TO: Board Members

THROUGH: Bill Mullican, Deputy Executive Administrator, Office of Planning
Robert Mace, Division Director, Groundwater Resources Division

FROM: Cindy Ridgeway, Team Leader, Groundwater Availability Modeling Section
Phyllis Thomas, Team Leader, Agency Contract Administrator

DATE: June 18, 2007

SUBJECT: Consider authorizing staff to publish a Request for Statements of Qualifications for a total amount not to exceed $1,050,000 for groundwater availability modeling projects.

ACTION REQUESTED

Authorize the Executive Administrator to publish in the Texas Register a Request for Statements of Qualifications to be considered by the Texas Water Development Board (TWDB) for funding of research grants for groundwater availability modeling-related projects in a total amount not to exceed $1,050,000. These groundwater availability modeling projects will involve (1) developing structure for the Capitan Reef Complex Aquifer, (2) revisiting and developing structure for the Gulf Coast Aquifer from the Brazos River to the Rio Grande, (3) developing and documenting a groundwater availability model for the Yegua-Jackson Aquifer, and (4) developing a groundwater availability model using a refined mesh for the portion of the Seymour Aquifer that overlies Haskell and Knox counties.

BACKGROUND

In 2001, the Texas Legislature mandated that the Texas Water Development Board (TWDB) obtain or develop groundwater availability models for all major and minor aquifers in Texas in coordination with groundwater conservation districts and regional water planning groups (Texas Water Code, Section 16.012).

To date, we have developed or obtained groundwater availability models for the 9 major aquifers and for 7 of the 21 minor aquifers, not including a model for part of one minor aquifer.

We currently have seven contracts in progress:

1. add the Edwards-Trinity (High Plains) Aquifer to the model of the southern part of the Ogallala Aquifer;
2. develop a groundwater availability model for the Dockum Aquifer;
3. develop a groundwater availability model for the Nacatoch Aquifer;
4. develop a groundwater availability model for the remaining portions of the West Texas Bolsons Aquifers (Red Light, Green River, and Eagle Flat bolsons);
5. develop structure for the Yegua-Jackson Aquifer;
6. develop structure for the Llano Uplift Aquifers; and
7. develop structure for the Brazos River Alluvium Aquifer.

Several of these studies are to develop structure for the aquifers. The structure describes the top and bottom elevations and lateral extent of the aquifer or sub-aquifers. These elevations are required by the models and let users know where the aquifer is below the ground surface. Structure studies generally involve looking at well and geophysical logs, considering faulting, and then mapping the surfaces in a geographical information system.

Internally, we are currently working to develop models for the Blossom Aquifer and the Presidio-Redford Bolson portion of the West Texas Bolsons Aquifer. We are also expecting a model to be submitted by El Paso Water Utilities to the TWDB for consideration as a groundwater availability model for the Bone Spring-Victorio Peak Aquifer.

The remaining minor aquifers yet to be modeled include (see Attachment D):

1. the Yegua-Jackson Aquifer;
2. the Ellenburger-San Saba, Hickory, and Marble Falls Aquifers (Llano Uplift Aquifers);
3. the Brazos River Alluvium Aquifer;
4. the Capitan Reef Aquifer;
5. the Rustler Aquifer; and
6. the Marathon Aquifer.

<u>KEY ISSUES</u>

Unlike the groundwater availability models for the major aquifers, the legislature did not specify a due date for the minor aquifers. Nonetheless, staff plan to complete the models for the minor aquifers before the end of 2011 so that the models will be finished before the release of the 2012 State Water Plan.

This completion date allows us to use some of our budget to begin revising and improving existing groundwater availability models. Once a groundwater availability model is completed, it is important to be able to revisit the models to incorporate new information or understanding of the aquifers. New hydrogeologic studies are being completed routinely by municipalities, groundwater conservation districts, river authorities, universities, state agencies (including the TWDB), private companies, and others.

We are proposing four projects that would require funding from fiscal years 2008 and 2009 for a total cost of $1,050,000 (see Table 1). These projects include:

1. developing a groundwater availability model for the Yegua-Jackson Aquifer,
2. developing a refined groundwater availability model for the Seymour Aquifer in the Haskell County and Knox County area,
3. developing structure for the Capitan Reef Complex Aquifer, and
4. developing structure for the Gulf Coast Aquifer from the Brazos River to the Rio Grande.

The groundwater availability model for the Yegua-Jackson Aquifer will use the structure being developed as part of a current contract. The refined groundwater availability model for the Seymour Aquifer in the Haskell County and Knox County area will involve extracting the “island” of the aquifer from the current groundwater availability model for the Seymour Aquifer and refining the grid to better simulate seasonal water level changes. Structure for the Capitan Reef Complex Aquifer is needed before a model can be developed for the aquifer. The project to develop structure for the Gulf Coast Aquifer is part of a long term plan to update the models for the central and southern parts of the Gulf Coast Aquifer. Recent studies in support of the LCRA-SAWS Water Project connected offshore geologic information related to oil and gas exploration to onshore geologic information, resulting in a more defensible interpretation of structure in the aquifer. This project would extend that work south to the Rio Grande in preparation for future modeling work.

TABLE 1. Proposed budgets for GAM-related projects for fiscal years 2008-2009.

Projects in support of GAM program	***FY 2008**	***FY 2009**	**Total**
Structure for the Capitan Reef Complex Aquifer	150,000	0	150,000
Structure for half of the Gulf Coast Aquifer	150,000	150,000	300,000
Develop groundwater availability model for Yegua-Jackson Aquifer	200,000	200,000	400,000
Develop a refined groundwater availability model for the Seymour Aquifer in the Haskell County and Knox County area	180,000	20,000	200,000
Total	**$680,000**	**$370,000**	**$1,050,000**

*FY - Fiscal Year

The annual budget for contracts related to the groundwater availability modeling program is $870,000 per fiscal year for the 2008 to 2009 biennium. This leaves $190,000 unallocated for fiscal year 2008 and $500,000 unallocated for fiscal year 2009. A separate Board item concerning matching funds to improve existing models item will address plans for the unallocated money in fiscal year 2008. Staff plan to return to the Board next year to request permission to publish a request for statements of qualifications to begin developing models for the Capitan Reef Complex, Rustler, and Brazos River Alluvium that will allocate the remaining $500,000 for fiscal year 2009.

Staff presented a draft project plan to the technical advisory group for groundwater availability modeling on April 20, 2007. This group is made up of stakeholders from groundwater conservation districts, regional water planning groups, consulting firms, and government. The plan staff presented to the group was slightly different in that staff proposed that work on the Seymour Aquifer would be focused on expanding the Blaine Aquifer; however, since that meeting staff decided that refining the model in the Haskell County and Knox County area is a higher priority because of greater pumping. The technical advisory group did not have any substantial comments on the draft plan presented at the meeting.

RECOMMENDATION

Staff recommends authorizing the Executive Administrator to publish in the Texas Register a Request for Statements of Qualifications to be considered by the TWDB for funding of research grants for groundwater availability modeling-related projects in a total amount not to exceed $1,050,000. These groundwater availability modeling projects will involve (1) developing structure for the Capitan Reef Complex Aquifer, (2) revisiting and developing structure for the Gulf Coast Aquifer from the Brazos River to the Rio Grande, (3) developing and documenting a groundwater availability model for the Yegua-Jackson Aquifer, and (4) developing a groundwater availability model using a refined mesh for the portion of the Seymour Aquifer that overlies Haskell and Knox counties. We anticipate that all of the projects will take no more than two years to complete, except for the Capitan Reef Complex structure project which should take no more than one year, once contracts are negotiated.

ANTICIPATED OPPOSITION

None.

ATTACHMENTS:

A: Requests for Statements of Qualifications for Water Research (Texas Register)
B: Guidelines for the Statements of Qualifications
C: Statements of Qualifications Review Criteria—Groundwater Availability Modeling Program
D: Proposed GAM Schedule

This recommendation has been reviewed by legal counsel and complies with applicable statutes and TWDB rules.

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Robert R. Flores
Staff Attorney

Attachment A
Requests for Statements of Qualifications for Water Research
(Texas Register)

Texas Water Development Board
Request for Statements of Qualifications for Water Research.

Pursuant to 31 Texas Administrative Code §355.3, the Texas Water Development Board (TWDB) requests the submission of Statements of Qualifications leading to the possible award of contracts for groundwater availability models and related work for the Capitan Reef Complex, Gulf Coast, Seymour, and Yegua-Jackson aquifers. Guidelines for Statements of Qualifications, which include an application form and more detailed research topic information, will be supplied by the TWDB upon request.

Description of Research Objectives
Since 1999, the Texas Legislature has approved funding for the Groundwater Availability Modeling Program. The purpose of the Groundwater Availability Modeling Program is to provide reliable and timely information on groundwater availability to the citizens of Texas to ensure adequate supplies or recognize inadequate supplies over a 50-year planning period. Numerical groundwater flow models of the aquifers in Texas will be used to make this assessment of groundwater availability. The development of models for Groundwater Availability Modeling Program (1) includes substantial stakeholder involvement; (2) results in standardized, thoroughly documented, and publicly available numerical groundwater flow models and support data; and (3) is capable of providing predictions of groundwater availability through 2060 based on current projections of groundwater demands during drought-of-record conditions.

In support of the Groundwater Availability Modeling Program, the TWDB is requesting Statements of Qualifications for (1) developing structure for the Capitan Reef Complex Aquifer, (2) developing structure for the Gulf Coast Aquifer from the Brazos River to the Rio Grande, (3) developing a groundwater availability model for the Yegua-Jackson Aquifer, and (4) developing a refined groundwater availability model for the Seymour Aquifer in the Haskell County and Knox County area. A separate Statement of Qualifications for each of the four modeling projects is expected.

Details on the modeling projects and project requirements are available from the TWDB. The TWDB website site includes (1) guidelines for the Statements of Qualifications, (2) copies of the attachments, (3) a list of Statement of Qualifications Review Criteria, and (4) some supporting material (http://www.twdb.state.tx.us/assistance/financial/fin_research/research.htm).

Research Objectives for the Structure Projects
The TWDB is seeking separate Statement of Qualifications for (1) developing structure for the Capitan Reef Complex Aquifer and (2) developing structure for the Gulf Coast Aquifer from the Brazos River to the Rio Grande. For the Gulf Coast Aquifer, TWDB expects structure to be developed in a manner similar to the approach used for the LCRA-SAWS Water Project: http://www.lcra.org/docs/lswp/findings/Conceptual_Model_Report_Part_1.pdf . The Gulf Coast

Aquifer structure should delineate the Beaumont, Lissie, Willis, Upper Goliad, and Lower Goliad formations. The approach used for the LCRA-SAWS Water Project relied on well-defined stratigraphic boundary markers, aquifer depositional environments, and a detailed, systematic, interpretive process based on depositional facies to identify depositional cycles that connected boundary markers using a carefully defined set of depositional facies.

The objective of these research projects is to have structure surfaces, in digital and geographic information system compatible format, for each of the hydrostratigraphic layers of the aquifers. If possible and applicable, net sand maps should also be delivered.

The following issues need to be addressed in each Statement of Qualifications:

- the hydrostratigraphy of the study area;
- approach to delineating structure, including possible resources that encompasses contacting local groundwater conservation districts as well as proposed methodologies;
- approach to determine net sand thicknesses, if possible and applicable; and
- how the information will be organized and interpreted in a geographic information system.

Deliverables shall include:

- maps of the interpreted surfaces;
- a groundwater availability modeling compatible, ESRI based ArcGIS geodatabase that includes source data by location, final interpreted structure surfaces, net sand, if possible and applicable, reliability factors of source data, and sufficient metadata to duplicate work; and
- a report documenting the above (hard copy and electronic version).

In addition, we expect potential contractors to indicate their abilities in:

- general hydrogeology,
- hydrogeology of the modeled aquifer,
- geographical information systems,
- technology transfer,
- producing high-quality reports, and
- meeting deadlines.

At a minimum, TWDB staff expects to meet with the project team at the beginning of the project and at the midpoint of the project. A formal talk discussing the results shall be presented to TWDB staff at the end of the project. The Statements of Qualifications shall not be more than nine pages in length (using Times Roman 12 font), excluding qualifications and experience of project staff.

Groundwater availability model of the Yegua-Jackson Aquifer

A research project detailing the geologic structure of the Yegua-Jackson Aquifer is expected to be completed by the fall of 2007. The development of a groundwater availability model for the Yegua-Jackson Aquifer shall incorporate relevant geologic structure data evaluated in this preliminary study. The geologic structure study will provide data for up to four aquifer layers; the Lower-Yegua, the Upper-Yegua, the Lower Jackson, and the Upper Jackson. A technical report of the geologic structure will be available later this fall that summarizes the data and methods used and documents the findings of stratigraphic correlation, structural interpretation, and lithology distribution. Digital deliverables will include the final report, a groundwater availability modeling compatible, ESRI© based geodatabase of well information (well identification, location, log datum, and so on), digitized logs, digital log analysis results, and maps of structure, fault location, sand thickness, and depositional environment for each of the four aquifer layers in geographic information system format. The report will also include several strike and dip cross-sections. Documentation will include three major products: (1) maps in ArcGIS format; (2) a geodatabase of the source data, control data, metadata, and grid data supporting the structure and lithologic maps; and (3) the final report in both Microsoft Word 2003 format and in Adobe Acrobat 7.0 PDF format.

The statement of qualifications for the groundwater availability model for the Yegua-Jackson Aquifer should include a discussion on how many layers is needed to develop a regional scale model but will at a minimum model the Yegua Aquifer as a separate layer from the Jackson Aquifer. The statement of qualifications should also discuss if the proposal is for developing one continuous model or multiple models to cover, at a minimum, the entire extent of the Yegua-Jackson Aquifer in Texas.

The following issues need to be addressed in the Statement of Qualifications for the groundwater availability model of the Yegua-Jackson Aquifer project:

- communication between the contractor and the stakeholder advisory forum, regional water planning groups, and groundwater conservation districts located within the study area;
- conceptual model of recharge and how recharge will be modeled;
- how surface-water/groundwater interaction will be modeled;
- how hydraulic properties will be distributed;
- hydrostratigraphy for the model;
- approach for modeling the down-dip boundary of the model (if appropriate);
- approach for calibrating the model;
- how environmental impacts will be gauged; and
- how the project will benefit statewide water planning and groundwater districts.

