fountain Darters

The science utilized for HSC modeling of this species is thorough. This is an apparently medium to shallow pool species and we would expect a very slow or low relationship to decreased discharge, as affecting depths and velocities. In fact it seems that fountain darter habitat is affected primarily by low flow effects on temperature or on vegetation that the analysis picks up through thorough analysis and presentation of these factors. Technical team multivariate analysis of habitat associations with depth, velocity, vegetation type, and height of vegetation (likely surrogates for cover) confirm the direction of the analysis, and advisability of revised modeling.

Page 44, Physical Habitat Modeling

The assumption that vegetation/substrate characteristics did not change as a function of flow rate seems counter to the analysis. We know the bed changed, e.g, after floods and upstream watershed activity. The 'dam removed' option at Cape's dam showed as much. For the case of the TWR, the point is made that low and high flows are associated with disturbance, either from recreation or the flood flows and sediment scour. With the extensive data monitoring that is being done on TWR beds, it would seem data could be derived to reflect the situation better.

<u>Page 45, Comal Springs Riffle Beetle Habitat Equation</u>

There is apparently a typo for the binary equation used for this macroinvertebrate. According to p37, second paragraph, beetles used water down to or >0.02 feet.

<u>Page 46, 47, 48 Comal Temperature</u>

From previous pages, 78 degrees represents approximately the 0.5 suitability point, and 80 degrees the 0.2 suitability point. Given that almost a mile of stream is brought to 78 degrees or 0.5 suitability at a flow rate of 100 cfs, stating that "60 or 30 cfs would reduce suitable darter habitat" is tentative and shouldn't be. According to Figure 32, 5/6 of the total length modeled would be at or above 78 degrees (0.5 suitability) at 30 cfs and over half the channel length would be at 0.5 suitability at 60 cfs.

The statement on P47 regarding water temperatures for the main stem is more clear: "A general warming trend is noticeable for all flow rates but its magnitude is minimized at larger total flow rates of 150 to 300 cfs. According to the graph (figure 33) minimized means over a mile of stream – the length that is 78 degrees or slightly above at 150 cfs total flow rate.

Report notes the large number of control structures and their influence on water temperature – an important point related to overall system connectivity.

<u>Page 48, 49, 50 Dissolved Oxygen</u>

Report acknowledges another detrimental aspect of low flows with high vegetation - potential for low DO. Noted also is the influence of control structures on maintaining DO through re-aeration. If system connectivity issues are addressed through channel restoration, these reaeration benefits must be kept in mind (e.g., through incorporation of built 'natural riffle' structures). The rationale for dropping DO, after review of the modeling results (Figure 34, 35) and reference to observed field values is acceptable, in spite of the very real diel impacts from vegetation.

<u>Page 50, 51, 52 Comal Springs Riffle Beetle</u>

Note text and disparity with binary equation - depths greater than 0.02 feet versus <0.02 feet. The additional simulation runs based on criteria developed from collection data on riffle beetles in the main spring is a good follow-up idea. The sampling design employed is robust. The results and statement of the conclusions is clear: greatest rate of habitat decline around 100-150 cfs. Discussion dealing with the question of 'why are the beetles still here if they are so affected by low flows, and what do the results indicate (directionally)', is comprehensive and direct.

Page 52-58 Fountain Darter

Fountain darter habitat is strongly constrained by temperature not physical habitat; highest WUA under the modeling for max daily temps occurred at Comal River flow of 150 cfs. Revised HSC increased the amount of WUA realized over the Bartsch et al. HSC (Table 11). The discussion of caveats relative to the modeled split flows (into the old channel and new channel) and results and updated modeling currently underway, left me wondering what to make of it. If the channel changes that were not reflected in the current analysis include topography and vegetation (caveat 1) and they show a strong physical habitat association with flow and darter habitat as well, the statement that thermal effects are more limiting than the amount of physical habitat will have to be withdrawn. If the use of a spring orifice temperature as a boundary condition (caveat 2) is important, would it affect the conclusion(s) as well?

page 62, San Marcos, Dissolved Oxygen.

There is agreement with the concern for potential depressed DO levels during night time respiration at low flows, in highly vegetated areas, likely at high temperatures, (typical of drought time). It should be addressed in on-going modeling efforts.

page 62, 63 San Marcos, Texas Wild Rice

The habitat conditions for this section are reflected in table 12. Given previous (1993) publications note of the decrease in TWR distribution at Spring Lake, narrowing down the cause of these apparently degraded habitat conditions should be a concern.

Texas Wild Rice habitat shows a consistent upward trend with increasing discharge, except in areas with backwater affects and other velocity limitations. The report does a good job of walking through the data results, step by step. The note under State Hatchery A, concerning flow rates near the historic mean having velocities still in range for wild rice are an argument for their existence and persistence there. The summary for this section is clear and reasonable.

A Review of

" Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer

December 28, 2009 Draft

Report to the Steering Committee for the

The Edwards Aquifer Recovery Implementation Program

by

The Edwards Aquifer Area Expert Science Subcommittee for the Edwards Aquifer Recovery Implementation Program"

Prepared by:

Ian Chisholm

Task 1: Analyze species requirements for springflow and aquifer levels as a function of recharge and withdrawal levels.

P. 12; Flow Regime. As recognized inherently by the Subcommittee's work and report, hydrology drives aquatic systems. The Subcommittee "chose to address the legislative charge within the context of a flow regime for the protection of all threatened and endangered species as well as the integrity of the ecosystem." Based on this, overall, the Subcommittee did a credible job. In the complex social and resource context of this system, the results are a laudable first step towards establishing an adaptive management approach for protection of the endangered species in the springs. In terms of addressing the long-term "integrity of the ecosystem", however, much work needs to be done.

P. 13; The trigger criteria seem disjunct from the charge the Subcommittee chose. The triggers are not part of a flow *regime*, which itself (hydrologic conditions, past and present) is not well established in the report. Baseline hydrologic conditions (natural, historic, predicted future) should be firmly described. Further, the report is proposing low flow minimums that, under conditions of demand, do not allow capture natural flow regimes and therefore are not supported by the natural flow regime paradigm. There is no evidence within the report to support that the listed triggers will restore a natural flow regime, which it references. The rationale for choosing the particular metrics is weakly supported within the document, which are then variably applied between San Marcos and Comal springs. As an interim, the use of hydrologic measures is acceptable, particularly for establishing or defining how intact or altered a current hydrology is from a natural or minimally altered condition. In such cases, these statistics should be: simple, non-redundant, easily understood by water managers and the public, account for the 5 major flow characteristics (timing, duration, frequency, rate of change, magnitude), and be linked (even conceptually) to ecological response (Apse et al. 2008). In the case of the report, the 3 statistics chosen specifically do not address the 5 major flow characteristics. The Subcommittee Report does take a major step forward, however, as an interim measure towards an adaptively managed system.

P. 14; paragraph 1. Regardless of how high flows are supplied, high flows are a necessary part of the natural flow regime, part of the Task 1 charge (to analyze species requirements in relation to spring discharge rates), and should be prescribed. The high flow trigger(s) would establish the means for testing whether or not the high flows are being impacted by management and ensure against unforeseen demand for high flow water. Assuming high flows will take care of themselves seems to be tenuous, given the potential demand for water and various engineering solutions to capitalize on imagined water surpluses.

P. 15; The description of channel changes within the Comal River Old Channel re-affirms the importance of connectivity in contributing to fountain darter habitat and population strength. The report describes habitat degradation and fragmentation within the study areas: the "reconstruction of a new culvert system on the Old Channel coupled with an extended period of high flow conditions (facilitated by the new culvert system) led to a scouring

P.18; The statement, "in all probability, the impact of habitat loss in the spring runs is minimal", is arguable, given the report's accounts of changes within the springs and the drivers of fountain darter habitat. Because fountain darter habitat is limited by temperature, which likely increases during hot weather as you move downstream from the springs, fragmentation of habitat and populations is probable. As the resilience of this ecosystem is tested, due to watershed changes (increasing runoff of water and some chemicals), alteration of hydrology, altered channel characteristics, loss of native riparia, increase in recreational activity, etc., any further decrease in connectivity should be considered alarming. Connection between habitats, particularly refugia, is a critical aspect of healthy river systems.

P. 20; The discussion of low and slowly rising springflows and their relationship to *Melanoides tuberculatus* provides evidence of the strength of the Subcommittee's biological science in this report. At the same time, it is not translated to actual management decisions regarding the recommended regime. Consideration of high flows as part of the natural regime and the recommendations for flows to sustain and promote endangered species may well provide additional protection to these populations and should be included in future recommendations.

P. 22; first full paragraph; these observations can be correct but in other systems, high flow events tend to mobilize pollutants to the detriment of riverine organisms. It's unclear what this paragraph is suggesting other than a statement of the obvious. If water quality degradation is an issue it would seem that specific mechanisms should be included here and potential strategies proposed to deal with those threats.

P. 24-25; Good discussion of the biology and rationale surrounding considerations of comal riffle beetles and flows for their habitat. More and more researchers are relating the importance of connectivity, in both terrestrial and aquatic arenas, as vital for long-term health of ecosystems. Maintaining connectivity in face of increasing use, increased potential for withdrawal stress (e.g., urbanization, climate change) is part of a considered management plan for genetic diversity. So-called sinks can become sources, whereby subpopulations supply genetic material to re-seed and maintain the populations under catastrophic disturbances. Under such a management scheme, environmental stresses are 'absorbed' by each species having access to the full aquatic network and the habitat it can provide.

P. 26; Additional information is needed to address, 1) the water quality trend in the aquifer, 2) the relationship of water quality and discharge.

P. 26; Analysis seems to assume variability and timing of flows are insignificant factors. Plots of gage data would help establish this assumption. Graphs of historical hydrology showing the range of flows or box plots by month are acceptable ways to begin the show the system hydrology.

P. 27; Figure 5; Final recommendations deviated from the long-term average, 6 month minimum, and 1 month minimum statistics for Comal Springs system. The process details resulting in the recommendations of 225, 75, and 30 cfs are not completely clear and undoubtedly relied on professional judgment. I support professional judgment but descriptions of the logic and decisions that led to these changes must be documented. This is true in all cases listed in the table. For example, previous text alludes to a conservative approach; what about negative synergistic effects under future conditions, e.g., long dry spell, hot weather, increased watershed development, decreased connectivity from in-channel engineering, increased demand for water, increased recreation, increased numbers and types of invasives, and increased infestation rates under low flow conditions? All of theses aspects are noted within the report. How these recommendations would be used to proactively manage the system is unclear. Forecasting of water year, based on full statistical description of natural and historic hydrology, antecedent moisture conditions, weather forecasting and agreed-upon decision criteria is being used in other systems to adaptively manage rivers and may have applicability here. Additionally, a "levels of evidence approach", used in epidemiology for years (see A.B. Hill, 1965, The Proceedings of the Royal Society of Medicine), would formalize many of the decisions now being referred to as " professional judgment". Hill (1965) lists and describes 9 causal criteria, in (his) order of importance: strength of association, consistency of association, specificity of association, temporality, biological gradient, biological plausibility, coherence, experimental evidence, and analogy.

P. 28; "The most important aspect of maintaining the long-term average component of the flow regime is that the system would not be able to have repeated 6-month or 1-month events also prescribed in the flow regime." What is the relationship of pumping (demand) and climate; could these two factors combine and negate this strategy?

