



JOINT FUNDING AGREEMENT No. 17-867-AM
BETWEEN THE
EDWARDS AQUIFER AUTHORITY
AND
UNITED STATES DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
FOR GROUNDWATER MODEL UNCERTAINTY ANALYSES

Agreement: _____
Customer No: TX043
Project No: _____
Tax ID No. 74-6026194

This Joint Funding Agreement ("Agreement") for groundwater model uncertainty analyses is made and entered into effective as of 1st day of October, 2017, by and between the EDWARDS AQUIFER AUTHORITY ("EAA"), a political subdivision of the State of Texas, with its principal place of business located at 900 E. Quincy Street, San Antonio, Texas 78215, and the UNITED STATES GEOLOGICAL SURVEY ("Survey"), an agency of the United States Government, with an office located at 1505 Ferguson Lane, Austin, Texas 78754. The Survey's legal authority to enter into this agreement is 43 USC 36C; 43 USC 50, and 43 USC 50b. Each of these entities is, at times, referred to individually as "Party," and both are referred to collectively as "Parties."

For and in consideration of the mutual promises and benefits contained herein, the sufficiency of which is hereby acknowledged, the EAA and the Survey agree as follows:

ARTICLE I
DESCRIPTION OF THE SCOPE OF WORK

Subject to the terms and conditions of this Agreement, the Survey agrees to perform the tasks set forth in the Scope of Work dated October 1, 2017, a copy of which is attached hereto as Exhibit A, is incorporated herein for all purposes, and is a part of this Agreement. The Survey accepts such engagement and agrees to devote its best talents, efforts, and abilities and furnish all labor, machinery, equipment, tools and transportation necessary in the furtherance of its engagement. The Scope of Work specifically identifies the tasks to be performed by the Survey over the term of this Agreement and contains a schedule for performance of the tasks and a budget broken down by the tasks that make up the Scope of Work. In exchange, the EAA agrees to fund a portion of the costs incurred by the Survey, as set forth in more detail in Article II below. The EAA may request changes or additions to the Scope of Work during the term of this Agreement, and upon mutual agreement, the EAA and the Survey will make the necessary written revisions to the Scope of Work and project schedule to reflect such requested changes as set forth in Articles III and VI below.

ARTICLE II JOINT FUNDING

- A. The total costs for the tasks as enumerated in the Scope of Work are estimated to not exceed the following amounts:

Task 1	\$ 19,500.
Task 2	\$ 24,800.
Task 3	\$ 44,000.
<u>Task 4</u>	<u>\$ 41,700.</u>
Total:	\$130,000.

The Survey agrees to be directly responsible for the payment of any invoices, costs or expenses incurred by it or any of its subcontractors in the performance of the Scope of Work.

- B. The EAA agrees to reimburse the Survey for a portion of the costs the Survey incurs in performing the Scope of Work, in the following amounts for each task:

<u>Task</u>	<u>EAA's Contribution</u>	<u>and USGS's Contribution</u>	<u>Total</u>
Task 1	\$10,350.	\$ 9,150.	\$ 19,500.
Task 2	\$13,163.	\$11,637.	\$ 24,800.
Task 3	\$23,354.	\$20,646.	\$ 44,000.
<u>Task 4</u>	<u>\$22,133.</u>	<u>\$19,567.</u>	<u>\$ 41,700.</u>
Total	\$69,000.	\$61,000.	\$130,000.

- C. As a prerequisite to receiving such reimbursement from the EAA, the Survey shall deliver to the EAA, separate quarterly invoices at the end of each December, March, June, and September for the costs and expenses incurred by the Survey in the previous quarter for the performance of each task identified in the Scope of Work. Payments of invoices are due within 60 days after the receipt of and approval by the EAA of each such invoice. If not paid by the due date, interest on unpaid amounts will be charged at the current Treasury rate for each 30 day period, or portion thereof, that the payment is delayed beyond the due date (31 USC 3717; Comptroller General File B-212222, August 23, 1983). The EAA's financial contribution to this Agreement will not exceed \$69,000. The Survey's contribution for this Agreement will not exceed \$61,000.

