Guidelines for Aquifer Testing and Hydrogeologic Reports

Southwestern Travis County Groundwater Conservation District
Travis County, Texas

Adopted by Board – November 11, 2020

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1.0 Basis and Applicability of These Guidelines

District Rule 3.4(A)(4) requires an applicant for a) a new Operating Permit for either a previously installed well or a proposed new well, b) certain alterations to a previously installed well, and/or c) certain amendments to an existing Operating Permit to conduct, analyze, and report to the District the results of prescribed aquifer tests in a technical report with prescribed content. The Report must address the potential hydrogeological impacts associated with the proposed groundwater production and is a required component of administratively complete applications for such requested authorizations.

The guidelines in this document describe how the aquifer tests must be conducted, how the test results are to be analyzed, and how the hydrogeologic information is to be reported. This document is complementary to the Well Drilling Authorization/Modification, and Operating Permit applications. The content of this document is therefore regulatory in nature and should be considered by applicants as required for an administratively complete application unless specifically modified in writing by the District General Manager. This guidance is provided primarily to assist applicants comply with the intent of District Rules and if any differences between the provisions of this document and the District Rules are perceived or imputed, the Rules shall take precedence.

Under current Rules, all those wells, whether "Existing Wells" or "New Wells" as defined by District Rules, that are or may be required by the District to obtain an Operating Permit from the District are required to conduct aquifer tests and prepare hydrogeologic reports. For wells that are to be authorized under Non-exempt Domestic Use General Permits by Rule, only proposed "New Wells" are required to perform aquifer testing and even so only to a limited extent, as described in Section 2.1, Tier 1 Wells. Exempt wells, whether "Existing Wells" or "New Wells", are not subject to this guidance and are not required to perform and report aquifer tests for regulatory purposes.

This version of the Guidelines document is the initial version and takes effect upon adoption by the District Board. Its requirements are applicable until the document or its applicability is subsequently amended by Board action. As the District learns more about the hydrogeologic characteristics of the District's aquifers and how its groundwater resources are utilized, it should be expected that these guidelines will be amended to cost-effectively manage those resources.

2.0 Scope of Aquifer Testing and Hydrogeologic Reporting

Hydrogeologic studies provide essential baseline information for water-resource management for both the District and the permittee. Aquifer tests are a key component of hydrogeologic studies, however as Butler (2009) states, "an assessment of the response of an aquifer to pumping over the long term should not solely depend on information from a pumping test of

limited duration; one must use other information on the regional hydrogeology, and so forth, to make that determination." The overall goal of these requirements is to provide data and estimates of aquifer properties, water levels, water chemistry, and analysis of impacts of a well, especially larger wells, in the given hydrogeologic setting.

To achieve this goal, the aquifer test must be performed on previously installed or test wells located or drilled on the property in question and in the proposed aquifer production zone, and it must be conducted and reported in accordance with hydrogeological testing procedures specified by or acceptable to the District. It is a requirement that the applicant and its technical representatives coordinate with the District and its technical representatives to ensure both local site-specific and regional information is considered in developing and approving the testing and reporting.

The District has established tiered requirements for aquifer tests and their associated reports, based on both the scale of prospective groundwater production to be permitted under an Operating Permit and whether the well to be permitted is an "Existing Well" or a proposed "New Well". These tiers are summarized in the table below:

Tier	Aquifer Test and Report Requirements	"Existing Wells" That Are Required to Seek Operating Permit	Proposed "New Wells" That Are Required to Seek Authorization to Operate at Volume Indicated
1	Abbreviated, single-well, short-term pump test ("Specific Capacity Test") and Report	Required of all "Existing Wells" seeking an Operating Permit, regardless of size.	<1,000,000 gallons per year under Operating Permit
2	Aquifer Test and Hydrogeologic Report; <u>may</u> require installation of new monitor wells if existing wells are not available or are inadequate for monitoring.	As a permit condition, may be required in future if a well with an Operating Permit at >1 MGY is suspected of causing unreasonable impact.	≥1,000,000 to 10,000,000 gallons per year under Operating Permit
3	Aquifer Test and Hydrogeologic Report; will require monitoring well network plan and installation of one or more new monitor wells as observation wells.	See Tier 2 above.	≥10,000,000 gallons per year under Operating Permit

The appropriate tier is determined solely by the District and will be assigned using information in the well registration, the Well Drilling/Modification Authorization application, and/or Operating Permit application, following initial consultation with the permit applicant. The production thresholds between tiers shown in the table are presumptive but not absolute; the trigger values between tiers may be higher or lower depending upon the hydrogeologic setting and the level or risk of unreasonable impacts that may be incurred by well operation, as determined by professional judgment of District staff.