In addition, we expect potential contractors to indicate their abilities in:
- general hydrogeology,
- hydrogeology of the modeled aquifer,
- numerical groundwater flow modeling,
- geographical information systems,
- communicating with the public,
- technology transfer,
- producing high-quality reports, and
- meeting deadlines.

The Statement of Qualifications shall not be more than 19 pages in length, excluding qualifications and experience of project staff. Applicants should be familiar with standards and requirements for the groundwater availability models.

Refined groundwater availability model for the Seymour Aquifer in the Knox County and Haskell County area

A regional groundwater availability model of the Seymour and Blaine aquifers was developed in 2004 that includes an upper layer incorporating the remnant areas (pods or islands) of the Seymour Formation and other Quaternary-age alluvium that comprise the Seymour Aquifer and a second layer encompassing the underlying Permian deposits. Characterization of the Blaine Aquifer was presented in greater detail than the other Permian units because it is the most important underlying stratum for water-supply purposes. Additional information on the groundwater availability model for the Seymour Aquifer is available on the TWDB Web site: http://www.twdb.state.tx.us/gam/symr/symr.htm. The topographic relief across the initial study area suggests a grid of one square mile was too coarse to capture the flow dynamics of individual portions of the Seymour Aquifer, especially in the shallower sections of the aquifer. This proposed project will concentrate on refining the mesh over one of the more productive and documented portions of the Seymour Aquifer in the Knox County and Haskell County area. In addition, because of the shallow unconfined characteristics of the aquifer, water levels are responsive to seasonal variations of climate and use. Therefore, instead of annual or a combination of monthly and annual stress periods, the localized model shall use monthly stress periods for the calibration period.

The following issues need to be addressed in the Statement of Qualifications for the localized groundwater availability model of the Seymour Aquifer in the Knox County and Haskell County area:

- communication between the contractor and the stakeholder advisory forum, regional water planning groups, and groundwater conservation districts located within the study area;
- conceptual model of recharge and how recharge will be modeled;
- how surface-water/groundwater interaction will be modeled;
- how hydraulic properties will be distributed;
- hydrostratigraphy for the model;
- approach for modeling the down-dip boundary of the model (if appropriate);
- approach for calibrating the model;
- how environmental impacts will be gauged; and
- how the project will benefit statewide water planning and groundwater districts.

In addition, we expect potential contractors to indicate their abilities in:

- general hydrogeology,
- hydrogeology of the modeled aquifer,
- numerical groundwater flow modeling,
- geographical information systems,
- communicating with the public,
- technology transfer,
- producing high-quality reports, and
- meeting deadlines.

The Statement of Qualifications shall not be more than 19 pages in length, excluding qualifications and experience of project staff. Applicants should be familiar with standards and requirements for the groundwater availability models.

Description of Funding Consideration
Up to $1,050,000 has been identified for water research assistance from the TWDB's Research and Planning Fund for the research for these four projects. It should be noted that for some of the proposed projects a portion of the funds will be available prior to September 1, 2008, and the remainder after September 1, 2008.

Projects in support of GAM program	**FY 2008**	**FY 2009**	**Total**
Structure for the Capitan Reef Complex Aquifer	150,000	0	150,000
Structure for half of the Gulf Coast Aquifer	150,000	150,000	300,000
Develop groundwater availability model for Yegua-Jackson Aquifer	200,000	200,000	400,000
Develop a refined groundwater availability model for the Seymour Aquifer in the Haskell County and Knox County area	180,000	20,000	200,000
Total	**$680,000**	**$370,000**	**$1,050,000**

Following the receipt and evaluation of all Statements of Qualifications, the TWDB may adjust the amount of funding initially authorized for water research. Oral presentations may be required as part of qualification review. However, invitation for oral presentation is not an indication of probable selection. Up to 100 percent funding may be provided to individual applicants; however, applicants are encouraged to contribute matching funds or services, and funding will not include reimbursement for indirect expenses incurred by political subdivisions of the state or other state and federal agencies. In the event that acceptable Statements of Qualifications are not submitted, the TWDB retains the right to not award funds for the contracts.

Deadline, Review Criteria, and Contact Person for Additional Information. Ten double-sided copies of a complete Statement of Qualifications, including the required attachments, must be filed with the TWDB prior to 5:00 PM, August 6, 2007. Statements of Qualifications must be directed either in person to Ms. Phyllis Thomas, Texas Water Development Board, Stephen F. Austin Building, 1700 North Congress Avenue, Austin, Texas; or by mail to Ms. Phyllis Thomas, Texas Water Development Board, P.O. Box 13231-Capitol Station, Austin, Texas 78711-3231. Statements of Qualifications will be evaluated according to 31 Texas Administrative Code §355.5 and the Statements of Qualifications Review Criteria rating form included in the TWDB's Guidelines for Water Research Grants. Research shall not duplicate work planned or underway by state agencies. All potential applicants must contact the TWDB to obtain these guidelines.

Requests for information, the TWDB's rules covering the Research and Planning Fund, detailed evaluation criteria, more detailed research topic information, and the guidelines may be directed to Ms. Phyllis Thomas at the preceding address or by calling (512) 463-3154. All technical questions should be directed to Ms. Cindy Ridgeway at (512) 936-2386.

Issued in Austin, Texas ____________________, 2007.

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Robert R. Flores
Staff Attorney

Attachment B
TEXAS WATER DEVELOPMENT BOARD
Guidelines for the Statements of Qualifications

I. GENERAL INFORMATION

1. Legal name of applicant(s).
2. Legal name of each participant(s).
3. Applicant's Official Representative, Name, Title, Mailing Address, Phone Number, Fax Number, if available,
   E-mail Address and Vendor ID Number.
4. Is the application in response to a Request for Statements of Qualifications in the Texas Register?

   Yes ☐ No ☐
5. If yes to number 4 above, list document's number and date of publication of the Texas Register.
6. A brief description of the research proposal (not to exceed 1 page).
7. If proposed project is specific to a geographic area, list location or site of proposed project.
8. A list of potential users and their possible involvement with the research.
9. Are you an individual member of the Texas Water Development Board, a Board staff member, or a member of their immediate families? Yes ☐ No ☐
10. Please include a completed Historically Underutilized Business Subcontracting Plan. The forms are available at: http://www.tbpc.state.tx.us/hub/forms/hubsubcontplan.html

II. RESEARCH PROJECT INFORMATION

11. Explanation of why this research is needed (not to exceed 1 page).
12. A detailed scope of work describing each task, a percent of effort per each task, a time schedule for each task, and the amount of time each team member will spend on the project (not to exceed 6 pages using Times Roman 12 font for projects related to just geologic structure and shall not exceed 15 pages using Times Roman 12 font for projects related to the development of a groundwater availability model).
13. A description of project-monitoring procedures.
14. Qualifications and experience of project staff that are ***directly related to this project only and no more than 2 pages in length per person.***

III. WRITTEN ASSURANCES

Written assurance of the following items:

- Proposed water research does not duplicate previously completed or ongoing research;
- If the contract is awarded to the applicant, the applicant agrees to discontinue existing contracts and not enter into new contracts with persons or entities other than TWDB and Regional Water Planning Groups for groundwater supply and availability studies involving the study area while working on the TWDB project without a prior no conflict of interest determination by TWDB and written authorization by TWDB.

Attachment C

Statements of Qualifications Review Criteria—Groundwater Availability Modeling Program

Name of Applicant: ____________________________ Reviewer's Name: ______________________________ Date of Review: _____________

Are the qualifications at least somewhat responsive to the TWDB's RFQ? (Circle either "yes" or "no")	**Yes** (if "yes", then continue review of the application)	**No** (if "no", discontinue review of application)

Review the application taking into consideration the following:

1	**Qualifications and experience**
	Project staff qualifications (e.g., education, publications)
	Project staff experience in general hydrogeology
	Project staff experience in hydrogeology of the modeled aquifer
	Project staff experience in numerical groundwater flow modeling (**groundwater availability modeling related projects**)
	Project staff experience in geographical information systems
	Project staff experience in technology transfer
2a	**Technical issues (structure related projects)**
	Hydrostratigraphy for the model
	Approach for mapping and interpreting structure
	Approach for organizing and presenting information
	Approach for mapping and interpreting net sand
2b	**Technical issues (groundwater availability modeling related projects)**
	Communication between the contractor and the stakeholder advisory forum for the model, regional water planning groups, and groundwater conservation districts
	Conceptual model of recharge and how recharge will be modeled
	How surface-water/groundwater interaction will be modeled

	How hydraulic properties will be distributed
	Hydrostratigraphy for the model
	Approach for modeling downdip boundaries (if applicable)
	Approach for calibrating of the model
	Approach for handling dewatered cells
	How the model will be used to assess effects on environmental resources
	How the model will benefit Regional Water Planning Groups and groundwater conservation districts
3	**Organization and management**
	Progress monitoring procedures
	Approach to organizing and managing the project
	Approach to organizing and managing stakeholder advisory forums (for groundwater availability modeling related projects)
4	**Reports and deliverables**
	Are capable writing abilities demonstrated in application?
	Specific and usable deliverables
5	**Your assessment of proposer's ability to perform this research and complete the project**

EXHIBIT B

SCOPE OF WORK

See________________________ of Exhibit A

and

Attachment 1:

Requirements of Groundwater Availability Models for theYegua-Jackson Aquifer and a localized model of the Seymour Aquifer (Knox and Haskell county area) in Texas

1.0 Introduction

The purpose of Groundwater Availability Modeling (GAM) is to provide reliable and timely information on groundwater availability to the citizens of Texas to ensure adequate supplies or recognize inadequate supplies over a 50-year planning period. The groundwater availability modeling effort will result in numerical computer models of the major and minor aquifers in Texas and will be used to help assess groundwater availability and the possible affects of various proposed water management strategies on the aquifer systems. The groundwater availability modeling process will include substantial stakeholder input and will result in standardized, thoroughly documented, and publicly available numerical groundwater flow models and support information. Groundwater availability models will provide one of the primary tools to evaluate regional water management strategies and the availability of groundwater in regional water plans and groundwater conservation district management plans. The models, source information, and final reports will be provided to the Texas Water Development Board (TWDB) for posting and distribution on the Internet.

This attachment to the request for qualifications has considerable detail because of:

- the need for standardization between the different models;
- the planned public dissemination of the models, supporting information, and results; and
- the assurance that the TWDB receives deliverables that meet program requirements.

Although the request for qualifications and this attachment include the Yegua-Jackson Aquifer and a localized model of the Seymour Aquifer in the Knox County and Haskell County area in a single discussion, we expect separate proposals for the two different projects.

Where appropriate, we have added specific requirements for specific aquifers and models. The major subheadings below (Stakeholder Participation, Model Development, Documentation, Project Management, and Project Schedule) list TWDB expectations and requirements for the modeling projects. Executed contracts for these modeling efforts will parallel the requirements described in this document.

2.0 Stakeholder participation

Stakeholder participation is critical to the success of the groundwater availability modeling 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, agricultural, environmental, 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. It will be the contractor's responsibility to meet with a Stakeholder Advisory Forum of the above stakeholders and hold key milestone meetings to discuss progress of the modeling effort and to solicit stakeholder comments. It is extremely important that regional water planning groups and groundwater conservation districts be informed about the model because they will use these models to assess groundwater availability or evaluate water management strategies. The contractor shall work with the TWDB in developing the initial invitation list for the stakeholder advisory forum. Stakeholder advisory forum attendees will participate voluntarily with no compensation. The modeling projects will have a stakeholder advisory forum password protected membership database accessed through the TWDB website.

Stakeholder advisory forums will be open to the public. The contractor shall work with the TWDB project manager or other appropriate TWDB staff to coordinate meeting dates and locations. It will be the contractor's responsibility to notify the stakeholder advisory forum participants of upcoming meetings. The preferred method of notification will be by email. Stakeholder advisory forum participants without email or with a preference other than email will be notified by letter. Stakeholder advisory forum participants with email shall be notified at least 21 days before the meeting and reminded again at least 7 days before the meeting about the meeting. Stakeholder advisory forum participants that have to be or prefer to be notified by letter will be mailed one notice at least 21 days before the meeting. The stakeholder advisory forum notice will include information about the meeting as well as an outline of what will be discussed at the meeting.

The first stakeholder advisory forum shall be a general meeting no more than two months after the contract starts that describes:

1. the basics of groundwater flow in the aquifer;
2. the concept of numerical groundwater flow modeling;
3. experience from previous models of the aquifer, if applicable;
4. the planned approach for modeling the aquifer;
5. a request for local scientific data and model input information; and
6. the proposed schedule for the project.

Expectations of the model (what the model will or will not do) shall also be discussed. It will be extremely important to provide a well-defined schedule to the stakeholders on when input and data are needed for the model. In this way, stakeholders' expectations can be managed and contractors will not have to work with late arriving data. At a minimum, the remaining stakeholder advisory forums should be scheduled as follows:

1. after the conceptual model portion of the project has been completed,
2. after the model has been calibrated, and
3. after the final draft report has been submitted for review.

Additional stakeholder advisory forums may be scheduled at the contractor's discretion. Each meeting shall result in a memo report (submitted to TWDB in Word and Adobe Acrobat compatible formats), summarizing the presentation, the questions and issues that arose from the stakeholder advisory forum attendees, and how the questions were or will be addressed. These memo reports will be posted by the TWDB on the TWDB web page for public viewing. Contractors shall submit copies of the stakeholder advisory forum PowerPoint presentations to the TWDB contract manager to preview at least 48 hours prior to the scheduled SAF meeting. Digital copies of final presentations at each stakeholder advisory forum meeting (in both PowerPoint and Adobe Acrobat compatible formats) shall also be given to the TWDB for posting on the web within two business days of the stakeholder advisory forum meeting. For easier website accessibility and due to e-mail limitations, the Adobe Acrobat compatible format deliverables should not exceed 10 megabytes in size. Therefore, some deliverables may need to be submitted in parts. In addition, an attendance sign-up sheet shall be provided at each meeting. The list of attendees and their affiliation shall be given to TWDB for posting on the TWDB web page for each stakeholder advisory forum. New and revised stakeholder contact information shall be reviewed and updated, as applicable, on the stakeholder advisory forum password protected membership database accessed through the TWDB website. There will be one day-long seminar for TWDB staff and at least one day-long seminar for stakeholders to learn how to use the model after the model is finished and the draft report has been submitted, if needed.

