Technical Memorandum

Recommendations for Development of the Ecological Modeling Work Plan

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The Edwards Aquifer Habitat Conservation Plan (HCP) states:

> *The EAA will oversee and retain a contractor to develop a predictive ecological model to evaluate potential adverse ecological effects from Covered Activities and to the extent that such effects are determined to occur, to quantify their magnitude. The model results will help the Applicants develop alternative approaches or possible mitigation strategies, if necessary.*

Following initial work plan development, a two-day ecological modeling workshop was conducted in August to receive input from a panel of experts regarding the best model(s) or methodology to use to meet the purpose and objectives of the HCP ecological modeling measure. This Memorandum outlines the background for this work plan element, summarizes the ecological modeling workshop findings, identifies key ecological questions, provides a cursory review of existing data/models and offers specific recommendations to the Science Committee on proposed 2013 work plan development.

Background

The HCP specifies two primary purposes for including a predictive ecological model in the Adaptive Management Plan (AMP) and three objectives associated with each as follows:

1) Identify and describe specific ecological responses:
   - to predict specific ecological responses of the Comal and San Marcos Springs/River ecosystems and associated Covered Species to various environmental factors, both natural and anthropogenic;
   - to assist in establishing potential threshold levels for these ecosystems and associated species relative to potential environmental stressors; and
   - to assist the overall scientific effort to better understand the interrelationships among the various ecological factors affecting the dynamics of these ecosystems and associated species.

2) Quantify, predict, and project impacts:
   - to assist in identifying and quantifying the effects of various environmental factors, including groundwater withdrawal, recreation, parasitism, restoration, etc. on ecological changes in these ecosystems and associated species;
   - to project long-term effects of the Covered Activities on these ecosystems and associated species to facilitate designation of Phase II biological goals and strategies for achievement; and
   - to assist in mitigation design, implementation, and monitoring, where applicable.

Throughout the HCP, the importance of data collection and coordination amongst each measure is highlighted relative to incorporation into ecological models, where appropriate and practical. This data collection and coordination will be particularly important for the following HCP Measures: applied research, native aquatic vegetation restoration and monitoring, gill parasite monitoring and control, expanded biological and water quality monitoring, non-native species control and monitoring, and Texas wild-rice restoration and monitoring.

Work Plan Development Process

Following initial work plan development, a panel of experts was invited to participate in an ecological modeling workshop to facilitate discussion on models/tools/methodologies/processes that might be applicable to meet the goals and objectives of the HCP ecological modeling measure. A two-day meeting was held at the Edwards Aquifer Authority (EAA) on August 28-29, 2012. The expert panel consisted of:

George Ward, University of Texas at Austin
Bill Grant, Texas A&M University
Anthony Starfield, Retired, formerly from the University of Minnesota
Terry McLendon, Texas Tech University
Mac McKee, Utah State University

Ed Oborny (BIO-WEST) and Thom Hardy (Texas State) also participated on the panel. Also in attendance at the meeting were:

Jose Hidalgo	Melani Howard	Nathan Pence	Chris Abernathy
Jenna Cantwell	Robert L. Gulley	Geary Schindel	Jim Winterlie
Franziska Giger	Marcus Gary	Kevin Connally	John Waugh
Steve Bereyso	Ken Diehl	Chad Norris	Doyle Mosier
Steve Raabe			

At the conclusion of these discussions, the expert panel made the following recommendations:

1. Use Simple Models to Identify Knowledge Gaps and Understand Existing Data.
Begin the process by identifying a finite number of key questions to be answered. For each question identify the state of knowledge and identify models that have been or may need to be developed. Analyze how those models have been used to guide the next step in the direction of answering the questions. Recommendation #1 will be satisfied when, for each of the key questions, you can articulate the possible range of answers (at this stage), the prioritized steps that need to be taken to improve the answers, and what you can expect to gain in predictive capability, as you add more and more complexity to the models.

2. Comprehensive Data Management and Computation Framework
In parallel with the first step, decide if a comprehensive data management and computation framework is necessary by evaluating prototypes (simple models) and assessing data holdings. Such a framework would have the capabilities to handle the mathematics of solving coupled models, and to transfer data and model results among the components. Capability for versatile and cogent graphical output will be helpful in communicating with stakeholders.

3. Data Mining
As part of the initial step, formulate specific questions and have existing data reevaluated to determine if the answers can be identified from existing data. Such a reevaluation may involve approaches such as those discussed by Dr. McKee.

4. Integrative Complex Ecological Model
When sufficient information is obtained through Recommendation #1 regarding the efficacy of the prototypes (simple models), decide if an integrative complex ecological model or series of linked simple models would be useful. If the former, formulate a list of necessary attributes such a model must have to employ in reviewing available software.

Following the workshop, EAA contracted BIO-WEST and Dr. Thom Hardy to 1) identify and articulate key ecological questions, 2) provide an overview of the state of knowledge for Covered Species specific to those questions and identify models that have been or may need to be developed or modified, and 3) provide recommendations for proceeding with the Ecological Modeling work plan.

As part of completing these tasks, a public meeting to solicit input was held October 24th, 2012 at the Meadows Center for Water and the Environment. The meeting was attended by the following individuals:

Thom Hardy – Texas State University	Ed Oborny – BIO-WEST
Ken Diehl – SAWS	Jose Hidalgo – Public
Cinde Jimenez – GBRA	Glenn Longley – Texas State University
John Waugh – SAWS	Jenna Cantwell – EAA
Janelle Baca – SeaWorld	Annalisa Aguirre – SeaWorld

After a brief introduction by Ed and Thom, the proposed process for development of the 2013 work plan for the ecosystem modeling was discussed by the group and although no specific technical approach(s) were provided, everyone appeared in agreement that the process as described for moving forward was sound.