ARTICLE III ALTERATIONS TO AGREEMENT AND STATEMENT OF WORK

Either Party may request, in writing, changes or additions to the Scope of Work during the term of this Agreement. Upon such request, the Survey will propose the necessary revisions to the specific Tasks, associated schedule and costs. These revisions must be accepted by both Parties in writing. No amendments to this Agreement shall be considered valid unless the amendments have been approved by both Parties in writing.

ARTICLE IV COMPLETION OF WORK

The Survey shall have until March 31, 2019, to complete the Scope of Work. All work shall be completed in compliance with the schedule of tasks and budget as set forth in the Scope of Work.

ARTICLE V TERM OF JOINT FUNDING AGREEMENT

This Agreement shall be effective on the date indicated in the first paragraph above and shall continue in effect through March 31, 2019. This Agreement is subject to annual appropriations by the Survey and the EAA, but the Survey and the EAA represent that they will use their reasonable best efforts to obtain the proper appropriations to fund this Agreement as necessary for any future year or portion thereof during which this Agreement will be in effect. The Parties acknowledge that it may be desirable to continue the tasks identified in the Scope of Work after March 31, 2019, beyond the term of this Agreement. If so, the Parties may, by separate written agreement, contract for additional services to continue the tasks identified in the Scope of Work for an additional period of time and upon the terms and conditions and for such consideration mutually agreed upon by the Parties at such time.

ARTICLE VI INSPECTION AND TERMINATION

During the term of this Agreement, all operations of the Survey pertaining to the Scope of Work shall be open to the inspection of the EAA, and if the work is not being performed in a mutually satisfactory manner, the EAA may terminate this Agreement upon the failure of the Survey to cure the unsatisfactory condition within 60 days after receipt of written notice to the Survey. Either Party may, with or without cause, terminate this Agreement by giving 30 days' written notice to the other. In the case of any termination of this Agreement, the Survey will be reimbursed by the EAA for the EAA's pro rata share of costs incurred up to the time of termination in accordance with Article II above. In the event of early termination, insofar as possible, all work in progress will be brought to a logical termination point and a final settlement of payments shall be made. Copies of all finished and unfinished documents, data, studies, surveys, drawings, maps, reports, photographs, and other materials prepared by the Survey will be delivered to the EAA and will become the property of the EAA. If applicable, the Survey shall be entitled to receive from the EAA, the EAA's pro rata share of reasonable compensation for any additional costs associated with terminating the tasks prior to completion.

ARTICLE VII DATA SHARING

- A. The Parties agree to freely share with each other all data generated from the performance of the Scope of Work. The Survey shall furnish copies of reports of the results of investigations performed by the Survey to the EAA for internal use and review upon completion of necessary review. Review of report manuscripts by the EAA and the Survey shall be completed

expeditiously. Both Parties shall have the privilege of publishing the records, reports, and report manuscripts provided that all publications by either Party shall contain a statement of the cooperative relations between the Parties. Original tracings of all drawings and illustrations, which are a part of these reports, shall be furnished to the EAA to permit their reproduction for publications and reports by the EAA.

- B. The original records from each individual task identified in the Scope of Work shall be retained by the Survey. Copies of all such data shall be furnished to the EAA.
- C. When requested by the EAA, the Survey shall make reasonable efforts to allow and accommodate EAA staff or representatives to accompany or observe Survey personnel to perform the Scope of Work.

ARTICLE VIII SURVEY PERSONNEL AND CONTRACTORS

- A. The Survey will provide any personnel necessary for its performance of the Scope of Work. The Survey will be responsible for its employees in all respects, including, without limitation, its compliance with applicable laws and their safety, including without limitation, all Occupational Safety and Health Administration (OSHA) standards, requirements and regulations.
- B. The Survey will be responsible for its contractors in all respects, including without limitation, their compliance with applicable law and their safety, including without limitation, OSHA standards, requirements, and regulations.