P.29; The report reiterates discussions emphasizing flow recommendations for Comal Springs are based on best available science and professional judgment. "*We understand that these threatened and endangered species in the Comal Spring System can withstand short time periods of habitat loss and even some direct impact to the species themselves without resulting in long-term harm to the overall population. With that said, several unknowns still exist. One of the questions that remains is: What frequency or duration of these events could be tolerated by these species without long-term consequences?*" The obvious starting point for the answer is natural flow conditions. Even the answer of natural flow conditions also assumes similar watershed, riparia, and channel characteristics, which is just as clearly not in evidence. The likelihood that connectivity, water quality, geomorphology, and biological conditions are not the same as when historic natural flows occurred stresses the importance of a precautionary approach to recommending flow minimums. And yet, "no flows below 5 cfs" are prescribed.

P. 34; An Appendix listing of all data available for these systems would be an important tool in planning future monitoring and modeling efforts.

P.36, last paragraph, P 38, Table 6; Consideration of meso-habitat conditions at various flows in the San Marcos; showing riffles decreasing below 80 cfs. Again, further evidence of a complete examination of habitat, species, and flow relationships. Riffles very typically are the most hydraulically sensitive to flow changes (along with shallow backwaters) and should, as a general rule, always be examined. This provides strong argument for a cutoff flow around 80 cfs.

P. 40; Text discussion is fairly lengthy and comprehensive, discussing darter and flow relationships with parasites, invasives, declining water quality, and increased sedimentation. System connectivity and its impacts on genetics via fragmentation and meta population dynamics is not touched on, but what is more striking is how the description of available fountain darter habitat being maximized at 65 cfs apparently dominates all other considerations. Because fountain darters are a pool species associating with vegetation, you would expect insensitivity to decreasing flows until depths became restrictive.

P.56; San Marcos gambusia. This species should be removed from the analysis. It is reportedly "likely extinct", and yet the fountain darter habitat "are assumed to be sufficient to support any remaining San Marcos gambusia without incurring harm to the species." Given that fountain darter have always been there, and gambusia are thought to be extinct since 1982, assuming habitat for fountain darter is adequate for them is either in error or is not the limiting factor. Assuming it is accepts a logical weakness unnecessarily.

Task 2: Analyze withdrawal reductions and stages for critical period management.

P. 69; "Among other items, Section 1.14 of the Edwards Aquifer Authority Act states that the Edwards Aquifer Authority shall (1) protect the water quality of the aquifer, (2) protect the water quality of the surface streams to which the aquifer provides springflow, (3) achieve water conservation, (4) maximize the beneficial use of water available for withdrawal from the aquifer, (5) recognize the extent of the hydrogeologic connection and interaction between the surface water and groundwater, (6) protect aquatic and wildlife habitat, (7) protect species that are designated as threatened or endangered under applicable federal or state law, and (8) provide for instream uses, bays, and estuaries." (Edwards Aquifer Area Expert Science Subcommittee Report, 2009).

Based on this wording, the Subcommittee limited their task to adjusting pumping reduction levels and stages for critical period management. What they didn't do is consider water quality more generally, or protection of aquatic and wildlife habitat downstream or in the estuaries and bays (see quote below).

P. 70; "With respect to the charge, we did not extensively address all elements under Section 1.14 of the Edwards Aquifer Authority Act. Although we considered the need to protect the water quality of the aquifer and that of the aquatic and wildlife habitats in and near the springs with respect to movement of the bad water line and potential contamination, water quality in general was not explicitly considered. We did not consider the protection of aquatic and wildlife habitat in the downstream reaches of the river and its associated bay and estuary. We did not explicitly consider provisions for instream uses (Senate Bill 3 created a separate process . . . .)" (Edwards Aquifer Area Expert Science Subcommittee Report, 2009).

Given the circumscribed work, the report represents a strong interim measure towards active management of the federally listed endangered species.

Approach

P. 71-75; Model runs (simulations) fell into three broad categories. Over 40 different runs were evaluated with various assumptions and sensitivity analyses. This was a most useful exercise that illustrates how the present management the model can be is used for listed species protection. This was a retrospective analysis, where the flow limits and period of flow record were matched to determine what the affect would have been. This does not constitute predictive modeling or enable proactive management of the aquifer.

Use of the MODFLOW-NR for Task 2 is state-of-the-art for groundwater modeling. As a finite-difference model, the grid node points and boundary conditions are of key interest relative to the strength of the data being used to specify values of transmissivity and storativity. Specifying the boundary conditions, whether of known head or flux, is mandatory for solving the groundwater-flow equation(s). In some cases, the boundary conditions will be mixed, with some portions of the aquifer having known head and some portions having known flux. GIS layers can be used to specify cell parameters, layers (e.g., conductivity at depth). These conditions may vary over time as well, as a function of aquifer stage and the specifics of conduits to and from other formations, requiring (or allowing for) even more layers, cells, and cell parameters. This can become exceedingly complex, in reality, and to model. And, even when current computing can handle it, *the question is: has the complexity increased the level of groundwater understanding?* (see Bredehoeft, J. 2010. Models and Model Analysis. Ground Water 48(3):328). Good decisions are based on complete understanding – of what we know, and just as importantly, what we don't.

For all of these reasons, additional information specifying the uncertainty surrounding the estimates of springs flows from the aquifer modeling effort is an important area of further disclosure. Because the spring flows are an expression of the state of the aquifer, a thorough description of baseline hydrology is imperative. Full characterization of the system hydrology: past, present, and potential, including all elements of characterization: magnitude, duration, frequency, timing, and rate of change would improve the report and ultimate acceptance of management prescriptions derived from it. Confronting the degree that these elements have been altered, as well as the likely watershed changes (e.g., trends in population growth, i.e. impervious cover has been correlated to population size/density), effects on aquifer recharge rate and other hydrologic effects (e.g., climate change) that will influence the hydrology further are important areas of further discovery and delivery.

Just as a complete accounting of the groundwater modeling (data, estimates, uncertainty) would benefit understanding of the aquifer status, springs hydrology, subsequent habitat conditions, and management opportunities, it would also allow wider participation in the assessment of 'future conditions'. One such area of potential expanded consideration is to formally review the impacts of climate change on pumping, watershed conditions, aquifer stages, and spring flows. By looking at global climate models you get an idea of the magnitude of change for each group of hydrologic descriptors (magnitude, duration, frequency, timing, and rate of change) and can provide the basis for sensitivity analysis and refinement of water management decision making. The hydrologic time series analysis suggested for the habitat evaluation(s) provides the foundation for incorporating climate change information with appropriate sensitivity analysis, into management models; where expected changes to each water year type are characterized and used to indicate the range of conditions that may be faced.

In terms of a strong first step to dealing with a complex and controversial issue, the Subcommittee has proposed actions that will likely lead to the protection of endangered species. Further refinement, as noted within the report, and likely resulting from proposed study and monitoring results, is necessary and critical for actual 'recovery' of these species. Additional considerations of all 5 components of the resource (hydrology, geomorphology, water quality, biology, and connectivity) in context with the surrounding watershed, and human dimensions will provide necessary information for long-term management of the ecosystem.

P. 90-95; Further Studies. This is an impressive list of studies and modeling improvements and appears to be thorough. The Subcommittee obviously is at the point where: "further work is indicated". While admittedly unfamiliar with the broader work not presented here (e.g., MODFLOW, demand trends, watershed characterizations) I am compelled to relate several paragraphs from Bredehoeft's editorial on 'Models and Model Analysis' in Ground Water (cited above).

> " There is another way to conduct this investigation many thoughtful modelers advocate. That is to use the model as a tool to organize our thinking. One starts the investigation by assembling all the readily available information. On the basis of this preliminary information, you arrive at a conceptual model, or perhaps several conceptual models of the system. Armed with your concept and the preliminary data, you create a fairly simple numerical model of the system. You run this model, varying both the boundary conditions, and the range of potential inputs; you see how the system responds. For example, you ask: *Can the system sustain the magnitude of planned development?* Usually you realize, during this exercise, that some of your conceptual ideas are infeasible and can be ruled out. In the process, you identify the most sensitive parameters by using optimizing techniques. In this way, you use the model to guide data collection. You are continually running the model to reorganize your thinking as you collect more data. You refine the model as necessary – add more cells, or more layers, but you do this for a reason.
>
> With this method of investigation, you are always in a position to write a progress report. This scenario requires great flexibility – you are following where the information leads rather than a prescribed project plan. Managers have to trust the integrity and the capability of their investigators.
>
> For me, the model is not an end in itself, but rather a powerful tool that organizes my thinking and my engineering judgment. I may be like Don Quixote jousting with windmills; but

> to build bigger groundwater models just because it is feasible, or in vogue, seems to me meaningless – certainly it does not lead to increased understanding."

This may well be the same tack already being followed, and will confirm for outsiders (those, like myself, not intimate with the entire system, data collection, modeling and synthesis effort) that the level of modeling complexity is well matched by the level of groundwater and overall system understanding. If not, perhaps it will stimulate discussion and help increase the degree of shared vision among team scientists and managers.

Appendix G. Utility of the graphs of scenario runs would be greatly improved by plotting a reference condition with each run, providing an immediate view of the magnitude and pattern of change each scenario represents relative to a common baseline.

A Review of

"Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer"

December 28, 2009 Draft

for

Report to the Steering Committee for the Edwards Aquifer Recovery Implementation Program

by

The Edwards Aquifer Area Expert Science Subcommittee for the Edwards Aquifer Recovery Implementation Program

Prepared by:

Allan Locke

Summary

For the sections that I reviewed, I fully endorse the Edwards Aquifer Area Expert Science Subcommittee's (EAAESS) approach to analyzing species requirements in relation to spring discharge rates and aquifer levels and developing withdrawal reduction levels and stages for managing the long-term survival of the aquatic communities of the Comal and San Marcos springs, in particular the federally listed and endangered species. I find no serious flaws or errors in their methodology or their findings.

Assumptions of the approach are well documented and are reasonable given today's less than complete understanding of aquatic ecosystems. The tools and methods of analysis employed, with respect to fish habitat, are appropriately used based on best available information. With regards to the "natural flow paradigm", this construct has been more than adequately addressed. As stated in the report, *"...minimum flows are a necessary part of a flow regime of a given aquatic ecosystem for the protection of its component species, but the maintenance of minimum flows alone is not considered sufficient to maintain a sound ecological environment."* They further quote from their previous work in 2008, *"...minimum springflows are required within the context of a system flow regime for the survival and recovery of each species...A system flow regime includes low flows which support the survival of individuals for limited periods of time, normal flows which support reproduction within the population, and higher flows that periodically rejuvenate the system."*

I specifically note the following with respect to the various components:

<u>Hydrology:</u>

The team focussed in on periods of time that were of significance to them, e.g., when species were extirpated, the period of time since the fountain darter was reintroduced. They then compared these smaller periods of time to a very long hydrological period of record, 1927 to 2009. Eighty-two years of hydrology should be a sufficient period of time to capture the variability in the flow regime in these systems. The process of following the concept of the natural flow paradigm, by taking the observed data for a period of interest and conduct an evaluation of the historical hydrology is to be commended.

Notwithstanding their rigorous approach to using the hydrology data, they propose further effort is needed to, *"(1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on recharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the management module, and (10) refine model calibration between San Marcos and Barton springs."* The team has more than thoroughly understood and importance of how important hydrology serves as the foundation for carrying out these type of studies.

