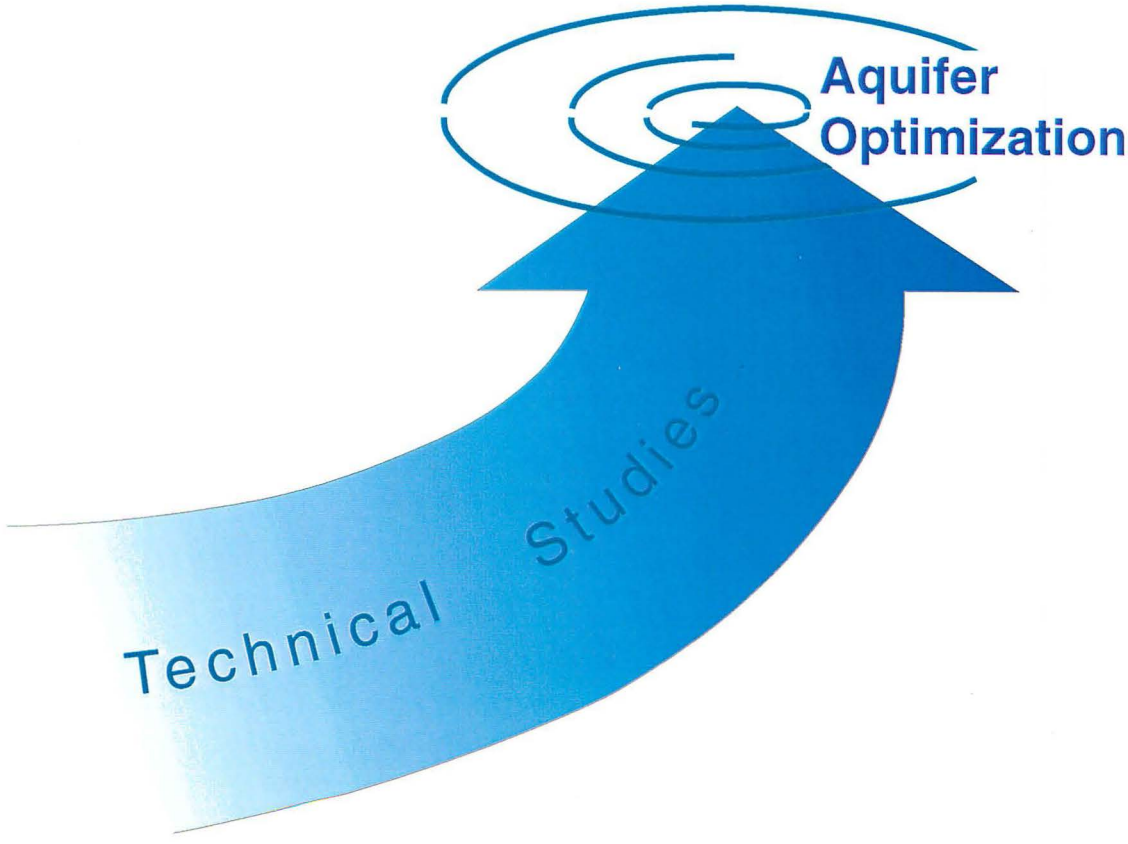
EDWARDS AQUIFER
AUTHORITY

Optimization Technical Studies

in support of the Edwards Aquifer Optimization Program

Todd Engineers
Emeryville, California

May 1999



Edwards Aquifer Authority
San Antonio, Texas

OPTIMIZATION TECHNICAL STUDIES IN SUPPORT OF THE EDWARDS AQUIFER OPTIMIZATION PROGRAM

May 1999

Todd Engineers
Emeryville, CA
510-595-2120

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

OPTIMIZATION TECHNICAL STUDIES IN SUPPORT OF THE EDWARDS AQUIFER OPTIMIZATION PROGRAM

I. Introduction

The Edwards Aquifer Authority (the Authority) was given the responsibility in the Edwards Aquifer Authority Act (73rd Texas Legislature, Senate Bill 1477 as amended, herein referred to as the Act) to manage, conserve, preserve, and protect the Edwards Aquifer. Pursuant to this mandate, the Authority has undertaken a series of inter-related research studies to obtain necessary data and information to manage the aquifer not only to benefit users of the available water resource but also to preserve the environment supported by the aquifer. Optimization of groundwater management requires consideration of irrigation, domestic, municipal, and industrial aquifer users; environmental and recreational interests associated with Comal and San Marcos Springs; and downstream users in the Nueces, Guadalupe and San Antonio River Basins.

One can envision optimization as the process by which a most favorable result can be achieved. It is important to note that optimization does not mean maximization. Without restrictions, one could pump a much larger quantity from the aquifer than is currently being extracted simply because an extremely large volume of water exists within the aquifer, in particular below the elevation of the springs. However, if pumping is increased without appropriate optimization strategies, the Authority's goals such as guaranteed springflows or protection of endangered species (the Act) cannot be reached. Applying optimization concepts to managing an aquifer involves a process with the end result yielding an aquifer operation that enables all of the desired benefits to be accomplished. The most water will be produced at the lowest cost simultaneously with preserving and protecting the aquifer as well as associated ecological systems. To achieve these benefits, data gaps and uncertainties about the aquifer system and the ecosystem that it supports must be addressed. Additional focused research undertaken by the Authority will support an optimization program that is technically-sound from a hydrogeologic perspective, meets the needs of water users, and respects the requirements of the environment.

The purpose of this document is to summarize the program of research studies herein referred to as the Optimization Technical Studies (OTS) that will provide the technical underpinnings for an Edwards Aquifer Optimization Program (EAOP). The OTS was conceived and designed by members of the Authority's Technical Advisory Group (TAG) and staff and consultants. The OTS was summarized in a draft document on March 1, 1999 and a revised draft titled *Revised Draft Optimization Technical Studies in Support of the Edwards Aquifer Optimization Program* was approved by the Authority's Research & Technology Committee (R & T Committee) on March 31, 1999. The board of directors approved the OTS on April 13, 1999.

The OTS is a mission-directed research program of hydrogeologic and biological research studies to reduce the uncertainties of aquifer optimization strategies. This program should not be viewed as a broad scientific endeavor; rather, it is focused on

specific questions and issues relating to the concept of aquifer optimization. This program supports the Authority's regulatory aquifer management responsibilities mandated in the Act. The OTS is designed to provide the information necessary to evaluate optimization strategies and develop operational details of optimization alternatives. The OTS also supports other Authority activities such as the long-term planning process associated with a comprehensive water management plan. The Act anticipates the necessity of additional aquifer and ecosystem research, allowing the Authority to conduct research to:

> "(1) augment the springflow, enhance the recharge, and enhance the yield of the aquifer;
> (2) monitor and protect water quality;
> (3) manage water resources, including water conservation, water use and reuse, and drought management measures; and
> (4) develop alternative supplies of water for users" (Section 1.27(b)).

The OTS supports an overall vision of optimizing management of the aquifer for the benefit and protection of all aquifer uses including the environment. The program schedule considers deadlines imposed on the Authority for limiting withdrawals by 2008 unless aquifer yield can be increased and providing for minimum continuous springflow by 2012 as set forth in the Act:

> "...beginning January 1, 2008, the amount of permitted withdrawals from the aquifer may not exceed 400,000 acre-feet of water for each calendar year." However, "if, through studies and implementation of water management strategies... the authority determines that additional supplies are available from the aquifer, the authority...may increase the maximum amount of withdrawals provided by this section and set a different maximum amount of withdrawals" (Section 1.14 (d)).
>
> "(T)he authority...shall implement and enforce water management practices...to ensure that, not later than December 31, 2012, the continuous minimum springflow of the Comal Springs and the San Marcos Springs are maintained to protect endangered and threatened species to the extent required by federal law" (Section 1.14(h)).

Although the aquifer has been the subject of hundreds of studies for more than 100 years, new questions require additional analysis. Some of the data gaps were identified by the San Antonio Mayor's Citizens Advisory Committee on Water Policy in 1996. This committee, along with its technical advisors, proposed the concept of optimizing aquifer management on a regional basis and identified specific aquifer optimization strategies for further investigation. In their report to the mayor and city council, *A Framework for Progress*, the committee recommended specific items relating to technical study for aquifer management and included continuing the studies of the saline/freshwater interface, recharge enhancement, and aquifer optimization (SAWS, 1997).

When the San Antonio Water System (SAWS) was asked by the City Council to consider these recommendations, they realized the need to bring together regional and local technical expertise as a technical steering committee led by the Authority. Thus

the idea of forming a technical advisory group (TAG) was first conceived. It was envisioned that TAG members would work together to develop a scope of work for proposed studies, identify priority studies, and provide technical review of study results.

The Authority agreed to take on the challenge of forming a TAG, envisioning it as support for the EAOP. The Authority recognized the benefits of TAG assistance in developing a research program that would provide the technical basis for implementing aquifer optimization alternatives as well as assist in other Authority technical activities such as the development of a comprehensive water management plan for the aquifer. The Authority, as the lead agency, would provide technical oversight through its R & T Committee and staff, and final oversight and approval through the board of directors.

With the assistance of SAWS, a TAG was assembled consisting of more than 30 representatives from federal, state, regional and local agencies, aquifer users, and academia (Figure 1). TAG members, listed on Table 1, included local and regional experts in hydrology, geology, biology, and engineering, combining an unprecedented wealth of technical knowledge on the aquifer and the communities and ecosystems that it supports.

TAG was charged with addressing the issues identified by the Citizens Committee including the following major topics:

- Recharge enhancement
- Flowpath studies
- Springflow augmentation
- Springflow recirculation
- Biological assessment of endangered species
- Range management
- Saline water study

From these issues identified by the committee, the following nine specific questions were developed by the TAG for consideration:

1. Can significant additional recharge be provided for aquifer users and to maintain springflow?
2. Where should we put recharge dams, pumping centers, injection wells for maximum efficiency?
3. Are we receiving accurate predictions of aquifer conditions from our current flow model?
4. Can the "bad water" line move during extended periods of low aquifer levels?
5. Can springflow be augmented during extended periods of low aquifer levels?

6. What are the actual minimum flow requirements of the various endangered species and habitats?
7. Can excess springflow be captured and returned to the aquifer during wet periods?
8. Will control of Ashe juniper in the recharge zone increase recharge to the aquifer?
9. Can we increase annual rainfall in the catchment and recharge zones of the aquifer?

These questions provided a starting point for addressing the technical uncertainties that currently limit the ability to make technically defensible aquifer optimization decisions. To provide specialized expertise in addressing these issues, TAG members formed three subgroups consisting of qualified TAG members in each of three categories of study: Biological Assessments, Flowpath/Modeling Studies, and Recharge Enhancement Studies. Using recommendations from these subgroups, specific studies to support the EAOP were developed, prioritized and structured as the OTS by the TAG, Authority staff and consultants. The board of directors provides the final oversight and approval.

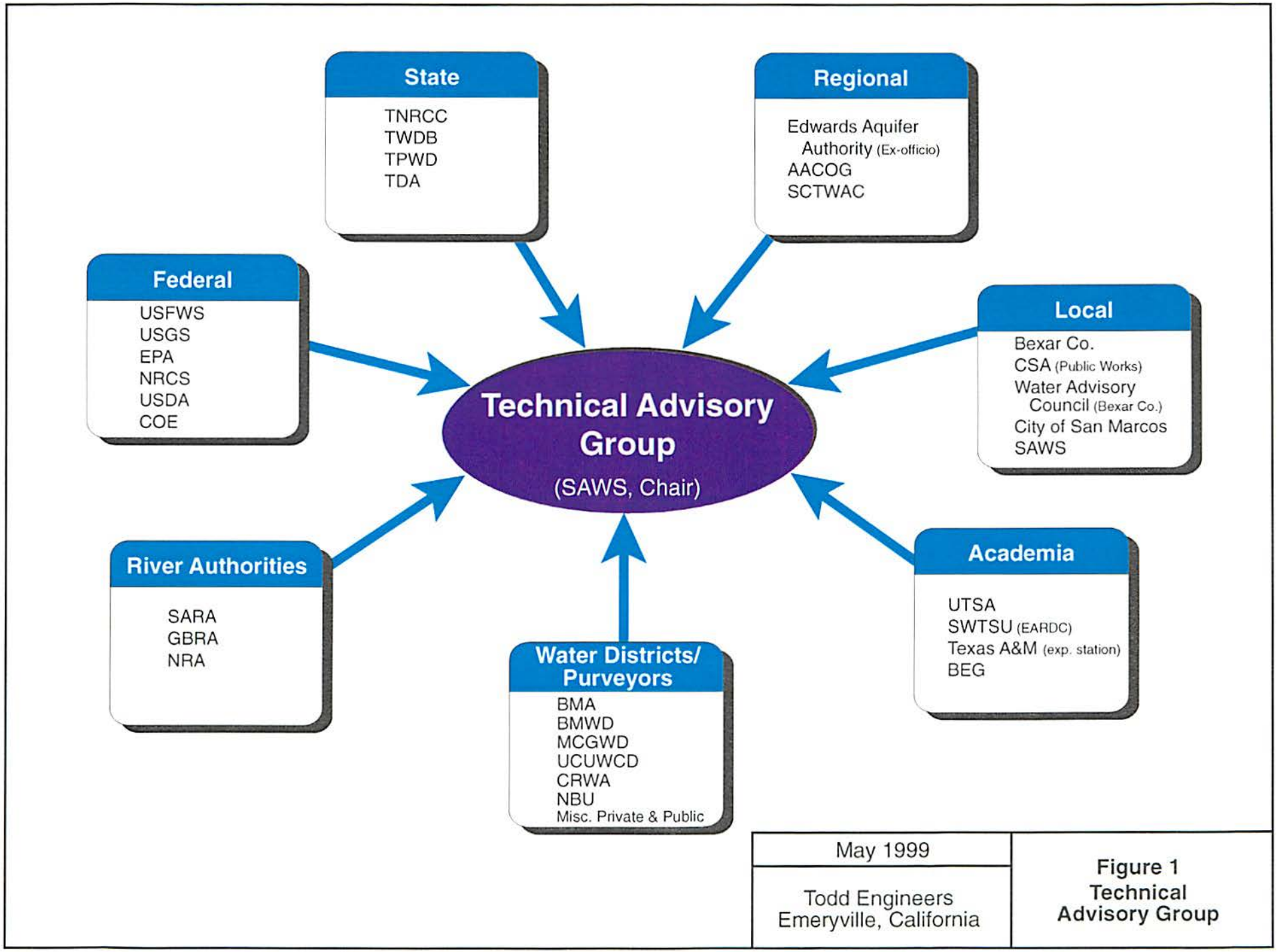

State
TNRCC
TWDB
TPWD
TDA
Regional
Edwards Aquifer Authority (Ex-officio)
AACOG
SCTWAC
Federal
USFWS
USGS
EPA
NRCS
USDA
COE
Local
Bexar Co.
CSA (Public Works)
Water Advisory Council (Bexar Co.)
City of San Marcos
SAWS
Technical Advisory Group
(SAWS, Chair)
River Authorities
SARA
GBRA
NRA
Water Districts/ Purveyors
BMA
BMWD
MCGWD
UCUWCD
CRWA
NBU
Misc. Private & Public
Academia
UTSA
SWTSU (EARDC)
Texas A&M (exp. station)
BEG
May 1999
Todd Engineers
Emeryville, California
Figure 1
Technical
Advisory Group

Table 1
TECHNICAL ADVISORY GROUP MEMBERS

Mr. Roy Akiona
Public Works Department
P.O. Box 839966
San Antonio, Texas 78283

Mr. Chuck Ahrens
Bexar Metropolitan Water District
2047 W. Malone
San Antonio, Texas 78225

Mr. Michael Albach
United States Filter Corp.
5413 Bandera Rd., Suite 405
San Antonio, Texas 78238

Mr. Roger Biggers
New Braunfels Utilities
263 E. Main Plaza
New Braunfels, Texas 78130

Dr. David Bowles
Texas Parks & Wildlife
P.O. Box 1685
San Marcos, Texas 78667

Ms. Luana Buckner
Medina County Ground
Water District
1613 Ave. K., Suite 105
Hondo, Texas 78861

Mr. Michael Bechdol
U. S. Environmental Protection
Agency
1445 Ros Avenue
Dallas, Texas 75202

Mr. David Davenport
Canyon Regional Water Authority
850 Lakeside Path Drive
New Braunfels, Texas 78130