The assigned tier determines what the applicant must include in its aquifer test plan and the depth and breadth of information contained in the Hydrogeologic Report. Each of the tiers is characterized in the subsections below, along with a variance request procedure.

2.1 Tier 1 Wells

The lowest tier pertains to: all Operating Permits sought for "Existing Wells", regardless of amount of groundwater production to be permitted; to proposed "New Wells" seeking a Non-exempt Domestic Use General Permit by Rule; and also to relatively small, proposed "New Wells" that seek to permit less than 1 million gallons (MG) per year under an Operating Permit. Tier 1 Permits may be authorized to employ an abbreviated aquifer test using a single well, that is, the well to be permitted, which is also known as a "specific capacity test". In addition, previously conducted successful specific-capacity tests performed for a pre-existing Tier 1 well may be used in lieu of conducting a new test on that well, and Hydrogeologic Reports based on new aquifer tests conducted at an "Existing Well" may be submitted up to six months after the date the well is permitted.

Tier 1 wells, regardless of permit type, also may use a short-form template to report findings and conclusions of the abbreviated aquifer tests, in lieu of the full Hydrogeologic Report that is required for Tier 2 and 3 wells. This template is designed so that it may be completed by the well driller, pump installer, or even the well owner rather than requiring a technical consultant. Access to the Tier 1 report template will be provided to the applicant or well driller/pump installer at the initial consultation meeting with the District representatives.

The purpose of the Tier 1 Tests and Reports is to establish baseline information of the well and aquifer (yield, parameters, water quality). The Tier 1 tests and Reports are primarily intended for those wells that pump a relatively small volume and have a low risk for unreasonable impacts. Key elements of the Tier 1 Abbreviated Aquifer Test and Report include:

a. **Estimated aquifer properties:** Transmissivity needs to be calculated from an aquifer test using the standards outlined in these guidelines. Typically, these will be single-well (specific capacity) tests, however monitoring of nearby wells may be required if existing wells are readily accessible and adequate for monitoring. Storativity should be calculated if sufficient monitor well response is measured.

b. **Estimated extent and magnitude of well interference:** The report should address the short- and long-term impacts from the anticipated pumping on existing surrounding water wells. This can be done with simple distance-drawdown graphs (e.g. Cooper-Jacob) that project the effects of at least seven years of pumping.

c. **Water quality:** The report should document and establish water chemistry of the groundwater produced at the end of the test, which at a minimum includes field parameters (conductivity, temperature, pH) and, as warranted by the hydrogeologic setting, possibly laboratory results (major ions and anions, and common nutrients).

An existing well that has been operating for an extended time generally indicates that there has not been an unreasonable impact from its operation. However, if the proposed operation of a Tier 1 well under an Operating Permit is different than that previously practiced at the well, or if new data suggests that adverse impacts are or may be attributable to operating that particular well, or if complaints of adjacent well owners are received by the District indicating that a previously installed well is causing extraordinary and/or unanticipated groundwater problems, the District may require the owner/operator of that well to undertake the aquifer testing and reporting described under a higher tier than that indicated by the permitted volume to elucidate the magnitude and scope of problems caused in the groundwater system.

2.2 Tier 2 and Tier 3 Wells

Tests and Reports for Tier 2 and Tier 3 wells are intended for those well systems that have proposed pumping volumes greater than 1 MG per year, with Tier 2 wells having annual permitted amounts between 1 and 10 MG, and Tier 3 wells having annual permitted amounts greater than 10 MG. For both tiers, the purpose of the aquifer testing and reporting is the same: to make an assessment of the short- and long-term potential for unreasonable impacts to the regional aquifer system and existing surrounding water wells from the proposed pumping. An aquifer test is a key part of that evaluation, but other relevant hydrogeologic data, as described above, may also be evaluated, if available. Geophysical logging following drilling of proposed wells that are either Tier 2 or 3 is required as part of this evaluation, and the suite of logs to be run will vary with the hydrogeologic setting of the well and will be determined in consultation with the District before the well is authorized to be installed; a gamma ray log, a resistivity log, and a caliper log are typically recommended, and a temperature log, an electric self-potential log, and possibly other logs may also be useful. Similarly, as a special provision for authorizing well drilling at certain locations, the District may require the collection of drill cuttings at ten-foot or twenty-foot intervals by the drilling contractor, upon timely request of the District, for inspection by the District's own geologist/consultant.