<u>Fish Habitat, Macroinvertebrates, Vegetation:</u>

The approach of defining thresholds for loss of habitat using a number of metrics; a long-term average, minimum 6-month average, minimum 1-month average and an instantaneous flow threshold below which no water should be taken, is consistent with similar studies throughout North America.

Balancing the needs of a multitude of species specific requirements is a common issue in making one overall flow regime recommendation. The process undertaken by the team of taking the higher flow requirement for any particular species in each case, and then to ensure this requirement would not negatively impact the other species or overall ecosystem integrity is once again, a common approach used in many other studies. These two approaches are consistent with current thinking, understanding of flowing aquatic ecosystems and ecological theory.

<u>Legal and Institutional Setting</u>

The legal and institutional mandate of the Edwards Aquifer Authority is clearly articulated, "*...the Texas Legislature created the Edwards Aquifer Authority to regulate pumping in the aquifer and to ensure that, by December 31, 2012, endangered and threatened species dependent on springflow are protected to the extent required by federal law.*"

Managing Uncertainty

One of the most important tasks in carrying out these type of studies is to clearly articulate the uncertainty associated with data collection, modeling and data analysis. The team has done an excellent job in documenting uncertainty throughout the report, as noted when it is stated, "*...all commonly used models and methods for setting instream flow requirements have been criticized for their overly simplistic and reductionist treatment of complex ecosystem processes and interactions...they provide little insight into complex ecosystem dynamics...*" They further note, "*Management decisions based on...a limited number of species...may actually result in undesirable effects on the ecosystem...*" It is somewhat puzzling why, "*The subcommittee made a conscious decision not to add a margin of safety to the proposed recommendations.*" The team clearly evaluated the best available science in an objective fashion, yet decided to not factor in a margin of safety. While it is common to adopt "the precautionary principle", this team obviously discussed this issue at length, and agreed as a group not to factor in a margin of safety. It is not known to this reviewer if the legal and institutional setting will allow for changes to the water management plan, "*...if it is later revealed that significant impacts are not captured in the model results...*" Generally speaking, should information come forward in the future that the ecosystem is able to tolerate short periods of lower flow conditions or more frequent occurrences than is recommended without significant consequence, then more water can be allocated for out of stream use. The opposite is not so easy. Ultimately, this is a decision about how the team wants to manage risk.

Overall Approach

The team clearly recognizes that understanding species requirements relative to flow is very complex and not one single method is without its pros and cons. The best possible overall approach is to use the most appropriate flow model(s) in conjunction with the target species life-history information, coupled with ecosystem based approaches, natural flow theory, and ultimately in the end, will rely on professional judgment to make a flow recommendation. The team is to be commended for using components of all of these assessment tools and for their in-depth analysis to understand the limitations and applicability of the tools, methods and approaches they used to complete their assigned tasks.

The following are specific comments, suggestions and questions. Overall, I believe the recommended flows and more specifically, the commitment to monitoring, is an acceptable approach to ensuring the long-term survival of the aquatic communities, including the federally listed and endangered species of the Comal and San Marcos springs.

Specific Comments:

1. On page 4, it is stated, *"For the aquifer-dwelling listed species such as the Texas blind salamander, Peck's cave amphipod, and Comal Springs dryopid beetle, maintaining the same amount of discharge needed for the protection of surface dwelling species would likely protect these species also; however, potential impacts on these*

species are considered." This is a reasonable assumption and one that is applied in many studies of this type.

2. On page 11 it is stated, *"In instances where natural flow variability can be maintained...benefits to the native communities can be substantial. However, this is an unrealistic scenario...and it is implausible in the Comal and San Marcos springs ecosystems. These two spring ecosystems have been altered by humankind for at least 150 years."* It is a reasonable assertion to suggest that a recommendation to restore the natural flow regime would be impractical. However, given the target species of interest evolved in the system since the last ice age, it may be worthwhile to at least use the natural flow regime as a benchmark against which the flow recommendations can be compared. These species have survived, to some degree for the last 150 years in altered flows, but the time since the last ice age is orders of magnitude longer. Will the long term survival of the target species be better ensured by *"maintaining a flow regime similar to the recorded hydrograph"*, or the one that existed for a much longer period of time? Examining the natural flow to better understand the frequency, duration and magnitude the recommended flow regime is changed from natural, could be revealing. To be clear, an examination of the natural flow regime is not the same as recommending the natural flow regime.

3. On pages 11 and12 it is stated, *"One assumption...[is]... there is consensus that any period of zero flow or flows below what was historically observed would greatly increase the risk for reduced survival of the surface dwelling species."* Given the information in the report, this is a very reasonable assumption.

4. On page 12 it is stated, *"...dedicated scientists...have spent much of their careers working with the threatened and endangered species in these springs' ecosystems...professional judgment is inherently embedded in our decisions. We have used the best available science for the determination of recommendations which in some cases is a direct result of professional judgment at this time."* This represents the state of the art / science for these type of studies. In the end, there isn't a model or process that guides you to the answer. The team is to be commended for clearly articulating the process and the very real fact that professional judgement must be used.

5. On page 12 it is stated, *"...conditions cannot go beyond thresholds that would not allow for the survival and recovery of any of these species in their natural environment."* Given the preceding discussion about the system not being natural for the past 150 years, and that "*natural flow variability...is an unrealistic scenario...*", perhaps this sentence could be clarified.

6. On pages 12 and13 the flow recommendation to meet the stated objectives is provided, *"Based on...best available science...professional judgment...underpinnings of instream flow science...natural flow theory, we selected the following components of the flow regime for evaluation:*
    - *long-term average flow,*
    - *minimum 6-month average flow, and*
    - *minimum 1-month average flow with an embedded minimum flow requirement."*

    The rationale for selecting these metrics is provided:

"The long-term average provides high quality habitat conditions throughout most of the spatial distribution of the species evaluated...The minimum 6-month average flow was incorporated into the flow regime to provide a safeguard from extremely low flow events...The minimum 1-month average flow was incorporated...to provide a threshold condition below which...the system should not fall...because it is widely acknowledged....that ecological systems are naturally defined by extreme events on both the high- and low-flow end of the spectrum."

Selecting a range of metrics that accounts for the long, medium and short term, including a threshold below which no water should be removed from the river, is consistent with many studies carried out in other areas of North America.

7. On page 13 it is stated, *"...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."* While this is a statement that is considered to be widely accepted by the ecology community, it is not clear how only looking at the last 150 years of altered flows achieves this.

8. On page 14 it is stated, *"...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.

9. The process stated on page 14, *"...first started by...examining the overall condition of the system as we know it today...examining the available information to assess when impacts to a given species might first be evident...concluding with an evaluation of potential flow-related thresholds for the species [by starting]...with...monitoring data...[and]...modeling results...considered the historical hydrology, and finally confirmed or rejected based on professional judgment."*, represents the most common approach to developing a set of recommended flow values in North America today.

10. On page 17, it is stated, *"This, coupled with warm weather conditions present in the summer, leads to the development of extensive mats of green algae (this is not the filamentous algae previously described as high quality habitat)."* Perhaps it should be indicated whether the green algae is native or non-native.

11. On page 26 it is stated, *"To develop an ecologically protective flow regime, a balancing of species specific requirements was conducted where results did not align identically. In instances where there were competing species specific requirements, the higher flow requirement was conservatively chosen in each case following an analysis and understanding that this recommendation would not negatively impact the other species or overall ecosystem integrity."* It is noted this is a common and accepted practice to balance the needs of many species and life stages.

12. Pages 27 - 30 (Figure 5; Table 2): This is the heart of the report where they set the flow regime for the Comal Springs. I can see how the L-TA, M6-MA and M1-MA were determined. I do not see how they determined there should be "no flows below 5 cfs". I think the true test of their logic would be to see if others arrive at the same numbers.

13. On page 29 it is stated, *"The model assumes that the aquatic vegetation community will remain the same, which is certainly a false assumption to some unknown degree."* It is not clear what is being said here.

14. On page 30 it is stated, *"All the unknowns logically lead one to a conservative mindset in the setting of flow related requirements. However, we made a conscious decision not to incorporate a margin of safety into the proposed recommendations. It was our interpretation of the legislative charge that the subcommittee should evaluate the best available science objectively, clearly state the assumptions associated with the recommendations, and acknowledge the need for further study where appropriate. For instance, if it is later revealed that significant impacts are not captured in the model results or efforts to control the parasite or its host are not in place or successful in the future, then one needs to be cautious with strict implementation of the proposed flow recommendations. However, should information come forward that these species are able to aggregate in areas of suitable habitat more frequently or for longer durations than currently thought without significant consequence, or mitigation activities are in place that could be effective in providing additional levels of protection, then the proposed flow regime recommendations for the Comal Springs system would also need to be revisited. One thing is clear, long-term*

monitoring of this system is essential, and further study and research specifically during critical low flow periods (or simulated critical low-flows) are needed to accurately determine the potential impacts to the species at Comal Springs." As stated previously, it is interesting the team made the decision not to incorporate a margin of safety. I once again caution the team to ensure the legal and institutional setting allows for the changes that should occur in the future if it is determined the flows need to be more conservative.

15. I agree with the assessment of Figure 9 on pages 39 and 40 where it is stated, "*Figure 9 demonstrates that the measured channel changes between 1997 and 2001 resulted in a scaling of the predicted fountain darter habitat magnitude rather than a considerable change in the overall shape of the weighted usable area to discharge relationship...*" and "*the maximum amount of available habitat predicted for the fountain darter occurs at 65 cubic feet per second. As flow declines to 30 cubic feet per second, approximately 75 percent of the maximum available habitat remains.*" It is suggested the team should refine the modeling efforts and use a finer scale of flow increments between 30 and 80 cfs to see if there is an obvious breakpoint in the slope of the curve.

16. On page 60 it is stated, "*The long-term average value flow of 140 cubic feet per second is supported by long-term monitoring data and modeling results. At these total discharge levels, populations of each of the threatened and endangered species are anticipated to maintain or increase their respective populations. The most important aspect of maintaining the long-term average component of the flow regime is that the system would not be able to have*

repeated 6- month or 1-month events also prescribed in the flow regime. As such, the lower flow criteria were developed with the understanding that if they should occur, they would rarely be experienced in the future." 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 what ever best suits the assemblage of flora and fauna, can be seen to better illustrate the point.

17. Pages 60 - 66 (Figure 19; Table 11) This is the heart of the report where they set the flow regime for the San Marcos Springs. I can see how the L-TA, M6-MA, M1-MA and low flow cut-off were determined. As above, I think the true test of their logic would be to see if others arrive at the same numbers. We should discuss this when we meet. I particularly like the statement, *"The minimum 6-month average flow of 75 cubic feet per second is supported by a combination of observed data, model results, and aspects of historical hydrology woven together with professional judgment."* P 63 - What is not clear to me is, " The historic minimum 6-month average was approximately 61 cubic feet per second during the 1950s drought." I can't find a clear explanation for this hydrological statistic, and why it was selected.

18. The text on page 63, *"There was considerable discussion amongst subcommittee members over the interpretation and integration of the observed data, model results, historical hydrology, changing conditions in the river, and potential frequency of occurrence of this flow component within the context of implementing the flow regime. As with the Comal Springs recommendations, we used best*

professional judgment to interpret and integrate these components and determined that 75 cubic feet per second for a minimum 6-month average would be protective with the associated assumption that the flow regime is implemented as designed, which would mean that this 6-month average would be experienced very infrequently in the future.", is a great example that clearly outlines the process of how the various data sources were used and ultimately it was the collective professional judgement of the team that ultimately set the recommended flows. It is an excellent summarization of the process.

