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. The development of ecological models/methodologies will be driven in part by the schedules and activities associated with these HCP measures and their respective work plans.

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 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
Kevin Diehl – SAWS
Cinde Jimenez – GBRA
John Waugh – SAWS
Janelle Baca – SeaWorld
Ed Oborny – BIO-WEST
Jose Hidalgo – Public
Glenn Longley – Texas State University
Jenna Cantwell – EAA
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.

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:

Tier A

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 right now as the highest priority questions. Additionally, it is anticipated that cumulative evaluations regarding other Covered Species beyond the fountain darter will also be addressed during Phase 1, but again these are not recommended up front.

Data/Model Review and Recommendations

<u>EQ1 – Aquatic Vegetation Response/Dynamics</u>

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:

- 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.

<u>Recommendation</u> – 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.

<u>Schedule</u> – Data analysis and Model development to be initiated in 2013.

<u>EQ2 – Aquatic Macroinvertebrate Response/Dynamics</u>

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 amphipod populations within select aquatic vegetation types is slated for completion in 2013. The HCP highlights *Gammarus* as a key macroinvertebrate upon which fountain darters feed and is 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 comprehensive 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). Based on this literature review and 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).

Mora et al., (2012) 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. 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. 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 comprehensive literature review be undertaken in 2013, with the focus on developing an applied research component to be initiated in 2014. 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 on 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 – Literature review and model formulation in 2013.
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.

<u>Recommendation</u> – 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

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 -
EQ1 - Aquatic Vegetation Response/Dynamics	Model development and Initial calibration	Model calibration and Initial model validation	
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	
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	
EQ6 - Gill Parasite and Nonnative snails Response/Dynamics	Formulation	Model development and Initial calibration	Initial model validation
EQ7 - Fountain Darter Cumulative Evaluation		Formulation	Model development, calibration and validation

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.

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