Dr. Alan Dutton
Bureau of Economic Geology
University Station, Box X
Austin, Texas 78713

Mr. Greg Ellis
Edwards Aquifer Authority
1615 N. St. Mary's Street
San Antonio, Texas 78215

Mr. Stephen Jenkins
City of San Marcos
630 East Hopkins
San Marcos, Texas 78666

Mr. Mike Gonzales
San Antonio River Authority
P.O. Box 9284, Gilbeau
Station
San Antonio, Texas 78204

Mr. Vic Hilderbran
Uvalde Underground Water
Conservation District
P.O. Box 1419
Uvalde, Texas 78802

Mr. Thomas Hill
Guadalupe Blanco River Authority
933 E. Court
Seguin, Texas 78155

Mr. Rob Esquilin
Edwards Aquifer Authority
1615 N. St. Mary's Street
San Antonio, Texas 78215

Mr. Bob Hall
Edwards Aquifer Authority
1615 N. St. Mary's Street
San Antonio, Texas 78215

Dr. Glenn Longley
Edwards Aquifer Research & Data
Center
Southwest Texas State University
San Marcos, Texas 78666

Mr. Lester Perrin
US Corps of Engineers
P.O. Box 17300
Attn:CESWF-EC-T
Ft. Worth, Texas 76102

Mr. Harald Petrini
Texas Water Development Board
P.O .Box 13231
Austin, Texas 78667

Mr. Con Mims
Nueces River Authority
P.O. Box 349
Uvalde, Texas 78802

Dr. Randy Moss
Texas Park & Wildlife
P.O. Box 1685
San Marcos, Texas 78667

Mr. Phil Nordstrom
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711

Mr. Al Notzon
Alamo Area Coucil of Governments
118 Broadway, Suite 400
San Antonio, Texas 78205

Mr. George Ozuna
United Stated Geological
Survey
435 Isom Rd., Suite 234
San Antonio, Texas 78216

Mr. DeWayne Burns
Texas Department of Agriculture
P.O. Box 12847
Austin, Texas 78711

Mr. Mike Murry
Texas Department of Agriculture
P.O. Box 12847
Austin, Texas 78711

Dr. Weldon Hammond
University of Texas at San
Antonio
6900 N Loop 1604 W.
San Antonio, Texas 78249

Table 1 (Continued)

Mr. Steve Raabe
San Antonio River Authority
101 E. Guenther
San Antonio, Texas 78204

Mr. Rodney Reagan
Uvalde Underground Water
Conservation District
P.O . Box 1419
Uvalde, Texas 78802

Ms. Alisa Shull
United States Fish & Wildlife
10711 Burnet Rd. #200
Austin, Texas 78758

Mr. Johnny Ward
Bexar Medina Atascosa Water
District
226 Highway 132
Natalia, Texas 78059

Mr. Kenneth White
Texas A & M Experimental Station
Drawer 1708
Uvalde, Texas 78801

Mr. Philip Wright
USDA-NRCS-Seco Creek
1616 Avenue M, Suite 100
Hondo, Texas 78861

Mr. Pat Wright
City of Leon Valley
6400 El Verde
Leon Valley, Texas 78238

Ms. Cara Tackett
City of San Antonio
P.O. Box 839966
San Antonio, Texas 78283-3966

Ms. Kathy Ozment
Guadalupe Blanco River
Authority
933 E. Court Street
Seguin, Texas 78155

Mr. Marshall Jennings
Edwards Aquifer Research &
Data Center
Southwest Texas State University
San Marcos, Texas 78666

Mr. Geary Schindel
Edwards Aquifer Authority
1615 N. St. Mary's Street
San Antonio, Texas 78215

Mr. Jerry McCrory
US Corps of Engineers
P.O. Box 17300
Attn: CESWF-EC-T
Ft. Worth, Texas 76102

Mr. Wayne Cockroft
City of Victoria
P.O. Box 1758
Victoria, Texas 77901

Mr. Jerry James
City of Victoria
P. O. Box 1758
Victoria, Texas 77901

Mr. John Waugh
San Antonio Water System
1001 E. Market Street
San Antonio, Texas 78298

Mr. Larry Allen
USDA-NRCS-Seco Creek
1616 Avenue M, Suite 100
Hondo, Texas 78861

Ms. Liza Contreras
Alamo Area Coucil of Governments
118 Broadway, Suite 400
San Antonio, Texas 78205

II. Optimization Technical Studies

The Optimization Technical Studies (OTS) is a research program of 17 technical studies being recommended for adoption by the Authority. Each of the studies, along with their general relationship to aquifer optimization and priority status, is listed in Table 2 organized by TAG subgroup. In addition, a description of each study is included in the following sections and on templates, labeled *Summary of Proposed Study*, compiled in an Attachment.

The 17 studies in the OTS include six biological assessments, eight aquifer flowpath and modeling studies, and three recharge enhancement studies. To illustrate the comprehensive nature of the studies and the predominant portion of the aquifer being investigated, each of the studies can be loosely associated with one of the three major components of an aquifer water balance, inflow, outflow, and storage. Although many of the studies relate to more than one water balance component, this categorization can assist in organizing the study plan around the aquifer. Figure 2 illustrates this concept and lists each of the 17 studies under the respective water balance component.

Ten of the studies are being recommended by the TAG, Authority staff and consultants for funding in 1999 (Year 1 of the program). These are identified along the right side of Table 2. The Recharge/Flowpath study in northern Medina County and the Fracture/Conduit study, were identified by the TAG as having a high priority for Year 1 funding, but were deferred into Year 2 due to budgetary constraints. Joint funding is being sought for many of the studies and it is recommended that these two studies be moved back into Year 1 if additional funds become available.

The layout of the OTS, including schedules and costs, is presented in Table 3. Additional study details including project sequencing and duration is shown in Table A-1 in the Attachment. The OTS encompasses eight years (1999-2006) to ensure that study results are available for consideration to meet the re-evaluation of withdrawal limits by 2008 and requirement to maintain continuous springflow by 2012. The OTS design considers the inter-dependence of one study on another. For example, the continued evaluation of springflow recirculation and recharge enhancement is scheduled in Year 3 to allow the use of the management computer model being constructed in Years 1 and 2.

Many of the studies in the program are multi-year studies that require multi-year funding commitments to complete. Two such studies, the Saline Water Study and the Range Management of Woody Species Study, are underway. Authority staff and consultants will monitor the progress of each study and will re-visit the scopes as necessary to ensure that the technical issues are being adequately addressed.

Total OTS costs to the Authority are estimated at $6,040,000 over eight years. The program was originally designed to commit the largest annual dollar amounts to Years 1 and 2, with dollar amounts decreasing in subsequent years throughout the program. However, in consideration of 1999 budget constraints, several projects were

deferred into later years or spread out over several years. As a result, the largest dollar commitments are envisioned in Years 3 and 4. This action impacts the program by deferring the relatively high-cost flowpath studies and their results until late in the program. If additional funding becomes available, it is recommended that the flowpath studies move up into Years 1 and 2 on the schedule.

Authority consultants and TAG members have formed an Alternative Funding work group to identify and pursue possible outside funding to support the OTS. Potential sources of contributions include state and federal grants, private foundations, in kind contributions and cooperative agreements with other agencies.

All of the studies listed in Tables 2 and 3 are described in the following sections, organized by the TAG subgroup – Biological Assessments, Flowpath/Modeling Studies, and Recharge Enhancement Studies.

Table 2
Optimization Technical Studies
in Support of the Edwards Aquifer Optimization Program

Study	Relationship to Aquifer Optimization	Priority Project For Year 1 Funding
Biological Assessment Studies:		
Variable Flow Biological Monitoring Plan and Ongoing Monitoring	Provides a better understanding of springflow-related requirements of key indicator species at aquifer-fed springs for establishing future aquifer operating levels.	YES
Texas Wild-rice Mapping	Documents Texas wild-rice distribution over the last 10 years using a GIS format. Provides information on flow requirements for optimization strategies that may impact flow at San Marcos Springs.	YES
Texas Wild-rice Growth and Reproduction	Provides data on flow requirements of Texas wild-rice to aid in evaluating impacts of management strategies on flows at San Marcos Springs.	YES
Potential Water Quality Impacts	Provides a comprehensive literature review and field investigation of water quality for measuring the impact of optimization strategies on Comal Springs and San Marcos Springs biota.	YES
Cagle's Map Turtle Flow Requirements	Time-sensitive opportunity for combination with ongoing instream flow study. Provides turtle habitat requirements as input to springflow recirculation strategies.	YES
Well Sampling of Aquifer Biota	Provides baseline data for distribution of biota in the aquifer by conducting biological sampling in new and existing wells.	
Flowpath/Modeling Studies:		
Management Model/GIS Data Sets and Model Re-calibration	Develops a technically-improved tool for evaluating aquifer management decisions in an easily-updated, user-friendly format. Envisions future updates and support from other studies to better simulate and predict aquifer response to management strategies.	YES
Saline Water Study	Collects data from saline-freshwater interface, evaluates interface dynamics, and establishes a monitoring program to evaluate future management strategies	YES
Recharge/Flowpath (N. Medina Co.)	Provides recharge and flowpath data in one of four major areas of uncertainty. Provides data for computer model re-calibration.	YES*
Focused Flowpath Studies: Knippa Gap, San Marcos Springs, and Comal Springs	Focused investigation in areas of flowpath uncertainty to refine conceptual model and support model re-calibration.	
Recharge Methodology	Refines the method of calculating recharge to more accurately estimate the volume and location of aquifer recharge. Relies on methodology currently under development by USGS.	
Statistical Analysis of Hydrologic Data	Statistical re-examination of historic hydrologic data developing relationships between rainfall, streamflow, water levels, and springflow.	
Fracture/Conduit Study	Outcrop and subsurface analysis to examine permeability distribution in the aquifer and support future modeling efforts.	YES*
3-D Interactive Visualization (Phase I)	Development of an analytical and educational tool for EAA to display complex structural relationships and illustrate water movement in the aquifer.	
Recharge Enhancement Studies:		
Range Management of Woody Species	Ongoing study to evaluate the increase in aquifer recharge by the removal of woody vegetation associated with extremely high water consumption.	YES
Springflow Recir./Recharge Enhancement	Continued evaluation of aquifer management strategies proposed in the Trans-Texas Water Program. Although identified as a high priority, evaluation requires the use of the computer model proposed above.	
Springflow Aug. (Supplement Phase I)	Addresses deficiencies in the initial feasibility study and makes recommendation for further development of augmentation as an aquifer strategy. Relies on biological assessment and modeling.	

* Identified as a high-priority project but recommended for deferral until Year 2 due to budgetary constraints. Projects should be moved back into Year 1 as outside funds allow for re-distribution of EAA budget.

INFLOW

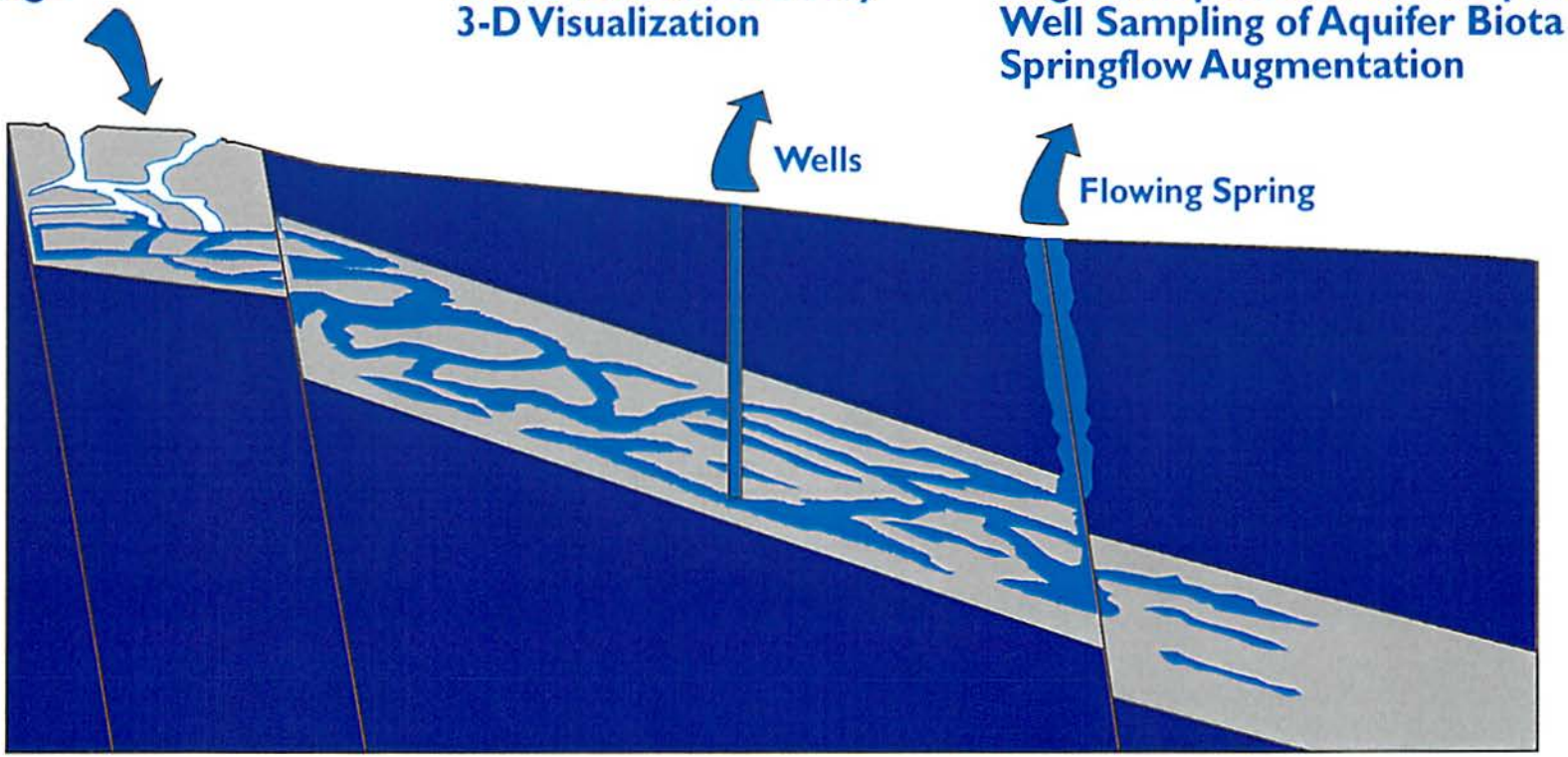
Range Management
Recharge Methodology
Medina Co. Recharge/Flow
Springflow Recirc. and Recharge

STORAGE

Management Model/GIS
Saline Water Study
Focused Flowpath
Statistical Analysis
Fracture/conduit Study
3-D Visualization

OUTFLOW

Variable Flow Biological Monitoring
Texas Wild-rice Mapping
Texas Wild-rice Growth/Reproduction
Potential Water Quality Impacts
Cagle's Map Turtle Flow Requirements
Well Sampling of Aquifer Biota
Springflow Augmentation



May 1999	Figure 2 Technical Studies and Water Balance Components
Todd Engineers Emeryville, California	

Table 3
Schedule and Costs of Optimization Technical Studies
in Support of the Edwards Aquifer Optimization Program

Study	Project Duration	STUDY COST Total*	EAA COSTS Total	YEAR 1 1999	YEAR 2 2000	YEAR 3 2001	YEAR 4 2002	YEAR 5 2003	YEAR 6 2004	YEAR 7 2005	YEAR 8 2006
Variable Flow Biological Monitoring Plan	1 year	$ 50,000	$ 50,000	$ 50,000							
and Ongoing Monitoring	8 years	$ 200,000	$ 200,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
Texas Wild-rice Mapping	1 year	$ 50,000	$ 50,000	$ 50,000							
Texas Wild-rice Growth and Reproduction	5 years	$ 300,000	$ 300,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000	$ 60,000			
Potential Water Quality Impacts	5 years	$ 300,000	$ 300,000	$ 15,000	$ 60,000			$ 75,000	$ 75,000	$ 75,000	
Cagle's Map Turtle Flow Requirements	2 years	$ 100,000	$ 100,000	$ 50,000	$ 50,000						
Well Sampling of Aquifer Biota	3 years	$ 90,000	$ 90,000		$ 30,000	$ 30,000	$ 30,000				
Management Model/GIS Data Sets	2 years	$ 400,000	$ 400,000	$ 300,000	$ 100,000						
and Model Re-calibration	0.5 year	$ 100,000	$ 100,000					$ 100,000			
*Saline Water Study	10 years	$ 9,742,324	$ 1,200,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000	$ 150,000
Recharge/Flowpath (N. Medina Co.)	3 years	$ 600,000	$ 600,000		$ 200,000	$ 200,000	$ 200,000				
Focused Flowpath Studies: Knippa Gap, San Marcos Springs, and Comal Springs	6 years	$ 1,800,000	$ 1,800,000			$ 200,000	$ 400,000	$ 400,000	$ 400,000	$ 200,000	$ 200,000
Recharge Methodology	3 years	$ 300,000	$ 300,000		$ 100,000	$ 100,000	$ 100,000				
Statistical Analysis of Hydrologic Data	0.25 year	$ 40,000	$ 40,000	$ 40,000							
Fracture/Conduit Study	0.67 year	$ 75,000	$ 75,000		$ 75,000						
3-D Interactive Visualization (Phase I)	1 year	$ 85,000	$ 85,000							$ 85,000	
*Range Management of Woody Species	8 years	$ 2,200,000	$ 200,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000	$ 25,000
Springflow Recir./Recharge Enhancement	1 year	$ 100,000	$ 100,000			$ 100,000					
Springflow Aug. (Supplement Phase I)	0.5 year	$ 50,000	$ 50,000			$ 50,000					
ESTIMATED COSTS		$ 16,582,324	$ 6,040,000	$ 765,000	$ 875,000	$ 940,000	$ 990,000	$ 835,000	$ 675,000	$ 560,000	$ 400,000

*Total Study Costs Include Joint Funding

A. Biological Assessments

The TAG recognized that optimizing the aquifer will require a better understanding of the biota that live within or are supported by the aquifer. There is insufficient data on the endemic and rare animal and plant species living within the aquifer or in lakes and streams sustained by aquifer-fed springs. Furthermore, the impacts of aquifer withdrawals and aquifer optimization strategies on these communities are uncertain. Springflow requirements of the biological community and the associated ecosystems, along with the potential environmental impacts of the aquifer optimization strategies must be better understood.