19. On page 64 it is stated, *"A component of the historical hydrology we examined closely was the relative gaps between historical events (during periods of drought and falling spring discharge) as represented by the proposed flow regime. For instance, the gap between the historical minimum 6-month average and the historical 1-day minimum was approximately 16 to 23 cubic feet per second. We used this analysis to help describe the 1-day minimum (75 cubic feet per second [6-month average] - 23 cubic feet per second = 52 cubic feet per second (proposed 1-day minimum). Additionally, the gap between the historical minimum 1-month average and historical 1-day minimum was approximately 8 to 15 cubic feet per second. We included an 8 cubic feet per second gap from the proposed minimum 1-month average (60 cubic feet per second) to the 1-day minimum (52 cubic feet per second)."*

A more detailed description of the calculation,

hist 6 mon ave - hist 1 day min = proposed 1 day minimum would be helpful to understand how the range of 16 - 23 cfs for the "gap" between the historical 6-month average and 1-day minimum was determined. As well, providing the rationale for why this calculation was used, as opposed to other methods to set the 1-day minimum would be helpful.

Tom / Ian / Clair: For me, this is a critical piece of the overall flow prescription since these cut off values tend to have the greatest impact on the water use licences.

20. On page 64 it is stated, *"As with the 6-month average recommendation for San Marcos, there was considerable discussion amongst subcommittee members over the interpretation and integration of the model results and embedded uncertainty, historical hydrology, changing conditions in the river, and potential frequency of occurrence of this flow component within the context of implementing the flow regime. We again used best professional judgment to interpret and integrate these components and determined that 60 cubic feet per second for a 1-month average with a minimum flow of 52 cubic feet per second would be protective with the associated assumption that the flow regime is implemented as designed resulting in a 1- month average that would be experienced very infrequently in the future."* Once again, it is clear there was considerable discussion by the team and that in the end, there was consensus on the process and the application of professional judgement. While not presented here in the text, it is the assumption of this reviewer the details of the conversations and the sequence of the logic for these discussions has been captured in minutes and are available to anyone who seeks to see them.

21. On pages 64 and 65 it is stated, *"... several questions remain: What frequency or duration of these events could be tolerated by these species without long-term consequences? How many individuals (or cover) can be lost before recovery is impeded or impossible? How long does recovery take, particularly in a population with diminished reproductive capacity? How much can the range be contracted before the probability of a stochastic event wiping out the species becomes significant? In the absence of those answers, we have chosen to exceed the historically observed flow statistics at San Marcos Springs because the condition of the threatened and endangered species populations following the 1950s drought is unknown."*

Tom / Ian / Clair: The team clearly states they made the best recommendation possible and acknowledge there are many unanswered questions. Based on that uncertainty, they appear to me to justify choosing to exceed historically observed flow statistics. I do not follow the logic here. I think it is more than likely the modeling and empirical data would not produce a flow recommendation that is identical to the historical flow record.

22. On pages 65 and 66 it is stated, *"All the unknowns logically lead one to a conservative mindset in the setting of flow related requirements. However, we made a conscious decision not to build in cushion to the proposed recommendations. It was our interpretation of the legislative charge to evaluate the best available science objectively, clearly state the assumptions associated with the recommendations, and acknowledge the need for further study where appropriate. For instance, if it is later revealed that significant impacts are not captured in the model results or efforts to control the*

parasite or its host, sedimentation, or recreation are not in place or successful in the future, then one needs to be cautious with strict implementation of the proposed flow recommendations. However, should information come forward that these species are able to tolerate short periods of lower flow conditions or more frequent occurrences without significant consequence, or mitigation activities are in place that could be effective in providing additional levels of protection, then the proposed flow regime recommendations for the San Marcos Springs System would also need to be revisited. One thing is clear, long-term monitoring is essential and further study and research specifically during critical low flow periods (or simulated critical low flows) are needed to accurately determine the potential impacts to the species at San Marcos Springs." As with my previous comments, it is clear the team 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 to this reviewer 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 team wants to manage risk. Perhaps the team should recommend an institutional analysis be carried out to determine the likelihood of such a change in the future being implemented.

23. On page 70 the following text, "*We used an existing numerical groundwater flow model of the Edwards Aquifer to develop withdrawal reductions and stages for critical period management. We used the model to consider different "scenarios", where a scenario included adjustments to critical period management, maximum pumping, or a model parameter such as an initial condition. After deciding on a scenario we wanted to investigate or*

consider, we filed a request with staff at the Edwards Aquifer Authority to run the model to simulate the scenario, what we refer to as a "model run request". Edwards Aquifer Authority staff used the model developed by Lindgren and others (2004) using MODFLOW-NR (Southwest Research Institute 2007). We used this model because it is (1) the best available tool at this time to evaluate the effects of pumping and recharge on water levels at J-17 and J-27 and springflows at Comal and San Marcos springs, (2) it is used by the Edwards Aquifer Authority for managing the aquifer, and (3) it is recognized by the Texas Water Development Board as a groundwater availability model for the San Antonio segment of the Edwards (Balcones Fault Zone) Aquifer. Where appropriate, the Edwards Aquifer Authority's management module was used to evaluate scenarios. The management module applies withdrawal reductions based on the triggers placed into the module. Edwards Aquifer Authority staff wrote a report of the results and, after internal review at the Edwards Aquifer Authority, delivered the report and output files to the chair of the subcommittee.", clearly outlines the approach that was used. Accounting for groundwater and surface water is a very complex undertaking and the team outlined very clearly how this was done in context of evaluating a number of flow alternatives. The team is to be commended for addressing this complexity in a comprehensive and reasonable fashion.

24. The text on page 71, *"...we used the model to look at meeting or exceeding three flow criteria for each of the two springs: a 1-month minimum, a 6-month minimum, and a long-term average for Comal Springs and a 1-month minimum, a 6-month minimum, and a long-term average for San Marcos Springs. Our requested model runs (simulations) fell into three broad categories: (1) runs at constant*

pumping, (2) runs to investigate the sensitivity of the model to various parameters and scenarios, and (3) runs to attempt to meet springflow requirements while maintaining the permitted pumping cap recognized in Senate Bill 3. We also requested a simulation to serve as a baseline application of current critical period management...to gain an understanding of springflow at different levels of pumping (that is, no critical period management reductions to investigate the sensitivity of different parameters and scenarios to gain an understanding of how springflows might respond to changes in these parameters the effects of limiting the non-critical period pumping at 437,000 acre-feet per year...Based on draft springflow requirements and what we learned from the constant pumping and sensitivity runs, we requested runs intended to meet or exceed the minimum springflow requirements for the endangered species of concern...", once again clearly outlines the process of selecting a broad range of alternatives and then from what was learned, focussed in on time-series analysis specific to the requirements of the species of concern. This is a very reasonable approach of casting the net wide, and then zeroing in on the matters of interest. While not stated in this report, it is assumed the total range of time-series analysis that were undertaken will meet the requests of all stakeholders involved in the process.

25. On pages 74 and75, it is stated, *"assumptions that may affect our results, which are ultimately related to predicting springflow. While some assumptions probably overestimate springflow, other assumptions probably underestimate springflow. With this task, we assumed that:*

- *all reductions and increases in pumping due to critical period management were instantaneous,*
- *the maximum amount of groundwater that could be pumped under any given scenario would be pumped,*
- *climate and drought in the future would look like climate and drought in the past (specifically from 1947 through 2000),*
- *there was no movement in the location of pumping,*
- *the model accurately simulates springflows at Comal and San Marcos springs and water levels at J-17 and J-27, and*
- *the subcommittee did not consider either the minimum amount of pumping needed to maintain human health and safety requirements or potential strategies to meet those requirements."*

The team has worked on a very complex system and with studies of this type, it is a simple fact there will be assumptions, uncertainty and knowledge gaps. The team is to be commended for clearly stating the assumptions in an objective and transparent fashion.

26. The text on page 75, *"The assumption that climate and drought in the future will statistically resemble climate and drought in the past probably leads to overestimated springflow. Global climate models used by the International Panel on Climate Change suggest that Texas will be warmer and most suggest that Texas will be drier (Kundzewicz and others 2007). Warmer temperatures increase evapotranspiration which decreases runoff (all other factors remaining the same), an important factor for recharge to the Edwards Aquifer. A recent study commissioned by the Lower Colorado River Authority and the San Antonio Water System showed that even with increased rainfall, runoff was expected to decrease in*

the contributing basins to the Highland Lakes (CH2M Hill 2008).", clearly shows the team attempted to address the very uncertain topic of climate change as best they could. If the climate models show the possibility of decreased flows in the future, the team could create an artificial flow set, for example the 1:100 and 1:200 year return low flow on a weekly basis and see how that would affect water use while trying to meet the flow recommendations for the species of concern.

27. On page 76 it is stated, *"The assumption that the model accurately simulates springflows at Comal and San Marcos springs and water levels at J-17 and J-27 probably leads to underestimates and overestimates in springflows."* It is good to point out that errors in model predictions are not in one direction.

28. The text on page 79, *"We evaluated the potential effectiveness of this critical period management approach by using the Edwards MODFLOW model with critical period management module to simulate several different management scenarios to determine which trigger approach gets us through the "drought of record".",* once again shows a reasonable approach in using the accepted practice of sensitivity analysis.

29. On page 79 it is stated, *"The current critical period management plan in the Edwards Aquifer Authority Act (Table 12) does not achieve the springflow requirements in Task 1 (Table 13; figures 22 and 23). In fact, the groundwater model (Run 001) suggests that Comal Springs would stop flowing for 13 consecutive months and 29 months total. Under this scenario, pumping decreases from the*

maximum permitted amount (572,000 acre-feet per year) to about 362,000 acre-feet per year (EAA 2009)." This is an important piece of information where the team shows how the current critical management plan, (Table 12, page 80), *"...does not achieve the springflow requirements in Task 1."*, the recommendations set forth in this report by the EAAESS.

30. On pages 81 to 84, Table 13 and Figures 22 to 24 clearly show the various pumping scenarios and how the scenarios do or do not meet the biological criteria. Figure 24 is particularly good as it shows the three criteria operating in concert for the model runs presented. The figure clearly shows there isn't just one criterion that is tripping. All criteria trip demonstrating there isn't just one isolated instance of low flows in the entire period of record that is the issue. And if only one of the criteria that was tripping, then further work would be necessary to try to understand why that was occurring.

31. On page 85 it is stated, *"We recognize that this final run that reduces permitted pumping by 85 percent at Stage I does not take advantage of the Edwards Aquifer Authority's current critical period management approach... Given the legislatively mandated deadline for the report, we did not have time to investigate multi-stage critical period management with the final springflow requirements..."* And again on p 92 it is further stated, *"...we did not have time to request and consider model runs to potentially refine those reductions. For example, given additional time, we would have requested model runs to investigate different trigger levels and withdrawal reductions."* It is unfortunate this line of reasoning could not be further investigated. It appears obvious the plan to protect the

species of interest and the current use of water for humans will create serious discussion. Further exploring any possibility is warranted considering the circumstances. It is highly recommended the team be able to continue their suggested line of investigation. As with all these studies, there are time limits imposed and more often than not, further work should be carried out.