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 do not hold degrees in geology, hydrology, engineering, or geostatistics. However, technically minded stakeholders shall be encouraged to ask technical questions and contractors shall answer these questions at the same technical level of the question. In addition, technical questions should also be 'translated' for the non-technical audience.

3.0 Model development

The basic steps in model development and completion include:

1. developing the conceptual model,
2. defining the model architecture,

3. calibrating the model, and
4. conducting a sensitivity analysis.

3.1 Conceptual model

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

1. physiography and climate;
2. geology;
3. hydrostratigraphy;
4. structure;
5. water levels and regional groundwater flow;
6. recharge;
7. rivers, streams, lakes, and springs;
8. hydraulic properties;
9. discharge; and
10. 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, U.S. Geological Survey, groundwater conservation districts, river authorities, or other appropriate entities shall be contacted for relevant information. Published papers and reports on the aquifer shall be compiled, reviewed, and documented. If applicable, earlier modeling efforts on the subject aquifer shall be thoroughly reviewed and documented.

Development of the conceptual model and any information entered into the numerical model shall only use publicly available information or information that will be made publicly available at project completion. Each element of the conceptual model shall be thoroughly described, documented, and referenced in the final report (see section 4.0). Development of the conceptual model shall be based on published work as much as possible. The conceptual model shall be visually summarized with a block diagram demonstrating major components of flow in the aquifers (that is, recharge, cross-formational flow, flow directions). See Section 4.4 for requirements of the final report.

3.1.1 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 of:

1. physiographic delineations and features;
2. topography;
3. general climate characteristics;
4. spatial and temporal variability of precipitation;
5. spatial and temporal variability of temperature;
6. spatial and temporal variability of evaporation; and, if available,
7. evapotranspiration.

This section shall also describe the aerial extent of the study area.

3.1.2 Geology

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

1. a detailed stratigraphic chart;
2. a description of each of the geologic formations that includes the formation thickness characteristics, depositional environment, and mineralogic composition;
3. a map of the surface geology;
4. several cross sections throughout the study area; and
5. a brief discussion of the geologic and tectonic history including regional and local structural features.

3.1.3 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 and information on the rationale for the hydrostratigraphic units. At a minimum, we expect the following for each of the models:

- Yegua-Jackson Aquifer– The development of a groundwater availability model for the Yegua-Jackson Aquifer shall incorporate relevant geologic structure data evaluated in a preliminary research study documenting the structure for the aquifer. The geologic structure study will provide data for four aquifer layers: the Lower-Yegua, the Upper-Yegua, the Lower Jackson, and the Upper Jackson. The structure ends along the Rio Grande to the southwest and Toledo Bend Reservoir in the northeast. A technical report of the geologic structure will be available late in 2007 that summarizes the data and methods used and documents the findings of stratigraphic correlation, structural interpretation, and lithology distribution. Digital deliverables will include the final report; a groundwater availability modeling compatible; ESRI© based geodatabase of well information (well identification, location, log datum, and so on); digitized logs; digital log analysis results and maps of structure; fault location; sand thickness; and depositional environment for each of the four aquifer layers in geographic information system format.

The report will also include several strike and dip cross-sections. Documentation will include three major products: (1) maps in ArcGIS format; (2) a geodatabase of the source data, control data, metadata, and grid data supporting the structure and lithologic maps; and (3) the final report in both Microsoft Word 2003 format and in Adobe Acrobat 7.0 PDF format. The aquifer model report shall discuss the rationale for how the stratigraphic units are grouped into hydrostratigraphic units and how the hydrostratigraphic units will be translated in the groundwater availability model.

- Localized model of the Seymour Aquifer (Knox County and Haskell County vicinity)– A regional groundwater availability model of the Seymour and Blaine aquifers was developed in 2004 that includes an upper layer incorporating the remnant areas (pods or islands) of the Seymour Formation and other Quaternary-age alluvium that comprise the Seymour Aquifer and a second layer encompassing the underlying Permian deposits. Characterization of the Blaine Aquifer was presented in greater detail than the other Permian units because it is the most important underlying stratum for water-supply purposes. Additional information on the groundwater availability model for the Seymour Aquifer is available on the TWDB Web site: http://www.twdb.state.tx.us/gam/symr/symr.htm. The aquifer model report shall discuss the rationale for how the stratigraphic units are grouped into hydrostratigraphic units and how the hydrostratigraphic units will be translated in the groundwater availability model.

3.1.4 Structure

Structure 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. Land-surface elevations shall be used as layer tops in outcrop areas. For downdip model areas, the top of the model layer should follow structural delineations consistent with the assumed confining layer. Layer thickness maps shall also be developed. Information considered for the structure shall include previously published structure maps/analysis and may include new well-log interpretation where needed. Subsurface structure elevations shall be properly integrated with the outcrop (where the formation contact intersects the land surface). Land-surface elevation shall be defined by USGS 3-arc-second or appropriate digital elevation models (DEMs). All information used to develop the structure surfaces shall be fully documented as to data source, data interpolation techniques, and data quality.

3.1.5 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 four water-level maps shall be generated for each of the hydrostratigraphic units included in the model: one for predevelopment conditions (for the steady-state model), one for the beginning of the transient calibration period, one for the middle of the transient calibration period, and one for the end of the transient calibration period (information on the transient calibration period is included in Section 3.3). The predevelopment maps shall be based on historical water-level information, but may include older or more modern information to help guide water-level interpretation. Long-term historical hydrographs shall also be developed for the study area, as the data permits. These hydrographs will help define water-level declines and seasonal fluctuations throughout the model area, and will also serve as calibration targets for the transient model.

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

3.1.6 Recharge

Texas Water Code §36.001, subdivision 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 through the outcrop, irrigation return flow, stream losses, leakage from overlying reservoirs, and possibly vertical leakage from geologic units above. Previously published estimates of recharge for the aquifer shall be compiled and assessed using Scanlon and others (2002) as a start, if applicable. Important factors related to how the aquifer is recharged and effects of seasonal variations shall be examined and discussed. Recharge shall be distributed according to infiltration characteristics of the outcrop (for example, soil properties, geologic formations, and topography), precipitation rates, and losing streams, if applicable. Maps of recharge potential or recharge coefficients (for example, Mace and others, 2000) shall be generated for the model area.

Realistic conceptual models of recharge must be developed for each of the aquifers and these conceptual models must be implemented in the numerical models. Where appropriate, these conceptual models, and similarly the numerical models, must include the concept and effect of 'rejected recharge' (for example, Theis, 1940, summarized in Domenico and Schwartz, 1990, p. 200-202). Although past models may have successfully simulated current or historical aquifer conditions without considering rejected recharge, groundwater availability models will be predictive and will need to realistically model the effect of large cones of depression on local flowpaths (that is, rejected recharge) in aquifer outcrops. Therefore, the models should be capable of simulating changing flow patterns due to changing aquifer conditions. This may be accomplished by modeling evapotranspiration and surface water/groundwater interactions, for example.

3.1.7 Rivers, streams, springs, and lakes

Rivers, streams, springs, and lakes describe the interaction of groundwater with surface water and must be addressed. The primary rivers, streams, springs, and lakes 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. TWDB funded research on surface water/groundwater interaction (Slade and others, 2002) must be incorporated into the analysis, as applicable. Any specific or general information on streambed conductance shall also be addressed. Elevations of riverbeds, streambeds, spring orifices, and lake levels shall be determined from the best-documented available sources. Information needed for the MODFLOW streamflow-routing package (Prudic and others, 2004) shall also be correctly estimated and discussed (that is, streambed top and bottom, channel width and slope, and

Manning's roughness coefficient). Information needed for the MODFLOW reservoir package (Fenske and others, 1996) shall also be estimated and justified (for example, reservoir conductance, cell-to-cell connectivity, and reservoir levels). All surface-water features that are important elements of the hydrologic flow system shall be incorporated into the model with an appropriate MODFLOW package.

3.1.8 Hydraulic properties

Hydraulic properties that help define the flow characteristics of the aquifer must be addressed. This includes the transmissivity, hydraulic conductivity, storativity, and specific yield of the aquifer(s). Results from available aquifer tests for the model area shall be compiled and assessed. Specific-capacity tests shall also be compiled from TWDB files, and possibly Texas Commission on Environmental Quality files, and transmissivity and hydraulic conductivity estimated using analytic or empirical techniques (for example, Mace, 2001). Contractors may propose additional aquifer tests if they believe the budget can support them.

Transmissivity, hydraulic conductivity, storativity, and specific yield shall be 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 layer 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, net-sand thickness maps). If net-sand thickness maps are available or created, how they were developed shall also be presented. Specific or general information on vertical hydraulic conductivity for each layer 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, net-sand thickness maps). Horizontal anisotropy shall also be defined, discussed, and estimated, if appropriate.

3.1.9 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 (rivers, streams, springs, and lakes are discussed in section 3.1.7). Available TWDB estimates of historical amounts of pumping will be included in the Pumpage geodatabase for the transient calibration period extending from 1980 to 1997. If needed, additional information supporting estimates of early aquifer use should be developed. The most accurate information, whether it is from the TWDB, the Regional Water Planning Groups, the Groundwater Conservation Districts, the Stakeholder Advisory Forums, or other sources, shall be used in the final model. However, written permission from the TWDB will be required to use any information other than TWDB information.

For model areas outside Texas, the contractor is expected to compile and use pumping estimates from outside sources, as appropriate.

3.1.10 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 gage groundwater availability. Therefore, total dissolved solids and other constituents of concern should be presented as part of the conceptual model.

3.1.11 Potential sources of information

The following is a list of potential sources of information for developing the conceptual model. Additional information can be found at the groundwater availability modeling web page http://www.twdb.state.tx.us/gam/.

- **Physiography and Climate**–Information on the physiography of Texas can be found from several different sources. A couple potential sources are:

  http://www.lib.utexas.edu/maps/atlas_texas/physiography_tex.jpg,
  http://www.lib.utexas.edu/geo/physiography.html , BEG (1996), and
  http://water.usgs.gov/GIS/metadata/usgswrd/XML/physio.xml .

  Climate data can be found from a number of sources:
  http://www.ocs.oregonstate.edu/prism/
  http://www.ncdc.noaa.gov/oa/ncdc.html
  http://www.ncgc.nrcs.usda.gov/products/datasets/climate/docs/fact-sheet.html

- **Geology**–Texas Natural Resources Information System (TNRIS) has completed a geology layer for the Texas Strategic Mapping Program (STRATMAP) program. Please check: http://www.tnris.state.tx.us/news.aspx?id=244 for an overview of the program and ftp://ftp2.tnris.org/Geology/Raster/ to download raster files. Vector files are available upon request through your groundwater availability modeling contract manager..

- **Structure**–Structure surfaces for the aquifers will need to be researched and developed from existing publications, well logs, and/or other information. The Source Water Assessment and Protection (SWAP) program implemented by U.S. Geological Survey and funded by Texas Commission on Environmental Quality (formerly Texas Natural Resource Conservation Commission) includes geographic information system feature datasets of structure for the aquifers of Texas. Source Water Assessment and Protection team contact information is located:
  http://www.tceq.state.tx.us/permitting/water_supply/pdw/contact/pdws_contact.html

- **Water levels**–The TWDB maintains a database of water levels at the TWDB web page: http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/GWdatabaserpt.html It is important to review User Manual (UM)-50 (http://www.twdb.state.tx.us/publications/manuals/UM50%20Data%20Dictionary/um50.pdf) before querying the data. We recommend using only publishable water-level measurements taken when the wells were not actively pumping. Careful quality assurance of the data should be attempted; all anomalies should be reviewed and omitted if unreasonable or unfounded, as well as notifying TWDB staff to correct or to flag for additional research. Groundwater districts are another good source of water-level information. Previous publications may also include potentiometric surfaces.

- **Recharge**–Scanlon and others (2002), in their TWDB supported study, include a review of previous estimates of recharge for the state's major aquifers and a review of methods and techniques of modeling recharge. This report is posted at the groundwater availability modeling web page (http://www.twdb.state.tx.us/GAM/resources/resources.html).

  Soils data may be obtained from a number of sources:
  http://www.tnris.state.tx.us/StratMap.aspx?layer=124
  http://datagateway.nrcs.usda.gov/
  http://www.essc.psu.edu/cgi-bin/essc.cgi?database&index.html
  http://water.usgs.gov/GIS/metadata/usgswrd/XML/ussoils.xml
- **Rivers, Streams, Springs, and Lakes**–Geographic information system feature datasets of rivers and streams can be downloaded from the Texas Natural Resource Information System web page: http://www.tnris.state.tx.us/StratMap.aspx?layer=120 . Slade and others (2002), in their TWDB supported study, summarized all available gain-loss studies for the rivers of Texas: http://pubs.usgs.gov/of/2002/ofr02-068/. Lake levels may be acquired from river authorities or other entities. Useful information may also be found at: http://www.texaswaterinfo.net/.

- **Hydraulic Properties**–TWDB Report 98 (Myers, 1969) is a compilation of aquifer tests for Texas (http://www.twdb.state.tx.us/GAM/resources/resources.html). Additional aquifer test data may be found in TWDB well files, http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/GWdatabaserpt.html . The Source Water Assessment and Protection program implemented by Texas Commission on Environmental Quality also includes geographic information system feature datasets of hydraulic properties for the aquifers of Texas. Source Water Assessment and Protection team contact information is located at: http://www.tceq.state.tx.us/permitting/water_supply/pdw/contact/pdws_contact.html

- **Discharge**–The TWDB has estimates of annual pumpage by water use category for 1980 through 1997. The TWDB has also provided geographic information system feature datasets for population density. This information is included in the Pumpage Geodatabase. We are updating the Pumpage Geodatabase to include monthly estimates for the Seymour Aquifer project.

- **Water Quality**–The TWDB maintains a database of water quality at the TWDB web page: http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/GWdatabaserpt.html.

  It is important to review User Manual (UM)-50 (http://www.twdb.state.tx.us/publications/manuals/UM50%20Data%20Dictionary/um50.pdf) before querying the data. Careful quality assurance of the data should be attempted; all anomalies should be reviewed and omitted if unreasonable or unfounded, as well as notifying TWDB staff to correct or to flag for additional research. Groundwater districts are another good source of water-level information.