The Authority is mandated by the Act to ensure that aquifer withdrawals do not harm the environment. As stated in Section 1.14, aquifer withdrawals shall be limited to:

(1) protect aquatic and wildlife habitat;
(2) protect species that are designated as threatened or endangered under applicable federal or state law; and
(3) provide for instream uses, bays, and estuaries.

Further, the Authority is required by the Act to ensure continuous minimum springflow at Comal Springs and San Marcos Springs to protect endangered and threatened species to the extent required by federal law.

To achieve these objectives, additional information is needed about the flow requirements and potential aquifer optimization impacts on the biological community and the associated ecosystem. The TAG prioritized six biological assessments to provide answers to these issues and identified five of the six assessments for funding in Year 1. Additional studies of potential environmental impacts maybe required as specific optimization projects are proposed. The six biological assessments are described below.

Variable Flow Biological Monitoring Program

Aquifer optimization strategies, combined with natural climatic conditions, have the potential to alter flow rates at aquifer-fed springs. To ensure that the endangered species and the supporting ecosystem are protected, the effects of flow extremes, especially low flows, must be better defined. This project develops and implements a monitoring plan that collects biological data during extremely high and low flows, as well as annual baseline data. It is recommended that this study be commenced immediately to take advantage of changing hydrologic conditions and to allow sufficient time to monitor the effects of flow extremes, especially low flows.

Texas Wild-Rice Mapping

Texas wild-rice is one of the most impaired endangered-listed species endemic to the San Marcos system and is only found in the upper San Marcos River area. Although once pervasive in Spring Lake and the river, the distribution and abundance has been fragmented and reduced. Historic distribution and concentration patterns of the Texas wild-rice are not well known. Currently, the distribution of Texas wild-rice is limited to a few dozen relatively small stands.

This project will allow for the examination of the stand by stand population and distribution changes of the Texas wild-rice over the last decade by organizing and converting previously collected monitoring data into electronic form. An analysis of the data, in combination with current instream flow models for the system, may provide information about the fate of stands under various flow scenarios. This project has been recommended for potential funding by Texas Parks and Wildlife Department (TPWD) and is a candidate for a joint-funding agreement between the Authority and TPWD.

Texas Wild-Rice Growth and Reproduction

There is insufficient information on the influence of physical factors such as water depth, velocity and temperature on Texas wild-rice growth and reproduction. More detailed information is essential to evaluate flow requirements of Texas wild-rice stands. Plans for maintaining Texas wild-rice in the San Marcos River ecosystem will require knowledge of natural growth and reproduction in various flow regimes. This study will develop information on plant response to these physical factors that vary with varying flow. It is a multi-disciplinary, multi-year study, including both laboratory and field validation, and will examine ranges of parameters.

Potential Water Quality Impacts

Several optimization strategies, such as springflow augmentation, recharge enhancement, and local recharge at the springs have the potential to alter water quality in the aquifer and at the springs. The tolerance ranges of the rare and endangered species for water quality parameters such as temperature, pH, dissolved oxygen, and total dissolved solids are poorly understood. This study combines a comprehensive literature review with field collection, examination, and documentation of existing water quality and habitat conditions needed to protect and sustain spring biota. Tolerances for changes in water quality will be established for select indicator species. A monitoring program will be developed that tracks water quality and indicator species before and after implementation of optimization strategies.

Cagle's Map Turtle Flow Requirements

Aquifer optimization strategies that impact springflow also have the potential to impact downstream flows in the river systems to which they are connected. Although many of the aquifer optimization strategies are meant to increase springflow, the concept

of springflow recirculation has the potential to decrease downstream flows if not properly managed. The Authority is mandated by the Act to provide for downstream uses, including the habitat requirements of threatened or endangered species in the downstream Guadalupe River. The Cagle's map turtle (*Graptemys caglei)*, is endemic to the Guadalupe River basin and has been identified as "warranted for listing" on the Endangered Species List by the U.S. Fish and Wildlife Service (USF&WL).

Although preliminary work has been conducted on the turtle's life history, instream flow requirements are unknown. An instream flow study on the Guadalupe River is currently being conducted for the Guadalupe-Blanco River Authority (GBRA) in support of a TNRCC permit application. The study is funded predominantly by the Texas Natural Resource Conservation Commission (TNRCC), TPWD and the GBRA. The timing of this study provides the opportunity to gain information on the turtle's flow requirements by adding a turtle expert to their team. Flow data already being collected and analyzed can be combined with data on turtle occurrence and habitat at a relatively inexpensive cost. It is recommended that joint funding sources be explored for the study. However, due to the time-sensitive nature of the study, it is recommended that these efforts be expedited.

Well Sampling of Aquifer Biota

Previous examination of selected water samples from wells has revealed the presence of at least 44 unique species living within the aquifer (Bowles and Stanford, 1997), including the widemouth blindcat (*Satan eurystomus)* and the toothless blindcat (*Trogloglanis pattersoni)*. However, the distribution and population of these species are unknown. This study examines aquifer biota distribution by combining biological sampling with routine well sampling. Once the distribution is better understood, a better evaluation can be made of whether aquifer optimization strategies may impact the species.

B. Flowpath/Modeling Studies

The TAG identified eight flowpath/modeling studies for inclusion in the OTS. The purpose of these studies is to build on the current understanding of recharge and groundwater flow through the aquifer, focusing on areas that have the potential to impact optimization strategies. The studies build on the previous work conducted by the Authority, SAWS, the U. S. Geological Survey (USGS), and others. The eight, high-priority Flowpath/Modeling studies are listed in Tables 2 and 3 and briefly described below.

Management Model/GIS Data Sets

A computer model capable of simulating aquifer response to optimization strategies is the most important evaluation tool necessary for the EAOP. Once the model is constructed and calibrated to match historical measurements, it then becomes

the primary means for predicting the impacts of optimization strategies. The current computer model, GWSIM-IV (developed in 1979 and updated in 1992) was based on a now out-dated computer code that is cumbersome to work with and difficult to revise.

A major improvement for the model will be conversion to the widely accepted MODFLOW computer code, or other appropriate code that is more easily manipulated, user friendly and widely supported with programs and graphics. The new model will refine the grid to enhance the resolution and take into account information gathered since GWSIM-IV was constructed. This study also includes the organization and conversion of existing and new modeling data sets into geographical information system (GIS) format to facilitate data update and analysis.

A re-calibration of the model to include new aquifer data is included with this study. Model construction is recommended for funding in Years 1 and 2, with the recalibration occurring in Year 5 after other supporting studies, such as the Recharge Methodology and Fracture/Conduit studies, have been completed. The computer model is an integral part of all future technical analyses with widespread applications within the Authority. It is recommended that this project be given the highest priority for funding.

Saline Water Study

This study addresses the interface between freshwater and saline water in the aquifer. It is a long term investigation involving the installation and/or monitoring of more than 50 new and existing wells. An analysis of the dynamics of the freshwater/saline water interface in response to pumping and aquifer levels is also included. . Monitoring data will also be used to support the groundwater flowpath studies. The study is underway, largely funded by SAWS and USGS. The Authority has participated in this study in past years and continued support is recommended.

Recharge/Flowpath Study – North Medina County

Flowpaths along which groundwater travels within the aquifer must be better understood to reduce uncertainty in implementation of optimization strategies. Current understanding indicates that groundwater flowpaths in certain areas are complicated by faulting and other aquifer heterogeneities. Predicting aquifer response to recharge and pumping is dependent upon an understanding of flowpath geometry and aquifer connectivity.

North Medina County is one area where flowpath uncertainties that may affect aquifer optimization strategies are likely to occur. Recent USGS studies have indicated that recharge amounts may be significantly different than previously thought in this area. In addition, structural and stratigraphic complexities in this area likely create more complex flowpaths. This study will examine local flowpaths through well installation, water level measurements and water quality (isotope) sampling. Because of its potential impact on optimization strategies and time required to install and monitor new wells, it

is recommended that this project move forward as soon as possible. The TAG originally prioritized this project for Year 1 funding, but deferred the study into Year 2, due to budgetary constraints. If joint funding allows a reallocation of funds, it is recommended that this study be moved back into Year 1.

Focused Flowpath Studies

This flowpath study addresses three other areas of concern: Knippa Gap, Comal Springs, and San Marcos Springs. Flowpaths through the Knippa Gap indicate constricted flow from the western portions of the aquifer to the east. The constriction in flow and changing flow directions may be used in a beneficial way to optimize the aquifer. Currently, too few wells exist in this area to adequately understand the constraints on flow. Flowpath studies in the vicinity of Comal Springs and San Marcos Springs will allow assessment of local recharge alternatives and the evaluation of impacts from other aquifer optimization strategies. All of the flowpath studies will include the installation of new monitoring wells.

Recharge Methodology

Recharge to the aquifer occurs primarily by direct precipitation and streamflow infiltration over the recharge zone. The Authority and the USGS maintain stream gauges to provide data for recharge calculations. The current methodology for recharge calculations is based on simplifying assumptions of recharge that may not be applicable to all areas. The USGS is currently developing a more comprehensive methodology for recharge calculations based on detailed monitoring in Medina and Bexar counties.

The new methodology will incorporate a new USGS surface water model based on a comprehensive water balance approach. Both precipitation and streamflow data will be modeled and directly related to aquifer recharge on a daily basis. The application of this new methodology to the entire aquifer watershed is recommended as part of the Authority's research program. This application will use the USGS surface water model to provide recharge data for the re-calibration of the management model, scheduled in Year 5.

Statistical Analysis of Hydrologic Data

Hydrologic data has been collected and compiled into electronic formats by various organizations such as USGS, Texas Water Development Board (TWDB), the Authority, and others. Although these data have been used in numerous technical evaluations of the aquifer, a methodical, statistical examination of the data sets has not been conducted to explore hydrologic relationships in the natural system. This study would involve multiple regression analyses using various time steps to see if predicted and unpredicted correlations exist. This could refine the current understanding of the aquifer.

Fracture/Conduit Study

The structural complexities in the aquifer include faults, fractures, and a subsurface network of conduits that likely influence groundwater flowpaths on a local and regional scale. This study combines an outcrop and subsurface investigation to develop relationships between outcrop-scale observations to regional understanding of groundwater flow through the aquifer. This study will result in a methodology for assigning aquifer transmissivities to cells in the computer model that incorporates an understanding of fractures/conduits within the aquifer, a concept that is not represented in the current computer model. Although originally identified by the TAG as a high-priority project for immediate funding, the TAG deferred the project until Year 2 of the program because of insufficient funds. If joint funding cannot be secured, the results of the study will not be incorporated into the computer model until the scheduled re-calibration in Year 5.

3-D Interactive Visualization (Phase I)

This study will develop an interactive computer depiction of aquifer components to inform and educate both technical and layperson audiences, by allowing them to "see" the aquifer. The visualization via computer display will allow the user to view complex relationships between key aquifer features including aquifer geometry, faulting, distribution of permeability, water table and potentiometric surface, aquifer wells, surface geology, and natural and cultural features at the ground surface. It is recommended that this be deferred until late in the research program to take advantage of the generation of data sets and results from other studies.

C. Recharge Enhancement Studies

Two of the studies recommended in this program, Recharge Enhancement/Springflow Recirculation and Springflow Augmentation build on the recommendations of the Trans-Texas Water Program and the Center for Research in Water Resources (CRWR), respectively. The other recommended recharge enhancement study, Range Management of Woody Species, is already underway with joint funding. The TAG recommended recharge enhancement studies are listed in Tables 2 and 3 and briefly described below.

Range Management of Woody Species

On a small scale, Natural Resources Conservation Service (NRCS) studies have indicated that flow from springs located within the catchment (drainage) area of the aquifer increases when invasive woody species such as Ashe Juniper is strategically removed. Because of the potential to provide additional runoff for recharge, this study expands the control of invasive woody species to a larger (watershed) scale. Areas of

woody plant removal will be re-vegetated with grasses that filter runoff and improve water quality for recharge. The study also recognizes that continued benefits in water quality and water quantity will require some level of continued future management of the re-vegetated areas. To quantify study results, a detailed monitoring program in both altered and unaltered watersheds will be implemented. It is an ongoing, eight-year program targeted for completion in 2006 and is being jointly funded by the United States Department of Agriculture (USDA), NRCS, USGS, the Authority and SAWS. It is recommended that the Authority continue to support this project in anticipation of the need to quantify additional aquifer recharge relating to the control of invasive woody species.

Recharge Enhancement/Recirculation

Recharge enhancement refers to the identification of sites along streambeds crossing the recharge zone where containment structures could be built to capture water for infiltration into the aquifer. Alternatively, enhanced recharge can also be achieved through injection wells. Recirculation is a variation on recharge enhancement and refers to the capture of springflow and/or flood flows downstream of the springs and diversion back up to the recharge zone for aquifer recharge.

Assessments of potential recharge sites and springflow recirculation were included in the Trans-Texas Water Program and related technical reports published from 1991 through 1998. After a preliminary evaluation, the Trans-Texas Water Program reports recommended additional analysis using an improved groundwater model to simulate and evaluate various scenarios and combinations of recharge enhancement strategies. This study will use the new management computer model, being developed in Years 1 and 2 of this program. Therefore, this study is recommended for funding in Year 3.

Springflow Augmentation (Supplement Phase I)

A preliminary evaluation of springflow augmentation strategies was conducted in 1995 by the Center for Research in Water Resources (CRWR) at the University of Texas at Austin for the Edwards Underground Water District. A number of augmentation alternatives were identified and ranked by the CRWR. The higher-ranking alternatives were direct augmentation to spring-fed lakes at Comal Springs and San Marcos Springs, regional recharge for Comal Springs and San Marcos Springs, and local enhanced recharge for San Marcos Springs. None of the alternatives were identified as fully feasible because many uncertainties exist, including hydrogeologic unknowns as well as potential impacts on the biological community.

This study is proposed as a supplement to the CRWR Phase I. It addresses some of the Phase I deficiencies and recommends an action plan for further evaluation. Because of the complexity of this strategy, it will likely require a series of evaluations over time.

D. Additional Studies

Some of the technical deficiencies in the understanding of the aquifer and the natural system that it supports are being addressed by studies outside of the OTS and are not included here. The results of these separate studies will compliment the OTS and will be incorporated into the EAOP as appropriate. One such study is the proposed synoptic well surveys that will provide data for water level contour maps, flowpath studies, and the management computer model construction.