32. On page 89 it is stated, *"Managing the aquifer in this fluctuating manner may not be good for the species (rapid swings in springflows) or for associated infrastructure (turning wells on and off). Furthermore, these pumping reductions result in long-term flow averages much higher than historical values which may also be detrimental to the species. It is also probably not realistic to bring permit holders in and out of critical period management on a monthly basis. Although less of a cutback at a relatively continuous rate might stabilize springflows, it is not possible to simulate such a scenario with the current management module."* These "real time" operational issues should be addressed in the next phase. The work that has been undertaken to date can only answer so many questions. These operational issues however, are most valid and I agree with the team's assessment. It is the assumption of this reviewer they will be addressed as the plan moves forward.

33. On page 90 the team presents a list of tasks that in their opinion should be carried out, *"...(1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on recharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the*

management module, and (10) refine model calibration between San Marcos and Barton springs." These recommendations are reasonable given there will be intense debate when a plan to protect the endangered species means there needs to be an 80% reduction in pumping. Doing the very best possible science to address the largest areas of uncertainty is reasonable and prudent.

34. On page 91 it is stated, *"Given the proven utility and cost-effectiveness of simulation-optimization models used in studies of aquifers with hydrogeologic characteristics and problems similar to those of the Edwards Aquifer, it is recommended that efforts be undertaken to develop an optimization model of the Edwards Aquifer and apply it toward obtaining a better understanding of (and more-effective management strategies for) the Edwards Aquifer. For example, rather than relying on the laborious, drawn-out process (using minimum springflow constraints) to evaluate the effects of different critical-period trigger levels and percent pumping reductions, a properly designed and calibrated optimization model might have saved the subcommittee significant time and effort toward arriving at the optimum balance among the choices for triggers and cutbacks while maximizing pumping."* This recommendation is most reasonable. It's not certain from reading the report the team had to rely "...on the laborious, drawn-out process...", however, the team has clearly learned a great deal and suggesting to use more appropriate tools is reasonable.

35. On page 92 it is stated, *"The hydrologic modeling analyses done in support of these results for critical period management are based on the climate history from 1947 to 2000. This period of time includes the drought of the 1950s. It would be valuable to know the chance that any one year will experience rainfall deficits at least as severe*

as the worst part of the 1950s drought. Reconstructed climate history based on tree-ring data (Cleaveland 2006) might be used to estimate the frequency of annual rainfall deficits as severe as or worse than those that occurred during the worst part of the drought of the 1950s." Addressing climate change when making flow presents an enormous challenge. This is not unique to this basin, it applies to any basin in North America. A suggestion for the team is they could consider looking at a number of climate change models and once they agree to one that predicts less water in the future, they could calculated the return intervals for whatever time period is most appropriate, e.g., monthly. For example if it was agreed the 1:200 low flow event based on the historical flow regime best describes what climate change could be like then this 1:200 year artificial year can be inserted into the period of record and evaluated.

36. **Tom / Ian / Clair: On page 94 they discuss hydrology and modeling and the incredible complexity of the system (e.g., surface water, groundwater, pumping at various locations from both surface and groundwater). They provide recommendations that all seem reasonable. However, I am not a hydrologist and cannot provide an opinion. (Late Note: Good thing Tom Wesche was added to our group.)**

37. On page 94 it is stated, *"The critical period management module does not accurately model the Edwards Aquifer Authority's rules for reduction of pumping by water rights holders."* There appears to be a critical shortcoming between how the water consumption licences are administered and what it means to flows in the system. It is excellent to point this out to the administrators and legislative authorities. This disconnect between the administration

of water and the desire to respect thresholds is not uncommon and occurs in many basins. The recommendation that *"...the Edwards Aquifer Authority...consider modification of its rules to provide for more immediate responses to critical period management triggers."* is most reasonable.

A Review of

"Technical Assessments in Support of the Edwards Aquifer Science Committee "J Charge" Flow Regime Evaluation for the Comal and San Marcos River Systems"

for:

The Edwards Aquifer Recovery and Implementation Program

by:

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Prepared by:

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Summary

For the sections that I reviewed, I fully endorse the technical analysis and output of the flow dependent characteristics of physical habitat for target aquatic species within the Comal and San Marcos Rivers. The process of assembling a team of knowledgeable scientists with specific experience in the Comal and San Marcos rivers, as well as first hand knowledge on the primary target species, to review all available biological data including the updated modeling results based on refined habitat suitability information for the three target species, Texas wild rice, Comal Riffle beetle, and fountain darter, is to be commended. Using group

workshop settings to seek consensus is to be commended. Carrying out model validation to predict locations of animals against observed locations of animals is considered to be "best practice". Developing influence diagrams for the three target species provided a valuable tool to understand both intrinsic and extrinsic factors that affect the target species. Additionally, considering other factors such as non-native species of plants and animals, parasites, recreation, and anthropogenic impacts due to watershed development shows a depth of investigation that is not commonly seen in similar studies of this type.

The overall approach used in this study is exceptional and the team is to be commended for their efforts. Providing the historical information along with the updated modeling based on new information (temperature and dissolved oxygen) and physical habitat for Texas wild rice, Comal Springs riffle beetle, and fountain darters, demonstrates the improvement to the science.

Combining the physical habitat modeling with the temperature and dissolved oxygen modeling represents the state of the art / science of carrying out these type of studies. The modeling was improved by using empirical data, e.g., vegetation distribution using historical vegetation mapping results.

I find there are no serious flaws or errors in the team's methodology, findings, and recommendations. Assumptions of the approach are well documented and are most reasonable given today's understanding of aquatic ecosystems. The tools and methods of analysis employed, with respect to habitat modeling, are appropriately used based on best available information.

The following are some comments, suggestions and questions for specific issues.

Specific Comments by Section:

1. On page 4 it is stated, *"...a series of workshops involving a multidisciplinary team of biologists ... were held to develop influence diagrams...[to:]*

    - *Help identify where existing modeling efforts could inform key influence diagram linkages*
    - *Direct modifications and/or analysis of the existing modeling work on behalf of Science Subcommittee*
    - *Help identify the potential needs of existing and future biological modeling efforts to best support future Habitat Conservation Plan (HCP) analysis (to extent feasible)*
    - *To help conceptualize and illustrate how spatial, flow-dependent biological modeling inter-relates with other factors*
    - *Provide a framework for use by other EARIP teams in HCP development, and the U.S. Fish and Wildlife Service (FWS) in Endangered Species Act (ESA) analysis"*

    This clearly demonstrates the team identified the outstanding key issues and the creation of influence diagrams was a great means to visualize the complexity of all factors and how existing knowledge could help guide them in the modeling.

2. It is also noted on page 4, that *"Appendix A provides a listing of all comments and submitted influence diagram revisions."* The team is to be commended for keeping a meticulous record of the conversations.

One of the most overlooked tasks is carrying out these type of studies is to "document your logic".

3. On page 14 it is stated, *"It should be noted that continued channel topography changes associated with sedimentation has continued through the present...Movement of these sediments downstream has also altered channel topography and bed material composition...Additional alterations since the revised topography of 2001 was obtained include alterations to the channel structure...Some sensitivity analysis has been conducted on the impact of measured channel changes...and indicates that the primary effect has been scaling the magnitude of the habitat versus flow relationships rather than changing the underlying relationship between flow and available habitat."* It would be helpful to the reader if there were quantitative data provided to verify the channel changes falls within scientific standards to use the channel topography data as a representative site for the river reach.

4. On page 14 it is stated, *"The specific algorithms evaluated were linear krigging, inverse distance weighting, Clogh-Tocher and natural neighbor."*

Tom / Ian / Clair: Perhaps there could be a statement regarding the acceptability of the use of these algorithms versus other commonly used ones such as, the Petrov-Galerkin upwinding formulation, or the Newton-Raphson iterative or Generalized Minimal Residual methods, or the 'Jacobian' matrix, or the Newton-Raphson iteration, or the Gaussian elimination, or Venant and Sabaneev's Equations, and how about the Courant-Lewy-Freidrichs condition?

5. **Tom / Ian / Clair - Note: p 14 - 22 - hydraulic modeling and hydrology assumptions are beyond my ability to comment**

6. **Tom / Ian / Clair - Note: p 22 - 25 - Vegetation Mapping & Hydraulic Modeling - beyond my ability to comment.**

7. **Tom / Ian / Clair - Note: p 25 - 35 - Water Quality Modeling - beyond my ability to comment.**

8. On page 35 it is stated, *"The original work by Hardy et al. (1998), Bartsch et al. (2000) and INSE (2004) ...from collection data over a two year period ... and additional work by Saunders et al. (2001)... Long-term fisheries monitoring data collected by the Edwards Aquifer Authority over the past 8 years ... using the basic sampling protocol developed by Hardy et al. (1998) was utilized to develop updated habitat suitability curves for depth and velocity for fountain darters...the annual Texas wild rice monitoring data collected collaboratively by the Texas Parks and Wildlife Department and USFWS..."* This shows a very open, transparent and collaborative process was used to gather and agree to the development of the Habitat Suitability Criteria (HSC) curves. The team is to be commended for this since the HSC curves are the primary factors that form the habitat versus flow relationships upon which a flow recommendation is ultimate made.

9. On page 36 it is stated, *"The most common approach is to utilize Habitat Suitability Curves (HSC) which parameterize the relative suitability of a factor (e.g., depth) on a scale between 0.0 and 1.0 over the range of potentially useable values. These relationships, when combined with the hydraulic and water quality simulations produce relationships between flow and the quantity and quality of available*

habitat." Normalizing the HSC curves, and resultant habitat versus flow curves is a very common and accepted practice.

10. Pages 36 - 44: HSC Curve Discussion - The overall process of developing HSC curves is good and meets the common accepted practice of the state of the art / science. The amount of data considered is comprehensive relative to many similar type of studies. On page 38 it is stated, *"The technical team reviewed the existing wild rice habitat suitability curves for depth and velocity used in previous studies as well as the existing monitoring data collected over the past decade. This included and examination of the location of persistent wild rice stands within the San Marcos system that were overlaid on the hydraulic model solutions at different flow rates indicative of the long term flow characteristics during the last decade. Based on this review and discussions, habitat suitability curves were revised for use in modeling physical habitat in the San Marcos River."* The combination of modeling data with empirical data which is then thoroughly discussed with all stakeholders represents the best possible way to develop HSC curves.

11. On page 41 it is stated, *"It should be noted that the vegetation suitability curve utilized in all the simulations was based on the original curve developed by Bartsch et al. (2000) rather than the updated curve based on the analysis of the updated data sets. This was due to incompatibility of vegetation types delineated from the original vegetation mapping and different vegetation coding used in the EAS data sets. This will be reconciled during the revised modeling currently underway for both the Comal and San Marcos Rivers using the updated vegetation mapping for both systems."* It is not clear to the reader what the "revised modeling currently underway" is referring to. Will there be

further modeling that will be used by the EAAESS in their current report that is being reviewed?

12. Pages 44 -45 - Physical Habitat Modeling - The modeling approach undertaken by the team is similar to the accepted standard practices for this kind of modeling.