  The Texas Commission on Environmental Quality also maintains a database of water quality of public water systems:

http://www.tceq.state.tx.us/permitting/water_supply/ud/iwud.html although care must be taken that analyses are of non-treated groundwater.

3.2 Model architecture

The models shall all use MODFLOW-2000 (Harbaugh and others, 2000) as the modeling code. All models will use MODFLOW components that are freely available (that is, proprietary modules or codes shall not be used). However, the final model (including supporting graphics) shall be fully compatible with Groundwater Vistas 4.0, a proprietary pre- and post-processor to the MODFLOW code. The final model shall be able to run on a personal computer under the Microsoft Windows-disk operating system (DOS) (Microsoft Windows 95 or later). Length units for model input will be in feet and time units will be in days.

3.2.1 Cell size, orientation, layering, and parameter assignment

Lateral uniform cell size shall be no greater than 1-mile-by-1-mile for the Yegua-Jackson Aquifer model. Lateral cell size may be reduced uniformly in order to mitigate model instabilities or if the density of available source data supports a smaller mesh size. The grid shall be oriented with the prominent grain of the structure and/or regional groundwater flow paths, as much as possible. The lateral uniform cell size shall for the Seymour project shall be less than 1-mile-by-1-mile.

Layers shall be assigned for the models such that layers are:

1. either confined or unconfined depending on the position of the water level relative to the top of the formation; and
2. transmissivity is calculated according to the modeled saturated thickness.

Storativity values shall be assigned according to the saturated thickness based on the specific storage values. However, due to limited information in some of the minor aquifers, contractors may elect to use constant transmissivity and storativity layer assignments. Model parameters determined through development of the conceptual model shall be assigned to the appropriate model cells. Spatial data shall be interpolated to model cells using an appropriate interpolation procedure.

3.2.2 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 chosen method shall 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 as discussed in section 3.1.6. A recharge method that includes rejected recharge will allow the effective recharge (or flow) to the confined aquifer to increase as water levels decline. Some MODFLOW packages to consider, depending on scale and flow conditions, may include:

- MODFLOW-2000 Evapotranspiration (EVT) Package,

- Evapotranspiration Segments (ETS1) Package,
- MODFLOW streamflow-routing (STR1) package (Prudic and others, 2004),
- MODFLOW-2000 Drain (DRN) Package, or
- Drain Return (DRT1) Package.

This is extremely important for realistically modeling the effects of withdrawals on water levels in aquifers. Contractors must consider that recharge rates may have changed over time owing to changes in land use and irrigation return flow.

All important rivers, streams, springs, and lakes shall be included in the model and considered realistically, using the appropriate MODFLOW package (for example, the streamflow-routing package for rivers and streams and the drain package for springs,). Contractors may use the River or Drain package for rivers and streams if they can demonstrate to TWDB staff that model predictions will not be affected. Similar to recharge (see Section 3.1.6), 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).

3.2.3 Model extents and boundaries

The extent of the models should follow natural boundaries as much as possible. The submitted proposal and report shall describe the rationale for the boundaries in the model for aquifers that extend outside of Texas. At a minimum, the extent of the models shall include the following:

- Yegua-Jackson Aquifer–the model will at a minimum include the extent of the Yegua-Jackson Aquifer in Texas as recognized by TWDB. The deliverables for the contract to develop the structure for the Yegua-Jackson Aquifer uses the Rio Grande in the southwest and Toledo Bend Reservoir in the northeast as project boundaries. If conceptually model boundary conditions suggest extending the model boundaries outside of the Texas, the consultant should includes a discussion on the methodology used to extend the structure, what boundary or boundaries were selected, and the reasoning for selecting the boundary or boundaries .
- Seymour Aquifer–at a minimum, the model will include the extent of the Seymour Aquifer that mainly exists in Knox and Haskell counties but may also extend to include parts of the surrounding counties, well. The consultant should include a discussion of how far to extend the model past the outline of this portion of the Seymour Aquifer to include communication with the underlying Permian units. The report shall also include a discussion of how far to extend the model into the underlying and surrounding Permian units.

3.2.4 Pumping

Groundwater pumpage shall be defined and assigned according to TWDB water-use categories: industrial (manufacturing), power, mining, irrigation, municipal, livestock, and rural domestic (county other). Industrial, municipal, and mining shall be distributed as point sources. If accurate point source information on irrigation and livestock pumping is not available from Groundwater

Conservation Districts, TWDB, and Regional Water Planning Group estimates, land-use maps shall be used to distribute pumping in the study area. If accurate point information on rural domestic use is not available from Groundwater Conservation Districts, TWDB, and Regional Water Planning Group estimates, appropriate census data at the block level shall be used to distribute pumping (that is, distribute pumping according to population density outside of the municipal areas and excluding surface-water features). Pumping shall be vertically distributed according to statistical analyses of information from the TWDB groundwater database or other reliable sources. Additional guidance on distributing pumping is available in Groundwater Availability Modeling (GAM) Technical Memo 06-01 at the TWDB web page (http://www.twdb.state.tx.us/gam/GAM_documents/GAM_memo_06-01_pumpage.pdf). The TWDB has a water use database of major groundwater users in the State (industrial, municipal, and others). Contractors shall associate groundwater users in this database with state well numbers in the TWDB groundwater well database for the major groundwater providers and producers.

Contractors are also required to retain regional water planning water user group (WUG) identification fields throughout data processing and the spatial assignment of pumpage. Standardized water user group identification fields and data that shall be retained include:

- WUG_ID,
- WUG_NAME,
- DATA_CAT,
- WUG_RWPG,
- WUG_COUNTY_NAME,
- WUG_BASIN_NAME,
- CITY_ID,
- WUG_COUNTY_ID, and
- WUG_BASIN_ID.

3.3 Calibration of the Model

There shall be steady-state and transient calibrations of the models. The steady-state calibration shall be performed to predevelopment conditions as defined in section 3.1.5. The mean absolute error between measured hydraulic-head and simulated hydraulic head shall be less than 10 percent of the measured hydraulic-head drop across the model area and better if possible. The error shall not be biased by areas with considerably more control points than other areas (that is, not spatially biased). Final calibration results shall report the mean absolute 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) shall be less than one percent and ideally less than 0.1 percent. Initial parameters for the models shall 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) shall 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 mean absolute error for matching hydraulic head or the error on the water balance, the contractor shall meet with TWDB staff to discuss how to proceed with the model. The TWDB does not want over-calibrated models.

The transient model shall start with the steady-state model and stop at the end of the most recent year for which TWDB provides pumping estimates (1997). Because of greater certainty on historical pumping, the last 17 years (1980 to 1997) shall be the focus of the transient calibration of the model. Stress periods may be of variable length according to the density of information on pumping and recharge, but the stress periods for the transient calibration period shall not be greater than 1 year for the Yegua-Jackson Aquifer model and monthly for the Seymour Aquifer model. Particular attention shall be paid to accurately represent water levels and fluxes during times of drought and in areas with large drawdowns. Mean absolute 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 and better if possible at the end of 1990 (or surrounding years depending on abundance of data) and at the end of the transient calibration period (1997).

The range of water-level fluctuation in the observation wells shall be matched as closely as possible during the transient calibration. Long-term hydrographs comparing measured hydraulic head and simulated hydraulic heads shall be developed and included in the report. The location of the wells used to generate the hydrographs should not be spatially or vertically biased; 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 for 1990 and 1997 shall be made for each layer and included in the final report. Larger known fluxes out of the aquifer (for example, springs and baseflow to streams) shall also be calibrated and matched to within 10 percent of measured values.

The mean absolute error for the spatial distribution of water levels for current conditions (as defined in the conceptual model) shall be reported as well as the mean absolute error for fitting the hydrographs and matching the magnitude of water-level variations. Temporal variations of larger known fluxes out of the aquifer (for example, springs and baseflow to streams) shall also be calibrated. The model shall reproduce the general distribution of water levels and the magnitude of water-level variations in the aquifer.

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 for 1990 and 1997), the calibration and perhaps the conceptual model shall 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.

A detailed table summarizing the water budget for the entire model and for the individual layers shall be made and included in the final report. This water-budget table shall include:

1. recharge to the outcrop,
2. gains or losses to rivers in the outcrop,
3. discharge to springs at the outcrop,
4. other natural discharge to the outcrop (for example, evapotranspiration),
5. flow to the confined aquifer (if applicable),
6. cross-formational flow,
7. discharge to wells, and
8. changes in storage.

This table shall include budget information for the steady-state model, the beginning of the calibration period (1980), the middle of the calibration period (1990), and the end of the calibration period (1997). The contractors shall also extract the water budget per county and per groundwater conservation district for 1997, the end of the transient calibration. This information, as well as an analysis of how well the model simulates measured targets at the end of the transient calibration per county, shall be included in the final report.

In addition, there shall be an accounting of the number of cells that change from artesian conditions to water table conditions and the number of cells that go dry during a simulation, if applicable. The contractor shall have a strategy for addressing dewatered cells during calibration simulations. If the aquifer has not historically gone dry, then the aquifer shall 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 must have a plan for allowing cells in the model to re-saturate or remain saturated.

The steady-state and transient calibration models shall be contained in the same model (that is, include the steady-state model with a very long stress period as part of the transient model). Including the steady-state model as part of the transient model ensures that any changes made to the model 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 sufficient 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 steady-state as been achieved as changes are made during the transient calibration and propagated to the steady-state model.

3.4 Sensitivity Analysis

After the steady-state and transient models are calibrated, a sensitivity analysis on each major parameter in the model shall be performed (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 insight to 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 shall be performed by globally adjusting each model parameter and assessing its impact on water levels and fluxes (for example, springflow, baseflow, and cross-formational flow). Model parameters include:

1. horizontal hydraulic conductivity,
2. vertical hydraulic conductivity,
3. confined storativity,
4. specific yield,
5. recharge,
6. pumping,
7. hydraulic head assigned at any constant head and general head boundaries, and
8. conductance values for drains, rivers, general head boundaries, or any other packages for each layer.

Model parameters shall be adjusted plus or minus 10 percent and plus or minus 50 percent from calibrated values and the mean error between the calibrated water levels and the simulated water levels at the calibration points for the adjusted parameter shall 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 shall be done (for example, confined storativity). Results of the sensitivity analysis shall 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 shall be done for transient simulations where the impacts of varying storage parameters on water-level fluctuations 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). Sensitivity analyses on groups of parameters (such as adjusting recharge and hydraulic properties together) are also strongly encouraged.

4.0 Documentation

Thorough documentation of the models is extremely important in ensuring their continued use. Each of the models shall be thoroughly documented and made available to the public upon completion of the project. Documentation shall include four major products:

1. the source and derived information from the development of the conceptual model in an ArcGIS geodatabase format,
2. the source and derived pumpage information calculated for each model grid cell in an ArcGIS geodatabase format,
3. the model input and associated files in both MODFLOW 2000 ASCII format and Groundwater Vistas format, and
4. the final report in both Microsoft Word 2003 compatible format and Adobe Acrobat 7.0 PDF format.

In addition to the discussion below, we have prepared data models in Environmental Systems Research Institute (ESRI) personal geodatabase format for the projects (Attachment 2). An optional ArcGIS geodatabase for organizing and storing all calibrated MODFLOW model grid cell parameters and time series variables (contact contract manager for details).

4.1 Software Requirements

All computer files and formats shall be 100 percent compatible with personal computer (PC) type systems. Electronic files may be physically shipped using digital video discs (DVD) or compact discs (CD). In addition, files may be zipped with a self-extracting software program such as WINZIP. Contractors shall deliver three sets (on separate digital video discs or compact discs) of all electronic files of documented source data and model files (when appropriate) used during the development of the:

1. conceptual report,
2. draft report, and
3. the final report.

Contractors shall deliver four hard copies of the conceptual report, four hard copies of the final draft report, and then ten hard copies of the final report (see contract for any exceptions). All files and data shall be transferred to the TWDB in ready-to-use format. Formats of all computer files provided to the TWDB by the contractors shall be fully compatible with the widely distributed versions of the following programs:

- Word Processor Files—Microsoft Word (MS Office 2003)
- Geodatabases data—ESRI ArcGIS (9.1 or later)
- Database files—Microsoft Access (MS Office 2003)
- Spreadsheet files—Microsoft Excel (MS Office 2003)
- Graphs, bar charts, pie-charts—Microsoft Excel (MS Office 2003)
- Internet ready reports in pdf format in parts not to exceed 10 megabytes—Adobe Acrobat (7.0)
- Turn-key models—Groundwater Vistas (version 4)

- MODFLOW 2000—ASCII data files
- Scanned files—uncompressed TIFF (8-bit for black and white and 32-bit for gray/color with at least 300 dpi or greater, if needed, to resolve image resolution)

The contractor shall seek the approval from the Executive Administrator as to the compatibility of alternative software. Contractors need to provide Environmental Systems Research Institute (ESRI) compatible files for all geographic information system information. All drawings and graphs included in all reports shall be provided separately to TWDB in their native file format. In addition, all figures shall also be provided separately to TWDB in JPEG formatted files with 300 dpi or greater resolution.

4.2 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 groundwater availability models for Groundwater Conservation Districts, Regional Water Planning Groups, Groundwater Management Areas, TWDB, and other users to support ongoing management issues and research. Therefore, we expect to receive all of the source data used in the development of the model. For example, we expect to receive all point data used to develop spatially distributed parameters. If map information was digitized from an existing scanned or paper document, we expect to receive the final geographic information system files of the digitized map(s) with documentation citing the source of the files. If information from geologic cross-sections within a published document is used, we expect a scanned image file or digitized vector file of the cross-section(s).The source data also allows alternative interpretations of parameter distributions to be investigated in future studies.

Source data refer to the tabular, point, line, and/or polygon information developed or used to create model input files. All the source data shall be delivered to the TWDB in the appropriate format (see Sections 4.1 and 4.4 and Attachment 2). Spatial information shall be projected into the groundwater availibility modeling coordinate system with units of measure in feet prior to and during any spatial analysis (see Attachment 2).