In conjunction with the HCP Science Committee meeting on November 29th, 2012, a second public meeting specific to ecological modeling was conducted. Comments from the second public meeting were incorporated to the degree practicable in this final memorandum. Additionally, written comments solicited at the November 29th meeting are presented in an attachment along with responses to each.

Key Ecological Questions

The over arching scientific question throughout the development and upcoming initial implementation (Phase 1) of the HCP is, "***Does the HCP provide sufficient protection to promote the survival and subsequent recovery of the Covered Species in the event of a repeat of the 'drought of record'?***" The expert panel emphasized that to most effectively address this broad question, it must first be broken down to more specific and targeted questions. The HCP and supporting technical studies identified several key ecological questions related to the efficacy of the long-term biological goals and flow-related objectives in relation to the modeled flow regimes and management actions under a repeat of the drought of record (see HCP Section 6.3). The first set were identified in terms of Tier A, B and C research questions (see Section 6.3.4.2) as follows:

<u>Tier A</u>

1. Low-flow effects on native aquatic vegetation
2. Low-flow effects on macroinvertebrates
3. Effects of flow levels on Comal Springs riffle beetle movement
4. Extended Low-flow period effects on Comal Springs riffle beetles
5. Test spring run connectivity

Tier B

1. Low-flow effects on fountain darter movement, survival, and reproduction
2. Low-flow effects on Comal Springs riffle beetle survival and reproduction

Tier C

1. Testing repeat occurrences of low-flow or combination of effects
2. Ecological Model Validation

Although these three Tiers were identified within the Applied Research section of the HCP, they in fact represent an integrated set of questions that are critical elements or functionality of the proposed Ecosystem Model in terms of its assessment focus:

1. (EQ1) What will be the response/dynamics of native and key nonnative aquatic vegetation during extended periods of low flow followed by increased flows as projected under the HCP?
2. (EQ2) What will be the response/dynamics of the aquatic macroinvertebrate community to potential responses/dynamics of the aquatic vegetation during the projected flow regimes of the HCP?
3. (EQ3) What will be the response/dynamics of fountain darter populations relating to growth, survival, and movement during projected flow conditions as anticipated under the HCP during a repeat of the drought of record?
4. (EQ4) What will be the response/dynamics of Comal Springs riffle beetles to projected flow conditions as anticipated under the HCP during a repeat of the drought of record?

Additionally, there are key ecological questions that extend outside of the Applied Research component but are directly addressed within other HCP measures (see HCP Sections 6.3.4.3, 6.3.5, and 6.3.6) and are critical to the Ecosystem Model:

5. (EQ5) How successful will native aquatic vegetation restoration (Section 6.3.4.3) and Texas wild-rice enhancement (Section 6.3.5) be?
6. (EQ6) What will be the response/dynamics of gill parasites and nonnative host snails (Section 6.3.6) to projected flow conditions as anticipated under the HCP during a repeat of the drought of record?

Finally, a key ecological question relates to the cumulative effects of multiple components of the questions asked above regarding the fountain darter:

7. (EQ7) What will be the response/dynamics of fountain darter populations relative to aquatic vegetation, macroinvertebrate, gill parasite, and nonnative species reactions to projected flow conditions as anticipated under the HCP during a repeat of the drought of record?

These seven questions form the foundation for ecological modeling activities to be conducted during the initial years of Phase 1 of the HCP. They are consistent with the direction of the HCP and directly address the fountain darter, Comal Springs riffle beetle, and Texas wild rice while indirectly assessing habitat for the San Marcos salamander. Other factors such as nonnative animal species interactions, recreation, pollutants, and others will undoubtedly be examined during Phase 1 to the degree practical, but are not recommended at this time given the higher priority questions identified above. Additionally, it is anticipated that cumulative evaluations regarding other Covered Species beyond the fountain darter and Texas wild rice will also be addressed during Phase 1, but are deferred to subsequent years with guidance provided through the adaptive management process.

Data/Model Review and Recommendations[1]

EQ1 – Aquatic Vegetation Response/Dynamics

Submerged aquatic vegetation provides extremely important habitat for the endangered fountain darter. Therefore, understanding factors that influence aquatic vegetation growth and reproduction is critical to maintaining fountain darter populations. We acknowledge that Texas wild rice does provide habitat for fountain darters but to be consistent with HCP Section 6.3.4.2, this task relates specifically to other native and nonnative aquatic vegetation and their ability to support fountain darter populations. Question EQ6 includes a detailed analysis of Texas wild rice consistent with HCP Section 6.3.5.

A complete delineation of the aquatic vegetation composition and distribution within the Comal and San Marcos rivers was completed in 1998, 1999, and 2000 by Dr. Robert Doyle and repeated approximately a decade later (2009) by the Meadows Center for Water and Environment. A repeat of a complete mapping effort for both systems will be conducted in early 2013 and every five years thereafter as part of the expanded Variable Flow study for the HCP. Additionally, from 2000 through 2012, all aquatic vegetation within four representative study reaches on the Comal River and three on the San Marcos River have been conducted over approximately 30 times and will continue during comprehensive and critical period HCP monitoring. As such, a wealth of aquatic vegetation data over time is available.