13. **Tom / Ian / Clair - Note: p 48 - 50 DO - no comment - will one of us make comments?**

14. On page 50 it is stated, *"The analysis of Comal Springs riffle beetle relied on a simple calculation of wetted surface area with depths greater than 0.02 feet. The analysis showed no change in total surface area at total Comal River flows between 300 and 150 cfs and then a linear reduction in available habitat below this flow magnitude. Additional simulations were run based on criteria developed from collection data on riffle beetles in the main spring runs as follows as an alternative to the surface area analysis."* There are two approaches discussed. One is a flow versus wetted surface area, the other is based on criteria developed from data in the main spring runs as an alternative to the surface area analysis. It is not clear to the reader if the intention was to demonstrate the second approach is superior to the first approach.

15. On page 59 it is stated, *"These results should be viewed with some caution however, given the known channel changes within the new channel not reflected in the current analysis that includes both topography and vegetation. These results are also cautionary in that the temperature simulations used a spring orifice temperature as the boundary conditions for flows entering the old channel rather than the simulated temperature at the node in Landa Lake where the culvert*

orifice is located. This will be rectified in the updated modeling currently underway." It is not clear to the reader what the "revised modeling currently underway" is referring to. Will there be further modeling that will be used by the EAAESS in their current report that is being reviewed?

16. On page 59 it is stated, *"Overall, the system wide temperature simulations using both mean daily and maximum daily temperatures strongly suggest that as total Comal River flow rates decrease, thermal affects on darter life stages become limiting rather than the amount of physical habitat in terms of suitable depth and velocities."* It is noted this is consistent with similar systems where the upper lethal limit for temperature for native cool water species is more limiting than physical space.

17. On page 62 it is stated, *"Bartsch et al. (2000) did not include dissolved oxygen simulations in their modeling evaluations, nor were they included in subsequent modeling efforts within the San Marcos River. As noted previously for the water quality simulations for the Comal, there is concern for the potential of depressed dissolved oxygen values during night time respiration at very low flows, especially in highly vegetated areas such as Spring Lake and sections of the San Marcos River upstream of Cape's Dam. If possible, this should be addressed in the on-going modeling efforts in support of the HCP."* This is a very reasonable recommendation given that systems that have abundant vegetation experience large diel fluctuations in DO as the daytime water temperature approaches that of the air temperature.

18. On page 66 it is stated, *"As part of the technical team evaluations, the spatial distribution of predicted cell suitabilities were examined on a* *computational cell by cell basis and compared to actual wild rice distributions based on 1989 to 2008 monitoring data at each simulated discharge. Figure 46 shows the section of the San Marcos River in the Rio Vista to Cape's Dam section with the simulated suitabilities for Texas wild rice at each computational cell at a simulated discharge of 65 cfs. The known 1989 to 2008 distribution of plant locations are overlain for comparative purposes (red dots).*

The results shown in Figure 47 for the 30 cfs simulation show Texas wild rice were associated with modeled cell suitabilities primarily below about 0.50 compared to results at 65 cfs, which show a proportional shift with modeled cell suitabilities above 0.50. This shift in proportionally more stands occupying modeled cells with suitabilities greater than 0.50 was observed at all higher flow rates modeled. Observed versus use frequency distributions at flow above 65 cfs are very similar to that reported for 65 cfs while the results for 30 cfs are indicative of the results at simulated flow lower than 30 cfs. This appears to be a systematic bias in the modeling results at lower flows that should be examined in more detail with the revised modeling currently underway. It should also be noted that in the simulations, the current calculations do not take into account if an existing plant species occupies the computational element. Modeling results were also examined for locations in which the simulations predicted suitabilities but were not occupied by Texas wild rice. Over 60 percent of these locations were occupied by native species." This appears to be a discussion on model validation, showing that the various species inhabit those areas the model predicts is of high habitat value and do not inhabit those areas the model predicts is of low habitat value. From the discussion it appears the argument is made that below 30 cfs, Texas wild rice is associated with modeled suitabilities below 0.5, and above 65 cfs, Texas wild rice occupied cells with suitabilities greater than 0.50. It is stated, " *This appears to be a systematic bias in the modeling results at lower flows that should be examined in more detail...*" I agree, it would be highly recommended to undertake more effort to understand why this occurs.

Tom / Ian / Clair: I cannot follow this discussion very well. It seems like the discussion is about classic WUA model validation. What I cannot figure out, is how do you do it for a species that is non-mobile? Or is the flow in the different channels is so stable that is doesn't change at all over the period of record? How does the text on page 66 relate to Fig 47 - low suitability cells were occupied with plants at 30 cfs; at 65 cfs, similar occupancy for low to high suitability except 0.5 which had the most?

19. Page 68 - Fig 46 The scale of the figure is such that it is difficult to see if the red dot occupies a low or high suitability cell at this scale.

20. On page 70 it is stated, *"The simulation results indicate... Texas wild rice habitat begins to decline below approximately 100 cfs and rapidly declines below 65 cfs. Care should be taken not to treat these specific flow rates as an 'absolute' break point given the somewhat large intervals between simulated discharges... revised modeling efforts should utilize a finer scale of flow increments below the long term average to better define these habitat versus flow responses in physical habitat."* This is an excellent suggestion. I agree there should be more simulations to refine the curve in the lower flow range.

21. On page 74 it is stated, *"The average water temperature was always at the upper limit of useable temperatures for the fountain darter, and at a temperature which may impact fountain darter breeding. Field*

observations have shown the slough to become a vegetation-choked backwater area with extremely low flow and elevated temperatures, confirming the modeling result." It is most fortunate to have empirical data to confirm the predictive modeling output. The team is to be commended for bringing these two data sets together.

22. On pages 76 - 83, the sensitivity of simulation results for channel changes and suitability curves was presented. This is an excellent task to have undertaken. It goes above and beyond what is found in similar type of studies.

23. It is stated on page 77, *"It should be noted however, that maximum habitat may in fact occur at flow rates between 65 and 100 cfs and a more refined increment of flow simulations will be utilized in the updated modeling."* This is an excellent suggestion. There should be a finer resolution of flows modeled. I would recommend 5 cfs increments in the 35 to 100 cfs flow range. Given the historic out of stream use of water and the requirements to protect endangered species, the discussion could very well get down to the single digit cfs range.

24. On page 82 it is stated, *"As can be seen, the changes in habitat suitability curves for fountain darter not only changed the magnitude of simulated habitat versus discharge relationship (Figure 51) but also changed the underlying habitat versus flow relationship. As noted previously, this is primarily attributed to the differences in the velocity suitability curve (see Figure 29)."* Agree. The reason is the new velocity HSC curve in Figure 29 is shifted to the left. It shows the model is working.

25. On page 83 it is stated, *"It is cautioned however, that more simulated flows between the 65 and 30 cfs flow range are needed in the revised modeling currently underway to better define where this rapid decline in available habitat begins."* As above, this is an excellent suggestion. There should be a finer resolution of flows modeled. Once again, given the historic out of stream use of water and the requirements to protect endangered species, the discussion could very well get down to the single digit cfs range.

26. Pages 83 - 84 it is stated, *"Assuming that flow regimes are maintained in the Comal River such that spring discharges are maintained to protect the Comal Springs riffle beetle and fountain darters, adequate protection would be maintained...[for the Comal Springs dryopid beetle as for the Peck's cave amphipod, San Marcos Gambusia, San Marcos salamanders]"* This is a reasonable assumption. Given predictive models are unlikely to be developed for such species, the proposed monitoring should validate this assumption.

27. On page 84 it is stated, *"Maintaining adequate spring flow regimes for protection of Texas wild rice and fountain darters will likely contribute to suitable flow and water quality conditions in these downstream reaches."* It is not clear if it is meant the flows will maintain suitable water quality conditions for the Cable's map turtle, or the ecosystem in general.

28. On page 89, a set of recommendations are presented,

" • *The current efforts to remodel by the Comal and San Marcos River systems should be undertaken with a single* *hydrodynamic model. This will allow for easier technology transfer and allow a consistent analysis framework.*

- *It is also recommended that a single water quality model be applied in both river systems for these same reasons. The model should simulate maximum daily temperatures and be applied system-wide for both rivers.*
- *Water quality modeling should consider non-point and point source pollutants to the extent these inputs can be approximated from available data.*
- *Analysis of alternative species beyond the three target species focused on in this report should also be undertaken. The specific species to be included should be determined after an analysis of the existing long-term monitoring data available for both river systems.*
- *Consideration should be given the potential vegetation changes if possible since vegetation responses to flow regime changes are critical to evaluation of available fountain dater habitat.*
- *A quantitative assessment of potential impacts associated with recreation should be considered that includes not only Texas wild rice but other aquatic vegetation.*
- *Analysis of channel topography changes due to fine sediment input should also be considered if possible.*
- *A finer resolution on the number of simulated flows is also important, especially for flow ranges below the average annual flow to better inform decisions on critical flow management.*
- *Refinement in the total Comal River discharge versus specific spring flow rates and flow rates at which specific springs cease to flow should be undertaken.*

- *Texas wild rice habitat simulations should be modified to account for computational cells occupied by other species.*
- *If feasible, system wide substrate mapping in the San Marcos "under" existing vegetation stands should be considered to allow evaluation of non-native plan removal on providing suitable Texas wild rice habitat beyond a depth and velocity evaluation.*
- *Evaluate the potential of including anthropogenic induced turbidity on light attenuation as a function of the longitudinal profile of the river systems and its implication on vegetation."*

All of these recommendations seem reasonable and prudent. Assuming there will be intense debate by the stakeholders regarding water use and the protection of endangered species, further study will help to eliminate uncertainties and guide the decision makers.

"Analysis of Species Requirements in Relation to Spring Discharge Rates and Associated Withdrawal Reductions and Stages for Critical Period Management of the Edwards Aquifer"

Review by Clair Stalnaker

General comments on the report:

Senate Bill 3 charges the subcommittee to (1) evaluate designating a San Marcos Pool, (2) evaluate the necessity of maintaining minimum springflows, and (3) evaluate whether adjustments to drought triggers for San Marcos Springs should be made.

Senate Bill 3 also required the subcommittee to (1) analyze species requirements in relation to spring discharge rates and aquifer levels and (2) develop withdrawal reduction levels and stages for critical period management associated with the species requirements. Given the charge from the Senate Bill 3 the subcommittee did indeed focus efforts on possible adjustments to the withdrawals and stages commensurate with the Edwards Aquifer Management Authority's ongoing critical period management process.

The subcommittee makes a point of stating that this report "can be considered as the beginning of a conversation among scientists, stakeholders, and various agencies on the ultimate management of the Edwards Aquifer to protect the endangered species that rely on the springflow for survival". They further state "One thing is clear, long-term monitoring is essential and further study and research specifically during critical low-flow periods (or simulated critical low flows) are needed to accurately determine the potential impacts to the species".

The subcommittee addressed the charge within the context of a protective flow regime. They interpreted a protective flow regime as one "that will ensure the 'survival and recovery of the species in the wild'". The recommendations did not take the form of recommended flow regimes for maintaining intra- and inter- annual hydrologic variability as is common practice and supported by the Instream Flow Council. Rather the subcommittee was constrained by the legislation to focusing recommendations to triggers for setting withdrawal reductions and pool levels in the San Marcos and Uvalde Pools for use during critical period management.

A subcommittee report submitted in November 2008 concluded; (1) there is not sufficient data to support the designation of a separate San Marcos Pool, (2) minimum springflows are required within the context of a system flow regime for the survival and recovery of each species, and (3) trigger levels for San Marcos Springs should not be adjusted at this time. The 2008 report further concluded that "minimum flows are a necessary part of a flow regime of a given aquatic ecosystem for the protection of its component species, but the maintenance of minimum flows alone is not considered sufficient to maintain a sound ecological environment".