Source data for the study area includes:

- 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 lakes, major roadways, Regional Water Planning Group boundaries, Groundwater Management Area boundaries, groundwater districts, physiographic delineations, river basins, and model boundary;
- geographic information system raster and/or feature datasets of the topographic elevations in the study area (digital elevation model source data and the contours);

- tabular data and geographic information system raster and/or feature datasets of average annual precipitation (including gage locations and associated time-series data);
- tabular data and geographic information system raster and/or feature datasets of net lake or pan evaporation;
- geographic information system feature datasets of the surface geology;
- tabular data and geographic information system raster and/or feature datasets of the net sand maps;
- geographic information system feature datasets of the major structural and tectonic features;
- tabular data and geographic information system raster and/or feature datasets of the top and bottom elevations for each model layer;
- tabular data and geographic information system raster and/or feature datasets of the water-level maps;
- tabular data for the historical hydrographs;
- tabular data for the stream-flow hydrographs;
- tabular data for the springflow hydrographs;
- tabular data for the lake level hydrographs;
- tabular data for the hydraulic conductivity, transmissivity, and storativity;
- geographic information system raster and/or feature datasets of the distributions of transmissivity, hydraulic conductivity and storativity;
- tabular data for the historical pumping at the resolution used to develop the model input datasets;
- tabular data and geographic information system raster and/or feature datasets of population density;
- tabular data and geographic information system raster and/or feature datasets of the recharge rates;
- tabular data and geographic information system raster and/or feature datasets of historical pumping information;
- geographic information system raster and/or feature datasets of water levels for the steady-state run and the beginning (1980), middle (1990), and end (1997) of the transient calibration run;
- geographic information system raster and/or feature datasets of final model parameters (e.g. horizontal hydraulic conductivity, vertical hydraulic conductivity, recharge, pumping rates) if different from distributions assembled during the conceptual model; and
- any other data used to develop the model.

Point data shall be delivered in two formats:

1. Microsoft Access 2003, and
2. ESRI Arc/GIS 9.1 (or later).

Interpreted data (for example, contoured data) shall be delivered in ESRI Arc/GIS 9.1 (or later) format. 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 2). All tabular data and geographic information system raster and feature datasets shall be delivered to the TWDB within the groundwater availability modeling source geodatabase schema provided to each contractor. The groundwater availability modeling source geodatabase schema defines file-naming protocol, database organization, and documentation of the tables, databases, and geographic information system spatial data (Attachment 2).

4.3 MODFLOW input files

All MODFLOW 2000 input files shall be submitted in ASCII format and the file format for Groundwater Vistas. The files for Groundwater Vistas shall also include ESRI geographic information system shape files of the:

1. model boundary;
2. county outlines; and
3. rivers, streams, and lakes.

Future users shall be able to:

1. run the model using MODFLOW 2000 from the Disk Operating System (DOS) prompt with the files provided and
2. run the model using Groundwater Vistas with the Groundwater Vistas files provided.

4.4 Final Report

The final report shall include the details of the conceptual model, input datasets, model construction, calibration, sensitivity analysis, and model results. There shall be a single report for each modeling project. TWDB intends to publish the final reports or summaries of the reports as TWDB numbered report(s). Therefore, the final report will be a reflection of the TWDB as well as the contractors. The final report for the TWDB model of the Trinity aquifer in the Hill Country area is an example of what is generally expected (Mace and others, 2000). Final approved report must follow Texas Board of Geoscientists guidelines (see http://www.tbpg.state.tx.us/index.html).

4.4.1 Report format

Each section of the submitted report shall address the data and analysis described in Section 3. Additional sections and subsections may be added to the submitted report to address aquifer-specific issues. Attachment 3 includes guidelines and suggestions for formatting documents and figures for TWDB reports. At a minimum, the final report shall include the following sections and subsections:

Executive summary: A brief summary of the modeling effort and discussion of model results.

1.0 **Introduction**: Describe the importance of the aquifer to the region and provides a general outline of the modeling study and report.

2.0 **Study area**

- 2.1 **Physiography and climate**: See Section 3.1.1.
- 2.2 **Geology**: See Section 3.1.2.

3.0 **Previous work**: Describe the previous modeling efforts and/or studies of the aquifer. Compare and contrast modeling efforts to each other and the new modeling effort as described in Section 3.1, as applicable.

4.0 **Hydrologic setting:** Discuss the information compiled and analyzed for developing the conceptual model (as discussed in Section 3.1) in the following subsections:

- 4.1 **Hydrostratigraphy:** See Section 3.1.3.
- 4.2 **Structure**: See Section 3.1.4.
- 4.3 **Water levels and regional groundwater flow**: See Section 3.1.5.
- 4.4 **Recharge**: See Section 3.1.6.
- 4.5 **Rivers, streams, springs, and lakes**: See Section 3.1.7.
- 4.6 **Hydraulic properties**: See Section 3.1.8.
- 4.7 **Discharge**: See Section 3.1.9.
- 4.8 **Water quality**: See Section 3.1.10.

5.0 **Conceptual model of groundwater flow in the aquifer:** Describe the concepts and assumptions of the aquifer that were used to guide the construction of the 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, faulting, lithology, and boundaries). This section shall include a figure summarizing the conceptual model and how the conceptual model was translated into the computer model.

6.0 **Model design**: Discuss the general attributes of MODFLOW and assembly of the model.

- 6.1 **Code and processor**: See Section 3.2.
- 6.2 **Layers and grid**: See Section 3.2.1.
- 6.3 **Model parameters**: See sections 3.2.1 and 3.2.2.
- 6.4 **Model boundaries**: See Section 3.2.3.

7.0 **Modeling approach**: Describe the approach, philosophy, and focus for calibrating the model (see Section 3.3 and overview of sensitivity analyses).

8.0 **Steady-State model**: Discuss the details of the steady-state calibration.

- 8.1 **Calibration:** Include a map showing the spatial distribution of water-level residuals for each layer, simulated water-level maps for each layer, a cross plot of measured and simulated water levels, and a report of the mean absolute error per layer and for the model overall. The water budget and how it compares to the conceptual model and hydrogeologic setting shall also be discussed in this section.

8.2 **Sensitivity analysis**: See Section 3.4.

9.0 **Transient model**: Discuss the details of the transient model calibration.

9.1 **Calibration**: Measured and simulated hydrographs from selected wells across the model area shall be presented. Contour maps comparing simulated water levels to maps of the measured water levels shall be presented and discussed for 1990 and 1997. The calibrated values of specific yield and storativity shall be reported.

9.2 **Sensitivity analysis**: See Section 3.4.

10.0 **Limitations of the model**: 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.

11.0 **Future improvements:** Indicate where additional improvements could be made to the conceptual model in collecting more data and to the model itself. Recommendations for how these issues could be addressed will be appreciated.

12.0 **Conclusions:** Summarize the modeling project and its results.

13.0 **Acknowledgments:** Acknowledge those organizations or specific individuals that assisted in the modeling project by supplying data, providing thoughtful discussion, or contributing more directly to the study.

14.0 **References:** All references cited in the report shall be included in the 'References' section following TWDB format.

Appendices: Model results per county (including water budgets for the end of the steady state and the end of the transient calibration period per county).

The following units shall be used in all data presentations:

- land area in square miles (mi^2);
- water volume in acre-ft (ac-ft);
- elevations relative to mean sea level (ft-MSL);
- demand and supply rates in acre-feet per year (ac-ft/yr);
- stream flows and reservoir releases in cubic feet per second (cfs);
- springflow 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); and
- recharge volumes in acre-feet (ac-ft).

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

4.4.2 Report figures

Drafted figures shall 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. If you use color figures, please keep in mind that the report may be photocopied or printed from the .pdf onto a black and white printer. For this reason, you should use symbols or patterns or make sure that colors print as different shades in grayscale. 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.

Minimum requirements are:

1. figures shall be designed such that a black and white printout is readable and understandable;
2. maps include a north arrow and a scale;
3. each figure has a caption that includes reference sources for the basemap or the included information; and
4. figures must follow Texas Board of Geoscientists guidelines.

Figures and tables required of the study area for the final report include:

Final Report Section 2.0:

- study area showing major towns and cities, county boundaries, major rivers and streams, major lakes, major roadways, location of the study area within Texas or any bordering states (if applicable), and the model boundaries;
- a map showing the location of the different Regional Water Planning Groups in the area;
- a map showing the location of the different Groundwater Management Areas in the area;
- a map showing the location of groundwater conservation districts in the area (documented with the date of the source reference);
- a map of the major river basins and major surface water features.

Final Report Section 2.1:

- a map of the delineated physiographic areas;
- a map of topographic elevation; and
- a map of climate classifications for the study area;

- a map of average annual precipitation over the study area in inches per year (1971 to 2000);
- a map of average annual temperature over the study area in degrees Fahrenheit (1971 to 2000);
- a map with several plots of average monthly precipitation measured at rain gages in the study area in inches per year (1971 to 2000);
- a map of average annual net lake or pan evaporation over the study area in inches per year (1971 to 2000); and
- a map of average evaporation or evapotranspiration, if available.

Final Report Section 2.2:

- a map of the surface geology;
- maps of spatially distributed geologic information used during the modeling study (showing the control data if possible);
- a map of the major structural and tectonic features in the area;
- detailed stratigraphic chart of aquifers in study area; and
- several geologic cross-sections through the study area.

Final Report Section 3.0:

- a map showing the extent of previous modeling efforts, if applicable.

Final Report Section 4.1:

- a schematic of the geologic units in the study area and the hydrostratigraphic units used in the model.

Final Report Section 4.2:

- maps of top and bottom elevations for each of the model layers including the control points, and
- maps of layer thickness for each of the model layers including the control points.

Final Report Section 4.3:

- maps of the potentiometric surface for each model layer for the steady-state, the beginning of the transient calibration (1980), the middle of the transient calibration (1990), and the end (1997) of the transient calibration including the control points; and
- several historical hydrographs demonstrating water-level fluctuations (including seasonal, if available) in the aquifer with a map indicating location of the wells.

Final Report Section 4.4:

- map(s) of estimated recharge rates, potential, factors, or coefficients.

Final Report Section 4.5:

- representative stream-flow hydrographs for the major streams in the study area with a map indicating gage locations;
- spring-flow hydrographs if appropriate with a map indicating spring locations; and
- hydrographs of lake levels if appropriate.

Final Report Section 4.6:

- histograms of hydraulic conductivity and (if appropriate) storativity and specific storage for each model layer;
- a map of hydraulic conductivity for each model layer; and
- net sand thickness maps, if applicable.

Final Report Section 4.7:

- bar chart(s) of yearly total historical groundwater usage;
- a map of rural population density; and
- tables of the historical pumping data according to major user group and summed over each county shall be included in the report.

Final Report Section 4.8:

- maps of water quality (total dissolved solids and any other constituents of concern).

Final Report Section 5.0:

- figure summarizing the flows in the conceptual model and how the conceptual model was translated into the computer model (for example, see Mace and others, 2000, fig. 50).

Final Report Section 6.2:

- maps showing the location of active cells in each of the model layers and the type of cell (e.g. lake, constant head, general-head boundary, drain, river, and inactive).

Final Report Section 6.3:

- a scatter plot of simulated hydraulic head and measured hydraulic head for the steady-state simulation, the simulation at the middle of the calibration period (1990), and the simulation at the end of the calibration (1997) period for each layer in the model; and
- maps showing the locations of the wells used to develop the above scatter plots.

Final Report Section 8.1:

- maps of the head residuals between simulated and measured water levels for each layer for the steady-state calibration including location of target wells;
- cross plots of measured and simulated water levels for the steady-state calibration;
- a table listing mean absolute error and the mean error for the steady-state calibration per layer; and
- steady-state calibration water budget.

Final Report Section 8.2:

- 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 section 3.4.

Final Report Section 9.1:

- table of range and mean of horizontal and vertical hydraulic conductivity and storativity as used in the calibrated model (if values differ from initially assigned values, please include initially assigned values as well as calibrated values);
- maps of the head residuals between simulated and measured water levels for each layer for 1990 and 1997 including location of target wells;
- cross plots of measured and simulated water levels for 1990 and 1997;
- a table listing mean absolute error and the mean error for the transient calibration per layer for 1990 and 1997;
- several hydrographs showing simulated and measured water levels for the transient calibration runs;
- water budget for 1990 and 1997;
- maps showing the distribution of any parameters adjusted during calibration of the model (for example, recharge, hydraulic conductivity, storativity, vertical hydraulic conductivity); and
- a table showing stress periods and corresponding time periods for combined transient model.

Final Report Section 9.2:

- several hydrographs demonstrating the sensitivity of water-level fluctuations to changes in important hydrologic properties of the model, also include additional plots, as applicable, discussed in section 3.4.

Sources of data/basemaps shall be clearly indicated on the figure or in the figure caption. Additional figures may be added as needed.

4.4.3 Report deliverables

There are three times when TWDB shall receive electronic copies of data used for the modeling effort and the deliverable report for review:

1. after completion of the conceptual model (conceptual report shall include Chapters 1 through 4, see Section 4.4.1);
2. after completion of the transient model (draft report shall include all information listed in Section 4.4.1); and
3. after completion of the project (final report shall include all information listed in Section 4.4.1).

For the conceptual report, and then later for the draft report, the contractor shall deliver to the TWDB:

- hard copies of the conceptual report or draft report,
- an Adobe Acrobat (pdf) file of the conceptual report or draft report for posting on the TWDB web site (broken in parts not to exceed 10 megabytes),
- all the related documented source and derived data in the appropriate geodatabase (see Attachment 2), and
- model input files (for MODFLOW-2000 and Groundwater Vistas with the draft report deliverable).

The Stakeholder Advisory Forum participants and the TWDB shall have two months to comment on the conceptual report. Stakeholder Advisory Forum participants and the TWDB shall have another two months to comment on the draft report. The contractor will have two months to address comments from the draft report (as well as the comments from the conceptual model review period) before issuing the final report.

At the end of the study, the contractor shall deliver to the TWDB:

- hard copies of the final report,
- digital copies of the final report including all figures,
- Adobe Acrobat (pdf) file(s) of the final report for posting on the TWDB web site (broken in part not to exceed 10 megabytes),
- individual digital copies of each of the figures in the report (see Section 4.1 for details),
- all source and derived model data in digital format in the appropriate geodatabase (see Attachment 2), and
- model input files (for MODFLOW-2000 and Groundwater Vistas).

The TWDB plans to publish the final reports or summaries of the final reports for the models as TWDB numbered reports. Therefore, it is important that the delivered reports are of high quality and that we receive the proper files to publish the studies. Consistent geologic, hydrologic, and technical terminology must be used throughout each report. Each report shall have an authorship list of persons responsible for the studies: firm or agency names as authors will not be acceptable. Final approved report must follow Texas Board of Geoscientists guidelines (see http://www.tbpg.state.tx.us/index.html) and shall be sealed by either a Professional Engineer or Professional Geoscientist.