Modeling of physical habitat for aquatic vegetation species in the San Marcos and Comal rivers has been conducted over the past two decades (e.g., Saunders et al., 2001; Hardy et al., 2011; Owens et al., 2011). These efforts have primarily focused on the spatial distribution based on depth, velocity and substrate. Hannan and Dorris (1970) provides some key insights to aquatic vegetation succession, community level respiration and potential carrying capacity in the San Marcos River. Supporting physical and water quality data is provided by Hardy et al., (2011) that includes the complete channel topography of the San Marcos and Comal River systems at 0.25 meter resolution, calibrated two-dimensional hydrodynamic models of both systems, and calibrated hourly water temperature models for both systems.

Additionally, a specific laboratory evaluation (BIO-WEST 2004) was conducted to evaluate the effects of varying spring flows and resulting water quality parameters on the growth of several aquatic plant species which occur in the Comal and San Marcos rivers. This study was conducted in two phases. In the first phase, *Vallisneria sp.* and *Ludwigia repens* plants in outdoor raceways were exposed to varying flows of Edwards Aquifer water. Under each flow level water quality parameters were closely monitored and growth of both species was measured at the end of the study and compared between treatments. In the second phase, flow levels and temperature were held constant, and carbon dioxide (CO_2) concentrations were manipulated between treatments to examine effects on growth of Texas wild-rice, *Ludwigia repens*, *Vallisneria sp.*, *Hydrocotyle umbellate*, *Riccia sp.*, and *Amblystegium sp.*

In 2013, HCP Applied Research includes three studies directly related to addressing EQ1 and informing the ecological modeling task:

[1] Appendix A provides a reference list of articles reviewed and screened by Dr. Hardy as supporting background material to recommendations

- Laboratory versus field comparison of flow conditions for native and non-native aquatic vegetation.
- Closed system pH drift experiment to evaluate bicarbonate utilization of *Hygrophila*, *Ludwigia*, *Sagittaria*, and bryophytes under CO_2-stressed conditions.
- Low-flow thresholds evaluation of native and non-native aquatic vegetation conducted in aquaria and ponds.

Additional detail on these studies is provided in the HCP work plans.

Independent of the HCP, the U.S. Army Corps of Engineers (USACE) Aquatic Plant Control Research Program at the Waterways Experiment Station has developed several mechanistic models of key aquatic vegetation species that are present within the Comal and San Marcos river systems. Of particular note, simulation models for the biomass dynamics of four common freshwater Submerged Aquatic Vegetation (SAV) species have been developed over the last decade, i.e. for *Hydrilla verticillata* (hydrilla; dioecious biotype) – HYDRIL, monoecious *Myriophyllum spicatum* (Eurasian watermilfoil) – MILFO, dioecious *Vallisneria americana* (American wildcelery)-VALLA, and monoecious *Potamogeton pectinatus* (sago pondweed)-POTAM (Best and Boyd 1996, 1999a, 1999b, 2001a, 2001b, 2003a, 2003b, 2003c, Boyd and Best 1996). These models can be used to simulate plant biomass over a 1- to 5-year period and include equations describing vegetation responses to current velocity and riverine epiphyte cover, to accommodate daily changes in water level, and they were recalibrated by the addition of species-characteristic values for the plant responses. In addition, Best et al., (2004) developed a simulation model for light competition using *Vallisneria* and *Potamogeton*. This suite of models is public domain, has a solid application history and is adaptable for use in the Comal and San Marcos River systems.

Recommendation – Close coordination with the three applied research efforts targeted for completion by late summer 2013 is recommended. We recommend that the existing USACE models described above be applied to the Comal and San Marcos rivers using the available aquatic vegetation monitoring data and hydrodynamic models to assess calibration and validation characteristics. The endpoint is a model or models that can assess the response/dynamics of native and key nonnative aquatic vegetation during extended periods of low flow. Coordination with resident experts including Ms. Jackie Poole (TPWD) and Dr. Robert Doyle (Baylor University) is also recommended.

Schedule – Data analysis and Model development to be initiated in 2013.

EQ2 – Aquatic Macroinvertebrate Response/Dynamics

Long term aquatic macroinvertebrate monitoring data outside of the spring runs and upwelling environments at Comal Springs is limited for the San Marcos and Comal river systems. At Comal Springs, drift net surveys within spring runs, along the western shoreline of Landa Lake, and at upwelling areas around Spring Island have been conducted since the inception of the Variable Flow Study in Fall 2000. However, those efforts have focused on the three federally listed Comal Springs invertebrates and have only involved sampling over open substrates. Sampling efforts in dominant aquatic vegetation types within the Variable Flow study representative reaches on both systems will be initiated twice yearly in 2013 as part of the expanded HCP biomonitoring protocol.

Additionally, one applied research study to evaluate the effects of low-flow on macroinvertebrate populations within select aquatic vegetation types is slated for completion in 2013. The HCP highlights amphipods as a key fountain darter food source and thus, they are proposed for applied research in terms of responses to vegetation dynamics.

Although extensive literature exists on the development of indices of biotic integrity primarily oriented toward assessment of pollution in rivers, some work on predictive modeling is available. Schleiter et al., (1999) utilized nueral networks to evaluate the relationship between water quality, bioindication and population dynamics in lotic ecosystems. Dalou et al., (2006) utilized artificial neural networks for predicting macroinvertebrate taxa. Park et al., (2003) used artificial neural networks to assess patterns and prediction of aquatic macroinvertebrate diversities. Goethals (2005) examined data driven development of predictive ecological models for benthic macroinvertebrates in rivers.