These two tiers are differentiated primarily because of the scale of their potential impacts, and the need to determine the magnitude and geographic area affected by those impacts as precisely as possible for the larger wells. This requires the use of a monitoring well network for all Tier 3 wells, which mandates the development of a District-approved monitoring well

network plan and generally the installation of new monitor wells for the aquifer test. Tier 2 testing will require the installation of new monitor wells only if existing wells in the study area are not available or are inadequate for monitoring. In contrast, Tier 3 testing requires a monitoring well network to be established in the prospective aquifer management zone by the installation of at least one or more new monitor wells for a test and identifying a sufficient amount of existing wells adjacent to the well or well field. A second monitor well may be required to measure the effects in different aquifers or in different locations of a widespread wellfield. The Tier 3 testing requirements are intended to ensure the best possible test and data collected for these larger permit requests.

The new monitor wells shall serve as a component of the "monitoring well network plan" submitted with the aquifer test work plan as required by the Rules. At a minimum, the monitoring network plan should use narrative, figures, and tables to address in summary fashion the purpose of the network, the network's design and construction details, monitoring well specifications including completion schedule, and details on the procedures and responsibilities for assuring oversight, maintenance, and continuing access. The monitoring well network plan must be approved by the District and the monitoring wells shall be installed and/or identified prior to the commencement of the aquifer test.

Key elements of the Tier 2 and 3 Hydrogeologic Test and Report include:

1. **Estimated aquifer properties:** Hydrogeologic parameters including *transmissivity* and *storativity* need to be calculated from an aquifer test using appropriate published analytical models. Additionally, the Report should also identify the presence of boundary conditions such as barriers to groundwater flow, recharge, and other factors inherent to the aquifer or hydrologic conditions that may influence pumping over time.

2. **Estimated extent and magnitude of interference:** The Report should address the short and long-term impacts from the pumping on existing surrounding water wells. The Report should contain a map of the maximum measured drawdown from the aquifer test for the surrounding monitored wells. In addition, projected future drawdown from analytical models shall be done for at least seven years. Results will be used to evaluate the potential for unreasonable impacts to existing surrounding water wells.

3. **Water quality:** The Report should document water chemistry and detectable trends during the aquifer testing. The Report should discuss the risk of water quality changes due to pumping. At locations where significant inter-aquifer flow could induce waters of differing and distinguishable water quality, further evaluations may be required. Results will be used to evaluate the potential for unreasonable impacts to the quality of water in existing surrounding water wells or the aquifer.

4. **Estimated impacts to regional water resources:** Regional water resources include aquifers, springs, and surface streams. The Report should attempt to quantify the short-

and long-term impacts from the pumping on these water resources and on the Desired Future Conditions (DFCs) for the relevant aquifer(s). Results will be used to evaluate the potential for unreasonable impact to DFCs, regional aquifer conditions, springflows, or base flows to surface streams.

2.3 Use of Alternative Specifications of Hydrogeologic Reports and Aquifer Test

The District may consider alternatives to certain requirements of these *Guidelines.* Technical information and a memorandum from a Texas licensed professional geoscientist or engineer supporting and documenting the rationale for using an alternative specification shall be submitted to the General Manger for consideration. Factors that may be considered include:

a. Relatively low requested production volume;
b. Sufficient data exist for the well or vicinity (e.g. existing hydrogeologic reports or aquifer tests);
c. Low potential for unreasonable impacts; and
d. Other specified relevant factors.

To accommodate these factors, deviations from the specifications in these *Guidelines* is possible but only with approval from the District's General Manager, which should be noted and described in the submitted work plan.

3.0 Aquifer Test Work Plan

Aquifer Test is defined in District Rule 2 as:

> *… a controlled field experiment used to estimate hydraulic properties of aquifer systems (transmissivity and storativity). The primary method is called a "pumping test" in which a well extracts or injects water at a controlled rate while water levels are measured in one or more surrounding wells. Guidelines and procedures for Aquifer Tests are outlined in the District's guidance document, Guidelines for [Aquifer Testing and Hydrogeologic Reports] ("*Guidelines*").*

Aquifer test design and operation should generally follow those discussed in Driscoll (1986) or other published resources. The work plan should briefly address each of the key aspects outlined in **Appendix A**, Guidance for Developing Aquifer Test Work Plans.

