GAM Standards

INTRODUCTION

The Texas Water Development Board (TWDB) develops numerical groundwater flow models of the major and minor aquifers in Texas. In addition, the numerical groundwater flow models developed through the Groundwater Modeling (GM) Program are meant to be “living tools” that can be updated as new information becomes available, adapted to reflect changing aquifer conditions, or refined to better address the needs and concerns of the groups using them.

The GAM process includes substantial stakeholder input and results in standardized, thoroughly documented, and publicly available numerical groundwater flow models and supporting information. The models, source information, and final reports are posted and distributed on the Internet or via other electronic means.

This document has considerable details because of the:

- need for standardization between the different models,
- planned public dissemination of the models, supporting information, and results, and
- assurance that the TWDB deliverables meet program requirements. For example, at a minimum, models should be able to successfully complete statutorily required tasks such as average historical water budgets for groundwater conservation districts and predictive simulations, such as desired future conditions.

The basic steps in model development and completion include:

- developing the conceptual model,
- defining the model architecture,
- calibrating the model,
- conducting sensitivity analyses, and
- simulating predictive scenarios.

Additional information on the various aspects and components required, as applicable to the scope of the project, is discussed in more detail in Attachments 1-4.

The major subheadings below (Stakeholder Participation, Documentation, Project Management, and Project Schedule) list TWDB expectations and requirements for the modeling projects.

STAKEHOLDER PARTICIPATION

Stakeholder participation is critical to the success of the GM Program and the development of the models. This includes participation from all levels of the public and private sector including regional water planning groups, groundwater conservation districts, Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, Texas Department of Agriculture, water utilities, educational groups, agricultural interests, environmental interests, private landowners, industry, and groundwater consultants. These groups will be relied upon to voice issues and provide information that will ensure that the models can address the important water resource questions for each aquifer.

Project managers are responsible for meeting with a stakeholder advisory forum of the above stakeholders, for holding key milestone meetings to discuss progress of the modeling effort, and for soliciting stakeholder comments and data. It is extremely important that regional water planning groups and groundwater conservation districts are informed about the models because they can use the models to assess groundwater availability or evaluate water management strategies. Stakeholder advisory forum attendees participate voluntarily with no compensation. The modeling projects have a stakeholder advisory forum database maintained through TWDB staff.

Stakeholder advisory forums are open to the public. The project managers work with the TWDB contract manager or other appropriate TWDB staff to coordinate meeting dates and locations. It is the project manager's responsibility to notify the stakeholder advisory forum participants of upcoming meetings by email. Stakeholder advisory forum participants with email accounts are notified at least 21 days before the meeting and reminded again at least 7 days before the meeting. The stakeholder advisory forum notice includes information about the meeting as well as an outline of what will be discussed at the meeting.

The first stakeholder advisory forum is held within 60 days after the project begins and describes the following:

- Basics of groundwater flow in the aquifer,
- Concepts of numerical groundwater flow modeling,
- Experience from previous models of the aquifer, if applicable,
- Planned approach—for example, investigating faults, investigating unconfined portions of the aquifer(s) that behave as confined, revising the model (if appropriate), and/or extending the model calibration period,
- Request for local scientific data and model input information,
- Proposed schedule for the modeling project, and
- Expectations of the model (what the model will or will not do).

It is extremely important to provide a well-defined schedule to the stakeholders on when solicited input and data are needed for the model. A well-defined schedule will help ensure that stakeholders' expectations are managed, and project managers will not have to work with late-arriving data. At a minimum, the remaining stakeholder advisory forums should be scheduled as follows:

- After the conceptual model report is delivered,

- After the draft model design,
- After the model is calibrated, and
- After the model has been developed, as applicable.

Additional stakeholder advisory forums may be scheduled at the project manager's discretion. Contracted project managers submit copies of the stakeholder advisory forum Microsoft PowerPoint presentations to the TWDB contract manager to preview at least 48 hours prior to the scheduled stakeholder advisory forum meeting. Presentations need to be easy to understand and informative to a non-scientific audience as much as possible. Although attendees are generally knowledgeable about groundwater, most may not hold degrees in geology, hydrology, engineering, or geostatistics. However, technically minded stakeholders are encouraged to ask technical questions and project managers must answer these questions at the same technical level of the question. In addition, technical questions should also be 'translated' for the non-technical audience.

After each meeting the following is submitted to the TWDB contract manager:

- Memo report that summarizes presentation and includes question and answers from attendees,
- Copy of the stakeholder advisory forum presentation,
- Attendance sign-up sheet, and
- Typed attendee and affiliation list.

An attendance sign-up sheet must be provided at each meeting, which includes attendee name, affiliation, and contact information. The list of attendees and their affiliation must be given to the TWDB in the memo report for posting on the TWDB web page for each stakeholder advisory forum. New and revised stakeholder contact information must be reviewed and updated, as applicable, and provided to the TWDB contract manager for updating the database of stakeholder contact information. Memo reports (submitted to the TWDB in Microsoft Word- and Adobe Acrobat-compatible formats) summarize the presentation, the questions and comments that arose from the stakeholder advisory forum attendees, how the questions were or will be addressed, and the list of attendees with their affiliation. The attendees' contact information will be excluded from the memo report. These memo reports will be posted by the TWDB on the TWDB web page for public viewing. Digital copies of final presentations at each stakeholder advisory forum meeting (in both Microsoft PowerPoint and Adobe Acrobat compatible formats) are also given to the TWDB for posting on the web within three (3) business days of the stakeholder advisory forum meeting. For people with disabilities, the documents, including presentations, should meet common accessibility standards, such as Web Content Accessibility Guidelines (WCAG) 2.0 and PDF/UA (Universal Access, or ISO 14289) or later; for example, figures should be tagged, and the language identified as English.

DOCUMENTATION

Thorough documentation of a model is extremely important in ensuring its continued use. Each model must be thoroughly documented and made available to the public upon completion of the project. Documentation must include four to five major products:

- Source and derived information from the development of the conceptual model in an ESRI ArcPro file geodatabase format (Attachment 3),
- Any additional interpretation of new geophysical logs or adjustments to existing analysis of geophysical logs must be provided in a format compatible with the BRACS database (Attachment 5),
- Source and derived information (pumpage, recharge, evapotranspiration, streams, general head boundaries, and drains) calculated for each model grid cell in an ESRI ArcPro file geodatabase format (Attachment 3), as applicable,
- Model input and associated files in MODFLOW 6 (or other version with TWDB approval) in ASCII format, and
- The final report for the numerical model must be submitted in both Microsoft Word 2010 compatible format or later and Adobe Acrobat 10.0 PDF format or later. The final model report may incorporate updates to the conceptual model in a chapter of the report (Attachment 1). This will be specific to each project and will be discussed and determined with the TWDB contract manager assigned to the project.

SOFTWARE REQUIREMENTS

All computer files and formats must be 100 percent compatible with personal computer (IBM-PC) type systems. Electronic files may be physically shipped using external hard drives. In addition, files may be compressed with Windows software compatible with 7-zip compression/extraction software.

Project managers must deliver a digital copy of the final draft numerical model report. All files and data must be transferred to the TWDB in ready- to-use format. Formats of all computer files provided to the TWDB by the project managers must be fully compatible with the widely distributed versions of the following programs:

- Word processor files—Microsoft Word (MS Office 2010 or later),
- Geodatabases data—ESRI ArcPro,
- Spreadsheet files—Microsoft Excel (MS Office 2010 or later),
- Graphs, bar charts, pie-charts—Microsoft Excel (MS Office 2010 or later),
- Internet-ready, accessible reports in PDF format—Adobe Acrobat (10.0),
- Turn-key models, if applicable—MODFLOW 6 (or other version with pre-approval by email from the TWDB Groundwater Modeling manager) — ASCII data files. In addition, contractors must provide georeferenced model orientation information; grid node/cell centroid spatial information that includes grid node/cell ID, county, basin, groundwater conservation district, aquifer (identify as confined or unconfined), groundwater management area, GAM X and Y coordinates, latitude/longitude, regional water planning area, layer (if applicable), grid

dimensions (if variable), active or inactive node/cell, and any other field(s) as needed; table of stress periods with time intervals; and target(s) file that identifies node/centroid and target information. ***Please note that the grid node/centroid spatial information must be submitted to TWDB for review and acceptance prior to model calibration***.
- Scanned files—uncompressed TIFF (8-bit for black and white and 24-bit color for gray/color with at least 300 dpi or greater, if needed, to resolve image resolution) for geophysical logs or associated data files.
- Geophysical log files and associated depth calibration files can be delivered in .tif, .las, .xml, .lic, or .dra file formats.

The project manager must request approval from the TWDB contract manager for alternative software. Project managers must provide ESRI ArcPro (or ArcGIS version 10.2 or later with pre-approval by email from the TWDB Groundwater Modeling manager) compatible files for all geographic information system information. All drawings and graphs included in all reports must be provided separately to TWDB in their native file format. In addition, all figures must be provided separately to TWDB in .jpeg formatted files with 300 dpi or greater resolution.

SOURCE INFORMATION

Important products from the modeling studies include not only the models but also the source information used to develop the models. These source data have potential use beyond the initial GAM for groundwater conservation districts, regional water planning groups, groundwater management areas, TWDB, and other users to support ongoing management issues and research. Therefore, TWDB must receive all source data used in the development of the model with sufficient metadata to decipher parameters and units reported. For example, TWDB must receive all point data used to develop spatially distributed parameters. If map information was digitized from an existing scanned or paper document, TWDB must receive the final geographic information system files of the digitized map(s) with metadata documentation citing the source of the digitized maps. If information from geologic cross-sections within a published document is used, TWDB must receive a digitized vector file of the cross-section(s) with metadata documentation of their original source. The source data also allows alternative interpretations of parameter distributions to be investigated in future studies. Contractor's project manager must seek prior approval from the GM contract manager to use proprietary data which cannot be distributed to the public.

Source data refer to the tabular, point, line, polygon, and/or raster information developed or used to create model input files. All the source data must be delivered to TWDB in the appropriate format (see Attachment 3). Spatial information must be projected into the GAM coordinate system with units of measure in feet prior to and during any spatial analysis (see Attachment 3).

Examples of source data for the study area include datasets in geographic information systems, in tabular form, and raw data.

Geographic Information Systems (GIS):

- Properly projected geographic information system feature datasets of the boundary of the study area including major towns and cities, county boundaries, major rivers and streams, major reservoirs, major roadways, regional water planning area boundaries, groundwater management area boundaries, groundwater conservation district boundaries, physiographic delineations, river basins, and active model boundaries,
- Geographic information system raster and/or feature datasets of the topographic elevations in the study area (digital elevation model source data and the contours in units of feet relative to mean sea level),
- Geographic information system feature datasets of the surface geology,
- Geographic information system feature datasets of the major structural and tectonic features,
- Geographic information system raster and/or feature datasets of the top and bottom elevations for each model layer in units of feet relative to mean sea level,
- Geographic information system raster and/or feature datasets of the distributions of transmissivity, hydraulic conductivity, and storativity and their units of measure,
- Geographic information system raster and/or feature datasets of water levels for the steady-state run at the beginning, during the transient run at a time negotiated with the TWDB, and end of the transient calibration run in units of feet relative to mean sea level,
- Geographic information system raster and/or feature datasets of final model parameters (e.g., horizontal hydraulic conductivity, vertical hydraulic conductivity, recharge, pumping rates, dispersivity, as applicable, and their units of measure) if different from distributions assembled during the conceptual model,
- Geographic information system georeferenced .tif files produced from scanned images depicting any of the above information not available in other GIS formats.

Geographic Information Systems (GIS) and Tabular:

- Tabular data and geographic information system raster and/or feature datasets of the net sand maps in units of feet relative to mean sea level, if applicable,
- Tabular data and geographic information system raster and/or feature datasets of average annual precipitation (including gage locations and associated time-series data and their units of measure),
- Tabular data and geographic information system raster and/or feature datasets of net lake or pan evaporation and their units of measure,
- Tabular data and geographic information system raster and/or feature datasets of the water-level maps in units of feet relative to mean sea level,
- Tabular data and geographic information system raster and/or feature datasets of the water quality maps and their units of measure,

- Tabular data and geographic information system raster and/or feature datasets of population density and their units of measure,
- Tabular data and geographic information system raster and/or feature datasets of the recharge rates and their units of measure,
- Tabular data and geographic information system raster and/or feature datasets of historical pumping information and their units of measure,

Tabular:
- Tabular data for the historical hydrographs and their units of measure,
- Tabular data for the long-term water quality graphs and their units of measure,
- Tabular data for the stream-flow hydrographs and their units of measure,
- Tabular data for the springflow hydrographs and their units of measure,
- Tabular data for the lake level hydrographs and their units of measure,
- Tabular data for the hydraulic conductivity, transmissivity, and storativity and their units of measure,
- Tabular data for the historical pumping at the resolution used to develop the model input datasets and their units of measure,
- Tabular data of calibration targets including target name, GAM coordinate, model row/column/layer, related hydrogeologic unit, measured value, and associated stress period and date in units of feet relative to mean sea level.

Other:
- Raw data and plots used to calculate hydraulic conductivity, transmissivity, and storativity and their units of measure, and
- Any other data used to develop the model and their units of measure.

Point data and interpreted data (for example, contoured data) must be delivered in ESRI ArcPro (or ArcGIS version 10.2 or later with pre-approval by email from the TWDB Groundwater Modeling manager) data formats. Any information associated with a state identification number (such as the state well number for located wells and the water use group [WUG] number and related fields [county, basin, region] for water users) must maintain that association in the final databases (Attachment 3).

All tabular data and geographic information system feature datasets must be delivered to TWDB within the GAM source geodatabase schema(s) provided to the project manager. The GAM source geodatabase schema(s) defines file-naming protocol, database organization, and documentation of the tables, databases, and geographic information system spatial data (Attachment 2). TWDB must be able to recreate all information from initial source to final derived data; therefore, metadata must contain sufficient information for replicating any processing used.

All raster data must be submitted in the Rasters template folder delineated by subject matter in either .tif or .nc format. If the Contractor Project Manager is unsure where specific rasters should be placed, contact the TWDB Contract Manager.