Recommendation – Given the lack of suitable data to guide a specific modeling approach we recommend that a literature review be undertaken to identify the most parsimonious modeling approach for predicting aquatic macroinvertebrate responses to changing physical, chemical and biotic (i.e., aquatic vegetation dynamics). It needs to be emphasized that the literature review proposed focuses on modeling approaches and life history parameters that may have potential for modification to HCP specific applications, including general life histories of communities or individual macroinvertebrate species. Based on this literature review, data collection activities and applied research conducted under separate HCP measures in 2013, recommendations should be formulated for future modeling activities, applied research, and biomonitoring to ensure that the relevant data for model calibration and validation are being collected. Coordination with resident experts including Mr. Randy Gibson (USFWS NFH&TC) is also recommended.

Schedule – Literature review and modeling recommendations in 2013.
Data analysis and Model development to be initiated in 2014.

EQ3 – Fountain darter Response/Dynamics

Critical life history information for fountain darters is fairly well developed and long-term monitoring data and habitat association information is readily available, including physical habitat models based on depth, velocity, substrate and vegetation type (e.g., Schenck and Whiteside, 1976; Chulick 1995; Bonner et al., 1998; Bartsch et al., 1999; Saunders et al., 2001; McDonald et al., 2006; Hardy et al., 2011; including the 2001 to present EAA annual Variable Flow Study results, BIO-WEST 2001-2012).

Dr. Miguel Mora and Dr. Bill Grant (Department of Wildlife and Fisheries Sciences – Texas A&M University) and colleagues have developed a compartment model for fountain darters that specifically targets key physical and biological factors affecting fountain darter population dynamics under scenarios of reduced spring flows that could occur as a result of a drought (Mora et al., 2012) . The model is an age- and sex-structured population model for the fountain darter and was nominally calibrated within the constraints of published parameter estimates such that populations simulated under historical spring flows resembling those documented in the field from 1973 to 2007. The existing model which is not spatially explicit is adaptable to incorporate the high resolution spatial data and water temperature models (i.e., 0.25 meter resolution hydrodynamic models and hourly temperature simulation model for the San Marcos and Comal rivers available from the Meadows Center for Water and the Environment) and can be linked to the output of the aquatic vegetation models (see above) (Grant, personal communication, November 2012).

Basic compartment models were constructed from the EAA Variable Flow data set and used in the HCP for an assessment of potential take. These existing models linked average densities of fountain darters per aquatic vegetation type and examined how changes in vegetation over time affected normalized population estimates. Several major assumptions were made regarding suitability and potential impacts in order to conduct that initial analysis. The information from this latter set of compartment models will be examined and used to the degree practicable, but it is anticipated that the spatially explicit linkage of fountain darter populations with aquatic vegetation will likely be accomplished via another more sophisticated approach.

Recommendation – Based on the wealth of existing information regarding fountain darters and associated habitat, we recommend that the available fountain darter, aquatic vegetation, and water quality data be data mined to see if any of the model parameters can be updated during the first quarter of 2013. Following this exercise, we recommend that the fountain darter model of Mora et al., (2012) be updated to be spatially and temporally explicit in terms of the available two-dimensional hydrodynamic models, aquatic vegetation mapping data and models, water temperature model outputs and then calibrated and validated against the EAA variable flow study monitoring results. The endpoint is a model that can assess the response/dynamics of fountain darter populations relating to growth, survival, and movement during projected flow conditions while incorporating a spatially explicit aquatic vegetation component for the Comal and San Marcos systems. This task ***does not*** include other factors such as gill parasites or nonnative species interactions or the cumulative effects of these along with other factors such as recreation or pollution. Coordination with resident experts including Dr. Mora, Dr. Grant, and Dr. Tom Brandt (USFWS NFH&TC) is also recommended.

Schedule – Fountain darter data analysis and Model development to be initiated in 2013.
Linked spatially to aquatic vegetation in the Comal and San Marcos systems in 2013.
Model calibration and validation in 2014.

EQ4 – Comal Spring riffle beetle Response/Dynamics

At Comal Springs, drift net surveys within spring runs, along the western shoreline of Landa Lake, and at upwelling areas around Spring Island have been conducted since the inception of the Variable Flow Study in Fall 2000. Additionally, since 2006, cotton lure sampling specifically for Comal Springs riffle beetles have been collected at these same locations. A range of flow conditions have occurred over this time period but not to the extent necessary to provide data on flow conditions anticipated to be experienced during a repeat of the drought of record.

BIO-WEST (2002) examined the movement of Comal Springs riffle beetles in response to reductions in both horizontal and upwelling flows. These studies were conducted at the USFWS NFH&TC. It appears that limited literature exists on riffle beetle population dynamics modeling or movement in relation to diminishing flows.

Recommendation – Given the lack of suitable data to guide a specific modeling approach we recommend that a literature review be undertaken in 2013, with the focus on developing an applied research component to be initiated in 2014. It needs to be emphasized that the literature review will focus on modeling approaches that may have potential for modification to address HCP specific applications, not on the Comal Springs riffle beetle itself. We recommend that the modeling component of this question be deferred to the 2015 work plan. This will allow information from the 2014 applied research specific to the Comal Springs riffle beetle and aquatic macroinvertebrate modeling activities scheduled for 2014 to inform specific decisions regarding a basic model structure and associated model parameters. Coordination with resident experts including Randy Gibson (USFWS NFH&TC) and Chadd Norris (TPWD) is also recommended.