Another example of technical studies outside of the OTS is the Authority's water quality protection program in the recharge zone. The Authority, in cooperation with USGS, collects water-quality samples from approximately 50 wells, 6 springs, and 8 streams to sample for both inorganic and organic chemical constituents. Analyses includes common major ions, minor elements (metals, including heavy metals), nutrients, pesticides, herbicides, volatile organic compounds and other selected analytes. Further, in association with the USGS, the Authority is monitoring 30 recharge zone wells to assess impacts to aquifer water quality from urban land use activities. These data will be used to develop rules and other aquifer protection strategies.

An additional recharge enhancement project involving enhanced precipitation is also underway. The Precipitation Enhancement Program was initially considered by the Citizens' Advisory Committee on Water Policy and was included as an issue for TAG consideration. The project has been approved by the board of directors and is being jointly funded by the Authority and TNRCC. It is progressing independently of the TAG.

Two of the studies in the OTS, Springflow Augmentation and 3-D Interactive Visualization, are included as Phase I studies and will likely include a recommendation for Phase II. Results from Phase I are required to develop a reasonable scope, budget and schedule for Phase II studies. Results from all studies will be monitored and formally reviewed on an annual basis to discuss redirection and recommendation of additional Phase II work.

III. Conclusions

The Edwards Aquifer Authority Act gave the Authority the mandate to manage, conserve, preserve and protect the aquifer. Pursuant to this mandate, the Authority has undertaken a series of inter-related research studies designed to obtain necessary data and information to support optimization of the aquifer. The optimization philosophy benefits the users of the water resource, as well as preserves the unique biota and aquifer ecosystems. In essence, the goal of the EAOP is to do all of the necessary research to identify all of the possibilities to increase the amount of *available* water in the aquifer for all beneficial uses. Technical studies are needed to support this goal.

The Optimization Technical Studies have been designed by technical and scientific experts to provide essential information for reducing uncertainties in implementing aquifer optimization strategies. Studies address springflow quantity and water quality requirements of the ecosystem, groundwater flowpaths and water levels within the aquifer, and aquifer recharge processes and quantities. The proposed management computer model will facilitate an evaluation of the impacts of optimization strategies on groundwater levels and springflow. Studies have been prioritized and sequenced to provide data for related studies in support of the overall vision of aquifer optimization.

These studies represent only minimal research efforts that the TAG recommended. As the Optimization Technical Studies progress, they may show the need for additional studies. The program will be reviewed on an annual basis to incorporate study findings and make recommendations for redirection or additional work.

References

Bowles, D. E., and Stanford, R., A New Distributional Record for *Haideoporus Texanus* (Coleoptera: Dytiscidae), A Stygobiontic Beetle From the Edwards Aquifer, Texas, ENT. NEWS 108(4): 297-299, September and October, 1997.

Edwards Aquifer Authority, Edwards Aquifer Hydrogeologic Report for 1997, Edwards Aquifer Authority Water Resources Team Report 98-02, December 1997.

Groschen, G.E., Hydrogeologic Factors that Affect the Flowpath of Water in Selected Zones of the Edwards Aquifer, San Antonio Region, Texas, U.S. Geological Survey Water-Resources Investigations Report 96-4046, 73 pp., 1996.

Groschen, G.E., and Buszka, P.M., Hydrogeologic Framework and Geochemistry of the Edwards Aquifer Saline-Water Zone, South-Central Texas, U.S. Geological Survey, Water-Resources Investigations Report 97-4133, 47 pp., 1997.

HDR Engineering, Trans-Texas Water Program, West Central Study Area, Phase I, Interim Report Vol. 2, May 1994.

HDR Engineering, Edwards Aquifer Recharge Enhancement Project Phase IVA, Nueces River Basin, Prepared for Edwards Underground Water District, June 1994.

HDR Engineering, Trans-Texas Water Program, West Central Study Area, Phase II, Summary Report of Water Supply Alternatives, March 1998.

HDR Engineering, Trans-Texas Water Program, West Central Study Area, Phase II, Edwards Aquifer Recharge Analyses, March 1998.

HDR Engineering, Trans-Texas Water Program, West Central Study Area, Phase II, Updated Evaluation of Potential Reservoirs in the Guadalupe River Basin, March 1998.

HDR Engineering, Trans-Texas Water Program, West Central Study Area, Phase II, Population, Water Demand, and Water Supply Projections, March 1998.

HDR Engineering, Trans-Texas Water Program, West Central Study Area, Phase II, Comments, March 1998.

HDR Engineering and Espey, Huston & Associates, Recharge Enhancement Study: Volume I, Executive Summary, and Volume II – Technical Report, Guadalupe-San Antonio River Basin, Prepared for Edwards Underground Water District, September 1993.

Hovorka, S. D., Mace, R. E., and Collins, E. W., Permeability Structure of the Edwards Aquifer, South Texas – Implications for Aquifer Management, Bureau of

Economic Geology, University of Texas at Austin, Report of Investigations No. 250, 55 p., 1998.

Legislature of the State of Texas, 1993, Senate Bill No. 1477 (S.B. 1477), An act relating to the creation, administration, powers, duties, operation, and financing of the Edwards Aquifer Authority and the management of the Edwards Aquifer.

Maclay, R. W., Geology and Hydrology of the Edwards Aquifer in the San Antonio Area, Texas, U.S. Geological Survey, Water-Resources Investigations Report 95-4186, 64 pp., 1995.

McKinney, D. C., and Sharp, J. M., Jr., Springflow Augmentation of Comal Springs and San Marcos Springs, Texas: Phase I-Feasibility Study, Center for Research in Water Resources Bureau of Engineering Research, Technical Report CRWR 247, February 1995.

PBS&J, Marshall Jennings, Senior Hydrogeologist, Personal Communication, December 4, 1998.

San Antonio Water System (SAWS), Water Resources Action Plan, Final Draft, April 1, 1997.

San Antonio Water System (SAWS), Securing Our Water Future Together, Water Resource Plan, 1998.

Small, T. A., and Lambert, R. B., Geologic Framework and Hydrogeologic Characteristics of the Outcrops of the Edwards and Trinity Aquifers, Medina Lake Area, Texas, U.S. Geological Survey, Water-Resources Investigations Report 97-4290, 17 pp., 1998.

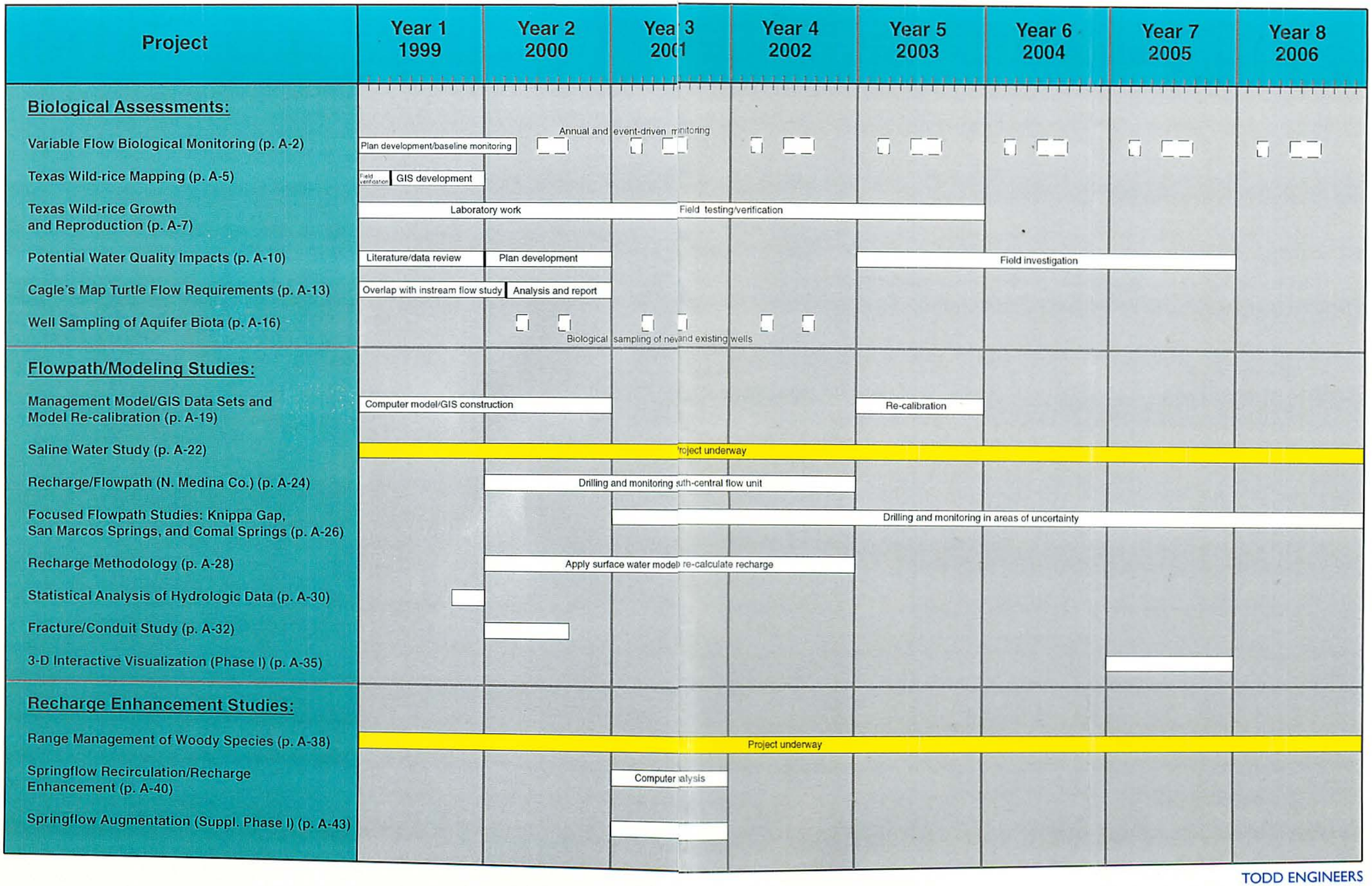
South Central Texas Water Advisory Committee, 1998 Assessment Report, Pre-Release Draft, October 1, 1998.

Turner Collie & Braden, Draft Groundwater Management Plan, Prepared for the Edwards Aquifer Authority, July 7, 1998.

W.E. Simpson Company, North Bexar County Water Resources Study for the Edwards Underground Water District, September 1993.

NOTE: Study-specific references are listed at the end of each summary in the Attachment

Table A-1
Optimization Technical Studies
Project Sequencing and Duration



TODD ENGINEERS

Summary of Proposed Study

EFFECTS OF VARIABLE FLOW ON BIOLOGICAL RESOURCES

Title: Effects of Variable Flow on Biological Resources of the Edwards Aquifer and Associated Ecosystems

TAG Subgroup: Biological Assessment Subgroup

Goal: Gain a better understanding of the effects of low springflows and extremely high springflows on biota and downstream ecosystems.

Abbreviated Scope: Develop and implement a biological monitoring program for target species and their ecosystem. Monitoring will be conducted when flows fall below an established limit (flow-triggered monitoring). Monitoring will also be conducted for very high springflows and baseline conditions.

Estimated Cost: Total $250,000 including $50,000 in Year 1 (plan and procedures development) and $25,000/year (including Year 1) for a minimum of eight years (flow-triggered/baseline monitoring).

Duration: Eight-year monitoring/data collection program on a flow-triggered basis. Program will be developed in Year 1 with monitoring through Year 8.

Prioritization Considerations: Before operational details of aquifer optimization strategies can be determined, flow requirements and tolerance ranges of endangered species at the springs must be known. While other ongoing and proposed biological assessments are designed to understand species' flow requirements, this study examines the effects of flow extremes including low and high springflow on the ecosystems and their biota. EAA staff and consultants, and TAG view this study as one of the highest priorities and recommend immediate funding.

Background/Previous Investigations: Habitat loss and fragmentation are well documented for their detrimental impacts to ecosystem structure and functioning, especially aquatic systems (Hynes 1970, Samways 1994, Resh and Rosenberg 1984, Thorpe et al. 1995). A decrease or cessation of aquifer flow into aquifer-fed springs, due to withdrawals, diversions, and natural phenomena such as drought, may result in a dewatering of the aquatic system. Dewatering is probably among the most severe form of habitat alteration for aquatic ecosystems, due to the immediate impacts placed on the system. Aquatic organisms must have water to survive. Even for species adapted to systems demonstrating seasonal drying, sustained water loss for excessive periods is detrimental. The process of dewatering can place enormous burdens on the

aquatic flora and fauna. These changes can include diminished water quality, increased temperature, increased sedimentation, concentration of contaminants, increased rates of disease, parasitism and predation, and disruption of other ecological processes such as feeding, reproduction, and life history. In situations where water is returned to a system following dewatering, or even periodic low flow, the recovery of the ecosystem may be retarded or permanently altered. In the case of systems having endemic species among its flora and fauna, permanent alteration of the ecosystem through extinction of one or more species can occur. This monitoring program will collect data necessary to further our understanding of flow tolerances of key indicator species and the impact of variable springflow on the ecosystem.

Related monitoring programs are currently being supported by various agencies. However, data are not being collected as part of a consistent, comprehensive monitoring program to fulfill EAA objectives. Further, when low flow events occur, insufficient staff and the absence of a specific plan prevent meaningful, comparable, and reliable data from being collected consistently. EAA staff and consultants will ensure coordination with ongoing programs and the collection of data pertinent to EAA goals and objectives.

Scope/Approach: A written biological monitoring plan will be developed and implemented over a minimum 8-year period to evaluate the effects of low and high springflow on the biological resources at Comal and San Marcos Springs. The plan will include baseline monitoring and flow-triggered monitoring to record impacts of high and low springflow on target species and the ecosystem. Field protocol, sampling methodology, definition of low and high flows, and reporting are to be included in the plan and reviewed by an appointed TAG subgroup member and EAA staff and consultants for recommendation to EAA. Plan will coordinate with USFWS and TPWD as permitting agencies.

Methodology: A detailed monitoring program will be developed for both broad ecosystem and sensitive species information gathering. Specific methodology will be proposed by the researcher and reviewed by TAG/EAA staff and consultants for recommendation to EAA.

Researcher Requirements: Monitoring will require a multidisciplinary approach with a cooperating team of experts in various fields including plant physiology, field ecology, fish, etc. and experience with water quality issues. Qualified researchers will be identified by the TAG Biological Assessment subgroup.

References:

Hynes, H. G. N., 1970, The Ecology of Running Waters, University of Toronto Press, Toronto, Canada, 555p.

Resh, V. H., and Rosenberg, D. M., 1984, The Ecology of Aquatic Insects, Praeger Scientific, New York, 625 p.

Samways, M. J., 1994, Insect Conservation Biology, Chapman & Hall, London, 358 p.

Thorpe, J. G., Gall, Lannan, J., and Nash, C. (eds.), 1995, Conservation of Fish and Shellfish Resources, Managing Diversity, Academic Press, London, 206 p.

Summary of Proposed Study
TEXAS WILD-RICE MAPPING

Title: Mapping the Historical Distribution of Texas Wild-rice (*Zizania texana*), 1989 to Present

TAG Subgroup: Biological Assessment Subgroup

Goal: Document and analyze historical Texas wild-rice distribution in relation to changes in flow to partially address Texas wild-rice flow requirements and support proposed aquifer management strategies that may impact springflows at San Marcos Springs and downstream in the Guadalupe River.

Abbreviated Scope: Convert handwritten field notes, data, and maps to a specified electronic format to facilitate the examination of historical Texas wild-rice distribution and changes over time in relation to changes in flow. Analyze stand size and persistence and population distribution over time. Correlate with historic flow regimes and incorporate known tolerances for water depth.

Estimated Cost: $50,000

Duration: One year scheduled to begin during Year 1 of the OTS.

Prioritization Considerations: There is a time-sensitive element to the project in that the field landmarks change and valuable institutional memory in interpreting field notes is lost over time. Data need to be converted into more precise, standardized and universally understood form to be preserved for analysis. This project also supports the proposed study, Texas Wild-rice Vegetative Growth and Reproduction, another high priority project. The U.S. Fish and Wildlife Service (USFWS) and Texas Parks and Wildlife Department (TPWD) have prioritized this project for funding. We recommend that the EAA and TPWD explore a cooperative agreement for joint funding to convert and analyze these data on a timely basis.