MODEL FILES

All MODFLOW 6 (or other MODFLOW version with TWDB approval) input files must be submitted in ASCII (or binary in the case of starting heads) format. The following ArcPro feature classes must be identified:

- model boundary,
- county boundaries,
- rivers, streams, reservoirs, and other hydraulic features simulated in the model,
- Any other boundary conditions associated approved through the TWDB contract manager,
- A table listing each stress period and corresponding time frame will be provided with the model files, and
- All targets used for calibration will be identified and clearly marked so verification of statistics may be performed.

Future users must be able to run the model using MODFLOW 6 (or other) code from the command prompt with the files provided. Therefore, a README file explaining exactly how to run the model is required. All scripts and the README file must follow standard programming and documentation guidelines.

FINAL REPORTS

The final reports must include the details of the conceptual model, input datasets, model construction, calibration, sensitivity analysis, and model results, depending on the objective of the project. There may be up to three or more final reports, determined by the Contract Manager, depending on the scope of work—conceptual model report, model calibration report, predictive scenarios report, and/or special studies (see contract for specifics for deliverable requirements). The final reports will follow TWDB guidelines and must be clearly written without spelling or grammatical errors. Final approved reports must follow Texas Board of Professional Geoscientists (see www.tbpg.state.tx.us) and/or Texas Board of Professional Engineers (see https://pels.texas.gov/) guidelines. All Microsoft Office documents must comply with federal standards for people with disabilities. Additional information is available through the following web site: gov.texas.gov/organization/disabilities/accessibledocs.

Report Format and Figures

Each section of the submitted reports must address the data and analysis described in Attachments 1 and/or 2, depending on the scope of the project. Additional sections and subsections may be added to the submitted reports to address aquifer-specific issues after discussing this with the TWDB contract manager.

Drafted figures must be similar in design to each other and include a legend and a descriptive figure caption and must fit on 8.5 by 11-inch paper. Any color figures should be designed in a manner such that there is no loss of legibility when printed with a black and white printer. All interval or ratio data (data measuring continuous phenomena, with each color representing an equal interval) need to be displayed either in a graded scale of a single color or should use symbols or patterns to distinguish intervals.

Minimum requirements for figures include the following:

- Figures must be designed such that a black and white printout is readable and understandable,
- Maps must include a north arrow and a bar scale,
- Figures and maps must include legends showing related features,
- Each figure must have a caption that includes reference sources for the base map or the included information,
- For unmodified illustrations, the reference source must be preceded by the word “from”,
- For illustrations modified less than 15 percent of the original, the reference source must be preceded by the word ‘after’,
- For illustrations modified more than 15 percent of the original, the reference source must be preceded by the words ‘modified from’), and
- Figures must follow Texas Board of Professional Geoscientists or Texas Board of Professional Engineers guidelines (https://tbpg.state.tx.us/tbpg/rules).

Sources of data/base maps must be clearly indicated on the figure or in the figure caption. Additional information may be added as needed.

At a minimum, the **final CONCEPTUAL MODEL report** or chapter must be designed with the public as the audience. We have included a checklist that details the format of the report, including figures and tables that are required, in Attachment 1.

At a minimum, the **final NUMERICAL MODEL report** must be designed with the public (Chapters 1 and 2) and a groundwater modeler as the audience (the remainder of the report). A checklist detailing the format of the report, including figures and tables that are required, in Attachment 2.

The following units must be used in all data presentations:

- Land area in square miles (mi^2),
- Water volume in acre-feet (ac-ft),
- Elevations relative to mean sea level (ft-AMSL),
- Demand and supply rates in acre-feet per year (ac-ft/yr),
- Stream flows and reservoir releases in cubic feet per second (cfs),
- Spring flow in cubic feet per second (cfs),
- Pumping rates in gallons per minute (gpm) or million gallons per day (mgd),

- Recharge rates in inches per year (in/yr),
- Annual precipitation in inches per year (in/yr),
- Evaporation in inches per year (in/yr),
- Evapotranspiration in inches per year (in/yr),
- Hydraulic conductivity in feet per day (ft/d),
- Transmissivity in feet squared per day (ft^2/d),
- Conductance in feet squared per day (ft^2/d),
- Specific storage in units of inverse length using feet (1/ft),
- Recharge volumes in acre-feet (ac-ft), and
- Solute (water quality) concentrations in milligrams per liter (mg/l).

Information may also be co-reported in other units such as metric equivalents.

Milestones and Deliverables

There are multiple times when the TWDB shall receive electronic copies of data used for the modeling effort and the deliverable report for review. For projects documenting **the conceptual groundwater flow process,** the following milestones will be required:

Milestone	**Deliverable**
After completing the hydrostratigraphy and development of the framework for the conceptual model—the goal of this milestone deliverable is to ensure the TWDB has sufficient information to replicate the framework and that the conceptualization of the framework meets the goals of the program.	The geodatabase with metadata and BRACS database information is submitted to the TWDB for review and acceptance (please see Attachments 3 and 5). This deliverable is to be re-submitted until an acceptable product is produced.
Draft conceptual model deliverable	The report shall include Conceptual Model Report information listed in Attachment 1, source data with metadata discussed in Attachment 3, and BRACS data discussed in Attachment 5. TWDB staff will provide comments to be addressed in the draft final deliverable. The report will be posted for public review and comment for 30 days.
For conceptual model projects, final conceptual model deliverable	The report shall include Conceptual Model Report information listed in Attachment 1, source data with metadata discussed in Attachment 3, and BRACS data discussed in Attachment 5). In addition, all review comments from the TWDB review of the draft deliverable are addressed with responses in an appendix of the report.

For projects documenting **the update to an existing model or models**, the following milestones will be required:

Milestone	Deliverable
After completion of the model **design** and prior to model calibration—the goal of this milestone deliverable is to ensure that the TWDB has sufficient information to replicate the model design and that the preliminary model meets the goals of the program.	Chapter 3 of the draft model report discussed in Attachment 2 (see checklist). TWDB staff will provide comments to be addressed in the draft final deliverable. In addition, the grid node attributes, preliminary model files (in MODFLOW), and geodatabase will be submitted. TWDB staff will review the grid node attributes to ensure model output will be compatible with official state boundaries. This deliverable is to be re-submitted until an acceptable product is produced.
After completion of the **calibrated** transient model—the goal of this milestone deliverable is to ensure TWDB has a model that meets the objectives of the program,	Chapter 4 of the draft model report must be submitted with information listed in Attachment 2 checklist for the Model Calibration Report TWDB staff will provide comments to be addressed in the draft final deliverable. In addition, model files in MODFLOW, attributed grid file, target files, stress period table, and all calibration statistics will be submitted for review. This deliverable is to be re-submitted until an acceptable product is produced.
Draft numerical model deliverable	Draft final Numerical Model report must include information listed in Attachments 1 to 4, as applicable) that includes the sensitivity analysis and predictive run(s) that use the current modeled available groundwater estimates. In addition, all review comments from the TWDB review of Chapters 1 to 4 and milestone deliverables and public review comments of the conceptual model are addressed with responses in an appendix of the report. The report will be posted for public review and comment for 30 days.
Final numerical model deliverable	The report must include Numerical Model Report information listed in Attachment 2, source data with metadata discussed in Attachment 3, and BRACS data discussed in Attachment 5. In addition, all review comments from the TWDB and public review of the draft deliverables are addressed with responses in an appendix of the report.

For the draft conceptual model report, or draft model and predictive scenarios report, the project manager must deliver to TWDB:

- An Adobe Acrobat (PDF) file of the draft conceptual model report or draft numerical model and predictive scenario (if applicable) report for posting on the TWDB website and the Microsoft Word 2010 format including figures—see Attachment 4 for formatting guidelines,
- All related documented source and derived data in the appropriate geodatabase and BRACS database (see Attachments 3 and 5), see contract for any exceptions,
- Model input files for model calibration and predictive scenario(s) in MODFLOW 6 (or other version), and
- All computer programs (source code, executable, and scripts) that were used during the conceptual model and/or model development.

The stakeholder advisory forum participants have a 30-day review period and TWDB has a 45-day review period to comment on the conceptual report. Stakeholder advisory forum participants and TWDB have the same amount of time to comment on the draft model and predictive scenarios report. The project manager will have at least 30 days to address comments from the draft model and predictive scenarios reports (as well as the comments from the conceptual model review period) before issuing the final report.

At the end of the study, the Contractor’s project manager must deliver to TWDB:

- Digital copy of the final conceptual or final model/predictive scenarios reports including all figures (in Microsoft Word 2010 format)—see Attachment 4 for formatting guidelines,
- Adobe Acrobat (PDF) file(s) of final conceptual or final model/predictive scenarios reports for posting on the TWDB web site,
- Individual digital copies of each of the figures in the reports,
- Digital copies of all source and derived model data in digital format in the appropriate geodatabase with proper documentation and formatting (see Attachment 3),
- Digital copies of all geophysical log files in the BRACS database with proper documentation and formatting (see Attachment 5), see contract for any exceptions, and
- Digital copies of the Model input files (MODFLOW 6 or other version) and supporting calibration and model related files, as applicable;
- Digital copies of all computer programs (source code, executable, and scripts that are used during the conceptual and/or model development.

It is important that the delivered reports be of high quality and that TWDB receives the proper files. Consistent geologic, hydrologic, and technical terminology must be used throughout each report. No acronyms may be used except for Texas Water Development Board (TWDB) after it is introduced in the text and the abbreviations for model files. Any references to aquifers in Texas must use the nomenclature used by TWDB. Each report must have an authorship list of persons responsible for the studies; firm or agency names as authors are not acceptable. Final approved reports must follow Texas Board of Geoscientists guidelines (see www.tbpg.texas.gov) and must be sealed by either a Professional Engineer or Professional Geoscientist, as applicable. The TWDB logo or state seal may not be used on final reports.

PRESENTATIONS AND WEB PUBLISHING

During the course of the project, the project manager will provide digital copies of presentations related to the model to assist TWDB in promoting the modeling efforts and informing the public (in Microsoft PowerPoint and Adobe Acrobat [PDF] formats).

Geodatabases, MODFLOW files, and the report will all be posted on the TWDB website or Amazon iCloud and will be distributed to interested parties.

TWDB will maintain centralized ownership and maintenance of the models. Because of the posting of model-related documents on the web, the presentations and documents must all comply with Web Content Accessibility Guidelines (WCAG) 2.0 and PDF/UA (Universal Access, or ISO 14289) or later.

PROJECT MANAGEMENT

Contractor must provide monthly letter reports for the duration of the modeling projects summarizing progress on the project. Any concerns must be documented in the progress reports and brought to the TWDB contract manager's attention as soon as possible. The TWDB contract manager may schedule appointments with the project manager and team members to gauge progress on the project. The Contractor's project manager must also hold project review meetings with TWDB, depending on the scope of the project, include:

- The beginning of the project,
- The milestone for framework,
- After the draft conceptual model is submitted,
- After delivery of the model design milestone,
- After delivery of the model calibration milestone, and
- After we have reviewed the draft final deliverables.

Advancement of the project to the next phase of work described above is contingent on TWDB approval of the efforts at each formal meeting. Each meeting will include discussions on the work that has been completed and the approach for the next phase of work. TWDB staff must also be invited and attend all the stakeholder advisory forums.

PROJECT SCHEDULE

All deliverables must be completed by the dates noted in the Contract. The draft conceptual or numerical model report (as applicable to the contract,), as well as all associated data and model files, must be delivered by the date noted in the Contract.

ATTACHMENT 1: Conceptual Model Guidelines

CONCEPTUAL MODEL

The conceptual model is a description of the best understanding of how groundwater moves through the aquifer system. In developing the conceptual model, the information necessary for developing the numerical model is compiled, organized, and described. The conceptual model includes information on:

- physiography and climate,
- geology,
- hydrostratigraphy,
- hydrostratigraphic framework,
- water levels and regional groundwater flow,
- recharge,
- rivers, streams, reservoirs, springs, and other surface water features,
- hydraulic properties,
- subsidence (if applicable),
- discharge, and
- water quality.

During the development of the conceptual model, the TWDB (including the Texas Natural Resources Information System), Texas Commission on Environmental Quality, regional water planning groups, Texas Parks and Wildlife Department, Texas Railroad Commission, U.S. Geological Survey, groundwater conservation districts, river authorities, or other appropriate entities are contacted for relevant information. Published papers and reports on the aquifer are compiled, reviewed, and documented. Earlier modeling efforts on the subject aquifer or adjacent aquifer(s) are thoroughly reviewed and documented.

Development of the conceptual model and any information entered into the numerical model uses only publicly available information or information that can be made publicly available at project completion. Each element of the conceptual model is thoroughly described, documented, and referenced in the final report (please see checklist at the end of this attachment). In addition, any assumptions are stated and adequately justified. Development of the conceptual model is based on documented field data as much as possible or published work. The conceptual model is visually summarized with a block diagram demonstrating major components of flow in the aquifers (that is, recharge, cross-formational flow, flow directions, and boundary conditions).

PHYSIOGRAPHY AND CLIMATE

Physiography (the study of physical features of the Earth’s surface) and climate of the study area shall be described and include descriptions and maps or graphs of

- physiographic delineations and features,
- topography,
- general climate characteristics,

- spatial and temporal variability of precipitation,
- spatial and temporal variability of temperature,
- spatial and temporal variability of evaporation, and
- evapotranspiration.

This section shall also describe the aerial extent of the study area and include research on vegetation and soil properties as it relates to evapotranspiration.

GEOLOGY

The general geology and structural geology of the study area shall be described and include:

- detailed stratigraphic chart showing lithostratigraphic units and facies correlations,
- description of each of the geologic formations that includes the formation thickness characteristics, depositional environment, and rock composition,
- map of the surface geology,
- sufficient cross sections throughout the study area to demonstrate the structural framework of the subsurface geology,
- brief discussion of the geologic and tectonic history including regional and local structural features, and
- previous studies conducted in the model area should be carefully reviewed and referenced as sources of information for this section.