Schedule – Literature review and applied research recommendations in 2013.
Applied research specific to the Comal Spring riffle beetle in 2014.
Data analysis and Model development to be initiated in 2015.

EQ5 – Aquatic Vegetation Restoration and Texas wild rice enhancement success

As described in EQ1, a wealth of aquatic vegetation data has been collected on both the Comal and San Marcos rivers over the past decade plus. Additionally, Texas wild rice mapping has been conducted within the San Marcos River since 1989. Modeling of physical habitat for Texas wild rice and other aquatic vegetation species in the San Marcos and Comal River has been conducted over the past two decades as well as considerable life history information collected on Texas wild rice (e.g., Power, 1996, 1997, 1998; Poole and Bowles, 1999; Hardy et al., 2011; Tower 2012). The majority of the modeling efforts to date have focused on the spatial distribution based on depth, velocity and substrate although Tower (2012) assessed the spatial persistence of Texas wild rice stands within the San Marcos River. Tower (2012) also provides detailed seasonal shading estimates for San Marcos River based on LIDAR and the three-dimensional canopy structure of the riparian system that integrated extensive seasonal field based densitometer readings.

From an aquatic vegetation restoration standpoint, Dr. Robert Doyle conducted numerous experimental plantings of native species in both the Comal and San Marcos rivers over the years, as have other researchers including personnel from TPWD and USFWS. Bormann (2012) recently completed a 2-year evaluation of techniques for establishing native aquatic plant species in the San Marcos River. Considerable literature is available on aquatic vegetation restoration, but until site-specific activities on a larger scale than experimental plantings are initiated, it is difficult to predict the success of restoration efforts.

Specific aquatic vegetation restoration activities on a large scale are scheduled to take place on both the San Marcos and Comal rivers in 2013. The Meadows Center for Water and the Environment at Texas State University and the USFWS NFH&TC are currently propagating Texas wild rice and other native aquatic vegetation in support of these activities. As discussed in HCP section 6.3.4.3, these efforts should be conducted in a manner applicable to obtain data on methodologies and transplant success to guide future ecological modeling efforts. In particular, evaluations should include:

- transplant methodologies for various types of native aquatic vegetation
- success of the transplants over an extended time period
- methodologies for removal on nonnative plants
- track maintenance required to keep nonnative species from re-establishing

Recommendation – We recommend that the existing USACE models described in EQ1 above be examined in 2013 in light of modification to simulate the characteristics of Texas wild rice and identify potential research necessary to parameterize Texas wild rice dynamics. Additionally, it is recommended that knowledge gained during 2013 restoration activities be used to determine 2014 data analysis and modeling activities relative to success and projected spatial distribution over time. Coordination with resident experts including Ms. Jackie Poole (TPWD) and Dr. Robert Doyle (Baylor University) is also recommended.

Schedule – Texas wild rice Model development in 2013.
Data analysis and spatial aquatic vegetation restoration modeling in 2014.

EQ6 – Gill Parasite and Nonnative snails Response/Dynamics

A plethora of peer reviewed publications specific to the host snail, gill parasite, and interactions with the fountain darter are available (e.g. Fleming 2002, Fleming et al., 2011; Kuhlman 2007; McDermott et al., 2012; McDonald, et al., 2006 and 2007; Mitchell et al., 2000 and 2002; Mitchell and Brandt, 2005, 2007 and 2009; Salmon 2000). It is important to note the extent and diversity of publications as they include several evaluations of snail and parasite response (temperature, ice-water, salt, chemicals, etc.) as well as evaluate the effects of the parasite on fountain darter growth, survival, and reproduction. Additionally, the EAA Variable Flow study has supported three independent master's thesis (McDonald 2003; Cantu 2003, Bolick 2007) at Texas State University. This does not include all the technical reports and investigations that have also been completed. As part of the Variable Flow study, snail counts and gill parasite infection evaluations are conducted every time fountain darters are collected from both systems (dip net and drop netting). Johnson et al. (2012) describes a pilot study conducted in 2010/2011 to specifically evaluate the effectiveness of snail removal on cercarial concentrations in the water column in the Comal River. Johnson et al. (2012) documented that cercarial densities both pre- and post-removal were correlated with the densities of snails at each hotspot. Although a valuable starting point, several unknowns remain regarding magnitude and duration of benefits from snail removal in the Comal system, and thus, Johnson et al. (2012) offered several recommendations for further study.

As part the of HCP 2013 work plan, an applied research and monitoring effort is slated to evaluate the gill parasite and host snail in the Comal River. The work involves conducting a system wide survey on the Comal River to determine *Melanoides tuberculatus* (non-native host snail) population densities and cercarial concentrations of *Centrocestus formosanus* (gill parasite). Following that effort and concurrent literature search, methods for the reduction of the gill parasite in the Comal system will be tested for effectiveness and efficiency. Finally, a gill parasite monitoring and reduction program (if necessary) will be developed for implementation in subsequent years.

Recommendation – Although a lot is known for this component, upon preliminary examination, existing models are not available and the complexity of the relationships between parasite, snail, fish, and birds leads to our recommendation of spending 2013 working on basic model structure and associated model parameters (termed model "formulation"). This also allows time for the knowledge gained during the 2013 HCP work plan activities on the Comal River to be incorporated into decisions. As such, we recommend modeling associated with this task not be initiated until 2014. Coordination with resident experts including Dr. Thomas Brandt (USFWS NFH&TC) and Dr. David Huffman (Texas State University) is also recommended.