Therefore the reader can conclude that the recommendation presented in this report are intended as interim triggers and levels as a beginning management effort ultimately expected to evolve as more understanding in gained from ongoing monitoring and improved modeling. This appears to be an excellent candidate program primed for adaptive management. The ongoing communications among and involvement of scientists, stakeholders, agencies and the management authority has set the stage and an Adaptive Management Program for the Edwards Aquifer should be considered.

The subcommittee has indeed used the best available science in support of a very narrowly constrained charge. Consequently the report is focused on minimum springflows, specifically identified as two tasks.
Task 1: Analyze species requirements for springflow and aquifer levels as a function of recharge and withdrawal levels, and
Task 2: Develop withdrawal reductions for critical period management associated with the species requirements.

The foundation assumptions adopted by the subcommittee in support of minimum flows within the context of a system flow regime were: "A system flow regime includes low flows which support the survival of individuals for limited periods of time, normal flows which support reproduction within the population, and higher flows that periodically rejuvenate the system".

Task 1 led to recommended long-term, 6-month, and 1-month average flow targets as triggers for determining a 85% reduction in pumping withdrawals. From the discussion presented in the report the subcommittee seems to assume that if the triggers as proposed were used in actual practice for critical period management the resulting flow regimes would maintain hydrological variability and "sustain an overall trend of maintaining or increasing the populations of the threatened and endangered species". This also assumes that "conditions cannot go beyond thresholds necessary for survival of any listed species". This seems hopefull and is not likely to result in increased populations but is a good first step in preventing further degradation of the listed species.

The subcommittee relied heavily on historical flow records to identify long-term, 6-month, and 1-month minimum flow statistics as a basis for maintaining hydrological variability and recommended minimum flow triggers similar these statistics but adjusted (usually to higher levels) based on the available science. The evidence used to further adjust the triggers primarily came from monitoring studies and modeling studies of water temperatures and physical habitat. This supporting biological and modeling evidence was summarized for the subcommittee and presented in the Hardy December 2009 report .The focus was on surface-dwelling species that were known to rely on spring discharge necessary for survival. The other aquifer-dwelling listed species were assumed to be protected if the needs of the surface-dwelling species were met. This assumption appears valid.

Task 2 was assumed by the subcommittee to be "limited to adjusting withdrawal (pumping) reduction levels and stages for critical period management". To meet this objective the subcommittee used an existing numerical groundwater flow model to develop withdrawal reductions and stages by considering different "scenarios" or adjustments. The model used was MODFLOW-NR presently used by the Edwards Aquifer Authority for managing the aquifer. This is a state-of-the-art model and with the recommended improvements to the model and data bases suggested by the subcommittee should become the vehicle for continual reevaluation of the flow triggers and species responses.

.Model runs (simulations) fell into three broad categories: (1) runs at constant pumping, (2) runs to investigate the sensitivity of the model to various parameters and scenarios, and (3) runs to attempt to meet springflow requirements while maintaining the permitted pumping cap recognized in Senate Bill 3. Over 40 different runs were made. After examining numerous model runs the subcommittee developed withdrawal reductions and stages that met or exceeded the flow requirement set for Task 1.

This is a reasonable approach representing common practice for water planning and management. As in all such modeling studies based on historical records the underlying assumption is "that climate and drought in the future will statistically resemble climate and drought in the past". While this is standard practice and provides the basis for time series analyses the committee recognized that evidence from global climate modeling indicates that for the southwestern U.S. the future is likely to become drier. This reinforces the fact that the flow recommendations presented represent the initial steps in maintaining the threatened and endangered species. Undoubtedly these levels and stages will need to be modified in the future supported by ongoing monitoring and updated modeling.

The subcommittee recommended flow and pool stage triggers would reduce pumping during stage I only, for the San Marcos Pool from the present 20% reduction level to 85% reduction and for the Uvalde Pool from the existing 0% reductions to 85% reduction. The model runs evaluated assumed instantaneous cessation of pumping when stage level I triggers were reached.
This was recognized as unrealistic for actual critical period management as pumping could not be stopped instantaneously for several reasons including existing policy that allows farmers to continue pumping after a crop is planted. None the less the subcommittee concluded "that pumping reduction will need to exceed 80 percent to achieve springflow goals during a repeat of the drought of record".

From the discussion presented in the report it is obvious that the subcommittee believes that their interim recommended flow and stage triggers would provide for some improvement in system conditions for the listed species, particularly during period of drought thus assuring survival. This appears to be a reasonable expectation given the background information. However, their stated goal of enhancing the system to allow the listed species populations to increase (recover) is not likely.

The Edwards Aquifer Authority should take these recommendations as initial system management steps and attempt to reduce stage I pumping levels by 80-85% during critical management periods and fund the recommended studies, research and model improvements. Under such a program the listed species should survive. With the kind of cooperation illustrated in these reports andwith interim guidelines set in motion a viable Adaptive Management Program should ultimately lead to sustainable populations for listed species and perhaps recovery toward historical levels. However, full restoration can never expect to be achieved due to the nearly two centuries of human activity and resulting degradation of the system.

Specific comments:

P 26-27- Figure 5 summarizes the rational for the long-term, 6-month, and 1-month average flow minimum recommended levels. These seem reasonable and support the recommendations. It was noted that the darter was extripated from Comal Springs during the drought of 1956 but has survived under favorable conditions since 1975. The historical flow record post 1975 represents the time period since the fountain darter was reintroduced to Comal Springs. In 1984 flows went below 60 cfs for 100 days and below 40cfs for over 40 days (down to 25cfs). This would support the recommended 1-year average of 30cfs but no biological rational is given for allowing the absolute minimum to go down to 5cfs. I do not accept the 5cfs level as supporting the goal for survival and increasing populations of the fountain darter in 'Comal Springs. If maintaining or increasing the populations is the goal then the absolute lowest level should be more like 25cfs rather than 5cfs.

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 is direct contrast to the selected absolute minimum of 5cfs discussed above.

P 30- The subcommittee report makes reference to the flow regime setting as reflecting a conservative mindset. Given the scientific evidence presented these recommendations are somewhat higher than historical statistics (other than the lowest minimum of 5cfs). The very fact that the species are listed indicates that present conditions are unfavorable to survival of viable populations and some improvements are necessary for maintenance. Significant improvements may be necessary for increased populations (recovery). A conservative approach is justified. I feel that the subcommittee's recommendations are not very conservative but should prevent the listed species from becoming extinct during the interim. The subcommittee acknowledges that additional study is needed and the proposed flow regime be revisited as more accurate information on species becomes available.

P 48-50- It is obvious that recreation use of the river is having an impact on wild rice and other aquatic vegetation. Some control measures will need to be developed.

P 61-Figure 19 summarizes the rational for the long-term, 6-month, and 1-month average minimum flow recommendations. The rational seems to be well supported. The subcommittee chose to exceed the historically observed flow statistics at San Marcos because of uncertainty associated with stochastic events wiping out 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.

P 66-68- The subcommittee's recommendations for future study are certainly on the mark for 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.

P 69- The subcommittee assumed that Task 2 was "limited to adjusting withdrawal (pumping) reduction levels and stages for critical period management". The subcommittee used an existing numerical groundwater flow model to develop withdrawal reductions and stages by considering different "scenarios" or adjustments. After examining numerous model runs they developed withdrawal reductions and stages that met or exceeded the flow requires set for Task 1. The model was MODFLOW-NR that is presently used by the Edwards Aquifer Authority represents the state-of-the-art and is appropriate for evaluating Task 1 minimum flows and stages.

P 71- Model runs (simulations) fell into three broad categories. Over 40 different runs were evaluated with various assumptions and sensitivity analyses. This was a most useful exercise that illustrates how the present management the model can be is used for listed species protection.

P 85- The recommendations would reduce pumping only during stage I. Changes in other stages were not evaluated due to lack of time. Further such evaluations were recommended in the future and are needed.

P 90-95- The subcommittee has identified further studies needed to (1) improve springflow measurement, (2) conduct sensitivity analyses, (3) run optimization models, (4) estimate the probability of recurrence of the 1950s drought, (5) evaluate the potential effects of climate variability on discharge, (6) conduct additional runs to refine withdrawal reductions, (7) update the model, (8) refine the calibration of the model, (9) enhance the management module, and (10) refine model calibration between San Marcos and Barton Springs. These recommendations are well thought out and appear to be consistent with modern scientific thought 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 waster quality and physical habitat modeling and guidance for addressing seasonal and interannual variability through improvements in modeling and time series analyses are outlined in my review of the Hardy 2009 report. The continued integration of these modeling efforts as improved by ongoing and future monitoring should provide a firm foundation for a viable Edwards Aquifer Adaptive Management Program capable of producing conservation plans in support of the Endangered Species Act.

"Technical Assessments in Support of the Edwards Aquifer Science Committee "J Charge" Flow Regime Evaluation for the Comal ad San Marcos River Systems"

Review by Clair Stalnaker

General comments on the report:

The gathering of experts and development of conceptual models as illustrated via influence diagrams for each of the species of concern is to be commended. This represents excellent communication among the stake holders and led to an agreed upon focus for analyses. Appendix A provides a permanent documentation of the deliberations and influence diagrams developed by the group. One important biological feature that should have more focus as the system planning and management advances is the timing of life stage events for the important surface dwelling species. This should focus both the monitoring and modeling efforts as species respond in time and space to flow and resulting physical habitat and water quality.

The report emphasizes that it is to provide support to the Science Subcommittee and does not make specific flow recommendations. That however this does not preclude providing guidance to the committee through illustrative analyses as was done. I would suggest that future guidance emphasize the timing and duration of hydrology driven events and associated species life stage development and population response.

More attention should be focused to the spatial distribution of suitable conditions including the timing and duration of these conditions in the system. This includes all aspect of the hydrology, water quality, physical habitat and species life histories.

It appears that the hydrology analyses driving the Physical Habitat and Water Quality modeling as well as the Hydrology analyses central to the Expert Science Subcommitee for the Edwards Aquifer Recovery Implementation Program were separately developed. For continuity all analyses should be based on the same underlying description of the system hydrology. How the flow is partitioned among the different springs and routed through the system is not only critical for obtaining realistic representations of the hydrology but is also the primary driver of the water quality and physical habitat models. Because each discipline tends to work independently the notion of being forced to agree on a common description and model representation of the system hydrology **before** the different analytical analyses are conducted remains a central issue for more holistic views of river systems. I have become convinced after reviewing many similar programs that the lack of a common description of the hydrology through time and space is the **primary** excuse for not conducting time series analyses of water quality and physical habitat followed by the identification of potential bottlenecks to species life stage development and population viability. The illustration of these types of analyses of spatial distribution and timing can provide a basis for identifying critical limiting events as bottlenecks to healthy life stage development for aquatic species. Such analyses in support of the Scientific Subcommittee should be pursued.

A positive indication from the reports is that the Edwards Aquifer Program appears to be philosophically open to continued monitoring, data collection and modeling to advance understanding for planning and management of the system. This suggests possible movement toward "Adaptive Management".

The report goes to considerable detail for calibration and verification of the water quality model. This is laudable and represents standard practice in this discipline. However similar verification for the hydrodynamic modeling is not given. This is essential as the velocity distribution predictions are critical input to the physical habitat simulations. Proper calibration and verification must become standard practice for stream physical habitat analyses. Controversy continues over the use of such models for biological analyses. See National Research Council (2008) for a through discussion of formulating and applying models in ecosystem management.