HYDROSTRATIGRAPHY

Hydrostratigraphy (the layering of aquifers and confining units) for the study area shall be presented and discussed. The discussion shall include:

- a detailed hydrostratigraphic chart showing aquifer and aquitard units;
- rationale for the delineation of hydrostratigraphic units;
- at a minimum, the hydrostratigraphic units that underlay or interact with the modeled aquifer;
- thoroughly documented exception and additions, pre-approved by TWDB staff; and
- previous studies, carefully reviewed and referenced as sources of information for this section.

HYDROSTRATIGRAPHIC FRAMEWORK

The hydrostratigraphic framework shall describe the elevation of the top and bottom of each of the hydrostratigraphic units. For each layer in the model, an elevation map of the top and bottom shall be generated that includes the location of the data used in the interpolation. Land-surface elevations shall be used as the top of the model domain. Land-surface elevation shall be defined by USGS 1-arc-second (30-meter) or appropriate finer resolution digital elevation models (DEMs). Thickness maps for each hydrostratigraphic unit shall also be developed. All information used to develop the hydrostratigraphic framework surfaces shall be fully documented as to data source, data interpolation techniques, and data quality.

WATER LEVELS AND REGIONAL GROUNDWATER FLOW

Water levels and water-level maps describe general groundwater flow directions, hydrologic boundaries, and provide information for the calibration of the model. At least two or four water-level maps shall be generated for each of the hydrostratigraphic units included in the model:

- For the pre-development historical conditions prior to significant well pumping,
- For the beginning of the transient calibration period (or end of the conceptual model study,
- During the transient calibration period (at a time-period chosen in cooperation with the TWDB for model related projects), and
- For the end of the transient calibration period for model related projects (information on the transient calibration period; see Attachment 2).

The pre-development condition maps shall be based on historical water-level information but may include more modern information to help guide water-level interpretation. Long-term historical hydrographs shall also be developed for the study area, as the data permit. These hydrographs will help define water-level fluctuations throughout the model area and will also serve as calibration targets for the transient model.

Project managers shall document and describe the following, if appropriate:

- Hydraulic-head differences between hydrostratigraphic units,
- Nature of the vertical connection between hydrostratigraphic units,
- Areas of water-level declines, and
- General water-level behavior in the aquifer.

Regional groundwater flow paths shall be identified, as well as any features that affect flow paths such as surface-water/groundwater interaction, significant well pumping, faulting, and cross-formational flow. Any information on cross-formational flow shall also be investigated, documented, and discussed.

RECHARGE

Texas Water Code §36.001(26), defines recharge as the amount of water that infiltrates to the water table of an aquifer. Depending on the aquifer, this may include precipitation infiltrating by percolation, irrigation return flow, injection wells such as Class II injection wells (www.epa.gov/uic/class-ii-oil-and-gas-related-injection-wells), and stream losses. Important factors related to how the aquifer is recharged and the effects of seasonal variations shall be examined and discussed. Previous studies on recharge in the model area should be carefully reviewed. Recharge shall be distributed according to infiltration characteristics of the aquifer outcrop (for example, soil properties, water table depth, and topography), precipitation rates, and losing streams, if applicable. Maps of recharge rates, recharge potential, or recharge coefficients (for example, see Mace and others, 2000) shall be generated for the model area.

Recharge can be influenced by water table fluctuation due to seasonal changes or groundwater extraction. As a result, the conceptual model and the numerical model must include the concept and effect of 'rejected recharge' (for example, see Theis, 1940, summarized in Domenico and Schwartz, 1990, p. 200-202). The groundwater model should realistically predict the effect of large cones of depression on local flowpaths (that is, capture of rejected recharge) in the aquifer. Therefore, the model should be capable of simulating changing flow patterns due to changing aquifer conditions. For example, this may be accomplished by modeling evapotranspiration and surface water/groundwater interactions. Recharge shall be incorporated into the model with an appropriate MODFLOW package (for example, the General Head Boundary package, Constant head package, or injection wells should not be used to simulate recharge. Any exceptions should be cleared with TWDB staff and the reasoning well-documented). In addition, recharge should represent the amount of water that infiltrates to the water table of an aquifer and therefore should not include runoff.

RIVERS, STREAMS, SPRINGS, AND RESERVOIRS

Surface water features, such as rivers, streams, irrigation canals, springs, and reservoirs, can interact with groundwater and thus must be addressed. The primary surface water features in the model area shall be identified and described along with historical flows. For rivers and streams, reaches with net gains and losses shall be identified and, if possible, quantified. Information from the previous modeling studies in the area may be incorporated into the model, as applicable. Any specific or general information on streambed conductance shall also be addressed. Elevations of riverbeds, streambeds, irrigation canals, spring orifices, and reservoir levels shall be determined from the best-documented available sources. Because of the interest in surface water/groundwater interactions, it is important to note areas of data and/or the lack of data. All surface water features that are essential elements of the hydrologic flow system shall be incorporated into the model, if applicable, with an appropriate MODFLOW package. For example, the General Head Boundary or Constant Head packages should not be used to simulate surface water features, with a few exceptions (such as the Gulf of Mexico).

HYDRAULIC PROPERTIES

Hydraulic properties of hydrostratigraphic units that help define the flow characteristics of the aquifer must be addressed. These include the transmissivity, hydraulic conductivity, storativity, and specific yield. Results from available aquifer tests for the model area shall be compiled and assessed including any information from the groundwater conservation districts. Additionally, information on hydraulic properties from previous modeling studies may be incorporated in the current project, as appropriate. Specific capacity tests shall also be compiled from TWDB files, and from Texas Commission on Environmental Quality files, and transmissivity and hydraulic conductivity estimated using analytical or empirical techniques (for example, Mace, 2001). Project managers are encouraged to conduct, analyze, and use additional aquifer tests, if they believe the budget can support them.

Transmissivity, hydraulic conductivity, storativity, and specific yield shall be defined and statistically analyzed for each hydrostratigraphic unit. Special care must be taken in considering the completion zones of the test wells and how they relate to the aquifer. Maps of the spatial distribution for these properties shall be presented for each hydrostratigraphic unit using the appropriate interpolation techniques given the amount of data and apparent trends (for example, geostatistical techniques). If the information is available, hydraulic properties shall be related to and distributed according to the known geologic characteristics of the aquifer (for example, texture and net-sand thickness possibly associated with cut banks and point bars or correlated sedimentary facies). Specific or general information on vertical hydraulic conductivity for each hydrostratigraphic unit shall be compiled and/or calculated and related to known geologic and hydrogeologic conditions. If possible, vertical hydraulic conductivity and storativity shall be distributed according to geologic information (for example, texture, net-sand thickness, horizontal beddings, and sedimentary facies). Horizontal anisotropy shall also be defined, discussed, and estimated, if appropriate.

DISCHARGE

Discharge describes the flow of water out of the aquifer either through cross-formational flow; baseflow to streams, springs, or other surface water bodies; and pumping. Cross-formational flow, baseflow to streams, and discharge to springs shall be identified, discussed, and, if possible, quantified. Additional information regarding historical pumping from the groundwater conservation districts located in the study area shall be requested, reviewed, and used, as applicable. It is the project manager’s responsibility to use the existing models, associated data, and other public data sources to quantify the groundwater discharge. Previous modeling studies in the model area, if applicable, may be a helpful source of information on discharge for many of the modeling projects.

WATER QUALITY

Although the models will not explicitly model water quality and solute transport, it will be important to document water quality of the aquifer so later users can more accurately gauge groundwater availability. Additionally, chemical analysis of groundwater can provide insight to water origin and migration patterns supporting the Conceptual Model. Therefore, total dissolved solids and other constituents of concern should be presented as part of the conceptual model. Analysis of fresh versus brackish water derived from geophysical log interpretation should be documented, as applicable.

REFERENCES

Domenico, P.A., and Schwartz, F.W., 1990, Physical and Chemical Hydrogeology: John Wiley and Sons, Inc., New York, p. 200-202.

Mace, R. E., Chowdhury, A. H., Anaya, R., and Way, S.-C., 2000, Groundwater availability of the Middle Trinity aquifer in the Hill Country area of Texas- Numerical simulations through 2050: Texas Water Development Board Report.

Mace, R. E., 2001, Estimating transmissivity using specific-capacity data (Geological circular): Bureau of Economic geology, University of Texas at Austin, 44 p.

Final Draft	Final	Conceptual Model Checklist
		Report deliverable:
		Received electronic version of report (word version).
		Received separate copies of figures.
		Received pdf of report/figures combined.
		Appropriate units of measure used (See GAM Standards, *Report Format and Figures*).
		Document formatting:
		12-point Arial for all text.
		Single-spaced text.
		Left justification for paragraph text.
		18-point bold for first-level headings.
		14-point bold for second-level headings.
		Page numbers are centered at the bottom of the page.
		Page setup should use one-inch margins on all four sides.
		Report Content:
		Executive Summary:
		Provide a summary of the conceptual model.
		1.0 Introduction
		Describe the importance of the aquifer to the region and provide a general outline of the modeling study and report.
		2.0 Study Area
		Discuss the study area and include the following maps:
		Maps of the study area showing major towns and cities, county boundaries, major rivers and streams, major reservoirs, major roadways, location of the study area within Texas or any bordering states (if applicable), and the model boundaries,
		Map showing the location of the different Regional Water Planning Groups in the area and Groundwater Management Area in the area,

		Map showing the location of groundwater conservation districts in the area (documented with the date of the source reference), and
		Map of the major river basins and major surface water features.
		2.1 Physiography and Climate
		See *Physiography and Climate section above* and include the following maps:
		Map of the delineated physiographic provinces and sub-provinces as delineated by the Texas Bureau of Economic Geology,
		Map of topographic elevation,
		Map of climate divisions for the study area as delineated by the National Climatic Data Center,
		Map of average annual precipitation over the study area in inches per year (1981 to 2020 or later),
		Map of average annual temperature over the study area in degrees Fahrenheit (1981 to 2020 or later),
		Map with several plots of average monthly precipitation measured at rain gages in the study area in inches per year (1981 to 2020 or later),
		Map of average annual net lake or pan evaporation over the study area in inches per year (1981 to 2020 or later),
		Map of average evaporation (include years used to average),
		Map of vegetation types (root depths if available or estimated),
		Maps of soil properties including infiltration (or permeability) and water capacity, and
		Map of estimated potential and actual evapotranspiration, if available.
		2.2 Geology
		See *Geology section above* and include the following maps:
		Map of the surface geology at a minimum scale of 1:250,000,
		Maps of spatially distributed geologic information used during the modeling study (showing the control data if possible),
		Map of the major structural and tectonic features in the area,
		Detailed stratigraphic chart of the geologic formations in study area and their geologic (lithostratigraphic) correlations, and
		Several geologic cross-sections through the study area that show the general framework of the subsurface geology.

		3.0 Previous Work
		Describe the previous studies of the study area. Studies related to groundwater extraction, groundwater levels, river flow, precipitation, water quality and their correlations should be thoroughly investigated and documented. If there have been previous groundwater flow models for the aquifers in the region, review and describe those models. These models may not necessarily cover exactly the same area or have the same objective; however, the previous groundwater models and their associated data sources may provide useful information for this project. Thus, the existing models and related databases/files shall also be reviewed and investigated.
		4.0 Hydrologic Setting
		Discuss the information compiled and analyzed for developing the conceptual model (as discussed in Hydrostratigraphy Section above) in the following subsections:
		4.1 Hydrostratigraphy and Hydrostratigraphic Framework
		See *Hydrostratigraphy and Hydrostratigraphic Framework sections* above and include the following maps/figures:
		Schematic of the geologic units in the study area and the hydrostratigraphic units used in the model - The corresponding model layer should be included in the final report. For example, the geologic age of the strata, group names (with group correlations if applicable), formation names (with formation correlations if applicable), brief geologic descriptions, hydrogeologic delineations (aquifer/aquitard) and the corresponding model layer should be provided,
		Maps of top and bottom elevations for each of the hydrostratigraphic units as well as model layers, in case they are different, including the control points, and
		Maps of layer thickness for each of the model layers including the control points.
		4.2 Water Levels and Regional Groundwater Flow
		See *Water Levels and Regional Groundwater Flow section* above and include the following maps/figures:
		Maps of the potentiometric surface for each hydrostratigraphic unit as well as model layer, in case these are different, for the pre-development calibration, the beginning of the transient calibration, during the transient calibration at a time period agreed-upon with TWDB, and at the end of the transient calibration including the control points,
		Several historical hydrographs demonstrating water-level fluctuations (including seasonal, if available) in the aquifer with a map indicating location of the wells, and

		Historical hydrograph selections should represent unconfined (and also confined portions if applicable) of the aquifer(s) from each county in the study if data is available.
		4.3 Recharge
		See *Recharge section* above and include the following:
		A discussion of the approach used to estimate recharge rates and map(s) of estimated recharge rates, potential, factors, and/or coefficients.
		4.4 Rivers, Streams, Springs, Reservoirs, and Other Surface Hydraulic Features
		See *Rivers, Streams, Springs, Reservoirs, and Other Surface Hydraulic Features section* above and include the following figures:
		Representative stream-flow hydrographs for the major rivers and any significant perennial streams or tributaries in the study area with a map indicating their gage locations,
		Spring-flow hydrographs if appropriate with a map indicating spring locations, and
		Hydrographs of reservoir levels if appropriate.
		4.5 Hydraulic Properties
		See *Hydraulic Properties section* above and include the following:
		A discussion of the approach used to estimate hydraulic properties,
		Histograms of hydraulic conductivity, specific yield (if appropriate), storativity/ for each hydrostratigraphic unit as well as model layer, in case they are different,
		Map of spatially distributed hydraulic conductivity, specific yield (if appropriate), storativity for each hydrostratigraphic unit as well as model layer, in case they are different (maps should show the locations of aquifer tests used to derive the data),
		Net sand thickness maps, if applicable, and
		Map of geologic sedimentary facies and paleo-geography, if applicable.
		4.6 Discharge
		See *Discharge section* above and include the following figures, maps, and tables:
		Bar chart(s) of yearly total historical groundwater usage,
		Map of rural population density,

		Map(s) of land use cover used to distribute irrigation and livestock pumping if applicable,
		Tables of the historical pumping data according to major user group and summed over each county shall be included in the report,
		Maps of pumping distributions for each hydrostratigraphic unit as well as model layer, in case these are different, for the pre-development calibration, the beginning of the transient calibration, during the transient calibration at a time period agreed-upon with TWDB, and at the end of the transient calibration according to major user group,
		Location of existing desalination plants, as applicable to the project, and
		Location of Class II injection wells with permits to store within the model domain, as applicable to the project.
		4.7 Water Quality
		See *Water Quality section* above and include the following maps:
		Maps of water quality (total dissolved solids and any other constituents of concern) for each hydrostratigraphic unit as well as model layer, in case they are different, for the pre-development calibration, the beginning of the transient calibration, during the transient calibration at a time agreed-upon with TWDB, and at the end of the transient calibration including the control points, and
		Long term water quality graphs demonstrating water quality fluctuations (including seasonal, if available) in the aquifer with a map indicating location of the wells.
		5.0 Conceptual Model of Groundwater Flow in the Aquifer
		Describe the concepts and assumptions of the aquifer used to guide the construction of the computer model. These concepts should include (1) identifying the modeled layers and confining units, (2) describing the movement of water from recharge areas to discharge areas through the aquifer, and (3) discussing important controls on groundwater flow (for example, structural framework, faulting, lithology, and boundaries) and on groundwater quality (for example, boundaries, cross-formational flow, pumping, groundwater ages, if available). Please include the following figure:
		Block diagram showing the hydrogeologic units and summarizing the flows within the conceptual model and how the conceptual model was translated into the computer model (for example, see Mace and others, 2000, fig. 50).
		6.0 Future Improvements
		Indicate where additional improvements could be made to the conceptual model in collecting more data or additional studies. Recommendations for how these issues could be addressed will be appreciated.