Schedule – Data analysis and Model development to be initiated in 2014.

EQ7 – Fountain Darter Response to multiple parameters

As described above, a wealth of information is available for the fountain darter in the Comal and San Marcos rivers. This modeling effort is designed to build upon the fountain darter population model constructed in EQ2 in 2013 and 2014. Upon completion of EQ2 in 2013, a model will be available that can assess fountain darter growth, reproduction, and movement and that is spatially tied to aquatic vegetation for the Comal and San Marcos rivers. However, three additional components including food source (aquatic macroinvertebrates [EQ2]), gill parasites [EQ6], and nonnative species interactions (no model proposed at this time) are likely to be factors that influence fountain darter populations during extended low flow periods as well.

Until significant progress with EQ1, EQ2, EQ3, EQ5 and EQ6 is made, it is impossible to predict just how this model or series of models will look. It may be a simple approach of keeping some or all models separate, or a more comprehensive approach of linking multiple components in time and space.

Recommendation – We recommend that this component of the modeling be deferred to the 2015 work plan to allow time for significant progress in the other EQ modeling efforts.

Summary of Recommendations and Timeline

Coordination with other HCP measures is critical during the duration of ecological modeling development and application. Data collection and coordination will be particularly important for applied research, native aquatic vegetation restoration and monitoring, gill parasite monitoring and control, expanded biological and water quality monitoring, non-native species control and monitoring, and Texas wild-rice restoration and monitoring. In fact, the development of ecological models/methodologies will be driven in part by the schedules and activities associated with these concurrent HCP measures. Simultaneously, experimental designs, monitoring components, types and amounts of data needed, etc. for other HCP measures will be guided by ecological modeling requirements under an adaptive management framework.

We believe that regardless of the specific direction the technical aspects of the ecological modeling process goes, it is vital to have a process that allows for extensive input from stakeholders and expert panel members; and review, input, and close coordination with the HCP Science Committee. We recommend that the seven technical questions described above and summarized below be submitted to the Science Committee for their consideration during the initial years of Phase 1 of the HCP.

Question	Ecological Modeling Timeline		
	2013	2014	2015 – Phase 1
EQ1 - Aquatic Vegetation Response/Dynamics	Model development and Initial calibration	Model calibration and Initial model validation	Application and refinement
EQ2 - Aquatic Macroinvertebrate Response/Dynamics	Literature Review	Model Development and Initial calibration	Initial model validation
EQ3 - Fountain darter Response/Dynamics	Model development and Initial calibration	Model calibration and Initial model validation	Application and refinement
EQ4 - Comal Spring riffle beetle Response/Dynamics	Literature Review	Applied Research	Model development
EQ5 - Aquatic Vegetation Restoration and Texas wild rice enhancement	Texas wild rice Model development	Restoration Model development	Application and refinement
EQ6 - Gill Parasite and Nonnative snails Response/Dynamics		Model development and Initial calibration	Initial model validation
EQ7 - Fountain Darter Cumulative Evaluation			Model development, calibration and validation

As shown in the above Table, proposed 2013 activities focus on getting a solid start on key components where existing information/models are available (EQ1 and EQ3). As EQ5 is directly linked to EQ1, progress relative to Texas wild-rice is also proposed for 2013. Limited model/methodology reviews are proposed for EQ2 and EQ4 in 2013 to stimulate discussions regarding 2014 work plans. Finally, no activities regarding EQ6 or EQ7 are proposed for 2013. In 2014, it is proposed that EQ1 and EQ3 be completed and ready for application. Additionally, EQ5 will be expanded in 2014 to include other aquatic vegetation restoration. EQ2 and EQ6 are proposed to be initiated in 2014, with EQ4 being slated for specific applied research relative to the Comal Springs riffle beetle. We feel these recommendations are consistent with Science team feedback received on November 29th. The Science Committee appeared amenable to starting on components that had existing data and available models. The Science Committee expressed concerns regarding the complexities of macroinvertebrate dynamics and ability to model these complexities. This is consistent with our proposal to initiate those activities in 2014 following a directed model/methodologies literature search, 2013 monitoring and applied research, and additional discussions. The Science Committee also recommended specific applied research to be conducted for the Comal Springs riffle beetle which is proposed in this memorandum for 2014 prior to initiating modeling activities the following year.

It is difficult to predict several years out, but presently the proposed approach for 2015 would be to near completion on EQ2 and EQ6, while initiating model development on EQ4. It is also proposed in 2015 that EQ7 be started in an attempt to start pulling together modeling components if appropriate and practical. Although the above table only has three columns with dates, ecological modeling activities are scheduled for each year of Phase 1 which extends through 2019. The initial years will be focused on model development, calibration, and validation. The focus will shift during subsequent years to model refinement and application which should address many of the written comments received regarding “causes” and potential effects.

We recommend that over the course of the next several years, flexibility in the ecological modeling work plans should be allowed to account for knowledge gained, whether breakthroughs or setbacks. We recommend close coordination with on-going HCP measures that directly influence ecological modeling activities. This will also require flexibility in the applied research, monitoring, and restoration activities during Phase 1 of the HCP. Finally, we recommend that adoption of a comprehensive modeling framework be deferred until results of the proposed FY 2013 / 2014 work plan elements identified above have been completed.