Background/Previous Investigations: Texas wild-rice has been monitored annually by the TPWD since 1989. Through the use of a system of reference points consisting of natural and man-made features, locations of stands of Texas wild-rice have been recorded and manually mapped. Due to the limitations of manual methodology, the accuracy of reference points and Texas wild-rice strands on available maps is questionable. In addition, this approach does not allow for the direct spatial comparison of distributions among successive years throughout the system.

Scope/Approach: Field book notes and manually generated maps will be converted into a Geographical Information System (GIS) for analysis. This process will be summarized in a report containing annual distribution maps of the wild-rice stands and database tables. After conversion, the data will allow for an analysis of the chronology of stands size and persistence, and how stands and population distribution have fluctuated over time. An initial evaluation of how past fluctuation correlates with historic flow regimes will also be conducted. The project approach will incorporate the methodology described below and will preserve valuable notes that might otherwise be lost with time.

Methodology: Reference points used in historic data collection will be identified and surveyed with specified survey equipment. Surveyed data will be converted to digital format (AutoCAD) to generate wild-rice reference points and identifiers. The field data will be transferred to a digital database referenced to the survey points and include plant identifier, length, width, percent cover, stand orientation, areal coverage, and additional data/notes recorded during the monitoring events. The AutoCAD drawing and database will be converted to GIS software (ArcView) for plotting maps over time.

Researcher Requirements: The contractor must have previous documented experience working with Texas wild-rice in its native habitat, intimate knowledge of its historical distribution, and experience with GIS database/map construction. Individuals having previous extensive experience working with Texas wild-rice include Jackie Poole, Dr. Francis Rose, Paula Power, and Karim Aziz. Ms. Poole must be involved in the project because of her role in initial data collection efforts.

Summary of Proposed Study
TEXAS WILD-RICE GROWTH AND REPRODUCTION

Title: Physical Factors Influencing Texas Wild-rice (*Zizania texana*) Vegetative Growth and Sexual Reproduction

TAG Subgroup: Biological Assessment Subgroup

Goal: Assess variable flow impacts on Texas wild-rice growth and reproduction to assist in evaluating potential impacts from aquifer optimization strategies and meet EAA goals of maintaining flows required by the species.

Abbreviated Scope: Conduct the necessary laboratory and field work to identify the physical factors that influence vegetative growth and sexual reproduction in general and the impacts of low flow scenarios on growth and reproduction.

Estimated Cost: $300,000

Duration: 5-year study including 3 years of laboratory work and 2 years of field validation (including a low flow year). Study will begin in Year 1 and continue through Year 5.

Prioritization Considerations: Aquifer optimization strategies have the potential to affect flow at San Marcos Springs and in the downstream river system. Potential impacts from these flow changes on the endangered Texas wild-rice cannot be assessed until more is known about the factors affecting its growth and reproduction and the specific impacts of varying flow regimes with an emphasis on low flow conditions. Because of the multi-year nature of the study and the importance of its findings relative to future aquifer management strategies, we recommend a high priority for the implementation of this project.

Background/Previous Investigations: Texas wild-rice, occurring only in the upper San Marcos River, is federally and state listed as endangered and is one of the most impaired listed species in the San Marcos system. Once pervasive in Spring Lake and the river, it was regarded as a pest species in irrigation canals and other areas used by man. Since at least the late 1960's, however, the distribution and abundance of Texas wild-rice has been reduced and fragmented, probably as a result of drought and low flows, dredging, predation, recreation, exotic species, and other threats. Several attempts at reintroduction have been unsuccessful. The species' current limited and highly fragmented distribution of mostly small stands is apparently very different from its historic condition, and makes the species very vulnerable. Many of its normal dynamic processes are likely impaired, including normal flowering, seed set and dispersal. The low level of recruitment of new

stands (through either seed or clonal material) in the last decade indicates that the species is unable to disperse to other favorable sites.

Reductions in depth or flow rates in Texas wild-rice stands are known to have significant detrimental effects, at least in the short term, and have the potential to cause weakening of stand robustness and loss of genetic variability. Overall recovery potential and expected recovery rates following low flows are not well understood.

With reintroduction techniques as yet unreliable, present conservation strategies require maintenance of the existing stands in the river. Plans for the maintenance of Texas wild-rice in the system under managed flow regimes will have to be developed, at least initially, using a site-by-site evaluation of the expected response of existing Texas wild-rice stands to changes in physical factors under various flow regimes. These expected physical factors would be derived through the use of hydrological models. These models would be evaluated for general field validity through collection of field data and examination of recent monitoring efforts, the wild-rice mapping study outlined above, and future monitoring data.

There is insufficient information about the influence of physical factors on Texas wild-rice growth and reproduction to support more than general ranges for species needs for depth and velocity. Previous studies have been predominantly observational or preliminary in nature and have not determined ranges of flow tolerances of Texas wild-rice. Better information about the influence of physical factors on Texas wild-rice is essential to support a more quantitative evaluation of its flow requirements and to evaluate potential impacts from changes in springflow that may be associated with aquifer optimization strategies.

Scope/Approach: Carefully controlled laboratory growth studies are needed to evaluate minima, maxima and optimal values for critical physical factors related to flow regimes (including but not limited to depth, velocity, free carbon availability, sediment texture, and temperature). Conducting most such studies requires specialized equipment to examine single variables as well as carefully constructed multi-variable combinations. Emphasis will be on understanding the essential physical factors supporting optimum growth and robust expansion of Texas wild-rice. Studies should also include an evaluation of low flow tolerance by examining minimum or near minimum physical characteristics with varying durations, and describing plant response characteristics that indicate stress and suboptimal growth conditions preceding plant death (such as low photosynthesis rates, thin and chlorotic leaves, very short leaves, or the production of a short inflorescence under stressful conditions). An objective is to be able to differentiate normal plant seasonal changes, senescence and death from environmentally induced stress responses.

While studies of physical factors that maintain general robust vegetative growth are needed, the relationship between physical factors and critical developmental processes for reproduction must also be examined. These studies would explore physical and other environmental cues that initiate or inhibit inflorescence formation, flowering, seed maturation, and seed germination and

viability (such as photoperiod, temperature, depth, velocity, predation, etc.). An examination of plant vigor and stand characteristics needed to support normal flowering and seed set (as opposed to stress induced flowering) and adequate gene flow in the population is needed. These studies would include analysis of plant biomass partitioning in plants that flower, overall stand size and/or maximum distance between stands needed to achieve pollination, factors influencing pollen viability and travel distances, and seed rain and dispersal characteristics. An understanding of these processes is needed to evaluate the impacts to Texas wild-rice from aquifer management scenarios that might reduce stand size, fragment existing stands, or result in greater distances between stands.

Methodology: A more detailed scope of work should be developed cooperatively between EAA and biological resource agencies responsible for Texas wild-rice that outlines critical areas of investigation, research qualifications, type of data collection and level of analysis and interpretation expected. Specific modifications, methods, and protocols will be proposed by the researcher and reviewed by TAG, EAA staff and consultants, and interested agencies prior to contracting. In addition, laboratory studies must be evaluated for validity or sensitivity under field conditions, to identify any additional practical limits or moderating influences imposed by the natural environment.

Researcher Requirements: This research requires a multidisciplinary approach, with a cooperating team of experienced research scientists proficient in plant physiology, physiological ecology, field ecology, and pollination and reproductive biology. Individual researchers would contribute appropriate studies through either a cooperative or subcontracted structure. Physiologists and physiological ecologists would be expected to conduct controlled laboratory studies and limited field evaluations. Field ecologists and pollination/reproductive biologists would be expected to conduct field validation studies, pollination and reproductive biology experiments. Alternatively, the investigations could be structured as a series of related studies/contracts, with individual researchers bidding on contracts for specific elements of the research as appropriate to their areas of species and research expertise.

Specialized experts with demonstrated experience working in these areas include: Dr. Robert Doyle (University of North Texas), Dr. Jerilyn Jewitt-Smith (Texas A&M, Laredo), Jackie Poole (TPWD), Dr. Irving Oelke (University of Minnesota), Dr. Christina Walters (USDA-National Seed Storage Lab), and Paula Power (USFWS).

References:

U.S. Fish & Wildlife Service (USFWS), 1984, San Marcos Recovery Plan for San Marcos River Endangered and Threatened Species, Albuquerque, New Mexico.

Summary of Proposed Study

POTENTIAL WATER QUALITY IMPACTS ON BIOLOGICAL RESOURCES

Title: Potential Water Quality Impacts on Biological Resources Resulting from Aquifer Optimization Strategies (Phase I)

TAG Subgroup: Biological Assessment Subgroup

Goal: Develop a database on historic water quality associated with Edwards Aquifer-dependent aquatic biota for future evaluation of potential water quality impacts on the biota and associated ecosystems from aquifer optimization strategies. As water quality changes are contemplated by optimizing strategies, build on the database through additional research and data collection. Upon completion, the project would allow direct comparison of biodiversity/community composition with water quality data in each habitat and tracking of changes as aquifer optimization strategies move forward.

Abbreviated Scope: Conduct a comprehensive literature search and compile and annotate historical data and information related to spring water quality and to the composition, diversity and distribution of aquatic biota in subterranean, orifice and spring pool/run habitats, focusing on the sensitivity of indicator species to various water quality conditions. Prepare a plan for researching and collecting new data and information related to existing water quality and habitat conditions; presence and abundance of vertebrate and invertebrate organisms; biological communities that support threatened and endangered species; and species tolerances to potential changes of water quality caused by optimization strategies. Establish a monitoring program for continuous data collection and interpretation as optimization details are developed.

Estimated Cost: Total cost of $300,000 with $15,000 in Year One (comprehensive literature search, compilation and annotation), $60,000 in Year Two (preparation of data collection and monitoring plan), and $75,000 in each of Years 5, 6 and 7 (data collection, research, interpretation and initial monitoring).

Duration: 5 years. Literature review and plan development are scheduled for Years 1 and 2 with field investigation planned for Years 5, 6, and 7.

Prioritization Considerations: Proposed and developing Edwards Aquifer optimization strategies, including recharge enhancement, springflow augmentation, springflow recirculation, and range management have the potential to affect aquifer water quality and possibly impact the aquatic biota within the aquifer, spring orifices and spring pools or runs. A search of historical data related to water quality and community and habitat conditions at the springs should be conducted followed by the collection of new water quality and baseline biological data. These activities should precede the implementation of any optimization strategy that may impact water quality. Additionally, a monitoring program should be established that provides new data for comparing conditions before and after implementation of an optimization strategy. This program would facilitate comprehensive evaluations and promote informed management decisions concerning aquifer resources and optimization strategies.

Background/Previous Investigations: Numerous publications on the aquatic biota and ecosystems supported by the Edwards Aquifer-fed springs contain water quality data on temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO), and other water quality parameters. Data and information from these publications along with new data will be compiled, analyzed and used to select representative indicator organisms to monitor for water quality tolerances and assess the potential for water quality impacts from optimization strategies.

Scope/Approach: The program for documenting historical and existing water quality and community composition, diversity and distribution of aquatic biota in subterranean, orifice and spring pool/run habitats for comparison with future conditions includes the following:

Year 1:
Comprehensive literature search, compilation and annotation of historical data and information related to spring water quality and to the composition, diversity and distribution of aquatic biota in subterranean, orifice and spring pool/run habitats, focusing on the sensitivity of various indicator species to a variety of water quality conditions.

Year 2:
Preparation of a plan for collecting data related to existing water quality and habitat conditions, presence and abundance of vertebrate and invertebrate organisms, biological communities that support threatened and endangered species, species tolerances to potential changes of water quality caused by optimization strategies, and establishment of a monitoring program for continuous data collection and interpretation.

Years 5, 6 & 7:
Implementation of research and monitoring plan developed in Year 2, and monitoring water quality and community/habitat conditions and comparing these conditions to historical data.

The gap between Year 2 and Year 5 will allow time for information and decisions on optimization strategies to be developed, so that potential water quality impacts of specific strategies likely to be implemented are evaluated.

Methodology: Specific methodology for Years 1,2, 5, 6 and 7 activities will be proposed by the researcher and reviewed by TAG/EAA staff and consultants for recommendation to EAA.

Researcher Requirements: This is a complex, multiphase project requiring a team approach to complete. This research may be carried out be a consulting firm that would assemble a team having expertise in the fields of water quality, ichthyology, invertebrate biology, instream flow biology, and aquatic habitat biology/ecology. The literature search may be performed as a stand-alone component of the project by a researcher that may be independent from the researchers that develop the monitoring phases of this study.

Entities with experience in these areas include: San Antonio River Authority, Texas Parks & Wildlife Department, , U.S. Fish & Wildlife Service, Texas Natural Resource Conservation Commission and Southwest Texas State University.

Summary of Proposed Study

CAGLE'S MAP TURTLE
INSTREAM FLOW AND HABITAT REQUIREMENTS

Title: Assessment of Instream Flow and Habitat Requirements for Cagle's Map Turtle (*Graptemys cageli*).

TAG Subgroup: Biological Assessment Subgroup

Goal: Assess the instream flow requirements and habitat characteristics of the Cagle's map turtle, a candidate for endangered species listing endemic to the Guadalupe and San Marcos River systems. Results will be used to address potential impacts on the turtle's habitat from changes in flow in the Guadalupe River potentially resulting from aquifer optimization strategies such as springflow recirculation.

Abbreviated Scope: A turtle expert will be added to the team of investigators currently studying instream flow requirements of the Guadalupe River fish community and downstream flow requirements of bays and estuaries. This expert will interact with the hydrologists and biologists currently involved in the study to combine expertise and avoid duplication of flow monitoring and analysis for both the fish community portion of the study and the turtle portion of the study.

Estimated Cost: $100,000

Duration: 2 years consisting of 1½ years to overlap with the ongoing instream/downstream study and an additional ½ years to analyze data from the field program. Study is scheduled for Years 1 and 2 of the OTS.

Prioritization Considerations: Aquifer optimization strategies have been proposed involving capture and recirculation of downstream water along the Guadalupe River system. Since this strategy has the potential to impact downstream flows on the Guadalupe River, flow requirements of downstream habitat must be considered, and therefore, we recommend this study as a high priority. An additional benefit of this study to the EAA will be the opportunity to capitalize on data collection being funded and conducted by others.

Background/Previous Investigations: The Guadalupe-Blanco River Authority (GBRA), the main water purveyor on the Guadalupe River, is currently conducting a major instream flow study in the Guadalupe River system. The study is associated with a GBRA permit application to increase the firm yield of

Canyon Lake reservoir. Releases from Canyon Lake are associated with hydroelectric operations and create dramatic fluctuations in instream flow, potentially impacting the aquatic system. The study is being jointly funded predominately by GBRA and the Texas Natural Resource Conservation Commission (TNRCC).

Phase I of this study has been completed. Phase II began July 1998 and is expected to continue into 2000. This study will examine the hydrologic conditions in the Guadalupe River as well as the fish and wildlife community, but the current study team does not include a turtle expert.

The Cagle's map turtle (*Graptemys caglei*) is endemic to the Guadalupe River Basin and has been identified as "warranted for listing" on the Endangered Species List by the U.S. Fish and Wildlife Service (USFWS). Although some preliminary work has been conducted on the turtle's life history, instream flow requirements and basic habitat characteristics of the turtle are unknown (Killebrew, 1991; Killebrew and Babitzke, 1996). Clarification of specific biological parameters could potentially preclude listing of the species as threatened or endangered and could be instrumental in developing a management plan for its conservation.

Scope/Approach: The Biological Assessment Subgroup has recommended adding a turtle expert to the team conducting the ongoing instream flow study on the Guadalupe River. This will allow the turtle expert to work closely with the hydrologic and biological experts on the team to ensure an integrated approach to the evaluation of the system. It will increase the efficiency of the study to conduct the investigations concurrently and allow the turtle expert to rely on the hydrologic data being collected outside his/her area of expertise. Specific biological investigations that would be more efficient when combined with the instream flow study include:

- Correlate turtle occurrence with detailed physical maps of stream reaches inhabited by the species
- Determine specific habitat requirements using instream flow methodologies and other techniques as appropriate
- Determine instream flow requirements

Methodology: Field investigation methods will be proposed by the researcher and approved by TAG/EAA staff and consultants for recommendation to EAA. Methodology will be coordinated with the ongoing instream flow study.