		7.0 Acknowledgments
		Acknowledge those organizations or specific individuals that assisted in the conceptual modeling project by supplying data, providing thoughtful discussion, or contributing more directly to the study.
		8.0 References
		All references cited in the report shall be included in the 'References' section following TWDB format.
		Figures check - photocopy all figures in black and white:
		Figures shall be designed such that a black and white printout is readable and understandable;
		Maps include a north arrow and a scale;
		Each figure has a caption that includes reference sources for the basemap or the included information; and
		Figures must follow Texas Board of Geoscientists guidelines, if applicable.
		Figures within margin of one-inch page margins
		Figure captions below figures
		Table captions above tables.
		Geodatabase Checks
		Rasters align with the snap grid (aka master grid)
		Files have metadata
		Files have clear names that follow GAM recommendations
		Data extents are reasonable
		Data value ranges are reasonable
		Interpolated surface reflects the source point data
		Rasters only have values where the features occur
		Subsurface rasters only have values that are less than the digital elevation model of the Earth’s surface. No geology mapped above the Earth’s surface!
		Top layer minus bottom layer > 0. No negative thickness values!
		Visually scan the rasters for anomalies. If something looks strange but is valid, it is discussed in the report.

		If lithology was mapped, none of it is thicker than the formation in which it occurs.
		BRACS database checks
		Used the tables and fields as described in the BRACS Data Dictionary
		All wells used in the study reference or have been given a BRACS well ID and are in the database
		Search for duplicate well records, delete and add additional well names to the foreign key table
		The folders DrillerWellLogs and GeophysicalWellLogs have been populated with the appropriate subfolders and file types
		All files are named properly
		All purchased logs have been documented and invoiced
		Well locations are in NAD83 decimal degrees
		Location method was documented in the database
		lithology and stratigraphic depth values appended to the table tblWell_Geology
		lithology from driller well reports converted to a simplified lithology
		Interpretation of sand/clay from geophysical well logs in either a two or a four-tier classification
		Lithology begins 100 feet shallower than the top of the geological formation of interest and end approximately 100 feet deeper than the base of the geological formation of interest.
		No gaps or overlaps in lithology or stratigraphy intervals
		No log interpretation in the cased portion of a well unless from Gamma Ray curves with significant character
		Separate table for best professional judgements made to aid in the interpolation
		Water quality measurements not in the TWDB GWDB have been added to the BRACS DB
		Well construction information added to the database
		Applied aquifer determination to water quality measurements and provide the table
		All well records, methods, input and output values, correction factors, and assumptions used to interpret total dissolved solids concentration from geophysical well logs are recorded in the BRACS Database.

		Documented source of porosity values used in TDS analysis from logs
		Links between water quality samples correlated to a geophysical well log documented
		If a new technique (or modification of an existing technique) is used, the table and its design are provided for addition to the BRACS data dictionary

ATTACHMENT 2: Numerical Model Guidelines

MODEL ARCHITECTURE

The models must use MODFLOW 6 (Langevin and others, 2021) or other MODFLOW code with pre-approval by email from the TWDB Groundwater Modeling manager. All models will use MODFLOW components that are freely available (that is, proprietary modules or codes shall not be used). The final model must be able to run on a personal computer under the Microsoft Windows operating system (Microsoft Windows 2007 or later). Length units for model input will be in feet and time units will be in days.

CELL SIZE, ORIENTATION, LAYERING, AND PARAMETER ASSIGNMENT

The models must be designed to be able to reasonably perform the following objectives:

A. Develop estimates of modeled available groundwater, which is the total volume of water produced on an average annual basis to achieve a desired future condition;
B. Develop values of total estimated recoverable storage for each aquifer in each groundwater management area. Total estimated recoverable storage is the estimated amount of groundwater within an aquifer that accounts for recoverable storage scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume; and
C. Develop estimates of the annual amount of recharge from precipitation, if any, to the groundwater resources within each groundwater conservation districts; the annual volume of water that discharges from the aquifer to springs and any surface water bodies, including lakes, streams, and rivers, for each aquifer within the district; and the annual volume of flow into and out of the district within each aquifer and between aquifers in the district.

Lateral grid cell size must be *no greater than* one-mile-by-one-mile for the aquifer model. We recommend lateral grid cell size be reduced in order to mitigate model instabilities or if the density of available source data supports a smaller grid size. The grid must be oriented with the prominent grain of the hydrostratigraphic structure and/or regional groundwater flow paths, as much as possible. The x-y coordinates for the lower left corner of the model grid (and the angle of rotation from true north, if applicable) must be noted within the model report and noted in the metadata of the geographic information system feature dataset within the geodatabase.

Cell type must be assigned for the models such that model cells:

- are either confined or unconfined, depending on the position of the water level relative to the top of the formation,
- are convertible, unless otherwise directed by TWDB,
- include transmissivity calculated according to the modeled saturated thickness,
- correspond to specific hydrostratigraphic units or groups of hydrostratigraphic units, and

- must not be of arbitrary thickness consisting of all hydrostratigraphic units within that thickness without prior written approval from the TWDB contract manager.

Hydraulic property values used for model construction must be based on field measurements and consistent with the conceptual model. It is the responsibility of the Contractor's project manager to review all available data and to correctly define the hydraulic property values. If certain properties are assigned to the model on cell-by-cell basis, then spatial data must be interpolated to model cells using an appropriate interpolation procedure. For MODFLOW 6 family codes, the Contractor must identify whether the storativity or specific storage is used. The contractor must document how the storage properties are estimated.

MODEL EXTENTS AND BOUNDARIES

The extent of the models must follow natural boundaries as much as possible. The report must describe the rationale for the boundaries in the model for aquifers that extend outside of Texas. The Contractor's project manager must describe the process to select the model base boundary location based on the hydrostratigraphic framework (and/or water quality criteria) as well as the boundary condition used to simulate the model base boundary.

MODEL PACKAGES

At a minimum, the following model packages must be used as inputs to the model:

- Grid Specification File (GSF) or Visualization Toolkit Unstructured grid (VTU) – if grid is unstructured
- Temporal Discretization package (TDIS)
- Discretization package (DIS, DISV, or DISU)
- Output Control Option package (OC)
- Initial Conditions package (IC)
- Name file (NAM)
- Well package (WEL)
- Node Property Flow package (NPF)

Additionally, the model should include the following packages when applicable:

- Horizontal Flow Barrier package (HFB)
- Constant-Head package (CHD)
- Drain package (DRN)
- River package (RIV) and/or Streamflow Routing package (SFR)
- General-Head Boundary package (GHB)
- Recharge package (RCH)

RECHARGE AND SURFACE WATER

It is extremely important that recharge and surface water-groundwater interaction be modeled in a realistic manner appropriate for historical and future predictive conditions. Constant head cells in recharge zones will not be accepted as an appropriate final method of simulating recharge. The Contractor's project manager must obtain written permission from the TWDB Groundwater Modeling Manager to use a package other than the MODFLOW Recharge package to simulate recharge in the GAM. The chosen method must provide recharge for local as well as regional flowpaths and allow for local discharge. The method chosen for simulating recharge must include the concept and effect of rejected recharge. A recharge method that includes rejected recharge will allow the effective recharge (or flow) to the confined aquifer to increase as water levels decline. In addition to the packages in the Model Packages section above, other MODFLOW 6 or later version packages to consider, depending on scale and flow conditions, include:

- Evapotranspiration Package,
- Evapotranspiration Segments Package,
- Riparian Evapotranspiration Package,
- River Package,
- Stream Package,
- Streamflow-Routing Package,
- Drain Return Package, and
- Reservoir Package.

It is extremely important to realistically model the effects of withdrawals on water levels in aquifers. Contractor's Project manager must consider that recharge rates may have changed over time owing to changes in land use and irrigation return flow.

Recharge can be influenced by water table fluctuation due to seasonal changes or groundwater extraction. As a result, the conceptual model and the numerical model must include the concept and effect of 'rejected recharge' (for example, see Theis, 1940, summarized in Domenico and Schwartz, 1990, p. 200-202). The groundwater model should realistically predict the effect of large cones of depression on local flowpaths (that is, capture of rejected recharge) in the aquifer. Therefore, the model should be capable of simulating changing flow patterns due to changing aquifer conditions. For example, this may be accomplished by modeling evapotranspiration and surface water/groundwater interactions. Recharge shall be incorporated into the model with an appropriate MODFLOW package (for example, the General Head Boundary package, Constant head package, or injection wells should not be used to simulate recharge. Any exceptions should be cleared with TWDB staff and the reasoning well-documented). In addition, recharge should represent the amount of water that infiltrates to the water table of an aquifer and therefore should not include runoff.

All-important rivers, streams, springs, and reservoirs must be included in the model and considered realistically, using the appropriate MODFLOW package (for example, the streamflow-routing or river package for rivers and streams and the drain package for springs,). Contractor's Project manager may use the River or Drain package for rivers and streams if they can demonstrate to TWDB GM staff that model predictions will not be affected. Like recharge, it is extremely important that rivers and streams are simulated realistically if water levels in the aquifer fall below the base of these rivers or streams (for example, they produce realistic downward fluxes of water). Discussing or implementing an approach to model or link models for surface water-groundwater interactions is encouraged if the data supports the additional complexity.

All surface water features that are essential elements of the hydrologic flow system shall be incorporated into the model, if applicable, with an appropriate MODFLOW package. For example, the General Head Boundary or Constant Head packages should not be used to simulate surface water features, with a few exceptions (such as the Gulf of Mexico).

PUMPING

Groundwater pumpage must be defined and assigned, as applicable, according to TWDB water-use categories: industrial (manufacturing), power, mining, irrigation, municipal, livestock, and rural domestic (county other). It is the Contractor's project manager's responsibility to evaluate the pumping data from the TWDB water use survey and adjust them, if necessary, so that the groundwater pumping is simulated correctly by the model. Project managers must document why and how the adjustment is made.

MODEL CALIBRATION

Calibration of the models must be both steady-state and transient. The steady-state calibration must be performed to predevelopment conditions. The mean absolute error or root mean squared error between measured hydraulic head and simulated hydraulic head must be less than 10 percent of the measured hydraulic head drop across the model area for each model layer. Any error must not be spatially biased (For example, not by areas with more control points than other areas). Final calibration results must report the mean absolute error, root mean squared error and the mean error (Anderson and Woessner, 1992, p. 238-241).

The difference between the total simulated inflow and the total simulated outflow (that is, the water balance) must be less than 1 (one) percent and ideally less than 0.1 percent for each model layer within each county. Initial parameters for the models must be derived from the data generated during the development of the conceptual models. Parameters adjusted during calibration (for example, recharge, hydraulic conductivity, and vertical hydraulic conductivity) must be within defensible limits within the framework of the conceptual model such that the resulting model has realistic values and realistic spatial distributions of parameters. Any changes to model parameters must be thoroughly documented in the final report. If unrealistic hydrologic parameters must be used to calibrate the model or the model cannot be calibrated to the above calibration criterion for matching hydraulic head or the error on the water balance, the project manager must meet with TWDB staff to discuss how to proceed with the model. TWDB will not accept over-calibrated models.

The transient model must start with the steady-state model for the first stress period and stop at the end of the most recent year with calibration data. Stress periods may be of variable length according to the density of information on pumping and recharge, but the stress periods for the transient historical calibration period must not be greater than one year. Particular attention must be paid to accurately representing water levels and fluxes during times of drought and in areas with large drawdowns. Mean absolute error or root mean squared error between measured hydraulic head and simulated hydraulic head should be less than 10 percent of the maximum hydraulic-head drop across the model area.

The range of hydraulic head fluctuations in the observation wells must be matched as closely as possible during the transient calibration. Long-term hydrographs comparing measured hydraulic head and simulated hydraulic heads must be developed and included in the report. The location of the wells used to generate the hydrographs should not be biased—spatially or vertically; however, as much as possible the wells selected should provide enough coverage to analyze the calibration of the model on a county level. A plot of the residuals and data points during and at the end of the transient calibration period must be made for each layer and included in the final report. Larger known fluxes out of the aquifer (for example, springs and base flow to streams) must also be calibrated and matched to within 10 percent of measured values if sufficient flux data are available.