References

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ATTACHMENT – Written Comments and Responses

Comment 1: EQ2 – Aquatic macroinvertebrate response/dynamics – To best understand the aquatic macroinvertebrate (MI) community dynamics and responses, we need more baseline data on the community structure. The spatial and temporal variation displayed by MI communities can be large and has been attributed to various factors. My experience sampling the MI community of smaller, yet persistent springs has shown large seasonal variation in the community structure, with wholly aquatic non-insect taxa (i.e. snails, amphipods, and planarians) persisting throughout the year in varying numbers and insect taxa capable of aerial dispersal as adults (i.e. dragonflies, damselflies, mayflies, and caddisflies) displaying large variations in abundance ranging from absence to dominance. While large spring systems are thought to be buffered from some of the factors implicated in creating variations in community structure, such as seasonal changes in water temperature or flow, little research has been done in the Comal Springs system.

The expanded HCP biomonitoring protocol calls for twice yearly sampling of the aquatic MI community in dominant vegetation types. It is recommended these efforts be expanded to quarterly sampling, at a minimum, to better account for seasonal variation as the primary food source may change according to season and availability. Extended periods of low flow could span several seasons and the full effect of low flows may be inaccurately estimated without seasonal baseline data.

Response: This is a question aimed at the macroinvertebrate sampling component of the HCP biomonitoring program. We agree that all HCP projects including biomonitoring, expanded water quality monitoring, applied research, restoration, etc. be thoroughly reviewed by the Science Committee to inform the ecological modeling process and future work plans as the HCP moves forward. This comment does not materially affect any of the 2013 recommendations presented in this memorandum.

Comment 2: The memorandum refers to the HCP highlighting Gammarus as a key macroinvertebrate upon which fountain darters feed. The amphipod Gammarus is not found in Comal Springs and is not in the same taxonomic Family as the amphipod Hyallela, which is found at Comal Springs. In terms of ecological modeling and the use of Gammarus as a surrogate species for Hyallela – the species occupy very different habitats (lotic vs lentic) and although they are in the same taxonomic Order and are somewhat similar morphologically, Gammarus does not appear to be an "ecological equivalent" to Hyallela.

Response: To clarify, *Gammarus* is not referenced in the HCP. We apologize that the reference in the Draft memorandum was inaccurate. The HCP refers to "amphipods" as a key food source for the fountain darter. As discussed at the Science Committee/second public meeting on November 29th, the discussion on *Gammarus* was never intended to be centric or ignore other more relevant species. We agree that *Gammarus* is not an ecological equivalent to *Hyallela* but can provide additional insights to important life history information. Text in the memorandum has been modified to clarify that the initial literature review conducted for this memorandum was far ranging with the intent of identifying potential models or modeling techniques that have been used in the field of ecology that may have the potential for modification or use moving forward.

Comment 3: EQ4 – Comal Spring riffle beetle response/dynamics – I don't believe a literature search in 2013 will be very fruitful or should be given a significant portion of limited financial resources at this point. The most immediate need for the Comal Springs riffle beetle is to gather some relevant life history information, such as life cycle and seasonal variation, population estimate, estimation of distribution within the Comal Springs system, information on movement, tolerance to water quality parameters. The topic for EQ4 relates to Comal Springs riffle beetle response/dynamics. It is not clear what a literature search will yield in that area as resident experts have thoroughly researched the riffle beetle and closely related species and there appears to be little to no information available in this area, making the applied research component even more important.

Response: Text has been added in the memorandum to clarify that the intent of the literature search is to evaluate potential tools or methodologies used for other species that have the potential to be modified and used in this process. We agree that a literature search specific to the Comal Springs riffle beetle is not an appropriate use of resources with the current knowledge of the species. Finally, we very much support additional life history research for the Comal Springs riffle beetle.

SAWS would like to provide a brief set of comments on the Technical Memorandum "Recommendations for Development of the Ecological Modeling Work Plan" as follows:

Comment 4: Page 4 – The meeting held on October 24th was attended and monitored on behalf of SAWS by Ken Diehl (rather than Kevin).

Response: Corrected in text.

Comment 5: Page 5 – SAWS is concerned with the recommendation that recreation impacts are not one of the "highest priority questions." Recreation can result in habitat conditions which are believed to influence the fountain darter and aquatic vegetation, for example: increased turbidity and fountain darter behavior modifications. The Memorandum's utility would be increased by discussion that outlines the authors' thinking about when and in what form the effects of recreation (i.e. turbidity) would be incorporated into any ecological modeling considerations, and why the effects of a Covered Activity occurring in the habitats is not a worthwhile consideration to have in-mind up-front.

Response: The focus of the ecological modeling is on ecological processes including responses of aquatic vegetation and fountain darters relative to water quality and water quantity. With the development of the tools to answer the high priorty ecological questions, we feel both the physical aspects (trampling) and water quality aspects (turbidity) of recreation can be addressed in subsequent years. For example, the ecological process under investigation is what a reduction in vegetation or food source means to the fountain darter reproduction, survival, etc. Once that relationship is determined, incorporating recreation or other factors as part of evaluating alternative scenarios will be performed.

Comment 6: Page 7 – Regarding Ecological Question #2, is the Gammarus sp. aquatic macroinvertebrate the only organism that will be studied in an applied research setting of some sort? If so, the Memorandum would be strengthened by including discussion of whether it is an appropriate indicator species for an entire macroinvertebrate community. If that determination cannot be made at this time, then appending this specific research question onto the 2013 literature review seems to be well-advised. We understand that there are significant logistical difficulties in maintaining and studying an entire macroinvertebrate community, or multiple communities, in a lab setting; therefore, firmly settling whether a single species is a suitable indicator early in the process could be important in the future acceptance of the results by HCP stakeholders. SAWS has additional questions about this topic, for example competition among different amphipods and varying macroinvertebrate communities, and any inter-relation (or lack), and any possible ecological competition with, the Pecks Amphipod?