Specific comments:

P 14- It is noted that a flood in 1998 altered the channel geometry and greatly affected the vegetation of the San Marcos River. Analysis of subsequent cross sectional data was judged that "the channel changes could potentially impact modeling results enough to warrant remapping of channel topographies". Later in the report analyses illustrate a scale change in the flow/physical habitat relations but little change in the overall shape of the relation. However, the scale is very import when conducting time series analyses. As the program progresses it would be important to periodically update the data base by resurveying the topography when significant change is evident from episodic driven but less intensive sampling. Likewise is the need for remapping the distribution of vegetation over time. As the time series is put together the different channel topographies and vegetation distributions would be entered into the data base at appropriate intervals to represent the channel for specific time periods in the series.

P 18- How does the partitioning among springs from Brune (1981) compare with the hydrology analyses discussed in the "J Change" report. It is very important that the same description of the system hydrology, including partitioning among spring flows and routing water through the system, be used for all water quality and physical habitat analyses.

P 29- The last paragraph refers to assumptions made to adjust flows. Such assumptions must be common for all flow based modeling input to obtain consistent understanding across disciplines of the system response.

P 30-31- The presentation of calibration and verification data for the water quality modeling as illustrated in Fig.23 represents the long established practice among water quality experts. This must also be included for the hydrodynamic (hydraulics) models. Also noted here is reference to modeling DO. Later in the report emphasis is placed on needing to know if DO depletions may occur during the night time. These water quality models are useful for such analyses of diel predictions by season and climatic condition and should be used for such examination.

P 35- Here and other places in the report identify the importance of aquatic vegetation as habitat features for darters. Habitat suitability criteria for these vegetation types should also be developed and included for future modeling exercises.

P 38-39- The differences between USFWS/USU and TPW HSC would obviously yield significantly different physical habitat simulations used in time series analyses. Improvement in HSC based on professional judgment should be verified with presence/absence analyses as illustrated later in Figure 46. Future modeling efforts should compare model output with field observations of wild rice distribution and the models "calibrated" to attain agreement with field observations. See further discussion of this issue below for pages 67-68. F

P 44- Not clear throughout the report just where velocity was simulated. Here for "fountain darters, the velocity at six inches (15cm) above the bottom was also evaluated…" For each figure it would be helpful to designate where in the water column the velocity is computed.

P 50- Comal Springs riffle beetle analysis relied on a simple calculation of wetted surface area with depths greater than 0.02 feet. However, the equation on page 45 indicates a suitability value of 1.0 for depths <0.02 feet.

P 52- 59- It is obvious that temperatures are limiting to darters in Comal River. Dramatic reduction is seen in darter physical habitat suitability by flow reduction from 40 cfs to 10 cfs. Suitability is even very low at 40 cfs. Presented data and figures indicate that as flow rate decreases, thermal effects on darter life stages becomes more limiting rather than the amount of suitable physical hydraulic based habitat. One statement indicates that this thermal effect results in potentially reduced larval survival. Here is one of the few times the report emphasizes life stage events. As the program matures such attention to the timing and duration of potentially limiting life stage events on species of interest should become routine practice. Time series of maximum daily water temperature distributions through the system by season (under simulated ambient air conditions representing hot, normal, and cool years) would be most informative.

P 62- Here the need for modeling DO is stressed and should be included in future modeling.

P 67-68- Figures 45 and 46 are useful to illustrate the value of physical habitat modeling through time and space. Such analyses start with the need for converting hydrologic time series data to habitat time series and the presentation of habitat duration plots representing the total system as well as specific reaches. In Figure 45 the flow/habitat relation is curvilinear. Typical for this kind of relation any time series analyses and duration plots for system hydrology and physical habitat would be quite different. In these cases (really all cases) it is important to translate the hydrology time series into physical habitat time series and subsequent summations and duration plots. When searching for potentially limiting habitat events this conversion is necessary. Figure 46 is an excellent way of presenting model results with actual field observations and should become standard practice in complex systems with high water use and where maintenance or even recovery of aquatic species is the goal. With system wide analyses driven by time series illustrations of the distribution of highly suitable physical habitats by season and year can be produced. With this information the biologist can start teasing out potential limiting events (and duration) that influence species life stage development and population response. Once these life stages and the timing and duration of limiting events become obvious management schemes can focus on control of water diversions and pumping to maintain areas and timing of highly suitable physical habitat conditions at appropriate seasons and places (even improving the extent and duration of suitable conditions if recovery or restoration is the goal). Excellent first step are presented in this report illustrating model use. Following suitable physical habitat time series study and identification of potential limiting events the most appropriate comparison of field observations on species distribution would be with those simulated conditions and areas shown to be most favorable during critical life stage events. For wild rice study good correlations with actual field observed distributions would be very unlikely at the discharge and quality conditions found at the time of field observation. Rather it is most likely that past events and duration have greater influence on the observed distribution. One would expect a much greater correspondence with areas experiencing repeated and sustained highly suitable conditions This can only be illustrated via time series simulations. Incidentally, these types of analyses are equally important when applied to the fish populations.

P 82- Figure 55 differences between "old HSC" and "new HSC" are quite dramatic and illustrate the significant changes in suitable physical habitat area that may occur between 40 cfs and 150 cfs. To maintain or enhance conditions for the darter populations through time series analyses of past habitat conditions the analyst determine **when** (seasons and years) and **where** (reaches having highly suitable as well as stable conditions with longer duration at critical times) physical habitat conditions occurred that had the potential for supporting healthy populations. From a management perspective the important question often becomes: can those conditions be maintained or even improved with similar timing and distributions in the future? The converse is equally true for identifying conditions of most unsuitable physical habitat conditions. Can the timing and duration of unsuitable events be reduced? Fine tuning HSC to these species distribution plots is the preferred way for calibrating and verifying suitable physical habitat mode output.

P 88- Impacts of recreation on sediments, turbidity and aquatic vegetation obviously need additional research leading to possible control.

P 89- These recommendations are all most pertinent and if followed should lead to improved understanding of system limitations and species distributions and trends over time. The statements recommending using the same water quality model in both systems is right on. Of equal if not even greater importance is the use of the same model for describing the hydrology of the systems for all analyses within each system. This description of the system hydrology and distribution over time and space should be the common input to the water quality and the physical habitat modeling. Finer resolution of simulated flows is best brought about through calibration and verification of all modeling efforts (hydraulic, water quality physical habitat). Verified models are more believable by stake holders when simulated conditions diverge from the sampled input conditions. This is critical for time series analyses of past conditions.

When accompanied by improved (through additional data collection, calibration, and verification) modeling efforts for flow distribution through time and space and coupled with water quality (temperature and DO at the least) and physical habitat future system modeling efforts can provide valuable support for an "adaptive management approach' undertaken by the Edwards Aquifer Program. Important first steps toward a viable Adaptive Management Program are presented in this and the "J Charges" report. As long as the stakeholders and management agree to periodic (2-5 year) updates of the data bases along with repeated model runs the program should reach a common understanding of limiting conditions and consensus on what would be necessary to protect or even enhance system conditions allowing recovery of the T & E species. However agreeing on actual implementation measures to achieve protection or recovery may be difficult or even not physically possible and/or politically unacceptable.

It is important to remember that good science can lead to common understanding and agreement on the conditions that are controlling the biological response of species and populations of concern. Disagreements may well arise over management measures and the political will to implement control over water use. An adaptive management program should move away from disagreements over the science and help focus discussion toward understanding potentials for protection by preventing further degradation (or even enhancing) by addressing the limiting system conditions found to be critical for maintaining viable species populations.

This report represents a good beginning for building a collaborative understanding of the ecology of the system.

References;

National Research Council. 2008 Hydrology, Ecology, and Fishes of the Klamath River Basin. The National Academies Press. Washington, DC

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23 April 2010

TO: Tom Annear
FROM: Tom Wesche
SUBJECT: Comments on Hardy report entitled, ATechnical assessments in suport of the Edwards Aquifer Science Committee AJ Charge@ flow regime evaluation for the Comal and San Marcos River systems@.
COPIES: Ian Chisholm, Claire Stalnaker, Allan Locke

As you requested, I have reviewed the Hardy report and offer the following comments:

General Comments:

1. Overall, I found this report to be a valid, defensible, science-based presentation of what is known regarding the physical habitat-flow relationships of the target species (fountain darter, Texas wild rice, Comal Springs riffle beetle) in the San Marcos and Comal Rivers. As such, the report presents a solid basis for describing these aquatic ecosystems and a valuable contribution to the Science Subcommittee for developing spring flow recommendations for these streams.

2. Strengths of the study are many and include 1) the updating and revision of habitat suitability curves (HSC) for the target species where new data were available, 2) the use of workshops with recognized species and river experts to generate influence diagrams for each target species and assist with HSC revisions, 3) the use of 2-dimensional hydraulic modeling, including development of water velocity adjustments based upon species-specific vegetation roughness, 4) the inclusion of water temperature and dissolved oxygen concentrations in the development of flow-habitat relations, where applicable, and 5) the identification of important research needs and management issues that need to be addressed in the future.

3. I recommend that future study of these flow-habitat relations include consideration of additional species life functions and stages (e.g. fountain darter spawning/incubation), seasonal variation in flow regimes and habitat availability, and time series analyses to compare habitat provided by different flow regimes and assist in identifying flow-related habitat bottlenecks.

Specific Comments:

1. On p. 11, Figure 10 (and others), are channelization and urban encroachment also influencing factors?

2. On p. 18, is it satisfactory to assume the flow splits of Brune (1981) are still valid just because no response was received from reviewers? Is there field evidence to suggest these should be validated almost 30 years after they were first reported?

3. On p. 24, how does Manning's n vary by season with changing vegetation size and condition?

4. On p. 25, 1st paragraph, the resultant velocities from the 2-D model are still modeled values, not actual values, whether they are adjusted by the velocity ratio or not.

5. On p. 25, the modeling exercise using maximum dissolved oxygen values would likely have been more meaningful had minimum or daily average values been used. Also, since an optimum temperature range was defined for fountain darters, it would appear that modeling minimum temperature values might also be insightful, especially if seasonal analysis were to be undertaken.

6. On p. 37, top 2 paragraphs, if flowing water is important for survival of beetles, why was just the depth criterion (<0.02 ft) used for habitat modeling? In 4th paragraph, has sufficient information been gathered over the years to develop a relationship between wild rice presence or abundance and turbidity? If so, could this be incorporated into the habitat modeling analysis for wild rice? Also, has nutrient loading been investigated?

7. On p. 39, Figure 27, the extension of optimum water velocity (SI = 1.0) leftward to 0.25 ft/s does not seem to be supported by the 1996 and 1933 observations discussed in the text. Further explanation for this curve modification is needed.

8. On p. 42, Figure 29, is this HSC curve for mean velocity or velocity near stream bed?

9. On p. 45, 1st paragraph, the equation for riffle beetle should be A1.0 for depths > 0.02 ft@ based on the discussion in the text.

10. On p. 46, how does water temperature vary seasonally, and if such variations exist, how do they influence physical habitat quality and availability?

11. On p. 48, the discussion of DO limitations in the last paragraph emphasizes the need to include minimum DO levels in the habitat modeling exercise.

12. On p. 50, 4th paragraph, the use of a limiting factor approach for DO is good, but ignoring