The model must reproduce the general distribution of water levels and the magnitude of water-level variations in the aquifer. Cross-plots of observed and calculated water levels for all targets at all times will be constructed. Symbols will indicate which model layer or hydrostratigraphic unit each target represents. If it is difficult to see targets per layer, then individual cross-plots of observed and calculated water levels for all targets at all times per model layer will be produced. Calibration statistics will be calculated for all times in the entire model and for each hydrostratigraphic unit or model layer.

If the model does not perform well during the calibration period (in other words, if the model error is greater than 10 percent of the maximum hydraulic head drop across the study area during and at the end of the transient calibration period), the calibration and perhaps the conceptual model must be revisited to improve the fit. It is important that the performance of the model during the calibration period and the strategies employed to improve the fit, if necessary, be thoroughly documented as they offer insight into the uncertainty of predictions made by the model. It is imperative that TWDB staff have a calibrated model in MODFLOW-formatted files.

A detailed table summarizing the water budget for the entire model, outcrop and subcrop, and for the individual layers must be included in the final report. This water-budget table must include:

- Recharge to the outcrop,

- Gains or losses to rivers in the outcrop,
- Discharge to springs at the outcrop,
- Other natural discharge to the outcrop (for example, evapotranspiration),
- Flow to the confined aquifer (if applicable),
- Cross-formational flow,
- Discharge to wells, and
- Changes in storage.

The water-budget table must include budget information for the steady-state model and transient model. The Contractor's project manager must also extract the water budget per county and per groundwater conservation district for the end of the transient calibration. This information must be included in the final report.

In addition, there must be an accounting of the number of cells that go dry during a simulation (or water levels that fall below the base of the aquifer), if applicable. The Contractor's project manager must have a strategy for addressing dewatered cells during calibration simulations. If the aquifer has not historically gone dry, then the aquifer must not go dry during the calibration period. If parts of the aquifer have gone dry in the past but have subsequently re-saturated, then the Contractor's project manager must have a plan for allowing cells in the model to re-saturate or remain saturated. Other tests should be conducted to ensure there are no isolated cells or model cells which experience flooding (or water levels above land surface in a model cell which represents an aquifer outcrop) where flooding does not occur historically.

The steady-state and transient calibration models must be contained in the same model (that is, include the steady-state model as the first stress at the beginning of the transient model). Including the steady-state model as part of the transient model ensures that any changes made to the hydraulic properties during the transient calibration will propagate to the steady- state model. It is important to verify that once the steady-state and transient calibration models are combined that a sufficient number of stress periods are included to transition from little to no pumpage in the predevelopment steady state to the transient calibration model. It is also important to confirm that the steady-state model calibration remains acceptable as changes are made during the transient calibration and propagated to the steady-state model.

SENSITIVITY ANALYSIS

After the steady-state (predevelopment or pre-desalination conditions for density flow models) and transient models are calibrated, a sensitivity analysis on each major parameter in the model must be performed (see, for example, Mace and others, 2000; Anderson and Woessner, 1992, Figure 8.15). Sensitivity analysis quantifies the uncertainty of the calibrated model to the uncertainty in the estimates of aquifer parameters, stresses, and boundary conditions (Anderson and Woessner, 1992, p. 246) and is an essential step in modeling (Freeze and others, 1990). Sensitivity analysis assesses the adequacy of the model with respect to its intended purpose (ASTM, 1994) and can offer insights into the non-uniqueness of the calibrated model. Sensitivity analysis also identifies which hydrologic parameters most influence changes in water levels, flows to springs, streams, and rivers, and can identify parameters that justify additional future study.

Sensitivity analysis must be performed by globally adjusting each model parameter and assessing its impact on water levels and fluxes (for example, spring flow, base flow, and cross-formational flow). Model parameters include:

- Horizontal hydraulic conductivity,
- Vertical hydraulic conductivity,
- Confined storativity,
- Specific yield,
- Recharge,
- Pumping,
- Hydraulic head assigned at any constant head and general head boundaries,
- Conductance values for drains, rivers, general head boundaries, or any other packages for each layer,
- Hydrodynamic dispersion through dispersivity values (density flow models),
- Initial total dissolved solids values (density flow models), and
- Boundary conditions for transport models.

Model parameters must be adjusted plus or minus 10 percent and plus or minus 50 percent from calibrated values and the mean difference between the calibrated water levels and the sensitivity run water levels as well as mean normalized absolute differences between simulated and measured total dissolved solids for density dependent values at the calibration points for the adjusted parameter must be determined (for example, see Anderson and Woessner, 1992, Figure 8.15). Where appropriate, the sensitivity of the model to order-of-magnitude changes in model parameters must be conducted (for example, confined storativity).

Results of the sensitivity analysis must be presented as in the Mace and others (2000) report on the groundwater model developed for the Trinity (Hill Country) Aquifer. A similar sensitivity analysis must be done for transient simulations where the impacts of varying flow and transport parameters on water level (and water quality fluctuations in density flow models) will be demonstrated. Sensitivity analyses on different conceptual models (for example, recharge, pumping distribution, and boundary conditions) are encouraged where appropriate.

Additional sensitivity analyses to address sub-regional or local issues are encouraged (for example, a specific stream or near a water-pumping center). Sensitivity analyses on groups of parameters (such as adjusting recharge and hydraulic properties or transport properties together) are also strongly encouraged.

REFERENCES

Anderson, M. P., and Woessner, W. W., 1992, Applied groundwater modeling—Simulation of flow and advective transport: Academic Press, Inc., San Diego, 381 p.

ASTM, 1994, Standard guide for conducting a sensitivity analysis for a ground-water flow model application: American Society for Testing and Materials Standard D5611-94e1, 6 p.

Freeze, R. A., Massmann, J., Smith, L., Sperling, T., and James, B., 1990, Hydrogeological decision analysis- 1. A framework: Ground Water, v. 28, no. 5, p. 738-766.

Langevin, C.D., Hughes, J.D., Banta, E.R., Provost, A.M., Niswonger, R.G., and Panday, Sorab, 2021, MODFLOW 6 Modular Hydrologic Model version 6.2.2: U.S. Geological Survey Software Release, 30 July 2021 https://doi.org/10.5066/F76Q1VQV

Mace, R. E., Chowdhury, A. H., Anaya, R., and Way, S.-C., 2000, Groundwater availability of the Middle Trinity aquifer in the Hill Country area of Texas- Numerical simulations through 2050: Texas Water Development Board Report.

Final Draft	Final	**Numerical Model Report Checklist**
		Report deliverable:
		Received electronic version of report (word version).
		Received separate copies of figures.
		Received pdf of report/figures combined.
		Appropriate units of measure used (See GAM Standards, *Report Format and Figures*).
		Document formatting:
		12-point Arial for all text.
		Single-spaced text.
		Left justification for paragraph text.
		18-point bold for first-level headings.
		14-point bold for second-level headings.
		Page numbers are centered at the bottom of the page.
		Page setup should use one-inch margins on all four sides.
		Report Content:
		Executive Summary:
		Provide a brief summary of the model development and calibration.
		1.0 Introduction and purpose of the model:
		Describe the importance of the GM program, how the model relates to planning for groundwater resources, and provides a general outline of the modeling study and report.
		Location map of study area/related aquifer(s) within model domain
		2.0 Updates to the conceptual model
		Please refer to checklist for conceptual model for the topic and associated figures needed
		Include original block diagram (if applicable) and updated block diagram if conceptualization of flow has changed.
		3.0 Model overview and packages
		Discuss the general attributes of MODFLOW including code, processor and packages (see Numerical Model Section 1.0).
		All MODFLOW input and output packages should be included in a name file.
		Summary of all model input packages and filenames. All MODFLOW packages

		used by the model should be documented in a separate section including packages not explicitly listed below (for example horizontal flow barrier package)
		Contractor must document how the parameters are defined and if the parameters are consistent with the conceptual model. Contractor must contact TWDB first before inconsistent parameters may be used for the model construction and calibration
		Summary of model output files and filenames
		3.1 Basic package
		Maps showing the location of active/inactive cells in each of the model layers and related hydrogeologic units
		3.2 Discretization packages (temporal, TDIS and spatial, DISU)
		Table of stress periods with time interval and related year and/or month
		At least two cross-section figures (perpendicular to each other) showing the numerical layers and related hydrogeologic units
		3.3 Node-property flow and storage packages or equivalent
		Map (e.g. raster image) of each of the property values for all model layers used by the node-property flow (NPF) and storage package or other property package (e.g. LPF)
		Tables of statistical summary of all property values at model cells used by the property package and their comparison with the related field measurements and conceptual model
		If different zones are used for the same hydrogeologic unit, the summary table(s) must also reflect the zones
		3.4 Well package
		Map(s) (e.g., raster image) showing well locations and if possible extraction/injection rate per model cell for each layer for the selected stress period(s)
		Table of total pumping (i.e., groundwater extraction) per county per stress period for each layer
		Table of total injection per county per stress period for each layer, if applicable
		3.5 Drain package
		Map showing the drain locations and type of hydraulic features simulated by drains
		Summary table of drain heads and conductance values as well as associated model layer/row/column and hydraulic features

		3.6 General-head boundary package
		Map showing the general head boundary (GHB) location and type of hydraulic features simulated by the GHB
		Table of GHB head and conductance values as well as associated model layer/row/column and hydraulic features
		3.7 Recharge package
		Map(s) (e.g. raster image) of showing distribution of total recharge for the selected stress period(s). The associated model layers and hydrogeologic units that receive the recharge must be identified on the maps. In addition, different types of recharge must also be presented on separate maps.
		Table(s) of total recharge per county per stress period for each type of recharges, if applicable.
		3.8 Stream and/or river package
		Map(s) showing locations of streams or rivers in the model
		Table(s) of water level, riverbed elevation, stream flow as well as other input information for each of the streams or rivers in the model
		3.9 Evapotranspiration (ET) package
		Map(s) showing distribution of ET rates and any other pertinent information
		Table(s) showing average root depths for vegetation types
		3.10 Output control file
		Contractor can use either words or numeric codes to specify the output control file.
		The output control file must define at least head and cell-by-cell flux saved per stress period.
		If multiple time steps are used for a stress period, the last time step of the stress period should be used to save the model outputs.
		The budget files should be saved as non-compact format.
		The output control file must be consistent with the name file if numeric codes are used.
		3.11 Solver
		Type of solver
		Head change and residual convergence criteria

		The criteria must be chosen small enough to ensure the volumetric mass balance for each stress period to meet the calibration goals as described in the "Model Calibration" section.
		4.0 Model calibration and results
		This section should summarize the procedure/method used for model calibration and calibration results (see Numerical Model, *Model Calibration*). Model calibration must include both steady-state and transient conditions. Details discussed in Numerical Model, *Model Calibration* must be included.
		4.1 Calibration procedure
		Contractor must state what measured or calculated targets are used for the model calibration.
		Contractor must do a QA/QC on the targets and select the reliable ones for the model calibration
		Contractor must provide reasoning if some targets are eliminated from the calibration process
		Contractor must document calibration results separately for steady-state and transient conditions
		Contractor must describe parameters adjusted during calibration of the model (for example, recharge, hydraulic conductivity, storativity, vertical hydraulic conductivity)
		4.2 Model simulated versus measured heads
		Contractor must show that the calibration is not biased laterally and vertically, and the simulated regional groundwater flow is consistent with observed data and the conceptual model
		Map(s) showing locations of head targets per model layer
		Scatter plots of simulated hydraulic head and measured hydraulic head for all head targets with statistic summary of residuals on the plots or in separate tables
		Scatter plot of simulated hydraulic head and measured hydraulic head **per layer** with statistical summary of residuals on the plots or in separate tables
		For transient model, maps must be shown for selected stress periods showing the head residuals at head target locations per layer for selected stress periods approved by TWDB
		Histogram of the frequency of residuals in each model layer
		Hydrographs at head targets with both simulated and measured heads including a map showing locations.
		Maps showing the simulated head contours and flow directions superimposed on measured/interpolated head contours
		Maps showing the change of water levels between pre-development and the beginning of the transient and the change of water levels between pre-development and the end of the transient

		Analysis of dry and flooded cells
		4.3 Model versus measured fluxes
		Map(s) showing locations of flux targets (such as springs, seeps, etc.) per model layer
		Scatter plots of modeled versus measured flux for all flux targets with statistical summary of residuals on the plots and in separate tables
		Scatter plot of modeled versus measured flux per layer with statistical summary of residuals on the plots or in separate tables.
		Hydrographs at flux targets with both simulated and measured fluxes
		4.4 Model water budgets
		Discuss water budget by county and groundwater conservation districts (Tables should be included in Appendix A).
		Table of steady-state calibration net water budget overall and summed per aquifer layer(s)
		Figures of transient overall net water budgets by flow component and subdivided by summed aquifer layer(s)
		5.0 Sensitivity analysis
		5.1 Procedure of sensitivity
		See Numerical Model, *Sensitivity*
		5.2 Results of sensitivity analysis
		Sensitivity plots of how water levels or appropriate fluxes (for example, baseflow, springflow) are affected by changes in all aquifer parameters (see Mace and others (2000) for the format of the plot) also include additional plots, as applicable, discussed in Numerical Model, *Sensitivity*.
		Several hydrographs demonstrating the sensitivity of water-level and flux fluctuations to changes in important hydrologic properties of the model, also include additional plots, as applicable, discussed in Numerical Model, *Sensitivity*.
		6.0 Predictive Simulation(s)
		Table with desired future condition compared to the results from the new model by county, aquifer, and/or desired future condition. Must include column with modeled available groundwater. Discuss baseline and final year used in the calculation (must match current desired future condition assumptions.
		Discuss in text all assumptions used in the predictive simulation.
		7.0 Model limitations