Response: No, *Gammuras* is not the only organism that will be studied. Please see comment 2, as *Gammarus* was never intended to be centric or ignore other more relevant species. As highlighted by Dr. Arsuffi and Chad Norris of the Science Committee at the November 29th meeting and by your excellent points, we acknowledge that there are a lot of complexities pertaining to macroinvertebrate communities. However, we feel the food source interaction relative to the fountain darter, and response of the Comal Springs riffle beetle to low-flow are critical questions that must be tackled during Phase 1 of the HCP. This memorandum is just step 1 of an extended and adaptive management driven process. We are hopeful that the specifics of whether communities or indicators, or combinations thereof, modeling techniques or methodologies will surface via directed literature searches, biomonitoring, applied research, Science Committee and public interactions, etc. as the HCP moves forward under its adaptive management framework.

Comment 7: Page 8 – We recall that temperature was one of the important limiting factors in the fountain darter biological modeling work conducted by Texas State University in 2009, largely due to safety-net assumptions concerning maintaining high atmospheric temperatures over an extended period of time in the model. Will the recommended model be capable of handling temperature in a more dynamic fashion? Would it be capable of incorporating the concept of the 'thermal refugia' discussed in Hardy et al. (Dec. 28, 2010)?

We also understood that dissolved gas levels and ratios had been identified as an important aspect to the health of the darters and the ecosystem/community as a whole. Does the Mora et al. ecological model have the capability to account for CO2 and DO during low flow conditions?

Response: The intent would be for the existing hourly temperature model to be linked to the other models (fountain darter, vegetation, riffle beetle) as those models move forward. At a simplified level the Mora et al model will link to temperature and dissolved oxygen and the pre-cursor to this model had incorporated other water quality constituents aimed at urban storm runoff. These other constituents would be a future year addition, if determined appropriate, once the watershed level models are providing calibrated input (i.e., USMWPP and CSOM Comprehensive Planning process). Carbon dioxide and its role will be an important discussion moving forward for which the HCP participants will be better informed following the 2013 round of applied research.

Comment 8: Page 9 – SAWS (and presumably other stakeholders) finds it difficult to evaluate the Memorandum's recommendation to use a fountain darter model that has not yet been published (Mora et al. 2012). What are the advantages of the Mora darter model over, for example, the Stella models or the various iterations of the Hardy instream assessment frameworks for the fountain darter? What are its drawbacks? What have other researchers and reviewers found to be important strengths and limits of this proposed model? We will need to review more information concerning this recommendation.

Response: As one of the primary reviewers, Dr. Hardy has received notification that the paper has been approved for publication in the Journal of Ecological Modeling. It was technically 'in press' at time the memorandum was written. The Mora et al model uses Stella to implement the equations and used results from Hardy et al from the San Marcos. The seminal Mora model was developed in the San Marcos River and was reviewed by the EARIP as it became available. The derivative model by Mora et al is a logical extension of the previous model, showed calibrations for darter densities over a multi-year time frame, is peer reviewed and published. We stand by our recommendation that this tool provides a solid starting point for fountain darter evaluations moving forward.

Comment 9: Ecological Question #4 – SAWS believes that it would be beneficial for the HCP if the field sampling technique for Comal Spring Riffle Beetles (cotton lures) is verified in the applied research setting (in 2014?) to determine whether the present technique is a valid means of obtaining a representative sample, and how the lures' selected placement changes, or not, the resulting collection of beetles.

Regarding the 2013 literature review, has the existing literature on other species of riffle beetles been fully explored to determine what applicability, if any, there is between other riffle beetles and Heterelmis comalensis?

Response: This question in the first paragraph is aimed at the riffle beetle sampling component of the HCP biomonitoring program and does not materially alter the recommendations in the memorandum. We agree that all HCP projects including biomonitoring, expanded water quality monitoring, applied research, restoration, etc. be thoroughly reviewed by the Science Committee to inform the ecological modeling process and future work plans as the HCP moves forward. The answer to the second is no, and is part of the goal of the proposed literature search.

Comment 10: Regarding Ecological Question 5 (aquatic vegetation restoration and Texas wild-rice enhancement success) – this seems like a question that is inseparable from the important role of disturbances (both from floods and from human recreational traffic). Again, SAWS has concern that this Covered Activity is not recommended as a worthwhile component of the modeling proposed. Is it due to limitations built-into the models recommended for use in Ecological Question #1 developed by the USACE Aquatic Plant Control Research Program at the Waterways Experiment Station?

Response: This is a matter of perspective as the money in year 2013 can only accommodate a certain amount of work. We recommended priorities in terms of low hanging fruit and strategic needs. Indeed, floods and recreational activity are inseparable components but are in fact being underpinned by the vegetation models being proposed. Please see response to Comment 5 for additional clarification. As the HCP moves forward, these questions can be effectively answered from the priority work products recommended.

Comment 11: Ecological Question 7 (fountain darter response to multiple parameters) seems to us to be another instance for the incorporation of the impacts of recreation, such as turbidity and vegetation disturbance, on “fountain darter growth, reproduction, and movement.”

Response: That is correct. It is just a matter of the timing for components of the ecosystem model to get accomplished. We have added text in the summary and recommendations section to clarify the timeline.

Appendix A – Reviewed and Screened Literature

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