ARTICLE IX EQUAL EMPLOYMENT OPPORTUNITY

In the performance of this Agreement, the Survey will comply with the provisions of Title VI of the Civil Rights Act of 1964 (42 U.S.C. 200d), and Section 504 of the Rehabilitation Act of 1973 (29 U.S.C. 794). The Survey shall not discriminate on the grounds of race, color, national origin, sex, religion, marital status, age, creed, Vietnam-Era or Disabled Veterans status or the presence of any sensory, mental or physical handicap.

ARTICLE X NOTICES

- A. All notices and communications under this Agreement to be mailed or delivered to the EAA shall be sent to the EAA's principal place of business as follows, unless and until the Survey is otherwise notified:

EDWARDS AQUIFER AUTHORITY
900 E. QUINCY STREET
SAN ANTONIO, TX 78215
ATTN: ROLAND RUIZ, GENERAL MANAGER

- B. All notices and communications under this Agreement to be mailed or delivered to the Survey shall be sent to the address as follows, unless and until the EAA is otherwise notified:

UNITED STATES GEOLOGICAL SURVEY
TEXAS WATER SCIENCE CENTER
1505 FERGUSON LANE
AUSTIN, TX 78754-4733
ATTN: TIMOTHY RAINES, DIRECTOR

- C. Any notices and communications required to be given in writing by one Party to the other shall be considered as having been given to the addressee on the date the communication is posted by the sending Party.

ARTICLE XI RECORDS AND RIGHTS TO MATERIALS

- A. The Survey and the EAA will collaborate as provided herein and as may be otherwise required for the proper performance of this Agreement. The Survey will, upon request by the EAA, at any time, provide the EAA with all financial information necessary to enable the EAA to determine the financial condition of the performance of the Scope of Work.
- B. The Survey shall retain a record or copies of all data developed in the course of performing the Scope of Work and said materials will be supplied to the EAA upon request after expiration or termination of this Agreement.

ARTICLE XII GENERAL

- A. Entire Agreement. This Agreement constitutes the entire agreement between the Parties regarding the data collection activities of the Survey and the EAA pertaining to the Scope of Work, and there are no representations, warranties, agreements or commitments between the Parties except as set forth herein. No amendments to this Agreement shall be binding on the Parties unless in writing and signed by both Parties.
- B. Non-Waiver. The waiver by any Party of a breach of any term or provision of this Agreement shall not be construed as a waiver of any subsequent breach.
- C. Governing Law. This Agreement is deemed to have been made and to be performable in the State of Texas, and all questions relating to the Agreement shall be governed by the applicable laws of the United States and the State of Texas.
- D. Counterparts. This Agreement may be executed in two or more counterparts, each of which shall be deemed an original, but all of which together shall constitute one and the same instrument.

- E. Binding Effect. The provisions of this Agreement shall be binding upon and inure to the benefit of the Parties and their respective successors and assigns; provided, however, that the Survey may not assign any of its rights nor delegate any of its duties hereunder without the EAA's prior written consent.
- F. Validity. The invalidity of any provision or provisions of this Agreement shall not affect any other provision of this Agreement, which shall remain in full force and effect, nor shall the invalidity of a portion of any provision of this Agreement affect the balance of such provision.
- G. Captions. The captions of the various sections of this Agreement are for descriptive purposes only and shall not alter or affect the terms and conditions of this Agreement.
- H. Independent Party. Nothing in this Agreement will be construed to constitute either Party as a partner, employee or agent of the other Party, nor will either Party have the authority to bind the other in any respect. Each Party will remain an independent Party responsible for its own actions except as otherwise specifically provided herein.

IN WITNESS WHEREOF, the Parties have executed this Agreement in duplicate counterparts, both having equal force and effect, on the date first above written.