		Discuss the limitations of the model. A general description of where and for what the model is applicable is needed as well as a discussion of how assumptions might affect model results, especially how they relate to predictions of water levels.
		8.0 Summary and conclusions
		Summarize the modeling project and its results.
		9.0 Future improvements
		Indicate where additional improvements could be made to the model. Recommendations for how these issues could be addressed will be appreciated and may result in future studies.
		10.0 Acknowledgments
		Acknowledge those organizations or specific individuals that assisted in the modeling project.
		11.0 References:
		All references cited in the report must be included in the 'References' section following TWDB format.
		APPENDIX A
		Water budgets by county and layer.
		Water budget for groundwater conservation districts
		APPENDIX B
		Tables including head target name, coordinates, well depth, modeled head, measured head, head residual, land surface elevation, and associated model layer/row/column/stress period/date
		Head hydrographs for individual head targets including measured values presented as dots and modeled values presented as line
		Tables including flux target name, coordinate (if applicable), modeled flux, measured flux, flux residual, land surface elevation (if applicable), and associated model layer/row/column/stress period/date/hydraulic feature
		Flux hydrographs for individual flux targets including measured values presented as dots and modeled values presented as line
		Other calibration results
		Figures check - photocopy all figures in black and white:
		Figures must be designed such that a black and white printout is readable and understandable;
		Maps include a north arrow and a scale;
		Each figure has a caption that includes reference sources for the basemap or the included information; and
		Figures must follow Texas Board of Geoscientists guidelines.
		Figures within margin of one-inch page margins

		Figure captions below figures
		Table captions above tables.
		Model data
		Model ESRI ArcPro geodatabase
		MODFLOW 6 (or other) ASCII format files
		ESRI GIS shapefiles of the:
		• model boundary;
		• county outlines; and
		• rivers, streams, and lakes.
		Stress period table
		Model(s) run
		Model(s) match results in report- water budget (overall and by county), statistics, hydrograph plots, contours, and residuals.
		Check:
		• Recharge
		• Rivers
		• Drains
		• Streams
		• Hydraulic Properties
		• Boundaries (GHB)
		• ET
		• Rewetting
		• Framework
		• HFB
		• Reservoir
		• Other packages
		• Other packages
		• Initial Heads
		• Targets
		• Grid Attribute Table
		• Predictive model run

ATTACHMENT 3: Geodatabase/Data Model for the Groundwater Availability Models

INTRODUCTION

To capture the various data types and information sources that go into a GAM, TWDB has developed a GAM data model. A data model is a logical construct for the storage, organization, documentation, and retrieval of digital information. The GAM data model is built upon the Environmental Systems Research Institute, Inc. (ESRI) ArcPro (or ArcGIS version 10.2 or later with pre-approval by email from the TWDB Groundwater Modeling manager) file geodatabase, optimized to manage GAM related spatial and non-spatial data. A file geodatabase is an organized collection of folders for storing geographically referenced datasets as well as tabular and image data files.

The GAM data model consists of a principal geodatabase product expected from each GAM project consisting of conceptual model source and unique derivative datasets used for the project, and the MODFLOW Feature Dataset for the final MODFLOW numerical model input data values. The geodatabase consists of natural and anthropogenic spatial features and associated time-series information, as well as any other spatial or non-spatial data used to develop the conceptual model and/or to generate numerical model grid input values. The MODFLOW Feature Dataset consists of the model grid referenced input values used for the final steady-state and transient numerical model calibration, sensitivity analysis, and predictive simulations.

The data model also contains a folder to store raster information. Rasters are to be stored in proper categories separated by the appropriate subfolders. Project manager(s) should contact the TWDB contract manager with questions about where specific rasters should be stored.

Before starting the modeling project, the project manager(s) must request copies of the most current GAM Geodatabases. which are maintained and periodically updated by TWDB. It is extremely important and a requirement that all spatially referenced source data for a GAM project be used within the GAM Geodatabase coordinate system prior to generating any derivative and/or numerical model grid input data sets. The GAM Geodatabase coordinate system uses the Albers Equal-Area projection to minimize the statewide spatial distortion of area and to maintain areal proportions true to the surface of the earth. The GAM Geodatabase projection parameters shown in Table A3-1 must be used for all GAM project related spatial data throughout the project. The GAM Geodatabase file geodatabase schemas will be provided preset with the correct GAM coordinate and projection parameters and any imported spatial data with a predefined coordinate system will be automatically projected into the GAM coordinate system during data loading.

Table A3-1. Projection parameters used for the GAM Geodatabase coordinate system. More information can be found at https://epsg.org/crs_10481/NAD83-TWDB-GM.html.

Projection:	TWDB GM (Albers Equal-Area)	
Units of Measure:	U.S. Survey Feet	
ESPG:	Horizontal: 10481	Vertical: 5703
Horizontal Datum:	NAD83	North American Datum 1983
Vertical Datum:	NAVD88	North American Vertical Datum 1988
Spheroid:	GRS80	
Longitude of Origin:	-100.00000°	100° 00’ West
Latitude of Origin:	31.25000°	31° 15’ North
Lower Standard Parallel 1:	27.50000°	27° 30’ North
Upper Standard Parallel 2:	35.00000°	35° 0’ North
False Easting:	4,921,250 (U.S. survey feet)	
False Northing:	19,685,000 (U.S. survey feet)	

DATA CONTENT AND ORGANIZATION

An enormous amount of spatial and non-spatial data will be generated by a GAM modeling study. Each contracted project manager must request from the TWDB contract manager an empty file geodatabase schema to organize and store all the source and derivative information used for the conceptual model, and/or for the MODFLOW numerical model grid input values.

ESRI ArcPro software is required to work with the TWDB GAM file geodatabases. The file geodatabase schema contains empty feature datasets ready to be loaded with project data. There is also a separate folder to store raster information. The contracted project manager or Groundwater Modeling project manager must use the geodatabase schema for organizing, processing, and archiving all GAM project data. The GAM geodatabase is extendable, but prior written approval from the TWDB Groundwater Modeling department manager must be obtained before any changes to the preset schema may be made.

The object of the Source Geodatabase is to provide all basic data and metadata used to conceptualize the model, which along with written descriptions of the derivation processes in the final project report, can be used to reproduce all the model grid referenced input values in the numerical model. A MODFLOW Geodatabase is intended to store all the input data used to run the final calibrated steady-state and transient numerical model calibration, sensitivity analysis, and predictive simulations with reference to the MODFLOW code model grid cells. Written pre-approval from the TWDB Groundwater Modeling department manager is required if for any reason the source or derivative data is not compatible with the geodatabase schema.

SOURCE GEODATABASE SCHEMA

Source and unique derivative information must be organized in the GAM Source Geodatabase. Source information is defined as original information collected and used to develop the final conceptual model of the aquifer system and to develop the gridded values used for the calibrated steady state and transient numerical models. Depending on the aquifer and methodologies used, we recognize that source and derivative data will be different for each project. Therefore, TWDB staff will review final contracts to identify the appropriate source and derivative data needed for the GAM Source Geodatabase to reproduce critical numerical model input values. Vector spatial data must be contained in feature classes that are organized into feature datasets. Each feature dataset contains thematically related point, line, and polygon feature classes. Non-spatial tabular data must be stored as .csv files within the Tables folder in the GAM Data Model. The Tables folder must include a README file specifying what is contained in each table. Raster data (such as interpolated or gridded surfaces; digital elevation models; satellite or other airborne imagery; and digitally scanned and georeferenced map graphics, logs, and cross- sections) must be stored in the Raster data folder, categorized by the empty subfolders, in either .tif or .nc format.

MODEL GRID FEATURE DATASET

A model grid feature dataset must be located within the Source Geodatabase Boundary Feature Class and consist of a vector polygon feature class of model grid cells and a point feature class of model grid cell nodes. The polygon feature class must consist of a rectangular grid structure of polygons representing a finite difference model grid with cells no larger than 1 mile by 1 mile. The point features must be centered on each of the polygon grid cells.

For structured grids a unique Cell_ID or relationship/index key consisting of a nine-digit integer data type and based on the layer, row, and column must be used to link the polygon and point feature classes with any parameter values and time series variables. For example, a Cell_ID value of 2004025 would refer to the grid-cell or grid-cell node for layer 2, row 4, and column 25. Consequently, the maximum model grid dimensions for GAM projects are limited to the following:

- Layers: 9
- Rows: 999
- Columns: 999

For unstructured MODFLOW-USG or MODFLOW 6 grids, the CELL_ID may not be unique and will refer to the Cell-ID for the parent grid. Each parent cell may have multiple grid nodes. A Hydrostratigraphy field should also be included specifying the hydro-unit the cell represents. Metadata explaining what each IBOUND value represents must also exist for the model grid. For unstructured grids a unique node field should also be included and it must be sequential.

MODFLOW GEODATABASE SCHEMA

The GAM MODFLOW geodatabase consists of a polygon feature class of model grid cells, a point feature class of model grid cell nodes, and tables/object classes for the final calibrated MODFLOW 6 or later version of MODFLOW input values and for time-series variables linked with relationship classes.

DATA QUALITY ASSURANCE AND CONTROL

Basic data quality assurance tactics are listed here and should be the minimum performed to find gross typos, errors, illogical geologic features, and inconsistencies in the geospatial data for the study.

- A project snap grid raster should be developed for each project using the GAM Geodatabase coordinate system, Albers Equal-Area projection described above. Each GIS raster file developed for a project should be snapped to this grid to ensure every grid cell in all rasters stack on top of each other without any offset.
- Check the extents of spatial datasets against your snap grid for incorrectly plotted data. A negative sign may be left off an XY coordinate resulting in location errors.
- Interpolated values in a raster dataset need to reflect the source point data used in the interpolation process.
- Raster surfaces for stratigraphic tops and/or bottoms should only have cell values within the horizontal extent of the formation they are representing. For example, there should not be raster values for a formation updip of its outcrop.
- Check stratigraphic tops and/or bottom raster surfaces for negative thicknesses.
- Visually scan interpolated raster surfaces for anomalies. If something looks strange but is valid, please discuss it in the report.
- The accumulative thickness of a lithology raster, such as net sands, cannot be greater than the stratigraphic raster for the formation of interest.
- Document the sources, processing steps, interpolation methods, and field definitions for geospatial data in the metadata.

DATA DOCUMENTATION

All datasets used for GAM projects must include metadata that documents the content, data structure, descriptions of table fields, units of measure for numerical data, categorical definitions for nominal data, data source(s), date(s), quality, and other characteristics of the data within the geodatabases. The TWDB-provided schemas include some basic metadata, which must be extended by the contracted project manager to completely document all source and derivative data.

Metadata must be created using the Federal Geographic Data Committee (FGDC) metadata editor within ESRI's ArcCatalog. If the source data was obtained without FGDC compliant metadata, the project manager must create the metadata within the ArcCatalog using ESRI ISO metadata standards. The contracted project manager must be responsible for ensuring that all data is accurately documented and in compliance with the Federal Geographic Data Committee 's Content Standard for Digital Geospatial Metadata, Version 2 (FGDC-STD-001-1998) or later.

REFERENCES

Federal Geographic Data Committee: https://www.fgdc.gov/metadata/csdgm/

Langevin, C.D., Hughes, J.D., Banta, E.R., Provost, A.M., Niswonger, R.G., and Panday, Sorab, 2021, MODFLOW 6 Modular Hydrologic Model version 6.2.2: U.S. Geological Survey Software Release, 30 July 2021 https://doi.org/10.5066/F76Q1VQV

ATTACHMENT 4: Guidelines for Authors Submitting Contract Reports to the Texas Water Development Board

INTRODUCTION

The purpose of this document is to describe the required format of contract reports submitted to the Texas Water Development Board (TWDB). Our reason for standardizing the format of contract reports is to provide our customers a consistent, and therefore familiar, format for contract reports (which we post online for public access). Another reason for standardizing the format is so that we can more easily turn a contract report into a TWDB numbered report if we so choose. Remember that your report will not only be seen by TWDB staff, but also by any person interested in the results of your study. A professional and high-quality report will reflect well on you, your company, and TWDB.

Available upon request, we will provide a Microsoft Word template (used to write these instructions) that gives the fonts, spacing, and other specifications for the headings and text of the report. Please follow this template as closely as possible.

FORMATTING YOUR REPORT

The TWDB format is designed for simplicity. For example, we use Arial for all text. We use 12-point, single-spaced text, left justification for paragraph text, 18-point bold for first- level headings, and 14-point bold for second-level headings. Page numbers are centered at the bottom of the page. Other than page numbers, please refrain from adding content to the document header or footer. Page setup should use one-inch margins on all four sides.

TEXT

The best way to format your document is to use the styles described and embedded in the template document (Authors_Template.dot) that is available on request from TWDB. To use the Authors_Template.dot file, open it in Word (make sure *.dot is listed under Files of type) and save it as a .doc file. Advanced users can add the .dot file to their computers as a template.

Make sure the formatting bar is on the desktop (to open, go to View□Toolbars□Formatting) or, to view all of the formatting at once, go to Format□Styles and Formatting and select Available Styles from the dropdown box at the bottom of the window. The formatting in the template document provides styles (such as font type, spacing, and indents) for each piece of your report. Each style is named to describe what it should be used for (for example, style names include Chapter Title, Body Text, Heading 1, References, and Figure or Table Caption). As you add to your report, use the dropdown list on the Formatting Toolbar or the list in the Styles and Formatting window to adjust the text to the correct style. The Authors_Template.dot file shows and lists the specifications for each style.

No acronyms must be used except for Texas Water Development Board (TWDB) after it is introduced in the text or the abbreviations for model files. Any references to aquifers in Texas must use the nomenclature used by TWDB. The TWDB logo or state seal must not be used without prior approval by TWDB.

TITLE

Give your report a title that gives the reader an idea of the topic of your report but is not terribly long. In addition to the general subject (for example, "Droughts"), you may include a few additional words to describe a place, methodology, or other detail focused on throughout the paper (for example, "Droughts in the High Plains of Texas" or "Evaluating the effects of drought using groundwater flow modeling"). Please capitalize only the first letter of the first word in the title and each proper noun. Never use all caps.

The title page must include the title of the report and TWDB contract number. Each report must have an authorship list of persons responsible for the studies; firm or agency names as authors are not acceptable. Final approved reports must follow Texas Board of Geoscientists guidelines (see www.tbpg.state.tx.us/) and must be sealed by either a Professional Engineer or Professional Geoscientist, as applicable.