4.4.4 Presentations and Web Publishing

During the course of the project, the consultant will provide digital copies of presentations related to the model to assist us in promoting the modeling efforts and informing the public (in powerpoint and Adobe Acrobat formats). Geodatabases, MODFLOW files, and the report may all be posted on the TWDB web site and will be distributed to interested parties on compact discs or digital video discs. TWDB will maintain centralized ownership and maintenance of the models.

5.0 Project Management

The TWDB shall receive monthly letter reports for the duration of the modeling projects summarizing progress on the project. The contractor shall also hold project review meetings with the TWDB at important points in the modeling process. These important points include:

- the beginning of the project,
- after development of the conceptual model,
- after the steady-state calibration of the model,
- after transient calibration, and
- after we have reviewed the draft report.

Advancement of the project to the next phase of work described above is contingent on TWDB Executive Administrator 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 will also attend the Stakeholder Advisory Forums.

6.0 Project Schedule

We expect that the conceptual model, all data collection associated with the development of the conceptual model, and a draft copy of the conceptual model sections of the final report (this includes the 'Study Area,' 'Previous Work,' 'Hydrologic Setting,' and 'Conceptual Model of Groundwater Flow in the Aquifer' sections of the report [see Section 5.4]) will be completed by the date noted in the contract. The draft copy of the report will be delivered by the date noted in the contract, as well as all associated data and model files. Please note that part of the funds will be available prior to September 1, 2008 and the remainder after September 1, 2008.

7.0 References

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Fenske, J.P., Leake, S.A., and Prudic, D.E., 1996, Documentation of a computer program (RES1) to simulate leakage from reservoirs using the modular finite-difference ground-water flow model (MODFLOW): U.S. Geological Survey Open-File Report 96-364, 51 p.

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Attachment 2:

Data Model for the Groundwater Availability Models

1.0 Introduction

To capture the various data types and sources that go into Groundwater Availability Models (GAMs), we have developed the groundwater availability modeling data model. A data model is a logical construct for storage, organization, documentation, and retrieval of digital information. The new groundwater availability modeling data model is built upon the Environmental Systems Research Institute, Inc. (ESRI) ArcGIS personal geodatabase (ESRI Press, 2004), which has been optimized by ESRI to manage related spatial and nonspatial data. The groundwater availability modeling data model consists of three principle data products expected from each groundwater availability modeling project: (1) the conceptual model source and unique derivative datasets within a Source geodatabase, (2) the source and unique derivative model grid pumpage values within a Pumpage geodatabase, and (3) the final MODFLOW specific input data files. An optional MODFLOW geodatabase will be made available for organizing and storing the final calibrated numerical model grid values (contact the TWDB contract manager).

The source and unique derivative datasets consist 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 values. The source and unique derivative model grid pumpage values consist of source data provided by TWDB within the Pumpage geodatabase and all derivative model grid pumpage values used for the final model calibration. The final MODFLOW specific data files consist of data files formatted for both MODFLOW-2000 and Groundwater Vistas. The grid values consist of the final grid-cell input data used for the calibrated steady state and transient numerical models.

Contractors shall use the groundwater availability modeling coordinate statewide mapping system to geo-reference all spatial data used in the modeling project. **It is extremely important and a requirement that all source data be projected into the groundwater availability modeling coordinate statewide mapping system prior to generating any derivative and/or model input data sets**. The groundwater availability modeling coordinate statewide mapping system provides complete statewide coverage with an equal-area projection that minimizes the spatial distortion of area. The projection parameters shown in Table A2-1 shall be used for the groundwater availability modeling coordinate statewide mapping system. The groundwater availability modeling personal geodatabase schemas will be preset with the correct coordinate and projection parameters so that spatial data with a predefined coordinate system will be automatically projected into the groundwater availability modeling coordinate system during data loading.

Table A2-1. Projection parameters to be used for the groundwater availability modeling coordinate statewide mapping system.

Groundwater availability modeling coordinate statewide mapping system

Projection :	Albers Equal-Area		
Units of Measure :	US Survey Feet		
Horizontal Datum :	NAD83	or	North American Datum 1983
Vertical Datum :	NAVD88	or	North American Vertical Datum 1983
Spheroid :	GRS80		
Longitude of Origin :	-100.00000	or	100^{o} : 00' West
Latitude of Origin :	31.25000	or	31^{o} : 15' North
Lower Standard Parallel 1 :	27.50000	or	27^{o} : 30' North
Upper Standard Parallel 2 :	35.00000	or	35^{o} : 00' North
False Easting :	1,500,000 (meters)	or	4,921,250 (US survey feet)
False Northing :	6,000,000 (meters)	or	19,685,000 (US survey feet)

1.1 Data content and organization

An enormous amount of spatial and nonspatial data will be generated by each groundwater availability modeling project. To facilitate management and public distribution of project datasets, the TWDB will provide each contractor with empty personal geodatabase schemas to organize and store source and derivative information for the conceptual model, and for model grid pumpage values. A personal geodatabase is a relational database that stores spatial and nonspatial data in a specialized Microsoft Access database.

ESRI ArcGIS 9.0 or later software is required to work with personal geodatabases. The schemas will contain empty feature datasets, feature classes, object classes, tables, and raster datasets ready to be loaded with project data. The contractor shall use the geodatabase schemas for organizing, processing, and archiving all groundwater availability modeling project data. The groundwater availability modeling geodatabases are extendable, but prior written approval from the Groundwater Resources Division Director shall be obtained before any changes to the preset schemas 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 derivation processes in the report, can be used to reproduce all input parameters for the gridded data in the model. The Pumpage geodatabase facilitates spatial distribution of pumpage from statewide TWDB datasets to a format that can be directly transferred to model grid cells. An optional MODFLOW geodatabase, intended to store all the input data needed to run the final calibrated steady state and transient groundwater availability modeling models with the MODFLOW-2000 code, will be made available upon request. If for any reason the source or derivative data is not compatible with the geodatabase schema, then that information shall be provided to TWDB in another format pre-approved by the Groundwater Resources Division Director that complies with software requirements noted in attachment 1, section 4.1.

1.1.1 Source and derivative geodatabase schema
Source and unique derivative information shall be organized in the groundwater availability modeling Source Data 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 source geodatabase to reproduce critical model input. Vector spatial data shall be contained in feature classes that are organized into feature datasets. Each feature dataset contains thematically related point, line, and polygon feature classes. Nonspatial tabular data shall be stored in geodatabase tables or object classes, which are not contained within feature datasets but participate in relationships with corresponding spatial features. Raster data (such as interpolated or gridded surfaces; digital elevation models; satellite or other airborne imagery; and digitally scanned map graphics, logs, and cross sections) shall be managed in the geodatabase as raster datasets or raster catalogs. Raster datasets, although managed by the geodatabase, are stored outside of the geodatabase, effectively allowing a personal geodatabase to be larger than the two-gigabyte limit of typical Access database files. The geodatabase schema will also contain rules to constrain and standardize project data.

1.1.2 Pumpage geodatabase schema
Pumpage shall be processed and distributed spatially within the groundwater availability modeling pumpage geodatabase. The geodatabase maintains traceability between input source data (well records, master water-use tables) and output tables and spatial features. The geodatabase comprises tables, spatial features, and geoprocessing (GP) tools. Some input data, such as wells and land use, must be prepared by the contractor. The rest of the input data, such as master pumpage tables, are built into the geodatabase and ready to use. The geoprocessing tools calculate spatially distributed pumpage volumes per square mile of land use, distribute point specific pumpage to individual wells, and maintain key identifying fields for relating output data to corresponding input data. The geoprocessing tools may be run repeatedly using different input data sets each time. Spatial distribution of pumpage will occur within the geodatabase. Vertical distribution of pumpage to model layers and assignment of pumpage volumes to grid cells will occur outside of the Pumpage geodatabase.

1.1.3 MODFLOW specific data files
The MODFLOW specific data files shall be organized into two primary directories or folders, one for MODFLOW-2000 standard ASCII files (Harbaugh and others, 2000) and the other for Groundwater Vistas 4.0 compatible files (Rumbaugh and Rumbaugh, 2004). Each directory or folder shall also contain: (1) a “files.txt” file containing a full list of each of the files in the directory or folder, (2) a “stress-periods.txt” file listing each stress period and its associated time length and date, and (3) a “readme.txt” file with a discussion of special instructions, tips, or information needed to use the files.

1.1.4 Model grid feature dataset
A model grid feature dataset shall be located within the Source and derivative geodatabase and consist of a polygon feature class of model grid cells and a point feature class of model grid cell

nodes. The polygon feature class shall consist of square polygons representing a finite difference model grid with uniform sized cells no larger than one mile by one mile. The point features shall be centered on each of the polygon grid cells. A unique Cell_ID or relationship/index key consisting of a seven-digit integer data type and based on the layer, row, and column shall 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 groundwater availability modeling projects are limited to the following:

Layers: 9
Rows: 999
Columns: 999

1.1.5 MODFLOW geodatabase schema

Using a geodatabase schema to organize and store model grid values is optional. The groundwater availability modeling 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-2000 input parameters and for time-series variables linked with relationship classes.

1.2 Data documentation

All datasets used for groundwater availability modeling projects shall include metadata that documents the content, data structure, source(s), date(s), quality, and other characteristics of the data within the geodatabases. Metadata shall be created using the Federal Geographic Data Committee (FGDC) metadata editor within ESRI's ArcCatalog. The TWDB-provided schemas include some basic metadata, which shall be extended by the contractor to completely document all source and derivative data. The contractor shall be responsible for making sure 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.

1.3 References

ESRI Press, 2004, ArcGIS 9 Building a Geodatabase: ESRI Press, 382 p.

Harbaugh, A. W., Banta, E. R., Hill, M. C., and McDonald, M. G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model—User guide to modularization concepts and the Ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Rumbaugh, J. O., and Rumbaugh, D. B., 2004, Guide to using Groundwater Vistas Version 4: Environmental Simulations Inc., 366 p.

Attachment 3

[1]Formatting Guidelines for Texas Water Development Board Reports[2]

Report[3]

by
Robert E. Mace, Ph.D., P.G.
Sarah C. Davidson
Edward S. Angle, P.G.
Merry L. Klonower[4]

Texas Water Development Board
P.O. Box 13231, Capitol Station
Austin, Texas 78711-3231
June 2007

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[1] This page is the report cover, so it does not figure into the page count.

[2] On the cover page, you may use artistic license in choosing a typeface and font size for the title. You will also want to include some sort of graphic.

[3] The TWDB Communications staff will place the report number here.

[4] List all authors here. If outside contractors wrote the report, their names should appear here without noting their affiliation. Affiliations will be displayed on the title page.

[1]Texas Water Development Board

Report ##[2]

Formatting Guidelines for Texas Water Development Board Reports

by[3]
Robert E. Mace, Ph.D., P.G.
Sarah C. Davidson
Edward S. Angle, P.G.
Texas Water Development Board

Merry Klonower
Some other agency

June 2007

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[1] This is the title page and will be page i, but no page number will appear.

[2] The report number will appear here. This number is assigned by the TWDB Communications staff and TWDB editor. Contractors do not need to include a report number

[3] This is the list of authors. As an example, I have included names and agencies as if the authors were from both TWDB and outside organizations. If this is an entirely in-house publication, then you would not need the affiliations.

This project was funded in part by the U.S. Bureau of Reclamation's Water 2025 Challenge Grants for States and by the Texas Water Development Board.[1]

[1] If your project received outside funding, then you need to acknowledge the funding source here, similar to this example. If it is solely funded by TWDB, no funding source needs to be mentioned and this page would instead say: This page is intentionally blank.

Texas Water Development Board

Published and distributed
by the
Texas Water Development Board
P.O. Box 13231, Capitol Station
Austin, Texas 78711-3231

June 2007
Report[1]
(Printed on recycled paper)

[1] Add report number here. This page should always be an odd-numbered page. This page is included only in final TWDB reports. ***It will not appear in contract reports or draft reports.*** Contract reports will begin on a title page on page i and a table of contents on page iii.

This page is intentionally blank.[1]

[1] This needs to appear on every blank page.

Table of Contents[1]

List of Figures[2]

List of Tables

[1] The table of contents is always on an odd-numbered page. Some reports may have special front matter pieces, such as a "Note from the Editor." These should precede the table of contents.

[2] The list of figures immediately follows the table of contents, followed by the list of tables.

1 Executive summary

In an effort to offer its readers professional, high quality reports, the Texas Water Development Board (TWDB) has developed formatting guidelines for its staff and contractors. These guidelines include information on text, graphic, and referencing standards.

Most reports will include an Executive Summary, which will be the first numbered heading in the report. An effective summary should be no longer than 10 percent of the document length. (In other words, an Executive Summary for a 100-page paper should be 10 pages or less.) Because some readers will only read the Executive Summary, write it so that it can be read independently of the report. Do not refer to tables and figures from the report text in the Executive Summary and always include any significant recommendations and findings.

More than one reader will share Winston Churchill's sentiment: "Please be good enough to put your conclusions and recommendations on one sheet of paper at the very beginning of your report, so that I can even consider reading it." Your Executive Summary may determine whether someone reads the rest of your report.

2 Introduction[1]

The purpose of this document is to describe the required format of Texas Water Development Board (TWDB) reports, both those written by in-house staff and those by contractors. Our reason for standardizing the format is to provide a consistent and, therefore, familiar format to our readers. 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 the authors and TWDB.

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. TWDB staff can find this template at: V:\PlanShare\Report templates and standards\Authors_Template_061807.dot. This formatting document is found at V:\PlanShare\Report templates and standards\TWDB report standards_061807.doc.

3 Formatting your report

The TWDB format is designed for simplicity. For example, we use Times New Roman for all text. (The exception to this is graphics. Please use Arial in all figures.) We use 12 point, single-spaced text, left justification for paragraph text, 16 point bold for first-level headings, and 14 point bold for second-level headings. Page numbers are centered at the bottom of the page. A

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[1] This is a level 1 heading.

Note: The header at the top of the page should begin on p. 1 and include the report number, if applicable, and title. If necessary, shorten the title. The header is 10 pt. Times New Roman, centered.

header with the report number (if applicable) and name should appear at the top of each page, beginning with page 1.