EDWARDS AQUIFER AUTHORITY

UNITED STATES
GEOLOGICAL SURVEY
TEXAS WATER SCIENCE CENTER

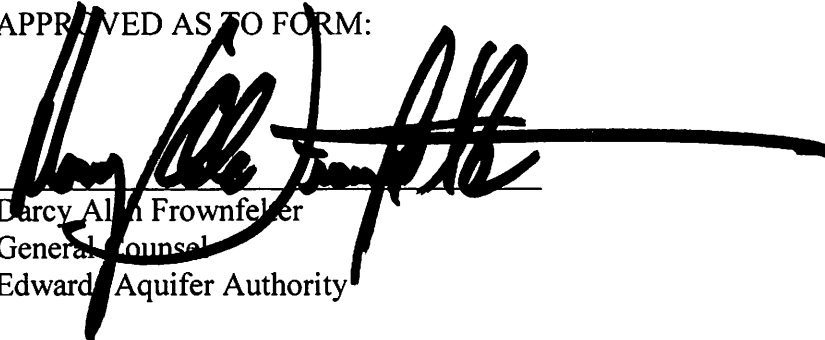
By: _____
Roland Ruiz
General Manager

By: _____
Timothy Raines
Director

ATTEST:

By: _____
Jennifer Wong-Esparza
Assistant to Board Secretary

APPROVED AS TO FORM:



Darcy Allen Frownfelter
General Counsel
Edward Aquifer Authority

EXHIBIT A
JOINT FUNDING AGREEMENT NUMBER No. 17-867-AM
BETWEEN THE
EDWARDS AQUIFER AUTHORITY
AND
UNITED STATES DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
FOR GROUNDWATER MODEL UNCERTAINTY ANALYSES

Scope of Work
October 1, 2017

BACKGROUND

The EAA recently updated and recalibrated its numeric groundwater model for the Southern Segment of the Balcones Fault Zone Edwards Aquifer (Aquifer) - known as the MODFLOW groundwater model¹ (Model). Prior versions of this Model have been used to simulate certain parameters of the Aquifer for the period from 2001 to 2015, and the drought of record (DOR) period from 1947-1958. While the Model is consistent with the conceptual understanding of the Aquifer system and is well-calibrated to a variety of Aquifer condition measurements, uncertainty may exist in the Model inputs which could in turn be propagated to the simulated Aquifer conditions that are the Quantities of Interest (QOIs) for the Model, such as springflow at Comal and San Marcos Springs and Aquifer water levels in the San Antonio and Uvalde Pools at Wells J-17 and J-27, respectively. A better understanding of how Model input uncertainties may influence the QOIs' uncertainty would provide an indication of Model reliability for the QOIs and provide a quantitative basis for focusing future data collection and Model refinements.

APPROACH

Quantification of the uncertainty that exists in the Model will require several tasks, each of which will require close cooperation and coordination between the Survey staff and EAA staff. Uncertainty will be conceptualized in a Bayesian framework (Doherty 2015), where Model input uncertainty is first described based on the existing knowledge about the Aquifer. This "Prior" uncertainty (statistical) distribution encapsulates and embodies the current state of understanding of the Aquifer system properties and boundary conditions. Following the construction of the Prior uncertainty distribution, the "Posterior" Model input uncertainty (statistical) distribution will be characterized using both first-order, second-moment (FOSM) and non-linear methods. These FOSM and non-linear methods will be applied to several QOIs that capture important uses of the updated Model. The Survey staff will work with EAA staff to determine QOIs in the following tasks:

Task 1: Wrap the Model within the PEST++ framework. A PEST++ (Welter and others, 2015) implementation for the Model will be developed to facilitate usage of the many sophisticated analysis techniques available in the PEST (Doherty 2010) and PEST++ software suites. PEST and PEST++ are software suites for the inversion and uncertainty

¹ Model documentation is being developed. Details of the original model prior to this update may be found in : Lindren, R.J., Dutton, A.R. Hovorka, S.D., Worthington, S.R.H. and Painter, S., 2004, Conceptualization and simulation of the Edwards Aquifer, San Antonio Region, Texas; U.S. Geological Survey Scientific Investigation Report 2004-5277, 143p.

quantification of large, complex environmental models. The Survey staff is currently involved with the development of these software suites, which affords the ability to adapt these tools as necessary to meet the objectives of the Scope of Work.