Use headings to help the reader follow you through the main sections of your report and to make it easier for readers to skim through your report to find sections that might be the most interesting or useful to them. The text of the report should include an executive summary. Headings for up to five levels of subdivision are provided in the template; however, we suggest not using more than three or four levels of subdivision except where absolutely necessary. Please avoid stacked headings (for example, a Heading 1 followed immediately by a Heading 2) and capitalize only the first letter of headings or words where appropriate—never use all caps.

FIGURES AND PHOTOGRAPHS

To publish professional-looking graphics, **we need all originals to be saved at 300 dots- per-inch** (dpi) and in grayscale, if possible, or in the CMYK color format if color is necessary. Preferred file formats for your original graphics are Adobe Illustrator (.ai), Photoshop (.psd), EPS with .tiff preview, .jpg, .png, or .tiff files. Refrain from using low resolution .jpg or .gif files. Internet images at 72 dpi are unacceptable for use in reports.

All graphics must be submitted in two forms:

1. Inserted into the Microsoft Word document before you submit your report. Ideally, inserted graphics should be centered on the page. Format the picture to downsize to 6 inches wide if necessary. Please do not upsize a graphic in Word.
2. Saved in one of the formats listed above.

OTHER GRAPHICS SPECIFICATIONS

It is easiest to design your figures separately and add them in after the text of your report is more or less complete. Graphics should remain within the 1-inch page margins of the template (6.5 inches maximum graphic width). Be sure that the graphics (as well as tables) are numbered in the same order that they are mentioned in the text. Figures should appear embedded in the report after being called out in the text. Also, remember to include a caption for each graphic in Word, not as part of the graphic. We are not able to edit or format figure captions that are part of the figure. For figures and photographs, the caption should appear below the graphic. For tables, the caption should appear above.

CREATING PUBLICATION-QUALITY GRAPHICS

When designing a graphic, make sure that the graphic (1) emphasizes the important information and does not show unnecessary data, lines, or labels; (2) includes the needed support material for the reader to understand what you are showing; and (3) is readable (see Figures 1 and 2 for examples). Edward R. Tufte's books on presenting information (Tufte, 1983; 1990; 1997) are great references on good graphic design. Figures 1 through 3 are examples of properly formatted, easy to understand graphics. Do not include fonts that are less than 6 points.

For good-looking graphics, the resolution needs to be high enough to provide a clear image at the size you make them within the report. In general, 300 dpi will make a clear image— 200 dpi is a minimum. Try to create your figures at the same size they will be in the report, as resizing them in Word greatly reduces image quality. Photographs taken with at least a two-megapixel camera (if using digital) and with good contrast will make the best images. Save the original, and then adjust color levels and size in a renamed image copy. Print a draft copy of your report to double-check that your figures and photographs have clear lines and show all the features that you want them to have.

Also remember that your report may be photocopied, scanned, or downloaded and printed in black and white. For this reason, you should use symbols or patterns, or make sure that colors print as different shades in black and white. All interval or ratio data (data measuring continuous phenomena, with each color representing an equal interval) need to be displayed in a graded scale of a single color (Figure 3). This way your figures will be useful even as a photocopy.

If you need additional guidance or have questions, please contact the TWDB contract manager.

USING OTHER PEOPLE'S GRAPHICS

Figures and photographs (and tables) need to be your own unless you have written permission from the publisher that allows us to reprint them (we will need a copy of this permission for our records). Avoid using any figures or photographs taken off the Internet or from newspapers or magazines—these sources are difficult to cite, and it is often time- consuming and expensive to gain permission to reproduce them.

TABLES

Tables should be created in Microsoft Word (see Table 1). Tables should include a minimal amount of outlining or bold font to emphasize headings, totals, or other important points. Tables should be numbered separately from figures, and captions should appear above the text of the table.

Table 1. A sample table. Note caption above table.

Table Text	1940	1950	1960	1970	1980	1990	2000	%GW
Table Text	15	441	340	926	196	522	83	97.4
Table Text	64	944	626	373	356	171	516	99.99
TOTAL	79	1385	966	1099	552	693	599	

* A footnote should look like this using 10-point Arial.
%GW = percent groundwater

Be sure to describe any abbreviations or symbols, and, unlike in this table, be sure to note the units!

UNITS

Measurements should be in English units. Metric units may be included in parentheses after the English units. All units of geologic time should conform to the most recent geologic timescale (Gradstein and others, 2004). A summary of this timescale is available from the International Commission on Stratigraphy's website at https://stratigraphy.org.

CITATIONS AND REFERENCES

It is important to give credit where credit is due. Therefore, be sure to use the appropriate citations and include references in your paper.

IN-TEXT CITATIONS

Each piece of information you use in your report that comes from an outside source must be cited within the text using the author's last name and the year of publication. If there are two authors, list the last name of each followed by the year, and if there are more than two authors, list the last name of the first author followed by "and others" and the year. For example: the end of the Jurassic

Period occurred approximately 145.5 million years ago (Gradstein and others, 2004).

REFERENCES

All sources that are cited within the report should be listed at the end of the paper under the heading References. The references should follow the guidelines in "Suggestions to Authors of the Reports of the United States Geological Survey" (Hansen, 1991). These are available online at https://pubs.usgs.gov/unnumbered/7000088/. Several examples of complete reference citations are listed at the end of these guidelines. Be sure that any citations that appear in tables or figures are included in the reference list. Also, before submitting the report, please check that all the citations in the report are included in the reference list and all references in the reference list are cited in the report. If at all possible, avoid web-based citations. These materials are often transient and therefore useless to future readers.

SUBMITTING YOUR REPORT

Before you submit your report, proofread it. Look for spelling and grammatical errors. Also, check to see that you have structured the headings, paragraphs, and sentences in your paper so that it is easy to follow and understand (imagine you are a reader who does not already know the information you are presenting!).

CONCLUSIONS

Following the instructions above and providing accurate and readable text, tables, figures, and citations will help to make your report useful to readers. Scientists may read your report, as well as water planners, utility providers, and interested citizens. If your report successfully conveys accurate scientific information and explanations to these readers, we can help to create more informed decisions about the use, development, and management of water in the state.

ACKNOWLEDGEMENTS

Be sure to acknowledge the people and entities that assisted you in your study and report. For example:

We would like to thank the Keck Geology Consortium, the American Society of Civil Engineers, and the Texas Bar CLE for providing examples to use in developing these guidelines. In addition, we appreciate Mike Parcher for providing information on how to create publication-quality graphics, Shirley Wade for creating the data used in sample Figure 1, and Ian Jones for providing sample Figure 3.

EXAMPLES OF REFERENCES

Arroyo, J. A., and Mullican, III, W. F., 2004, Desalination: *in* Mace, R. E., Angle, E. S., and Mullican, W. F., III, editors, Aquifers of the Edwards Plateau: Texas Water Development Board Report 360, p. 293-302.

Bates, R. L., and Jackson, J. A., 1984, Dictionary of geological terms: Anchor Press/Doubleday, Garden City, New York, 571 p.

Blandford, T. N., Blazer, D. J., Calhoun, K. C., Dutton, A. R., Naing, T., Reedy, R. C., and Scanlon,

B. R., 2003, Groundwater availability of the southern Ogallala aquifer in Texas and New Mexico–Numerical simulations through 2050: contract report by Daniel B. Stephens and Associates, Inc., and the Bureau of Economic Geology, The University of Texas at Austin to the Texas Water Development Board, variably paginated.

Fenneman, N. M., 1931, Physiography of Western United States (1st edition): New York, McGraw-Hill, 534 p.

Hubert, M., 1999, Senate Bill 1–The first big bold step toward meeting Texas's future water needs: Texas Tech Law Review, v. 30, no. 1, p. 53-70.

Kunianski, E. L., 1989, Precipitation, streamflow, and baseflow in West-Central Texas, December 1974 through March 1977: U. S. Geological Survey Water-Resources Investigations Report 89-4208, 2 sheets.

Mace, R. E., Chowdhury, A. H., Anaya, R., and Way, S.-C., 2000, A numerical groundwater flow model of the Upper and Middle Trinity aquifer, Hill Country area: Texas Water Development Board Open File Report 00-02, 62 p.

Maclay, R. W., and Land, L. F., 1988, Simulation of flow in the Edwards aquifer, San Antonio Region, Texas, and refinements of storage and flow concepts: U. S. Geological Survey Water-Supply Paper 2336, 48 p.

TWDB, 2015, Groundwater Database Well data, accessed July, 2015.

U.S. Geological Survey, 2014, National Elevation Dataset (NED), http://www.usgs.gov/pubprod/, accessed April 2014.

For more examples of references, see p. 239-241 of “Suggestions to Authors of the Reports of the United States Geological Survey” at https://pubs.usgs.gov/unnumbered/7000088/.

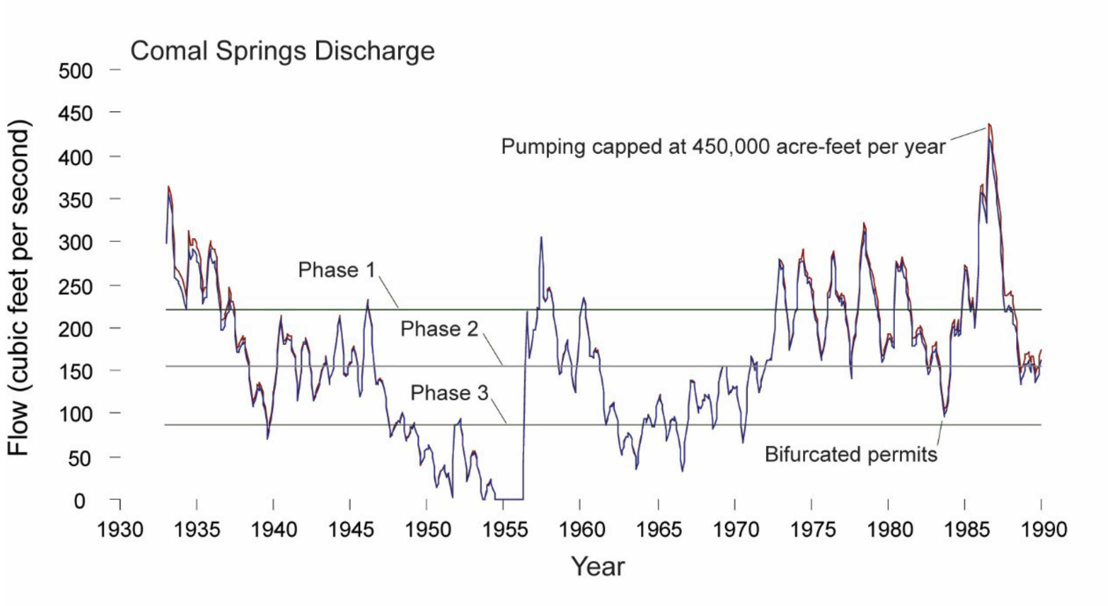

Figure 1. **A sample figure showing only the information needed to help the reader understand the data. Font size for figure callouts or labels should never be less than 6 point.**

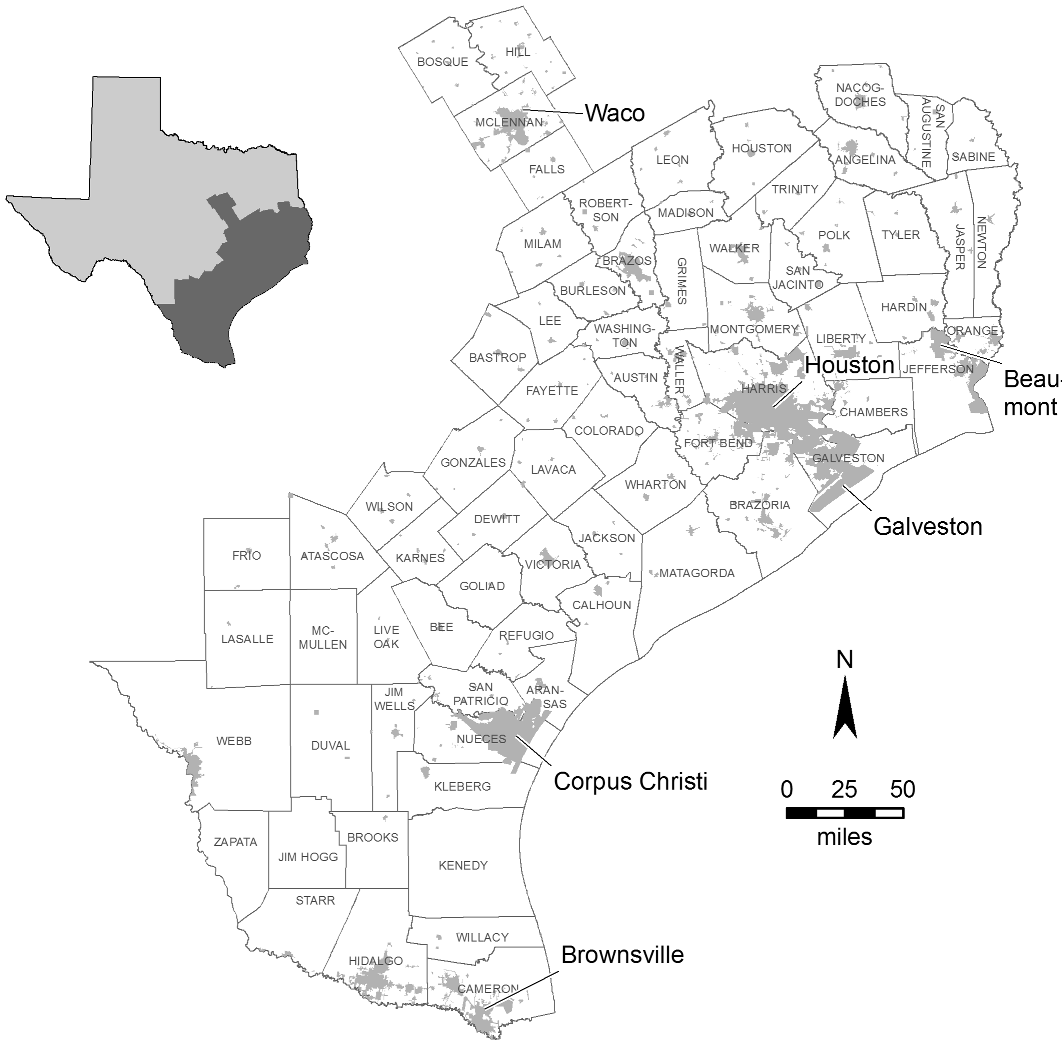

Figure 2. **A sample subject area map, giving the reader enough information to understand the location being discussed in this conference. For map figures, be sure to include a north arrow to orient the reader, a scale, and, if needed, a submap that places the figure in greater geographic context. Be sure that text is readable and that any citations listed on the figure or in the figure caption are included in the reference list. Font size should never be less than 6 point.**