3.1 Text[1]

The best way to format your document is to use the styles described and embedded in the template document (Authors_Template_061807.dot). Contractors may request this template from TWDB. To use the template file, open it in Word (make sure *.dot is listed under Files of type) and save it as a .doc file**.** (The easiest way to use it is to save it as a .doc file, then delete all the text in it. You can then start typing your material, and the template will be in place.) 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 Body Text, Heading 1, References, and bulleted list). 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.

You may also use this document, which is based on the same template as the stylistic foundation of your paper. To use it, erase the text and start typing your own text. In addition, a list of the formatting styles is included in the appendix of this document.

Because different computers have different defaults, when you use this document or the Authors_Template, your computer may add its own default styles to the template. If that happens, it can make formatting your document more difficult. To be certain that you are using only the TWDB styles, compare the styles that appear in your Styles and Formatting window with those in the screen capture on the following page (Figure 3-1). *Delete any styles in your formatting window that do not appear in this screen capture to eliminate unwanted default styles.*

The only formatting item that does not appear in the Styles and Formatting window is the caption format. See 3.3.2 for a discussion of captions.

1 This is a level 2 heading.

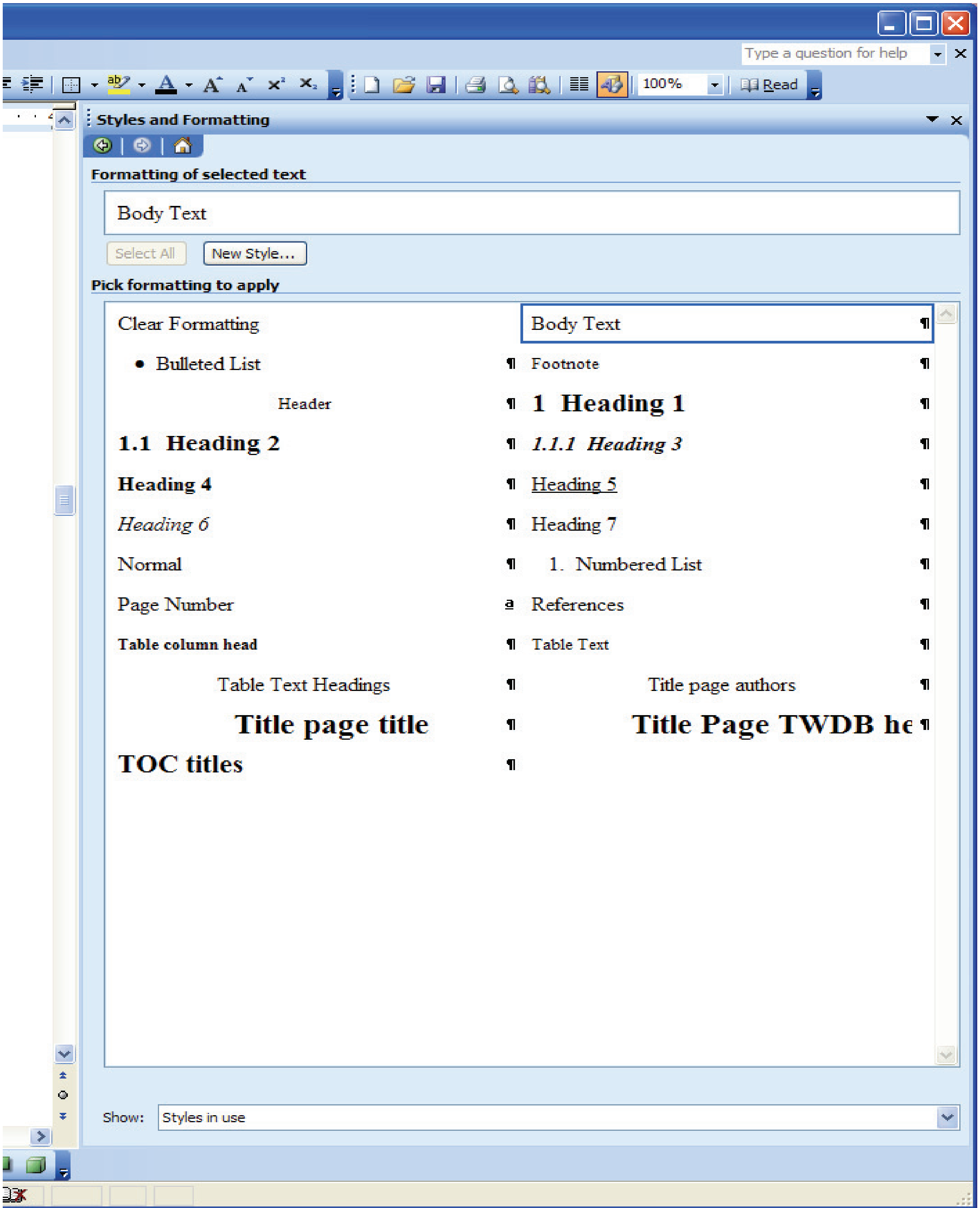

Figure 3-1. **TWDB formatting styles.**

3.1.1 Title[1]

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 each major word (usually any word that is four letters or more). Do not capitalize words like "the," "and," "to," and "of."

3.1.2 Headings

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. 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 neccessary. Please avoid stacked headings (for example, a Heading 1 followed immediately by a Heading 2), and capitalize only the first word of headings—never use all caps.

Using the headings in the Styles and Formatting window allows Word to automatically number your headings and then renumber them if you add or delete headings. They are also the basis for your table of contents.

3.1.3 Table of contents

The table of contents can be automatically generated from the level 1 and 2 headings. To generate a table of contents, place your cursor where you want it to insert it, go to Insert→Reference→Index and Tables. Choose the table of contents tab and click on OK.

3.1.4 Margins

Use 1-inch margins on all four sides of the page.

3.1.5 Page numbers and page headers

Page numbers are centered at the bottom of the page in 12 pt. Times New Roman. Please use roman numerals for the front matter of your report (the title page, Board member page, table of contents, and lists of figures and tables). Begin with page 1 on the first page of text (normally the Executive Summary). Page headers are 10 pt. Times New Roman, centered at the top of the page and also start on page 1. They should include the report number and name, using this format: TWDB Report 00: Title. If there is no report number, the header will include only the title.

---

[1] Level 3 heading

3.1.6 Report numbers

TWDB has a numbered report series, and many of its publications are included in this series. Very often contract reports are converted to TWDB numbered reports once they are submitted and reviewed. The numbers for these reports are generated by the TWDB Communications office after the report has been submitted and accepted for editing.

3.2 Front matter

The first few pages of your document should include in this order: title page, Board member page, and table of contents (which will include a list of figures and list of tables). Each of these pages should begin on an odd-numbered page. Any special pages, such as a "Note from the Authors," should be inserted between the Board member page and the Table of Contents on an odd-numbered page. *Please note that contractors should not include a Board member page.* TWDB staff should not include a Board member page in draft reports. Once a report is accepted for TWDB editing, the Board member page can be added.

3.3 Figures and photographs

To publish professional-looking graphics, **we need all originals to be saved at 400 dots-per-inch** (dpi) and in grayscale, if possible, or in the CMYK color format if color is necessary. Excessive use of color, especially color graphics that do not also work in grayscale, will prevent us from publishing your report as a TWDB numbered report (color reproduction costs can be prohibitive). Preferred file formats for your original graphics are Adobe Illustrator (.ai), Photoshop (.psd), EPS with .tif preview, .jpg, .png, or .tif files. Please do not submit Microsoft Excel graphics. Because it is difficult to create well-designed, polished graphics with this program, we prefer Adobe Illustrator. It allows us more flexibility in adjusting fonts, colors, positions, and other graphic characteristics.

Refrain from using low resolution .jpg or .gif files. Internet images at 72 dpi are unacceptable for use in reports.

All graphics shall 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.

3.3.1 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). Avoid landscape orientation because it makes the report more difficult to read. 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 in the report after being called out in the text. *Within the graphics, please use Arial typeface.*

3.3.2 Captions

Because we cannot edit captions embedded in figures, please include a caption for each graphic in Word. For figures and photographs, the caption should appear below the graphic, flush left in 10 point boldface Times New Roman. Table captions, however, should appear above the tables, flush left and also in 10 pt. boldface Times New Roman.

Automatic caption features and lists of figures and tables

This document is set up to take advantage of automatic caption features for lists of figures and tables. To generate a caption, go to Insert→Reference→Caption. You will need to select whether it is a table or figure caption. The menu will show you the appropriate caption number. Click on "OK" and the caption number will be inserted in your document in the correct format. Then type in your caption. It will generate the correct fonts as you type.

It is important to use this automatic feature because it will generate the lists of figures and tables for the table of contents. To create these lists, go to Insert→Reference→ Index and Tables. Then select the list of figures or list of tables and click on ok. This will fill in your lists for you. Because this feature picks up the entire caption, most of the time you will have to edit the entries in the Lists of Figures/Tables to make them more concise. If you need to update these lists later to reflect changes, place your cursor outside the lists and press F9.

3.3.3 Creating publication-quality graphics

When designing a graphic, make sure that it (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 at the end of this document for examples). Edward R. Tufte's books on presenting information (Tufte, 1983; 1990; 1997) are great references on good graphic design. Figure 3-2, Figure 3-3, and Figure 3-4 are examples of properly formatted, easy-to-understand graphics. Do not include fonts that are less than 7 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, 400 dpi will make a clear image. 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.

Figures and photographs should be in grayscale. Because color greatly adds to the cost of printing, we are trying to keep it to a minimum. Also remember that your report may be photocopied, scanned, or downloaded and printed in black and white. For this reason, you should use symbols, patterns, and colors that 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 10-1). This way your figures will be useful even as a photocopy.

If you need help with your graphics or have questions, please contact the TWDB graphics department at (512)936-0129.

3.3.4 Consistency

As readers move within a graphic or from one graphic to the next, they expect to see consistent fonts and font sizes. In TWDB reports, all figures should use Arial, and point sizes should be the same throughout the document. Point sizes should be no smaller than 7 pt. See Figures 3-2 and 3-3 for further information.

3.3.5 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. It is often time consuming and expensive to gain permission to reproduce them.

3.3.6 GIS and graphics

When exporting graphics or maps out of a geographic information system such as ArcInfo, please be sure to export your graphics and maps in a raster format such as .jpg or .tif (see guidance above). If you export in a vector format, such as Windows Metafile, there is a good chance that your graphics will not work on all computers. Because geographic information systems often use specialized font sets for symbols (such as for point data or north arrows), readers would have to have the same specialized fonts to see the graphics and maps properly. By saving your graphic and maps in a raster format, you have essentially turned them into photographs that no longer require specialized fonts.

3.3.7 Figure formatting summary

- Place caption underneath figure, flush left
- Capitalize the first word of the caption.
- Capitalize only the first word in the axis labels and tags (unless they are proper names).
- Place reference citations, if needed, within parentheses at the end of the caption. Do not cite TWDB if it is the only source of data.
- Use abbreviations, acronyms, and symbols sparingly. If needed because of limited space, please define them.
- Use Arial typeface.

- Use consistent point size for figure text, such as axis labels. Point sizes should be no smaller than 7 pt.
- Use 400 dpi resolution for graphics.
- Use a maximum graphic width of 6.5 inches.

3.3.8 Figure Examples

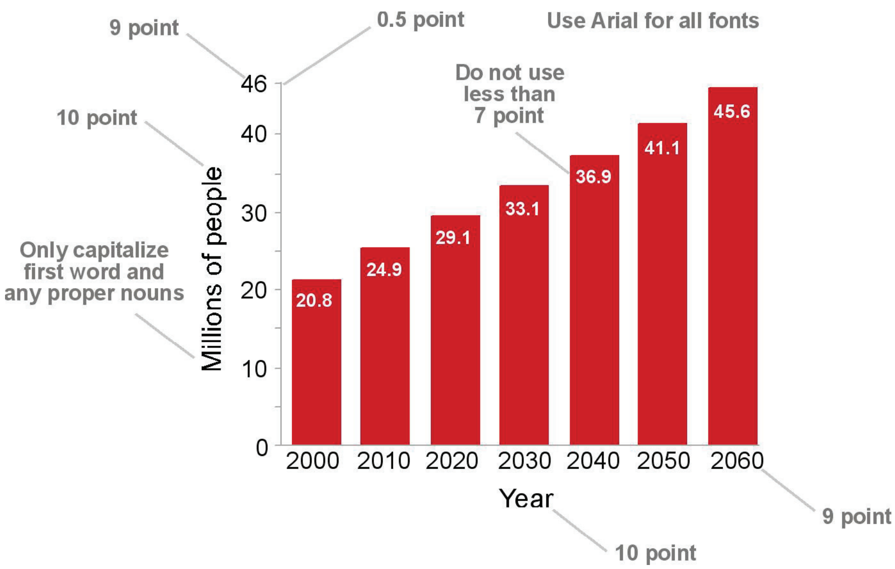

Figure 3-2. Font and design expectations for a bar chart (author, date).

Note that there are no grid lines. If a reference were necessary, it would go in parentheses before the period.