Wrapping the Model in a PEST++ framework will require parameterizing the uncertain Model inputs as well as developing an observation and Model-simulated equivalent dataset. This task will require assistance from EAA staff to define a parameterization scheme which is consistent with the conceptual model of the Aquifer, but that is also flexible so that any uncertainty in the Model inputs can be properly expressed and propagated to the QOIs. The design of the parameterization is the foundation of the uncertainty analysis process and must include all Model inputs for which data or other information suggests may have a material level of uncertainty.

The Survey will consult with EAA staff, regarding the specification of the observation dataset and associated objective function, especially as it relates to the measurement error model which affects the results of the uncertainty analyses process.

Task 2: Build Prior Parameter Uncertainty Distribution

Closely related to the parameterization process is the process of defining the “Prior” quantity in Bayes theorem. The Prior is a critical input into a Bayesian uncertainty analysis framework and requires that the uncertainty for each parameter be defined based upon the existing knowledge of the Aquifer system. While the Prior uncertainty of each parameter can be conceptualized as a plausible parameter range, expected correlation information can also be included. With EAA staff knowledge about the Aquifer, the Survey will rely on input from EAA staff to define this critical component of the uncertainty analysis process.

Task 3: Posterior Parameter and QOI Uncertainty Estimation

To complete the application of a Bayesian uncertainty analysis, the information contained in the Prior parameter distribution must be combined with the information contained in the observations of Aquifer conditions. This will be accomplished using two methods: 1) FOSM-based method and 2) non-linear method.

The FOSM-based uncertainty method uses a multivariate Gaussian assumption and a linear-model assumption. These two assumptions greatly reduce the computational burden related to the estimation of Posterior parameter and QOI uncertainty; these two assumptions also remove the need for actual values for parameters and observations to derive QOI uncertainty estimates. It is the absence of parameter and observation values in the FOSM uncertainty estimation process which facilitates efficient data-worth analyses. In this way, the Survey staff will work with EAA staff to complete both parameter and observation worth analyses. These analyses will identify which parameters (or combinations of parameters) are contributing most to QOI uncertainty, as well as which existing and yet-to-be-collected observation data are most important for reducing QOI uncertainty. The results of these analyses will provide valuable insights as to how uncertainty is being propagated through the Aquifer system dynamics and can be used to guide future studies and data collection efforts. The FOSM-based analyses will be completed using the pyEMU framework (White and others, 2016).

While FOSM-based analyses have been widely applied, including to a previous model of the Aquifer (Brakefield and others, 2015), the relatively short model run times of the Model make non-linear uncertainty analyses computationally tractable.

Non-linear uncertainty analyses focus on the generation of an ensemble of realizations from the Posterior parameter distribution. An ensemble is a collection of parameter sets for the Model. Each member of the Posterior ensemble, known as a realization, is a parameter set that will be in harmony with the Prior uncertainty (for example, a conceptual model of the Aquifer) while also reproducing the observation dataset used for history matching (calibration) acceptably well. This means each realization will adequately calibrate the Model, but potentially will be different from the other parameter sets in the ensemble.

The process of generating a Posterior ensemble is computationally-demanding, typically requiring many hundreds-of-thousands of model runs. To accommodate this demand, USGS staff will use the high-performance computing cluster at the Survey in concert with software specifically designed to take advantage of these parallel resources.