The aquifer test work plan shall be prepared prior to conducting an aquifer test. Results of the aquifer test will be included in the Hydrogeologic Report. Both the aquifer test work plan and Report need to be prepared by a Texas licensed professional geoscientist or engineer. Planning

and implementation of the aquifer test shall be closely coordinated with the District to ensure that the proposed report is consistent with District standards and expectations specified in these guidelines. Special attention should be given to the proper management of produced water during the test, such that it is used beneficially to the maximum feasible extent and it does not adversely affect local waterways and adjacent property. Prior to the commencement of the aquifer test, the applicant (or applicant's designated representative) shall have a meeting to discuss the proposed aquifer test work plan that shall be prepared pursuant to the guidance in **Appendix A**. A written aquifer test work plan shall be submitted to the General Manager for review and approval prior to commencement of the test and shall include the required information for aquifer test work plans as specified in these guidelines. Once approved by the District, the aquifer test shall be conducted and the Report completed pursuant to the approved work plan and these guidelines. The applicant is responsible for all costs associated with the aquifer test.

The aquifer test plan must be approved by District staff prior to commencement of the test but after a pre-test consultation with the District. These guidelines will be used as a checklist during the pre-test meeting with the applicant or their consultant. For an aquifer test of a prospective new well or major modification of an existing well, the aquifer test work plan must be submitted as part of the application for a Well Drilling Authorization, which must be approved before the well is installed. For permitting an existing well, the aquifer test work plan is submitted before making an application for a Production Authorization. In either circumstance, once approved by the District, the aquifer test must be conducted according to the approved plan, and the Hydrogeologic Report based on the approved aquifer test is submitted as part of the Production Authorization application.

4.0 Content of Hydrogeologic Report

The Hydrogeologic Report is defined in District Rule 2 as:

> *a report, prepared by a Texas licensed geoscientist or a Texas licensed engineer, in accordance with the District's guidance document Guidelines for [Aquifer Testing and Hydrogeologic Reports] (*Guidelines*). The report documents, describes, and interprets the results of an Aquifer Test with other information to evaluate the availability of groundwater in a study area and target formation. The primary goal is to assesses the response of an aquifer to pumping over time and the potential for unreasonable impacts.*

The Hydrogeologic Report shall provide findings and conclusions addressing the response of an aquifer to pumping over time and the potential for causing unreasonable impacts. Applicants may not rely *solely* on reports previously filed with or prepared by the District. Material, purposeful deviation from the guidance in this section of the *Guidelines* document may occur only upon prior written request providing justification by the applicant or its technical

representative and only with prior District approval (refer to Section 2.3, above, for more information on the procedure for using alternative specifications).

The District's staff will evaluate the application with the benefit of the Hydrogeologic Report to determine whether there is potential for Unreasonable Impacts (as defined by District Rule 2) and produce a written report of findings if unreasonable impacts are considered likely and as justification for staff recommendation concerning the permit issuance. The evaluation of the potential for unreasonable impacts will apply the best available science and be performed on the basis of the Report, the aquifer test, and other factors relevant to the proposed production from the subject well/well field including but not limited to:

a. local geology and aquifer conditions including water quality;
b. construction and location of the subject well/well field;
c. target production zone, production capacity, and proposed production rate of the subject well/well field;
d. construction/completion of existing wells in the area of influence;
e. drawdown over time and distance attributed to pumping from the subject well/well field;
f. drawdown attributed to drought conditions and seasonal increases in pumping from existing wells;
g. drawdown attributed to pumping from existing wells and from future domestic and livestock wells;
h. proposed production relative to the Modeled Available Groundwater;
i. projected impacts on the relevant Desired Future Condition(s); and
j. projected impacts to regional surface water resources (springs and streams).

Permit applications may be deemed incomplete due to Reports that do not meet the District's minimum standards or deviate significantly from these guidelines without prior District approval. An applicant who incurs costs related to conducting an aquifer test knowingly bears the risk that the permit request may be denied or modified.

While the applicant's technical consultant should use his or her best professional judgment as to how best present requisite information in a responsive report, the balance of this section is a suggested outline of topics, tables, and figures that should be addressed in the Tier 2 and 3 Hydrogeologic Report (Report), along with their respective topics described in Section 2.2 and 2.3 above. Tier 1 reporting is accomplished simply by completing the short-form Abbreviated Hydrogeologic Report template described in Section 2.1 above.

A. Summary, Results and Conclusions

i) Description of the type of permit request, aquifer (target production zone), use type, volume, and other relevant factors.
ii) Conclusions of the Report as they relate to the purpose described in Section 2.

B. Description of the Pumping Well Site and Water System

i) Description and map of the project area, the location of the well site(s), and system configuration including the location and volume of water-storage facilities.
   - Figure*: sketch (map) of the test site*
     - *Note*: *Describe and map potential interference from nearby pumping wells.*

ii) Description of the current and anticipated annual pumping demands, including typical pumping schedules such as frequency, duration, peak demand hours, and pumping rates of the pumped well(s).