Researcher Requirements: A recognized turtle expert with demonstrated previous experience working with Cagle's map turtle or closely related species in its natural habitats will be required. Qualified herpetologists initially identified by the Biological Assessment Subgroup include Dr. Flavius Killebrew (Department of Biology, West Texas State University), Dr. Andy Price (TPWD), and Dr. Randy Simpson and Dr. Francis Rose (Department of Biology, Southwest Texas

State University). Other individuals with extensive experience relevant to this proposed study include Doyle Mosier (TNRCC) and Kevin Mayes and Karim Aziz (TPWD).

References:

Killebrew, F. C., 1991, Habitat Characteristics and Feeding Ecology of Cagle's Map Turtle (*G. caglei*) within the Proposed Cuero and Lindenau Reservoir Sites. Texas Parks and Wildlife Department, contract Study No. 1, Pt. V, Austin, TX.

Killebrew, F. C., and Babitzke, J.B., 1996, Populations Analysis and Nesting Study of Cagle's Map Turtle, U.S. Fish and Wildlife Service Report, Austin, TX.

Summary of Proposed Study
WELL SAMPLING OF AQUIFER BIOTA

Title: Well Sampling of Aquifer Biota

TAG Subgroup: Biological Assessment Subgroup

Goal: Collect data on the distribution and abundance of aquifer biota to better evaluate potential impacts from aquifer optimization strategies.

Abbreviated Scope: Develop a sampling strategy and protocol for data collection. Coordinate biological sampling with other well sampling in both new and existing wells in the aquifer.

Estimated Cost: $90,000

Duration: 3 years scheduled for Years 2, 3, and 4.

Prioritization Considerations: Conducting aquifer biota sampling in wells is more efficient if combined with other sampling events when the well pump is pulled or in new wells before pumping equipment is installed. Sampling program protocol should be put into place to take advantage of new wells associated with other studies such as the Saline Water Study and several flowpath studies. Sampling is currently scheduled to begin in year two of the research program and data will be collected as wells are available for sampling over the three year duration (years two through four).

Background/Previous Investigations: The only known worldwide occurrence of the widemouth blindcat (*Satan eurystomus*) and the toothless blindcat (*Trogloglanis pattersoni*) is in parts of the Edwards Aquifer underlying Bexar County, Texas. These species have generated substantial interest in the scientific community because of their unique biology, very limited distribution, phylogenetic relationships, and evolutionary history. Because specimens have only come from wells deep within the aquifer, very limited information about their abundance, distribution, population trends, and other life history information have been developed. The last comprehensive survey of these species was in 1979 (Longley and Karnei). Without additional information being developed about these species, there will be increasing pressures exerted on regulatory agencies to protect these species through listing or other mechanisms. If new information about the distribution and population status for these species could be developed through sampling previously sampled and new wells, it could support better informed decisions about conservation efforts.

Additional sampling for subterranean invertebrates, as well as surface-dwelling forms, may show these taxa to be more widely distributed than previously thought. For example, a wider distribution recently was shown for a subterranean diving beetle previously known only from an artesian well at San Marcos (Bowles and Stanford, 1997). Numerous springs and wells occur throughout the region overlying the Edwards Aquifer and additional monitoring wells are proposed. All of these locations are potential sampling sites for subterranean and spring-dwelling invertebrates.

Scope/Approach: A more detailed scope will be developed for the Request for Qualifications (RFQ) process.

Methodology: Specific sampling protocol must be consistent in all sampling events. Written protocol will be developed as part of the RFQ process.

Researcher Requirements: Specialized expertise is required to conduct and analyze well sampling events. The project team should include, at a minimum, an experienced ichthyologist having relevant experience working with subterranean fishes, an invertebrate biologist having experience working with subterranean aquifer invertebrates, and a biologist having intimate understanding of the Edwards Aquifer. Experts with demonstrated experience working in these areas include Dr. Randy Moss and Dr. David Bowles (Texas Parks and Wildlife Department), Dr. Dean Hendrickson (Department of Zoology, University of Texas), Dr. Glenn Longley (Department of Biology, Southwest Texas State University), Dr. Paul Spangler (Smithsonian Institution), and Cheryl Barr (University of California at Berkeley).

References:

Bowles, D. E., and Arsuffi, T. L., 1993, Karst Aquatic Ecosystems of the Edwards Plateau Region of Central Texas, USA: A Consideration of their Importance, Threats to their Existence, and Efforts for their Conservation, Aquatic Conservation: Marine and Freshwater Ecosystems 3:317-329.

Bowles, D. E., and Stanford, R., 1997, A New Distributional Record for *Haideoporus texanus* (Coleoptera: Dytiscidae), A Stygobiontic Beetle From the Edwards Aquifer, Texas, Entomological News, 108:297-299.

Cooper, J. E. and Longley, G., 1980a., *Satan eurystomus* Hubbs and Bailey, page 473 in D.W. Lee, et al., editors, Atlas of North American Freshwater Fishes, North Carolina Biological Survey Publication 1980-12.

Cooper, J. E., and Longley, G., 1980b, *Trogloglanis pattersoni* Eigenmann, page 474 in D.W. Lee, et al., editors, Atlas of North American Freshwater Fishes, North Carolina Biological Survey Publication 1980-12.

Hubbs, C. L., and Bailey, R. M., 1947, Blind Catfishes From Artesian Waters of Texas, Occasional Papers, Museum of Zoology, University of Michigan: 499, 15p.

Langecker, T. G., and Longley, G., 1993, Morphological Adaptation of the Texas Blind Catfishes *Trogloglanis pattersoni* and *Satan eurystomus* (Siluriformes: Ictaluridae) to their Underground Environment, Copeia 1993 (4): 976-986.

Longley, G. and Karnei, H., 1979, Status of *Trogloglanis pattersoni* Eigenmann, The Toothless Blindcat, Endangered Species Report 5, Part 1, U. S. Fish and Wildlife Service, Albuquerque, New Mexico, 48p.

Suttkus, R. D., 1961, Additional Information about Blind Catfishes from Texas, Southwestern Naturalist 6: 55-64.

U. S. Fish and Wildlife Service, 1997, Endangered and Threatened Wildlife and Plants; Final Rule to List Three Aquatic Invertebrates in Comal and Hays Counties, Texas as Endangered, Federal Register 62: 66290-66304.

Summary of Proposed Study
MANAGEMENT COMPUTER MODEL/GIS DATA SETS

Title: Management Computer Model/GIS Data Sets

TAG Subgroup: Modeling/Flowpath Subgroup

Goal: Develop a computer model for analysis of aquifer and springflow response to various optimization alternatives

Abbreviated Scope: Using data from GWSIM-IV (the existing computer model of the aquifer) construct and calibrate an updated computer model with specified modifications to improve the model's analytical capabilities. This project should be combined with the compilation and organization of data sets into a Geographical Information System (GIS) to allow EAA staff and other parties the ability to access aquifer data. Because the model is a tool for current and future use, it must be updated periodically with new data from the aquifer monitoring program as well as new concepts and ideas originating from the results of other studies. Consistent with this future commitment, a model re-calibration, strategically scheduled in Year 6 is included as a part of this project.

Estimated Cost: $400,000 in Years 1 and 2 for model/GIS construction. $100,000 in Year 6 for model re-calibration

Duration: 18-24 months for construction; 6 months for re-calibration. Model construction is scheduled for Years 1 and 2 with a re-calibration in Year 5.

Prioritization Considerations: The management computer model will be required to analyze and optimize groundwater management strategies. Future studies, including recharge enhancement and cost benefit analyses, will require modeling. This study is an integral part of the technical analysis and optimization of the aquifer and is being designed with multiple uses and updates in mind. We recommend that this project be given the highest priority for research funding.

Background/Previous Investigations: In 1979, the Texas Water Development Board (TWDB) developed and published a computer model using the PLASM code (Prickett and Lonnquist, 1971) to simulate water levels and springflow associated with the Balcones Fault zone of the Edwards Aquifer (TWDB, 1979). In 1992, the TWDB conducted an update and re-calibration of the model. Some of the 1992 model improvements included calculating monthly recharge and discharge data from 1978-1989, changing from an annual to a monthly time step, and re-calibrating the model for the time period 1947-1959. After

additional model verification, monthly recharge data were calculated through 1990 and added to the model.

This model, commonly referred to as GWSIM IV, has been widely used in computer model applications relating to the Edwards Aquifer. However, the model is cumbersome in data manipulation and difficult to use, in part, because of the out-dated computer code. For this and other reasons, many model applications must be conducted by knowledgeable modelers at the TWDB, creating scheduling, priority, and funding issues. Researchers at the UTSA Center for Water Research have developed a helpful computer program (post-processors) to make the model easier to use, but numerous model limitations exist.

Since the development of GWSIM, another flow model computer code, MODFLOW, written by the U.S. Geological Survey (McDonald and Harbaugh, 1986) has become widely accepted. The modular format of the program allows for more straightforward data input and manipulation. Because of the widespread use of MODFLOW in the water resources and environmental fields, numerous add-on programs (pre- and post-processors) have been written to customize the model simulations and graphical outputs. Model tasks such as grid modification and sensitivity runs are much quicker and easier to conduct in MODFLOW than in PLASM.

To analyze the complex alternatives being proposed for the Aquifer Optimization Program, an updated computer model is necessary. Rather than attempt a costly update, modification, and re-calibration of GWSIM IV, we recommend using the current model input files along with a revised conceptual model of the aquifer to develop a more sensitive tool with MODFLOW or other appropriate computer code.

Scope/Approach: Model development will involve working with GWSIM input files, current data sets of recharge and pumpage (including pumping data obtained by EAA during their permitting process), the organization of data sets into a GIS, and construction of a management computer model. The new model will incorporate recent developments in the conceptual model of the aquifer including a re-positioning of the saline water line, more accurate time distribution of irrigation pumping, and more accurate spatial distribution of domestic and stock pumping. The project will also involve a re-assessment of system components for incorporation into the model such as Medina Lake recharge, Hays County recharge, Guadalupe River recharge, and the head-discharge relationship of San Antonio, San Pedro, and Leona springs. Transient calibration runs will be conducted at appropriate time steps for the entire data record as a first step toward calibration. The calibration process will also evaluate the model's ability to match water level maps from ongoing synoptic water level data mapping by EAA.

Methodology: Specific methodology will be proposed by the contractor and reviewed by TAG/EAA staff and consultants for recommendation to EAA.

Researcher Requirements: Qualifications and schedule are major considerations in the selection of an appropriate party to conduct this project. The modeler responsible for the technical portion of the project must have the following minimum qualifications:

- Working knowledge of GWSIM IV
- Working knowledge of Edwards Aquifer hydrogeology
- Experience in the construction and application of MODFLOW
- Experience in organizing data sets into a GIS format
- Commitment to project schedule

References:

Klemt, W.B., Knowles, T.R., Elder, G.R., and Sieh, T.W., 1979, Ground-Water Resources and Model Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas, Texas Department of Water Resources Report 239, 94 p.

Lowther, R.A., and Kuniansky, E.L., 1992, Documentation of Finite-Element Mesh Generation Programs Using a Geographic Information System, U.S. Geological Survey Water-Resources Investigations Report 92-4155, 188p.

Maclay, R. W., and Land, L. F., 1988, Chapter A, Simulation of Flow in the Edwards Aquifer, San Antonio Region, Texas, and Refinement of Storage and Flow Concepts, U.S.G.S. Water Supply Paper 2336-A.

Prickett, T. A., and Lonnquist, C. G., 1971, Selected Digital Computer Techniques for Ground Water Resource Evaluation, Illinois Water Survey Bulletin 55, 62p.

Thorkildsen, D. F., and McElhaney, P. D., 1992, Model Refinement and Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas, Texas Water Development Board Report 340, July.

Summary of Proposed Study
SALINE WATER STUDY

Title: Saline Water Study

TAG Subgroup: Flowpath/Modeling Subgroup

Goal: Conduct a regional investigation and data collection program to assess the likelihood of saline water encroachment across the currently-mapped freshwater/saline water interface during times of low water levels or periods of extended drought. Establish a regional, long-term monitoring program to continually monitor the dynamics of the interface.

Abbreviated Scope: Confirm the recently-revised interface position with new well transects, measure water quality in both zones, compare to historic data, incorporate structural and stratigraphic information, model the dynamics of the interface, and establish a regional, long-term monitoring program for the future. A regional network of 36 new monitoring wells and 22 re-worked wells will be established.

Estimated Cost: $9,742,766 is the estimated total study cost currently being jointly funded by SAWS, USGS, TWDB, and EAA. Requested contribution from EAA is $150,000/year for the remaining 8 years of the study for an estimated total EAA cost of $1,200,000, contingent upon continued participation by SAWS, USGS, and TWDB. This level is consistent with the $150,000 contribution to the Knippa Gap well transect approved in the 1998 EAA budget.

Duration: 10 years (1999 is year 3 of the study). Study will continue through the entire 8-year OTS program.

Prioritization Considerations: This study addresses one of the longstanding major technical concerns about groundwater withdrawal from the Edwards Aquifer. Until the issue is adequately investigated, permitted aquifer withdrawals will be subject to intense criticism. This study, recognized by the TAG as high priority, needs EAA funding to move forward on schedule. Given that the answers from the study are critical to EAA goals and that EAA's proposed contribution is only 15 percent of the total project cost, we recommend that the EAA continue to contribute $150,000/year in support of the study.

Background/Previous Investigations: The freshwater/saline-water interface of the Edwards Aquifer is a regional boundary between the fresh and saline portion of the aquifer and is defined by a mapped contour line representing 1,000 mg/l of

total dissolved solids (TDS). The interface varies both laterally and vertically in portions of the aquifer. Water quality concerns related to the position and stability of the freshwater/saline-water interface have been expressed for years. The limited water quality data collected during and since the drought of record in the 1950's is inconclusive as to whether encroachment of saline water is likely.

This ongoing study was proposed and funded by SAWS and USGS to address some of the technical unknowns of the interface and to test recent technical developments such as the more detailed depiction of the interface mapped by Schultz (1993) using geophysical logs. The drilling program to date has largely validated the re-mapping effort in several locations. Additional drilling, water quality analysis, modeling, and long-term monitoring will provide the necessary technical basis to assess the likelihood and location of potential saline water encroachment.

Scope/Approach: Construct or re-work 58 wells for a regional monitoring system. Wells will be located along transects near pumping centers, springs, and areas of uncertainties in the aquifer. Water level data and water quality samples will be collected from each well and incorporated into the overall understanding of the transect area. Continuous water level monitoring devices will be installed in each of the wells for future incorporation into the aquifer-wide monitoring program. A local-scale flow and transport model will be constructed for each transect area and may use portions of the new regional management computer model recommended for construction in another study. The modeling will assist in predicting the dynamics of the interface under different hydrologic conditions.

Methodology: Methodology incorporates accepted professional practice of field procedures including drilling and installing new wells, well sampling procedures, quality control of laboratory results, and monitoring equipment installation.

Researcher Requirements: Not applicable. Study has been scoped and supported by SAWS, USGS, and TWDB personnel.

References:

Schultz, A. L., 1994, 1994 Review and Update of the Position of the Edwards Aquifer Freshwater/Saline-Water Interface from Uvalde to Kyle, Texas, Edwards Underground Water District Report 94-05, November, 31p.

Schultz, A. L., 1993, Defining the Edwards Aquifer Freshwater/Saline-Water Interface with Geophysical Logs and Measured Data (San Antonio to Kyle, Texas), Edwards Underground Water District Report 93-06, July 1993.

Summary of Proposed Study
RECHARGE/FLOWPATH STUDY – NORTH MEDINA COUNTY

Title: Recharge/Flowpath Study – North Medina County

TAG Subgroup: Flowpath/Modeling Subgroup

Goal: Improve the understanding of groundwater flowpaths in northern Medina County, incorporating structural and stratigraphic complexities.

Abbreviated Scope: Drill and monitor 4-6 new wells in the USGS-defined Western Medina flow unit to determine recharge amounts into this flow unit and to better quantify groundwater flowpaths in the area.

Estimated Cost: $600,000

Duration: 3 years, currently scheduled in Years 2, 3, and 4. Recommend moving to Years 1, 2, and 3 as additional funds become available.

Prioritization Considerations: The results from this study are important for further evaluation of pumping redistribution, springflow recirculation, and recharge enhancement. Several recharge structures included in the Trans-Texas Recharge Enhancement study are located within the area. The field program envisioned in this study will take time to complete and monitoring wells must be measured during times of varying hydrologic conditions to examine groundwater flow direction changes over time. The TAG prioritized this study for commencement in Year 1, but the project was deferred into Year 2 based on EAA budgetary constraints. If outside funding sources can be obtained, we recommend the commencement of this project as soon as possible.