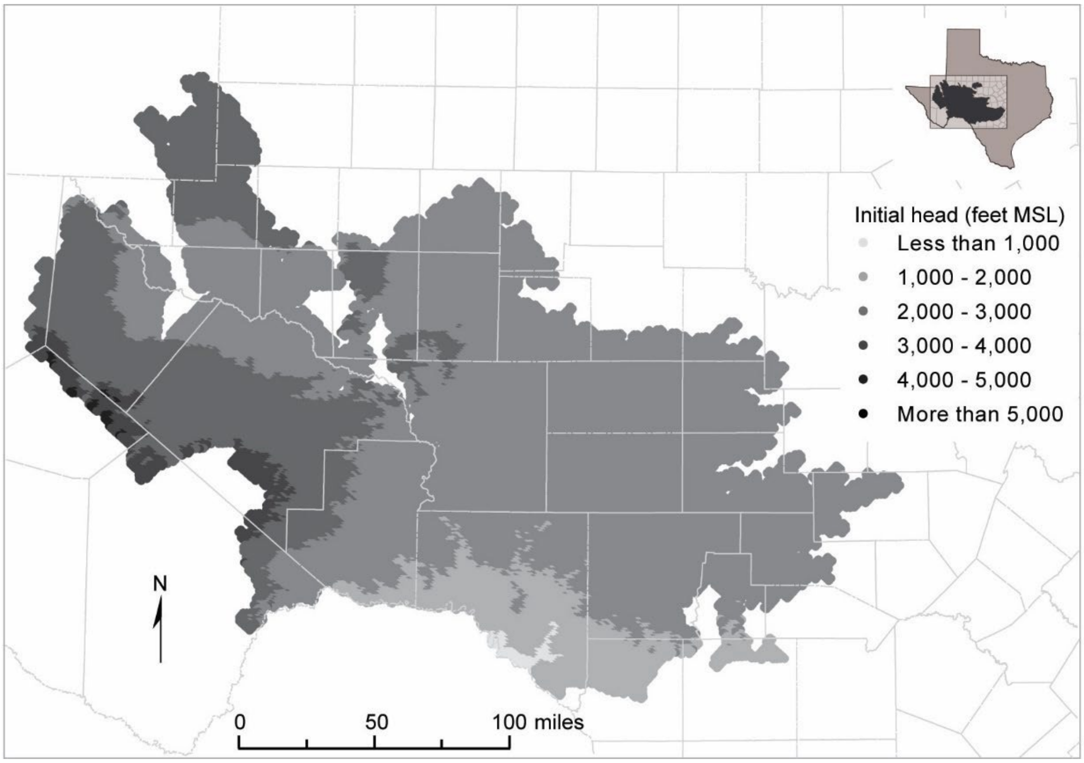

Figure 3. Initial hydraulic heads used in model simulations for layer 1. Note the use of grayscale shading to show differences.

ATTACHMENT 5: BRACS database

Please see http://www.twdb.texas.gov/innovativewater/bracs/database.asp for latest data dictionary and to download the database.

Introduction

The purpose of this document is to describe the required format and organization of well data submitted to the Texas Water Development Board (TWDB) Brackish Resources Aquifer Characterization System (BRACS) database. Using these standards will assist in the transmission, review, archival, and future use of the well data provided.

Organizing Source Well Control Information

Diligent data management is key to maintain control, organization, and usefulness of information as complicated as the multiple relationships between wells, various names for the same well, location information, well construction, logging, and analysis of the logs.

Basic Requirements

All data and information provided to TWDB must be non-confidential since it will be posted for public consumption. All well attributes should be added to the BRACS Database. All well reports, geophysical well logs, and other well information used in a project shall be provided to TWDB. Digital formats include:

- well reports, PDF
- Geophysical well logs, TIFF and LAS (if available)
- Depth registration (calibration) files (acceptable formats: xml, lic, dra).

Data storage folder structure

All well reports and geophysical well logs must be filed using this folder structure:

- Water well and supporting data will be filed in a folder named DrillerWellLogs with subfolders named by state_county codes.
- Geophysical well logs will be filed in a folder named GeophysicalWellLogs with subfolders named by state_county codes.
- State_County code: example 42_029 for Bexar County. TWDB can provide a Microsoft Excel spreadsheet with the state and county codes.

Digital file names

Q-logs from the Railroad Commission of Texas Groundwater Advisory Unit:

- Example: Q123_029.tif. If there are multiple logs per well, add log1, log2, … to file name as a suffix. If more than one well is assigned the same Q number, add letters a, b, c, … to Q number, example Q123a_029.tif, Q123b_029.tif.

All other well control must have the State and County code prefix added to the filename (Example: 42029_123456.pdf. The digital file name, file type, and folder name will be recorded in the BRACS Database table tblGeophysicalLog_Header or tblBracsWaterWellReports.

Duplicate wells

The database is designed to hold one record per well. Duplicate wells should be avoided, and every attempt should be made to ensure that this does not occur. Well name and number attributes should be added to the table tblForeignKey that will support identification of duplicate wells.

Purchasing well logs

All well data purchased for a project should be documented in an Excel spreadsheet that will include:

- the BRACS Well ID for the well record,
- API number of the well (if available),
- well number,
- raster image filename,
- depth calibration filename,
- number and type of log curves digitized (for LAS files), and
- unit cost per log.

The spreadsheet will be submitted to TWDB with a folder containing the log files so TWDB can determine: (1) if all of the logs have been submitted, (2) the quality of the logs, (3) potential duplication of logs, and (4) the cost of the logs for invoice evaluation.

Contractor will not be reimbursed for a log if the log already exists in the BRACS Database or was provided to the contractor from the TWDB unprocessed log collection except under the following circumstances: a better quality log is submitted; a more complete log is submitted; a log with different tool suites is submitted; a LAS file is submitted where one did not exist in the BRACS Database; a depth calibration file for the log is submitted where one did not exist in the BRACS Database.

Contractor will not be reimbursed for a log if it is illegible or missing key components such as tool scales or log header data. Exceptions may be made for logs from key wells used for stratigraphic interpretation.

The BRACS Database

The BRACS database is a Microsoft Access database developed and evolved to manage well data since 2009 and is publicly available for download from the TWDB website.

Basic Requirements

All new well control will be added to a copy of the BRACS Database. If the contractor would prefer to provide each of the tables in Microsoft Excel as opposed to Microsoft Access, please contact TWDB staff.

New data tied to existing well control in the BRACS Database, such as geology records (lithology; stratigraphic picks; porosity calculations; salinity zones) will have applicable

tables updated.
Download the latest version of the BRACS Database and data dictionary for well control using this web address: http://www.twdb.texas.gov/groundwater/bracs/database.asp.

Use Brackish Resources Aquifer Characterization System Database Data Dictionary (TWDB Open File Report 12-02, Third Edition, April, 2017) to understand table relationships, field names, and data types.

New well control provided by a contractor will begin with a specified well _id. Coordinate with TWDB BRACS staff for this starting well_id number. As a contractor appends new well control to their copy of the BRACS Database, TWDB staff will continue to update the official BRACS Database. When the project is complete, TWDB staff will take all new project well control records and append them to the official BRACS Database.

If the Contractor has any database questions, please contact TWDB staff prior to investing a large amount of time on a task. It is better for all parties to complete the task correctly the first time.

Well identification names and numbers

New well control added to the BRACS Database will have all well identification names or numbers added to the BRACS Database table tblBRACS_ForeignKey.

The BRACS Database table tblLkFK_ID_Name is a list types of foreign keys. This table is updated constantly as new sources of data are encountered. Consult with TWDB staff if this table needs updating during a project.

Wells used in a project cross section will have a record added to the BRACS Database table tblBRACS_ForeignKey using a very specific format. See this table for formatting.

Well Location

Latitude and longitude in decimal degree format will be used for each well. NAD 83 horizontal datum will be used for each well. Elevations using 30 meter DEM will be used. Location attributes will be recorded in the BRACS Database table tblWell_Location.

Geophysical well log data

All new geophysical well log data used for a project will be provided to TWDB as a deliverable. Paper documents will be scanned in TIFF format and filed in the appropriate state_county code folder in the GeophysicalWellLogs folder. Well control will be added to the BRACS Database, the digital file name and additional attributes will be added to the table tblGeophysicalLog_Header, and log tools will be added to the table tblGeophysicalLog_Suite.

Depth calibration files will be submitted to TWDB. LAS files for logs will be submitted to TWDB.

Digital geophysical well logs should be legible and scanned in at least 300 dots per inch or greater. If the original paper document was in color, the scanning must be in color. If the original was in poor condition and the scanned image is the best available, note this in the table tblGeophysicalWellLog_Header, field [remarks].

Geologic formation lithology and stratigraphy

Geologic formation lithology and stratigraphic top/bottom depth values will be appended to the table tblWell_Geology.

Geologic formation lithology from driller well reports is converted to a simplified lithology using the BRACS Database table tblLkLithologicName_to_SimplifiedLithologicName. This table is updated constantly as new terms are encountered.

Interpretation of sand/clay from geophysical well logs will use either a two tier (sand, clay) or a four-tier classification system consisting of the following terms and sand percentages:

- sand (100 percent sand)
- sand with clay (65 percent sand)
- clay with sand (35 percent sand)
- clay (0 percent sand)

Lithology interpreted from geophysical well logs will begin approximately 100 feet shallower than the top of the geological formation of interest and end approximately 100 feet deeper than the base of the geological formation of interest. No gaps in lithology will be permitted unless the geophysical well log includes a gap in tool coverage; in this situation, label the depth range as “no record” and list the reason in the remarks field.

Lithologic interpretation is not possible in the cased portion of a well with no geophysical tool curves. The portion of the cased hole should be labeled “no record” with the top and bottom depths recorded.

Stratigraphic interpretation is not possible in the cased portion of a well with no geophysical tool curves. For example, if the top of the geological formation is within the cased portion, do not provide a top depth value for the geological formation. Exceptions to this may be made where stratigraphic interpretations are made from Gamma Ray curves with significant character in cased sections of a well.

Stratigraphic interpretation is not possible below the bottom depth of a well. For example, when the logging terminates at bottom depth of the well above the geological formation bottom, do not provide a bottom depth value for the geological formation.

Lithologic and stratigraphic data provided for a well implies the data originated from the well, for example formation descriptions from the well driller or interpretations made from geophysical well logs. Do not back-calculate lithologic or stratigraphic data to wells from other sources. If this must be done, provide this information in a separate table of similar design to the table tblWell_Geology and indicate the exact source of the information, methods used, assumptions made, and reasons why this method was used to back-calculate the data. Examples include existing cross-sections or geological formation surfaces prepared from other studies.

If stratigraphic or lithologic values must be created based on best professional judgement to aid in the interpolation process, create a separate table and shapefile. This will prevent them from being mistaken as log interpretations.

Porosity values can have significant impacts on water quality calculations from geophysical well logs and volume calculations. These data can be difficult to locate. A thorough literature review and log search is required. Contact TWDB staff for literature suggestions or if tables in the BRACS database to assist in porosity calculations from geophysical well logs are desired.

Water quality data

All water quality data that is not in the TWDB Groundwater Database will be provided to TWDB as a deliverable. Paper documents will be scanned in pdf format and filed in the appropriate state and county folder in the DrillerWellLogs folder. Water quality well control will be added to the BRACS Database, and a digital file name for the pdf well documents will be added to the table tblBracsWaterWellReports.

Water quality data will be evaluated to ensure that samples are accurately assigned to the correct aquifer and/or geologic formation in a systematic and reproducible technique. The BRACS team refers to this as “Aquifer Determination”.

Water quality data, if not from the TWDB Groundwater Database, will be appended to tables tblBRACSWaterQuality and tlbBRACSInfrequentConstituents in the BRACS Database.

Interpreting total dissolved solids from geophysical well logs

There will be a dearth of measured water quality samples in various regions of the aquifer. Water quality can be interpreted from geophysical well logs and recorded in the BRACS database to fill some of these gaps.

The methods (computational, empirical) used to interpret total dissolved solids concentration from geophysical well logs will be fully documented in the technical report. All well records, input and output values, correction factors, and assumptions will be recorded in the BRACS Database. Links to water quality samples for specific depth zones within an aquifer will be provided with the geophysical well log record. If a new technique (or modification of an existing technique) is used, tables will be designed to link to the existing BRACS Database design to store the above mentioned parameters. A data dictionary description will be provided for the new table design. All geophysical well logs, if not in the BRACS Database, will be provided to TWDB.

A number of geophysical well log interpretation techniques are described in:

Estepp, J.D., 1998, Evaluation of ground-water quality using geophysical logs: Texas Natural Resource Conservation Commission, unpublished report, 516 p.

Groundwater salinity classification

Groundwater salinity classification	Salinity zone code	Total dissolved solids concentration (units: milligrams per liter)
Fresh	FR	0 to 1,000
Slightly saline	SS	1,000 to 3,000
Moderately saline	MS	3,000 to 10,000
Very saline	VS	10,000 to 35,000
Brine	BR	Greater than 35,000

- Use classification by:
  Winslow, A.G., and Kister, L.R., 1956, Saline-Water Resources of Texas, U. S. Geological Survey Water Supply Paper 1365, 105 p.
- The salinity zone code will be used for GIS file naming.
- Technical report figures showing salinity zones or well control showing total dissolved solids concentration will use these colors.
- Brackish groundwater is considered slightly and moderately saline (total dissolved solids concentration 1,000 to 10,000 milligrams per liter).