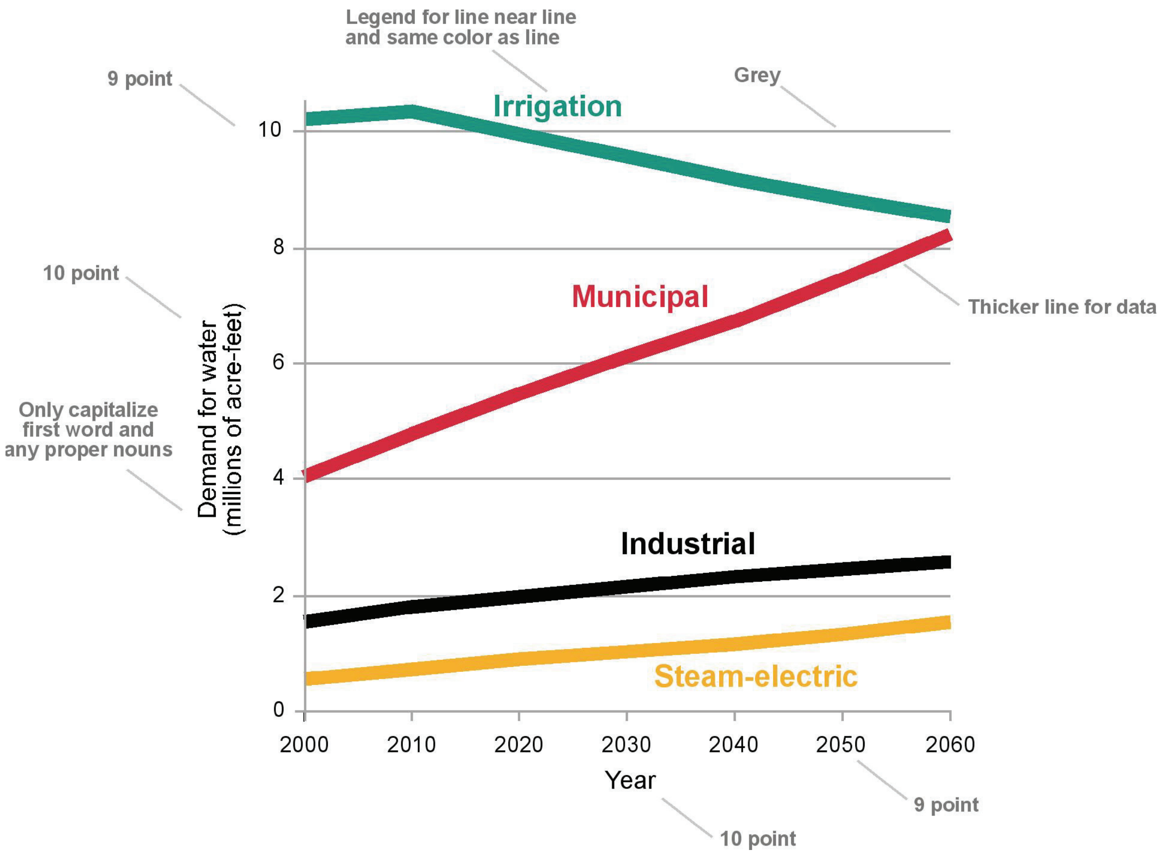

Figure 3-3. **Font and design expectations for a line chart (data from TWDB and author, date; author, date).**

Note that there are grid lines in a line chart. Also note the use of multiple citations in the caption.

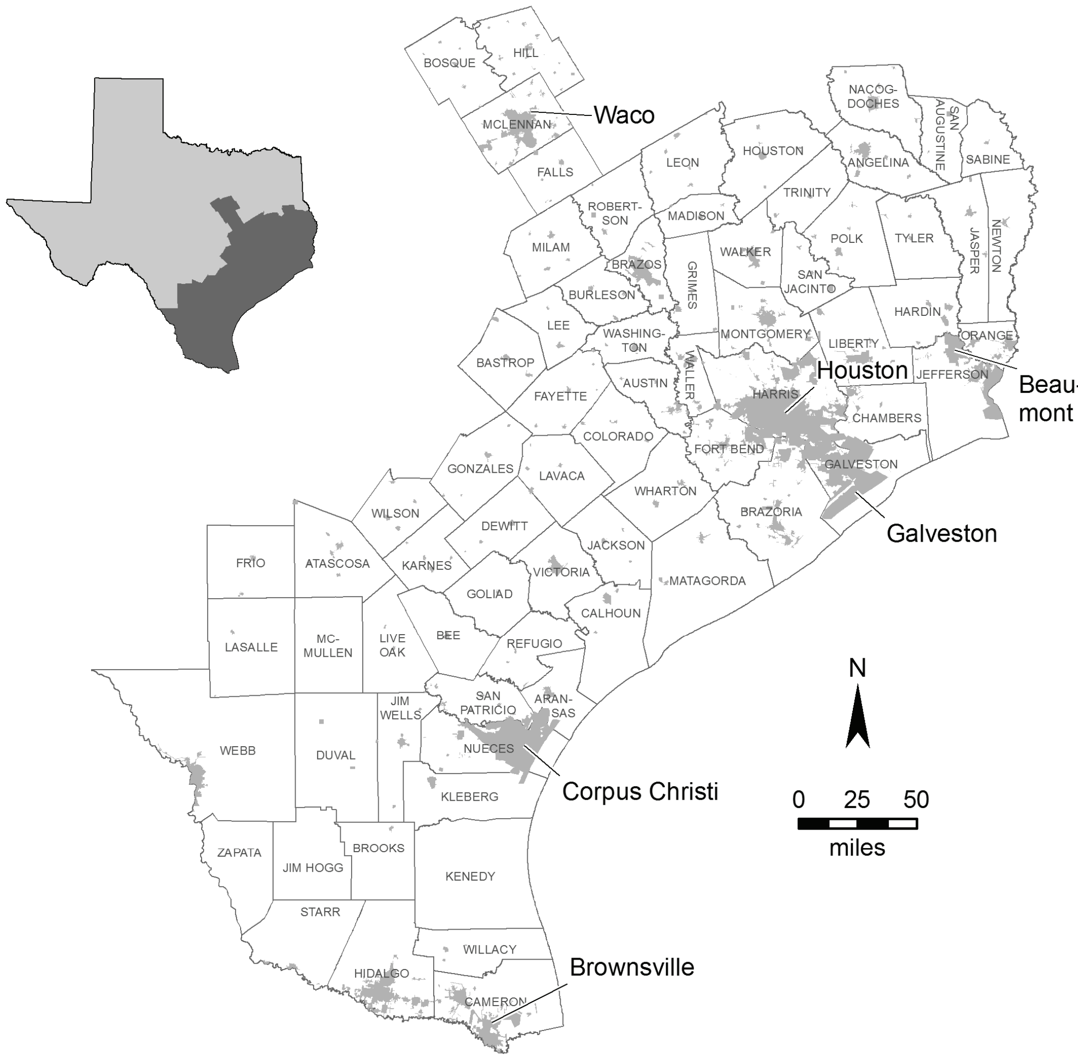

Figure 3-4. **A sample subject area map, giving the reader enough information to understand the location being discussed in this conference. For map figures, be sure to include a north arrow to orient the reader, a scale, and, if needed, a submap that places the figure in greater geographic context. 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 7 points.**

3.4 Tables

Tables should be created in Microsoft Word (Table 3-1). They should use outlining and bold font only to emphasize headings, totals, or other important points. All table text is in Times New Roman.

Table 3-1. A sample table. Note caption above table.

	Year and volume (acre-feet)[a]							
Column head	**1950**	**1980**	**1990**	**2000**	**1980**	**1990**	**2000**	**%GW**[b]
Table text	16,015	22,441	23,340	25,926	81,196	144,522	66,083	97.4
Winkler	10,064	9,944	8,626	7,173	8,356	3,171	5,516	99.9
Total:	255,811	549,592	660,934	754,099	621,194	310,308	447,935	

Note: Any explanatory table information should immediately follow the table.

Source: USGS (2000) Any table source should be next. (Please note this is not really USGS data.)

[a] Please use superscript letters for table footnotes. A footnote should look like this, using 10 point Times New Roman. Table headings are 12 point (the Year and volume heading). Table text is 10 point.

[b]%GW = percent groundwater. It is preferable to avoid abbreviations and acronyms. However, when they are necessary because of limited space, be sure to explain them.

3.4.1 Table formatting summary

- Justify numbers by their decimal points.
- Use commas beginning with thousands (1,000, 3,500, 10,000).
- Place reference information at the bottom of the table. If the table includes information generated solely by TWDB, it does not need a reference.
- Use Times New Roman for all text.
- Use 12 point for table headings and 10 point for table text.
- Capitalize only the first word of the caption and only the first word of any column and row heads and labels.
- Place caption flush left above the table in 10 pt. bold Times New Roman. Place a period at the end of the caption.
- Number tables consecutively (Table 1, Table 2). In long papers with numerous sections, number the tables with the section numbers (Table 1-1, 1-2, 2-1, 2-2, 2-3, and so on).
- Use acronyms and abbreviations sparingly. If you must use them because of limited space, define them at the bottom of the table.
- Avoid using vertical grid lines.

4 Units

Measurements should be in English units. Metric units may be included in parentheses after the English units; however, if you include metric units, you should include them for all English measurements.

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 Web site at http://stratigraphy.org/chus.pdf.

5 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.

5.1 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). If the author is an organization you may use an acronym and then spell it out in the Reference list, for example (TGPC, 2000). See the last entry in the list of references for the bibliographic entry.

5.2 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 http://www.nwrc.usgs.gov/lib/lib_sta.html (a link to the chapter "Preparing references for Survey reports," p. 234–241, is found here). 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. However, if you do need to use them, please include a date accessed.

6 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). TWDB staff members should use a routing slip to send the report through its appropriate channels. It is available at V:\PlanShare\Report templates and standards\Report routing slip_041607.doc.

7 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.

8 Acknowledgments

Be sure to acknowledge the people and entities that assisted you in your study and report. If there was an outside funding source, you will need to include them here, as well as on page ii. 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 and Ian Jones for providing Figure 10-1.

9 References[1]

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9.1 Examples of references

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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, variously paginated.

FAS (Federation of American Scientists), 2006, Resolution comparison: Reading license plates and headlines, http://www/fas/org/irp/imint/resolve5.htm, accessed March 2007.[2]

[1] Please note there are no spaces between author initials in the reference list.

[2] This is not an actual Web address, but an approximation of one for example purposes only.

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

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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.

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For more examples of references, see p. 239–241 of "Suggestions to Authors of the Reports of the United States Geological Survey" at http://www.nwrc.usgs.gov/lib/lib_sta.html.

10 Appendix

If you have an appendix in your document, it should be the last numbered section of the report.

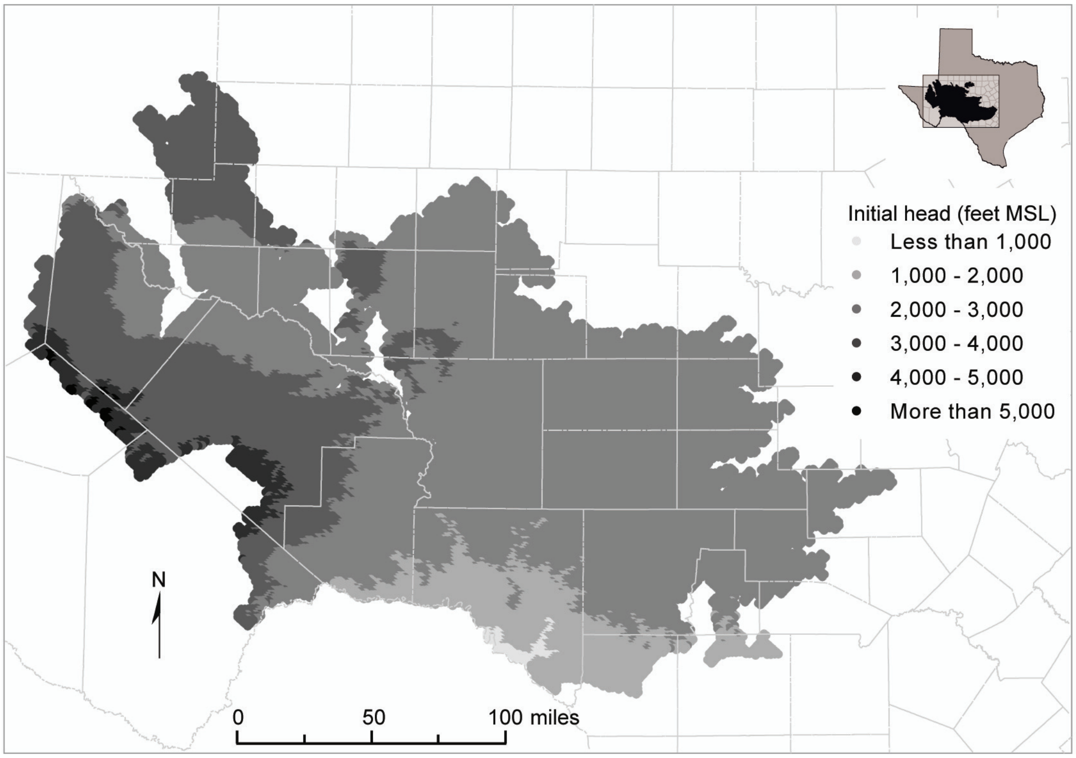

Figure 10-1. Initial hydraulic heads used in model simulations for layer 1. Note the use of grayscale shading to show differences. MSL = mean sea level.

Use abbreviations and acronyms only when necessary, and always define them.

Title page TWDB heading 22 pt.; 1.5" indent

Title page title 22 pt.; 1.75" indent

Title page authors: 12 pt.; 1.75" indent

11 Style specifications for text

All text is in Times New Roman.

12 Heading 1

16 pt. bold; no left indent; hanging indent 0.3 inches; 12 pt. space before; 6 pt. space after; keep with next; outline numbered, numbering style 1,2,3

12.1 Heading 2

14 pt. bold; no left indent; hanging indent 0.4 inches; 12 pt. space before; 6 pt. space after; keep with next; outline numbered

12.1.1 Heading 3

12 pt. bold italic; no left indent; hanging indent 0.5"; 12 pt. space before; 6 pt. space after; keep with next; outline numbered

Heading 4

12 pt. bold; no indent; 3 pt. space before; 3 pt. space after; no outline numbering

Bulleted List

- Left indent 0.25 inches
- Hanging indent 0.25 inches
- 3 pt. space before and after

Numbered list

3. Left indent 0.25 inches
4. Hanging indent 0.25 inches
5. 3 pt. space before and after

Table 12-1. Caption 10 pt. bold; hanging indent 1"; 18 pt. space before; 12 pt. space after; tabs 1"; automatically update. Table captions precede the table. Figure captions are placed below the figure.

	Year and volume (acre-feet)							
Column head	**1950**	**1980**	**1990**	**2000**	**1980**	**1990**	**2000**	**%GW[b]**
Table text	16,015	22,441	23,340	25,926	81,196	144,522	66,083	97.4
Winkler	10,064	9,944	8,626	7,173	8,356	3,171	5,516	99.9
Total:	255,815	49,592	660,934	754,099	621,194	310,308	447,935	

Table text headings: 12 pt.; single spacing; centered

Table column heads: 10 pt. bold; single spacing

Table text: 10 pt.; single spacing

References: No left indent; hanging indent 0.25 inches; 6 pt. space before

Header: 10 pt. centered (should contain title of report, shortened, if necessary)

Footer: 12 pt. centered

Footnotes:10 pt.; 3 pt. space after