Background/Previous Investigations: Previous regional water balance calculations have assumed significant amounts of recharge from both Medina Lake and Diversion Lakes. Field investigations conducted by the USGS in 1995 and 1996 indicate that at times of low lake levels, actual recharge amounts may be approximately one-half of the amounts calculated using current methodology. This inconsistency implies a problem with the regional water balance and deserves further investigation. Groundwater recharge and flows in this area are complicated by the surface geology, lake levels, stratigraphy, and faulting. The extent to which each of these heterogeneities controls groundwater flow is unknown. With only a limited number of wells and sparse water quality samples, data are not sufficient to examine the complexities. This study envisions the drilling of new wells and sampling for isotopic character to better define recharge and flowpaths in a critical area of the aquifer.

Scope/Approach: Install 4-6 monitoring wells in the USGS-defined Western Medina flow unit, collect water level and water quality data to determine groundwater flow, conduct an isotopic analysis data to refine groundwater flowpaths.

Methodology: Methodology will be proposed by the contractor and reviewed by TAG/EAA staff and consultants for recommendation to the EAA Board.

Researcher Requirements: Qualified hydrogeologists and potentially geochemists experienced in isotopes will be required for this study.

References:

Groschen, G.E., 1996, Hydrogeologic Factors that Affect the Flowpath of Water in Selected Zones of the Edwards Aquifer, San Antonio Region, Texas, U.S. Geological Survey Water-Resources Investigations Report 96-4046, 73 p.

Maclay, R.W., and Land, L.F., 1988, Simulation and Flow in the Edwards aquifer, San Antonio Region, Texas, and Refinement of Storage and Flow Concepts, U.S. Geological Survey Water Supply Paper 2336-A, 48p.

Maclay, R.W., and Small, T. A., 1984, Carbonate Geology and Hydrology of the Edwards Aquifer in the San Antonio Area, Texas, U. S. Geological Survey Open-File Report 83-537, 72p.

Lambert, R. A., 1999, Personal communication.

Small, T. A., and Lambert, R. A., 1998, Geologic Framework and Hydrogeologic Characteristics of the Outcrops of the Edwards and Trinity Aquifers, U.S. Geological Survey, Water-Resources Investigations Report 97-4290, 17p.

U. S. Geological Survey, 1997, Ground-Water flow and Storage Concepts in the Edwards Aquifer, San Antonio Area, Texas, 4p., February.

Summary of Proposed Study

FOCUSED FLOWPATH STUDIES – KNIPPA GAP, SAN MARCOS SPRINGS, COMAL SPRINGS

Title: Focused Flowpath Studies – Knippa Gap, San Marcos Springs, Comal Springs

TAG Subgroup: Flowpath/Modeling Subgroup

Goal: Improve the conceptual understanding of water moving through the aquifer in areas of hydrogeologic uncertainty.

Abbreviated Scope: Drill and monitor new wells in areas of uncertainty to better quantify groundwater flowpaths for the analysis of recharge enhancement, pumping redistribution, and other aquifer management alternatives.

Estimated Cost: $1,800,000

Duration: 6 years, currently scheduled for Year 3 through Year 8. Recommend to commence sooner in program if additional funds are available.

Prioritization Considerations: The flowpath studies are anticipated to be multi-year programs due to the requirement for drilling and monitoring new wells. In addition to the time-extensive logistics of a drilling program, well water level and water quality measurements must be taken over a period of time, encompassing a variety of hydrologic conditions. Yet, these results are crucial to understanding the aquifer and planning effective management strategies. This program is scheduled to be conducted in Years 3-8, placing a burden on the end of the program to produce quick answers. If joint funding becomes available, these projects should be better defined and moved up in the program.

Background/Previous Investigations: Previous investigators have documented the controlling impacts of structural and stratigraphic complexities on flowpaths in the Edwards Aquifer. The flowpath studies proposed in support of aquifer optimization build on previous work and focus on areas where well data is sparse and uncertainties in groundwater flow have been identified.

Scope/Approach: Project details for each area will be refined based on the results of other studies including the ongoing synoptic water level survey and, in part, preliminary results from the saline water study.

Methodology: Methodology to be proposed by contractor and reviewed by TAG/EAA Consultants for recommendation to EAA Board.

Researcher Requirements: Qualified hydrogeologists and geochemists will be required for this project.

References:

Groschen, G.E., 1996, Hydrogeologic Factors that Affect the Flowpath of Water in Selected Zones of the Edwards Aquifer, San Antonio Region, Texas, U.S. Geological Survey Water-Resources Investigations Report 96-4046, 73 p.

Maclay, R.W., and Land, L.F., 1988, Simulation and Flow in the Edwards aquifer, San Antonio Region, Texas, and Refinement of Storage and Flow Concepts, U.S. Geological Survey Water Supply Paper 2336-A, 48p.

Maclay, R.W., and Small, T. A., 1984, Carbonate Geology and Hydrology of the Edwards Aquifer in the San Antonio Area, Texas, U. S. Geological Survey Open-File Report 83-537, 72p.

U. S. Geological Survey, 1997, Ground-Water flow and Storage Concepts in the Edwards Aquifer, San Antonio Area, Texas, 4p., February.

Summary of Proposed Study
APPLICATION OF RECHARGE METHODOLOGY

Title: Application of Recharge Methodology

TAG Subgroup: Flowpath/Modeling Subgroup

Goal: Improve estimates of the amount and location of recharge to the Edwards Aquifer for incorporation into future modeling efforts.

Abbreviated Scope: Apply new recharge methodology developed by USGS to Edwards Aquifer river basins. Develop a data set of the revised recharge amounts and locations over time for incorporation into the management computer model.

Estimated Cost: $300,000

Duration: 3 years, currently scheduled for Years 2, 3, and 4 of the OTS.

Prioritization Considerations: Developing more accurate data sets for the aquifer water balance and computer modeling is a high priority and impacts future analysis of management strategies. An improved method of calculating recharge, being developed by the USGS, is scheduled for completion in 1999 and expected to ready for application in 2000. The application of this new methodology that is contemplated in this three-year study is recommended to begin in 2000, Year 2 of the program. After recharge has been recalculated, the new data will be incorporated into the new management computer model during re-calibration, scheduled for Year 5 of the program.

Background/Previous Investigations: The current computer model of the aquifer uses historic USGS estimates for recharge in each river basin. Recent USGS investigations in addition to historic problems with model calibration indicate that the amounts and distribution of recharge need revision. An ongoing USGS study in Medina and Bexar Counties indicates that methodology based on a comprehensive water balance approach produces more representative recharge amounts. The methodology incorporates a surface water model, Hydrologic Simulation Program – Fortran (HSPF), that uses measurements of precipitation and streamflow to derive groundwater recharge on a continuous basis. HSPF model results can be input directly into MODFLOW, the computer code likely to be used to construct the new EAA model.

Scope/Approach: A more detailed scope will be designed after review of the USGS study results.

Methodology: Adherence to the methodology developed by the USGS will be required.

Researcher Requirements: Contractor needs to provide an experienced hydrologist/surface water modeler to apply USGS model methodology to the Edwards Aquifer hydrologic data.

References:

Brown, D.S., 1998, Oral Communication - Presentation at the Workshop on Review of Edwards Aquifer Models and Supporting Hydrogeologic Data, October 7.

Klemt, W.B., Knowles, T.R., Elder, G.R., and Sieh, T.W., 1979, Ground-Water Resources and Model Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas, Texas Department of Water Resources Report 239, 94 p.

Thorkildsen, D. F., and McElhaney, P. D., 1992, Model Refinement and Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas, Texas Water Development Board Report 340, July.

USGS Program in Texas Website, 1998, Estimation of Volume and Quality of Stormwater Runoff and Associated Recharge Within the Edwards Aquifer Recharge Zone, http://tx.usgs.gov/program/TX173.html.

Summary of Proposed Study
STATISTICAL ANALYSIS OF HYDROLOGIC DATA

Title: Statistical Analysis of Hydrologic Data

TAG Subgroup: Flowpath/Modeling Subgroup

Goal: Using statistical methods, develop data relationships between Edwards Aquifer hydrologic data sets to further technical understanding of the relationships among springflow, streamflow, rainfall, and aquifer water levels.

Abbreviated Scope: Collect existing electronic hydrologic data sets, conduct multiple regression analyses using variable time steps, examine data for correlations and cause-effect relationships, develop temporal multiple-regression equations for separate data sets as well as positive changes in springflow and water levels, and document the analysis and resulting equations in a report to EAA.

Estimated Cost: $40,000

Duration: 3 months, currently scheduled during the 4th Quarter of Year 1.

Prioritization Considerations: Results from this project could provide technical support for discerning cause-effect relationships between specific components of the aquifer system and water balance. Although this study is exploratory in nature, it may also provide technical support for recharge credit rules, critical period management rules, and other EAA activities. This study is relatively inexpensive, based on existing data, straightforward to accomplish, and could provide significant technical benefits. We recommend that this study move forward on a high priority basis with a commitment for funding in Year 1.

Background/Previous Investigations: General relationships between Edwards Aquifer data sets have been examined by numerous investigators including EAA staff. However, a methodical, focused statistical analysis of data sets has not been published. A wealth of electronic data exists in the public record that has not been analyzed to specifically explore data relationships. To use these data to the fullest, a study such as this must be commissioned.

Scope/Approach: Contractor should compile and statistically analyze Edwards Aquifer data sets to develop relationships. Numerous combinations of data sets are envisioned for multiple regression analyses including:

1. Springflow vs. water levels, streamflow, rainfall, discharge from other springs, including Comal, San Marcos, Hueco, San Antonio, San Pedro, and Leona Springs
2. Water level changes in wells (by basin) vs. Edwards Aquifer inflows and outflows to examine details on regional flowpaths and storage.
3. Isolated rainfall events vs. springflows and water levels in wells. Exploratory variables for this analysis would at a minimum include all rainfall gauges, times since rainfall event, water levels, cumulative rainfall, cumulative streamflow, and cumulative channel loses during storm events (i.e. streamflow above recharge zone minus streamflow below recharge zone).

Multiple time steps appropriate to the data set should be considered for each of the analysis. Time steps would typically vary between annual and daily and should include monthly, bi-weekly, weekly, three-day, and daily as data allow.

Methodology: The study is based on temporal multiple-regression analysis, but the handling of the data sets and selection of regressions will be proposed by the contractor and reviewed by TAG/EAA staff and consultants for recommendation to the EAA Board.

Researcher Requirements: The project requires a qualified statistician and a hydrogeologist working together as a team. Both should have a good working knowledge of the Edwards Aquifer hydrogeology and existing data sets.

References/Data Sets:

Streamflow - USGS (continuous, daily, available on the Internet)
Rainfall - National Weather Service (CD-ROM, daily)
Springflow - USGS
Comal, San Marcos (continuous, daily)
San Antonio, San Pedro, Leona (periodic)
Water levels
EAA (daily for selected wells)
USGS (EAA wells in northern Bexar County, bi-weekly starting in 1998)
Water Use
USGS (annual by county and use/monthly irrigation for selected periods)
Texas Water Development Board (TWDB) (annual by county and use; monthly for municipalities
and some industries)
SAWS (monthly)
Edwards Aquifer Recharge - USGS (annual, monthly)
Groundwater Quality - USGS (periodic)

Summary of Proposed Study

FRACTURE/CONDUIT FLOW STUDY

Title: Fracture/Conduit Flow Study

TAG Subgroup: Modeling/Flowpath Subgroup

Goal: Provide aquifer transmissivity data for computer modeling to account for the influence of structural complexities on permeability and flowpaths.

Abbreviated Scope: Conduct additional outcrop studies of fault-conduit relationships and combine with a study of subsurface caliper logs and cave maps, develop a method for using small-scale data for model-scale (regional) problems, and assign transmissivities to fault zones and relay ramps for modeling purposes.

Estimated Cost: $75,000

Duration: 8 months, currently scheduled for Year 2 of the OTS program. Recommend initiating study in Year 1 as additional funds are available.

Prioritization Considerations: This study builds on previous studies and provides an improved data set to incorporate into the aquifer computer model for further evaluation of optimization strategies. The Flowpath/Modeling Subgroup recommended that this study be conducted on a high priority basis to support the new management computer model. The study was initially assigned a high priority by the TAG, but was deferred into the second year of the program due to EAA budgetary constraints. If additional funds for the program can be secured through joint funding, the study may be conducted in time to provide input into the construction of the management computer model, another high priority study.

Background/Previous Investigations: Fractured and karstic aquifers are notorious for their complexity and the resulting difficulty in predicting groundwater and solute flowpaths. The basic question of defining flowpaths in fractured and karstic aquifers is a function of scale, or area of interest. For example, at the regional scale, we know that water recharges the aquifer in the outcrop area (mostly through streambeds) and moves eventually to discharge points at wells and springs. The exact groundwater path between outcrop and springs is more difficult to determine owing to heterogeneities caused by faulting, fracturing, and dissolution. Clues to the groundwater pathways can be found by investigating hydrogeologic factors at various scales and understanding their

importance on flow and transport. These factors include the geometry of fractures and dissolution features, influence of faulting and lithology, relationship between local and regional scale measurements, and correlation between fractures and conduits and groundwater flowpaths and aquifer permeability. This study builds on and improves the following existing data sets:

- Regional structure map
- Kriged (geostatistical) map of transmissivity
- Analysis of relation of fault size to permeability distribution around faults, based on study of faults in five outcrops

Scope/Approach: The scope as designed by the TAG, EAA staff and consultants includes the following work:

1. Describe fracture and conduit geometry – Using outcrop and subsurface techniques, describe the size, shape, and spatial distribution of fractures and conduits and how they relate to aquifer permeability
2. Determine the influence of faulting and stratigraphy on fractures and conduits – Expand outcrop analysis from previous studies to relate to fault offset and stratigraphic setting
3. Assess the relationship between local and regional scale measurements – Develop a methodology for incorporating small-scale data collected during the study into regional-scale modeling
4. Investigate relationship of fractures and conduits to flowpaths and permeability – Using local-scale discrete-feature modeling, evaluate local flowpaths incorporating fracture and conduit data.

Methodology: Outcrop and subsurface techniques from related investigations will be used. New methodologies will be developed for incorporating the results of the study into computer modeling of the aquifer.

Researcher Requirements: A qualified geologic/hydrogeologic contractor familiar with the current transmissivity data sets and previous fracture investigations is desired.

References:

Collins, E. W., and Hovorka, S. D., 1997, Structure Map of the San Antonio Segment of the Edwards Aquifer and Balcones Fault Zone, South-Central Texas: Structural Framework of a Major Limestone Aquifer: Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties, Bureau of Economic Geology, Miscellaneous Map No. 38, University of Texas at Austin, 14p.

Hovorka, S. D., Mace, R. E., and Collins, E. W., 1998, Permeability Structure of the Edwards Aquifer, South Texas – Implications for Aquifer Management, Bureau of Economic Geology, University of Texas at Austin, Report of Investigations No. 250, 55p.

Hovorka, S. D., Mace, R. E., and Collins, E. W., 1995, Regional Distribution of Permeability in the Edwards Aquifer, Final Report, Bureau of Economic Geology, University of Texas at Austin, Edwards Underground Water District Report 95-02, January.

Mace, R. E., and Hovorka, S. D., 1996, Karst-conduit Characterization of the Edwards Aquifer Outcrop, Geological Society of America, South-Central Section, Abstracts with Programs, v. 28, no. 1, p. 51.

Summary of Proposed Study

3-D INTERACTIVE VISUALIZATION OF THE EDWARDS AQUIFER (PHASE I)

Title: 3-D Interactive Visualization of the Edwards Aquifer (Phase I)

TAG Subgroup: Flowpath/Modeling

Goal: Develop an interactive computer depiction of components of the Edwards Aquifer to inform and educate both technical and layperson audiences on aquifer geometry by allowing the parties to "see" the aquifer. The visualization via computer display will allow the user to see complex relationships between key features including (but not limited to): aquifer top and bottom; faulting, distribution of permeability; water table and potentiometric surface; depth, location, and screened intervals of wells; land surface geology; and spatial relationship between aquifer components and natural and cultural features at the ground surface.

Abbreviated Scope: This study is scoped into two phases with Phase I serving to develop a three-dimensional interactive visualization of the Edwards Aquifer including the review, selection and editing of appropriate data sets to display, and the creation of those images. Phase II will include the selection of a platform(s), and transfer of the product to EAA staff (including training). Phase II schedule and costs are dependent on the selected platform and number of images created, and will be determined after the completion of Phase I.