Once an appropriately-sized ensemble of Posterior parameter realizations is generated, any QOI that can be simulated with the updated Model can then be propagated through the Posterior ensemble to yield an approximation to the QOI Posterior distribution – a direct measure of QOI uncertainty. For example, to evaluate uncertainty in the Model-simulated water level and springflow response to DOR conditions, the DOR Model would be run for each of the parameter realizations in the ensemble (i.e. if the ensemble has 500 members, this would require 500 Model runs). The Model-simulated results of the repeated DOR simulations would then be collected for each of the Model runs and collated, yielding a Posterior distribution for the simulated water level and springflow resulting from DOR conditions. With the Posterior distribution, measures of uncertainty, such as 95% credible limits, can be easily calculated.

The Survey staff recognizes the EAA's interest in identifying a minimum number of realizations that appropriately and accurately represent the uncertainty implied by the full ensemble. To meet this objective, the Survey will work with EAA staff to identify a few representative realizations that can be further used by the EAA for Aquifer management without the computational burden of running the full ensemble.

Task 4: Reporting

The process and results of the above-described uncertainty analysis will be documented in a report or peer-reviewed journal publication. A complete description of the Model will not be included since the Model will have been previously documented. Instead, the publication will focus on the design, implementation, and results of the uncertainty analysis. Given the anticipated level of involvement by EAA staff, the Parties expect the publication to be co-authored by both the Survey and EAA staff.

Quality Assurance Plan

Quality Assurance (QA) measures will be followed to ensure the completeness of the information communicated during the performance of the uncertainty analysis. The QA objectives for the collection and communication of information will:

- Withstand scientific scrutiny
- Be obtained by methods appropriate for its intended use, and
- Be representative and of known completeness and comparability.

All digital data and analysis results will be reviewed by the Survey staff, in consultation with EAA staff as appropriate, to ensure proper documentation. This review involves checking of datasets discussed in the publication, as well as verifying the output of the scripting tools used in the analyses. The Scope of Work and project budget will be reviewed by the Survey management on a quarterly basis to ensure that all project timelines are met. The Survey shall ensure that all published Survey products will be impartial, credible, and relevant, provide timely information, and are equally accessible and available to all interested parties.

DELIVERABLES

All scripts and files generated as part of this Scope of Work will be provided to EAA staff, including:

- The Model-interface PEST++ dataset;
- The Prior and Posterior ensemble, in the form of sets of Model input files;
- The python scripts used to setup and process the analyses described herein, and;
- Files used to complete the data-worth analyses.

The process and results of the parameter and QOI uncertainty analysis will be documented in a report or peer-reviewed journal publication authored by the Survey and the EAA.

Timeline

The uncertainty analyses described above will be completed within 1.5 years. The work will be considered complete once a report has been completed or a manuscript documenting the analyses has been submitted to a journal for peer review.

Task	Survey Fiscal Quarters from Beginning of Project					
	Q1	Q2	Q3	Q4	Q5	Q6
Task 1: PEST++ Implementation						
Task 2: Build Prior Parameter Uncertainty Distribution						
Task 3: FOSM-based Uncertainty and Data Worth Analyses and Generate Posterior Ensemble						
Task 4: Reporting						

Data Management Plan

The results of the uncertainty analysis will be documented in accordance with the Survey data release policy for interpretive studies. All files and scripts developed as part of this study will be included in the data release.

PAYMENT

The EAA will pay its contribution share to the Survey on a quarterly basis upon demonstrated successful completion of the tasks outlined in this Scope of Work, scheduled for completion March 31, 2019, in accordance with the billing and payment provisions contained in Article II of the Agreement. Alternate payment arrangements may be established upon mutual agreement between the EAA and the Survey, as set forth in writing.

<u>Task</u>	<u>EAA's</u> <u>Contribution</u>	<u>and</u> <u>USGS's</u> <u>Contribution</u>	<u>Total</u>
Task 1	\$10,350.	\$ 9,150.	\$ 19,500.
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