Estimated Cost: $ 85,000

Duration: 1 year, currently scheduled for Year 7 of the OTS program.

Prioritization Considerations: This project is supported by data sets being generated in other studies such as the development of a management computer model, flowpath investigations, and maps generated from the synoptic water level measurements project being conducted by EAA and other agencies. While this project is a worthwhile endeavor for both education and analysis, we recommend that it be deferred until late in the research program to take advantage of the generation of data sets and results from other studies.

Background/Previous Investigations: Flowpaths in the Edwards Aquifer are complex owing to interactions between transmissivity and topography, Balcones faulting, Edwards Group stratigraphy, and aquifer evolution. Flowpaths vary on a local as well as on a regional scale. Conduits, fracture networks, and limestone matrix play interrelated roles in affecting the rate and direction of flow through the aquifer. Flowpaths of recharging water moving into the subsurface may be

circuitous because of aquifer offset along faults and connections through relay ramps. The multiple components of the aquifer system are difficult to interrelate in conventional map-view form because they require the user to recreate spatial relationships from memory while flipping through a stack of maps, each showing a different subset of data.

The three-dimensional visualization will capture multiple components in a single format and relieve the user from the burden of interpreting three-dimensional relationships, thus facilitating creative exploration of a number of management issues. The same tool will have multiple applications for both technical and layperson audiences by adapting associated images and text. A scripted version of the visualization will be of particular value for public education while a user-friendly version will facilitate application in Edwards Aquifer research. Research and management applications include but are not limited to using the visualization model to evaluate flowpaths or the degree of compartmentalization within different parts of the aquifer.

Scope/Approach: Phase 1 will begin with a compilation of data from EAA, USGS, and other sources. Paper maps will be scanned and digitized. Data that may be used include land surface topography, recharge zone geology, groundwater divides, freshwater/saline water interface, aquifer properties, faults, top and base of the Edwards, water levels. After a review of the data, contractor will convene an interagency review panel to capture and integrate existing data and resolve discrepancies in interpretations. The data sets will be improved as needed and digitized. Data sets will need additional revision to repair areas where poor numerical handling of surfaces is evident such as edge effects or small fault blocks. Once data are in digital format, an informational workshop will be held at EAA for discussion and selection of platforms. Contractor will prepare and present examples of products for construction and visualization.

Methodology: Methodology may depend on the data sets that are selected for display as well as the anticipated platforms on which data may be viewed. Contractor will work closely with EAA to select appropriate data sets for display, discuss options for the visualization and provide EAA with a clear sense of the capabilities and the limitations of the product.

Researcher Requirements: This project is reliant on very sophisticated computer graphics software and hardware. The successful contractor must demonstrate the capability of generating the figures as well as understanding and working with the data sets. Extensive knowledge of the geology and hydrogeology of the Edwards Aquifer is required.

References:

Collins, E. W., and Hovorka, S. D., 1997, Structure Map of the San Antonio Segment of the Edwards Aquifer and Balcones Fault Zone, South-Central Texas: Structural Framework of a Major Limestone Aquifer: Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties, Bureau of Economic Geology, University of Texas at Austin, Miscellaneous Map No. 38, map and 14p.

Hanson, J.A., and Small, T. A., 1995, Geologic Framework and Hydrogeologic Characteristics of the Edwards Aquifer Outcrop, Hays County, Texas, U.S. Geological Survey, Water-Resources Investigations Report 95-4265.

Hovorka, S. D., Mace, R. E., and Collins, E. W., 1998, Permeability Structure of the Edwards Aquifer, South Texas – Implications for Aquifer Management, Bureau of Economic Geology, University of Texas at Austin, Report of Investigations No. 250, 55p.

Hovorka, S.D., Dutton, A.R., Ruppel, S.C., and Yeh, J.S., 1996, Edwards Aquifer Ground-Water Resources: Geologic Controls on Porosity Development in Platform Carbonates, South Texas, Bureau of Economic Geology, University of Texas, Austin, Report of Investigations No. 238, 75p.

Kuniansky, E.L., and Holligan, K.Q., 1994, Simulations of Flow in the Edwards-Trinity Aquifer Systems and Contiguous Hydraulically Connected Units, West-Central Texas, U.S. Geological Survey Water-Resources Investigations Report 923-4039, 40 p.

Schultz, A. L., 1994, 1994 Review and Update of the Position of the Edwards Aquifer Freshwater/Saline-Water Interface from Uvalde to Kyle, Texas, Edwards Underground Water District Report 94-05, November, 31p.

Schultz, A. L., 1993, Defining the Edwards Aquifer Freshwater/Saline-Water Interface with Geophysical Logs and Measured Data (San Antonio to Kyle, Texas), Edwards Underground Water District Report 93-06, July.

Small, T. A., and Hanson, J. A., 1994, Geologic Framework and Hydrogeologic Characteristics of the Edwards Aquifer Outcrop, Comal County, Texas, U.S. Geological Survey, Water-Resources Investigations Report 94-4117, 10p.

Stein, William G., and Ozuna, George, 1995, Geologic Framework and Hydrogeologic Characteristics of the Edwards Aquifer Recharge Zone, Bexar County, Texas, U.S. Geological Survey, Water-Resources Investigations Report 95-4030, 8 p., 1 sheet.

Summary of Proposed Study
RANGE MANAGEMENT OF WOODY SPECIES

Title: Range Management of Woody Species

TAG Subgroup: Recharge Enhancement Subgroup

Goal: Quantify increased surface water available for aquifer recharge through the reduction of woody species (including Ashe Juniper) in two watersheds. As indicated in the Seco Creek Water Quality Demonstration Project, these species use a significant amount of rainfall and runoff through evapo-transpiration (ET), thereby decreasing the amount of water available for groundwater recharge.

Abbreviated Scope: Detailed monitoring equipment will be installed in three watersheds for precipitation, streamflow, runoff, water quantity, water quality, ET, soil infiltration and soil moisture data. The invasive woody species will remain unaltered in all three watersheds during the first year for baseline monitoring. During the second year, invasive woody species will be strategically removed in two of the watersheds, leaving the third unaltered for control. Monitoring will continue for approximately six additional years to quantify the results of the best management practice (BMP) of woody species removal.

Estimated Cost: $2,200,000 ($275,000/year for approximately 8 years). The U.S. Department of Agriculture (USDA) and the U.S. Geological Survey (USGS) have jointly committed funds of approximately $250,000/year for the 8-year project. EAA contribution is estimated to be $25,000/year for 8 years for a total cost to EAA of $ 200,000. EAA's approved 1999 budget already includes a $25,000 commitment for Year 1 of the project.

Duration and Schedule: 8 years and 3 months (total 99 months). Project began in October 1998 and is expected to continue through December 2006, Year 8 of the OTS.

Prioritization Considerations: This study is underway as of October 1998 and is being jointly funded by USDA, USGS, San Antonio Water System (SAWS) and EAA. EAA's financial involvement in the study will allow for easy access to data and project status. EAA will need to evaluate the effectiveness of the BMP effort to determine how to credit recharge enhancement, and therefore benefits from project involvement. We recommend assigning a high priority to continued support of this project.

Background/Previous Investigations: On a small scale, studies have indicated that flow from springs located within the catchment (drainage) area of the recharge zone increases when invasive woody species such as Ashe Juniper is strategically removed (see references on Seco Creek Demonstration Project). This study is being expanded to a larger scale to better predict amounts of additional runoff available for Edwards Aquifer recharge. The results of a larger study will indicate the appropriate funding level for more aggressive brush management in the region.

Scope/Approach: Three watersheds have been selected for the study including two similar adjacent watersheds in the catchment area of the Edwards Aquifer and one in the recharge zone. Detailed monitoring equipment will be installed in all three watersheds to monitor precipitation, streamflow, runoff, water quantity, water quality, ET, soil infiltration and soil moisture. All three watersheds will remain untreated during the first year for baseline monitoring. During the second year of the project, invasive woody species consisting predominantly of Ashe Juniper will be strategically removed from two of the watersheds. The third watershed will remain untreated for control. The detailed monitoring program will continue for approximately six additional years to quantify the results of invasive woody species removal. The Texas Parks and Wildlife Department (TPWD) is cooperating with the study and guiding the project to avoid impacts on endangered species in the watersheds.

Methodology: All work will be carried out according to USGS standards and USDA Natural Resources Conservation Service (NRCS) standards and specifications. Personnel from USDA-NRCS, Texas Agriculture Extension Service, Texas Agriculture Experiment Stations, and Texas Parks and Wildlife will be cooperating to ensure optimum management results with no adverse impacts to endangered species.

Researcher Requirements: Qualified personnel have been identified and the project is underway.

References:

U. S. Department of Agriculture, Texas Agricultural Extension Service, *Seco Creek Water Quality Demonstration Project*, USDA Special Project No. 94-EWQD-1-9518.

U. S. Geological Survey, 1999, *Geologic Framework and Hydrogeologic Properties of the Seco Creek Watershed, Texas*, USGS Fact Sheet, FS-104-98.

Summary of Proposed Study

SPRINGFLOW RECIRCULATION/RECHARGE ENHANCEMENT

Title: Springflow Recirculation/Recharge Enhancement

TAG Subgroup: Recharge Subgroup

Goal: Using computer modeling, evaluate alternatives of recirculation and recharge enhancement to develop optimization strategies for aquifer management.

Abbreviated Scope: Using the new management computer model, evaluate multiple scenarios of springflow recirculation and recharge enhancement. Scenarios should be evaluated with varying amounts of pumping including current pumping with associated reductions during critical periods. Analysis will include a cost/yield and increased yield with combinations of recharge enhancement and recirculation.

Estimated Cost: $100,000

Duration: 1 year, currently scheduled for Year 3 of the OTS program.

Prioritization Consideration: Springflow Recirculation and other recharge enhancement projects have the potential to assist in maintaining springflows during droughts, increase the amount of water available for pumpage, and stabilize and/or enhance aquifer water levels. Further evaluation of potential recirculation scenarios requires computer modeling to simulate and predict aquifer response. This study is recommended for commencement after construction of the management computer model (scheduled for completion in Year 2) because the model will be required for recirculation and recharge enhancement scenarios. The study will build on other evaluations of recharge and recirculation anticipated as part of the EAA comprehensive water management plan and S.B. 1 regional planning activities.

Background/Previous Investigations: Springflow recirculation involves recovering excess springflow downstream in the Guadalupe River and diverting it back to the recharge zone where it would be released for recharge in streams or recharge structures. The operational premise is to fill the aquifer during periods when springflow is high. Then, during drought, the stored water would sustain aquifer pumpage and help maintain springflows above critical levels.

A conceptual evaluation of springflow recirculation was conducted in 1998 through the West Central Trans-Texas Study. The study utilized the Texas Water Development Board's GWSIM-IV groundwater model of the Edwards Aquifer and the Guadalupe-San Antonio River Basin Model, developed by HDR

Engineering. Study objectives included estimating the impacts of springflow recirculation on (1) pumpage, springflow, and water levels in the aquifer, (2) water rights in the Guadalupe River, and (3) freshwater inflows and fisheries harvest in the Guadalupe Estuary.

The conceptual evaluation of springflow recirculation was performed for two management plans. The first plan assumed a fixed annual pumpage of 400,000 AFY and the second plan allowed pumpage to increase up to a rate that would not cause the monthly flow from Comal Springs to fall below the critical level of 60 cfs during a repeat of the drought of record.

For the 400,000 AFY management plan, water levels rose throughout the aquifer providing benefits to springs and wells. Springflow recirculation reduced the amount of time that flow from Comal Springs and San Marcos Springs was below critical levels and also reduced the amount of time that the San Antonio area was in the most severe stage of drought management. For the "sustained yield" management plan, model simulations indicated that pumpage could increase from 270,000 AFY to 357,000 AFY as a result of recirculation. Other pumping scenarios or the effects of combining additional artificial recharge with recirculation were not evaluated.

The Trans-Texas Program also included an evaluation of enhanced recharge potential in the Nueces River basin and the San Antonio and Guadalupe River basins; these studies were completed in June 1994 and March 1998, respectively. Seven potential recharge enhancement projects were recommended to move forward to a preliminary design and permitting phase. Operational details of these projects can be further evaluated with computer modeling. In addition, a combined program of recharge and recirculation would require computer modeling to optimize the implementation and operation.

Scope/Approach: Evaluation of springflow recirculation will involve computer simulation of various project alternatives and will build on evaluations being conducted separately form this research program Because evaluations of recirculation and recharge enhancement are likely to be involved in both EAA's comprehensive water management plan and the S.B. 1 regional planning process, the scope for this study will be refined based on those results.

Methodology: Specific methodology will be proposed by the contractor and approved by TAG/EAA staff and consultants for recommendation to the EAA Board.

Researcher Requirements: The successful firm must have a professional groundwater modeler with experience in GWSIM-IV applications and flow models based on the MODFLOW computer code, or other computer code if used to construct the management model. The project team must also include a hydrogeologist with demonstrated knowledge of the Edwards Aquifer.

References:

HDR Engineering, Trans-Texas Water Program, West Central Study Area, Phase II, Summary Report of Water Supply Alternatives, March 1998.

HDR Engineering, Trans-Texas Water Program, West Central Study Area, Phase II, Edwards Aquifer Recharge Analyses, March 1998.

HDR Engineering, Edwards Aquifer Recharge Enhancement Project Phase IVA, Nueces River Basin, Prepared for Edwards Underground Water District, June 1994.

Summary of Proposed Study
SPRINGFLOW AUGMENTATION

Title: Springflow Augmentation

TAG Subgroup: Recharge Enhancement Subgroup

Goal: Continue the evaluation of the feasibility of augmenting springflow during drought conditions to assist EAA in ensuring minimum springflows as required by the Act.

Abbreviated Scope: Using the 1995 Augmentation Feasibility Study as a starting point, identify the most promising alternative(s) that require additional technical analysis. Consider the data being collected in the OTS Biological Assessments and identify additional technical deficiencies that need to be addressed.

Estimated Cost: $50,000

Duration: 6 months, currently scheduled for Year 3 of the OTS program.

Prioritization Considerations: Further analysis of springflow augmentation depends, in part, on other proposed studies in this program including the results of several biological assessments which will examine species tolerances to variations in water chemistry and flow.

Background/Previous Investigations: In 1993, the Edwards Underground Water District sought the expertise of the Texas Water Development Board and Texas Parks & Wildlife Department, to develop a scope of work for evaluating the feasibility of enhancing or augmenting springflow at Comal and San Marcos Springs. The scope of work included three phases of potential work as follows: Phase I - Feasibility Study, Phase II - Detailed Engineering and Biological Studies for Highly Feasible Augmentation Alternatives, and Phase III - Design & Implementation of a Proven Augmentation Alternative.

The Phase I scope was developed into an RFP and a contractor (University of Texas at Austin - CRWR) and subcontractors (USGS and USBR) were selected. The study was completed in 1995 with the production of a technical report and recommendations. No additional work was performed on Phases II and III. The study examined and ranked six augmentation alternatives for each spring system. Although none of the examined alternatives were found to be fully feasible, the following alternatives were ranked by the contractor as Feasible/Uncertain:

For Comal Springs;

- Regional Enhanced Recharge
- Direct Addition to Lakes

For San Marcos Springs;

- Regional Enhanced Recharge
- Local Enhanced Recharge
- Direct Addition to Lakes

The CRWR study found that "uncertainties and gaps in the knowledge regarding the Comal and San Marcos Springs systems..." exist and indicated that "...many additional studies need to be performed in the future to reduce this level of uncertainty and risk associated with making decisions about (the springflow) systems." The Phase I report recommended several essential tasks for Phase II research including biological testing, hydrogeologic testing, and the need for a three-dimensional multi-layer aquifer model for future assessment of augmentation alternatives as well as general management of the Edwards Aquifer.

Scope/Approach: A detailed scope and approach will be proposed by the contractor and reviewed by TAG/EAA staff and consultants for recommendation to EAA.

Methodology: Methodology will be proposed by the contractor and reviewed by TAG/EAA staff and consultants for recommendation to EAA.

Researcher Requirements: To be determined

References:

McKinney, D. C., and Sharp, J. M., Jr., 1995, Springflow Augmentation of Comal Springs and San Marcos Springs, Texas: Phase I-Feasibility Study, Center for Research in Water Resources, Bureau of Engineering Research, University of Texas at Austin, Technical Report CRWR 247, February.