C. Hydrogeology and Conceptual Model (Tiers 2 and 3 only, except where indicated)

The data sources for this section should be the best available information, properly cited from the literature, and integrated with the data collected from this study.

i) Provide a description of the hydrogeologic conceptual model of the aquifer and well site. Discuss or provide:
   - Relevant hydrogeologic aspects of the aquifer such as aquifer conditions (e.g. confined, semi-confined, unconfined), hydrostratigraphy, faulting, and boundary conditions (recharge or barriers).
   - Map of wells (exempt and nonexempt), surface ponds or reservoirs, major karst features, springs, or any other source of recharge and discharge for the project well site and surrounding area of influence. Data sources should include all publicly available databases coupled with field reconnaissance or survey investigations.
   - Regional hydrogeologic elements such as recharge, flow, and discharge should be addressed in the conceptual model. Concepts such as pumping equilibrium, changes in storage, and capture related to pumping should be discussed.
   - *Figures: Regional and local scale geologic and potentiometric maps*
   - *Figures: Study area geologic and hydrogeologic cross sections*
     - The role of karst and fracturing and faulting in the conceptual model should also be directly discussed in addition to the heterogeneity and anisotropy of the aquifer and well field.

ii) Detailed well hydrostratigraphy and completion/construction information need to be presented in the Report. This should include geophysical logs of the pumping wells (required), and monitor wells (required for all wells used in a Tier 3 monitoring well network plan). Geophysical logs should include gamma ray, resistivity, and caliper logs.
   - *Figures: Pumping and monitor well hydrostratigraphy and well completion diagrams.*
     - Well inventories, drilling and geophysical logs, pump depths, casing/annular seal specs, state well reports, and other relevant records should be included in the appendices of the Report.
     - Electronic files (.PDF and/or .WCL) of geophysical logs should be made available.

iii) Potentiometric maps should be prepared showing the elevations of the potentiometric surface(s) of the aquifer(s) proposed for usage or that could be impacted.
    - Regional potentiometric maps can be based on existing or published data, while more local potentiometric maps should be based on water-level measurements taken prior to the aquifer test for the tested aquifer and, to the extent possible, all relevant aquifers that could be subject to capture.
- *Figure: Regional and local potentiometric maps*

D. Aquifer Test Work Plan and Results

i) Aquifer Test Work Plan. Summarize the aquifer test design and operation outlined in **Appendix A** and approved by the District.
    - *Note: Complete time-discharge records of the pumped well and water-level records of the pumped and monitor wells should be put into an appendix (and provided in digital format).*

ii) Aquifer Test Results. Discuss pre-test trends and water levels during the pumping and recovery phases as they might relate to influences from recharge, barometric effects, and pumping wells. Any problems or inconsistencies with pumping rates or measurements must be discussed and documented.
- *Figure: Map of the maximum measured drawdown during aquifer test. If more than one well is pumped, the sum of the maximum drawdown from each test must be presented. Maximum drawdown determinations may need to be adjusted for regional water-level trends.*
- *Figures: Annotated hydrographs (arithmetic or non-log) water-level elevations versus time for all the data from each well.*
- *Figures: Hydrographs of nearest stream flow, springflow, and rainfall station data covering a period of three months prior to the aquifer test through the recovery period.*

E. Analyses of Aquifer Test Data and Parameter Estimation

i) This section should describe the methods used and analytical model selected to estimate aquifer parameters.
    - All data manipulation (trend-correction) should be clearly described.
- *Table: Summary of input parameters used in the analytical solutions (pumping rate, aquifer thickness, distances, well construction details, etc.).*
- *Figures: Annotated semi-log and log-log graphs of measured drawdown versus time in pumping and monitor wells. Include select theoretical curves (analytical models) used to calculate the parameters.*
    - *Methods should include straight-line (Cooper and Jacobs, 1946) and type curve models such as Theis (1935) or other analytical models. If numerous plots are generated, they can be put into an appendix.*

ii) Storativity should only be calculated from monitor well (not pumping well) data. Data from monitor wells farthest out generally result in the best estimates of storativity (Butler and Duffield, 2015; Butler, 2009).

iii) Deviations from these theoretical curves must be discussed and may include effects from: hydraulic boundaries (recharge and no flow), partial penetration, fluctuating pumping rate, delayed yield, leakage, atmospheric responses, regional water-level trends, and interference from other wells.
   - *Table: Summary table of estimated aquifer parameters and methods. This should provide a range of results based on various selected methods. The preferred or averaged result and model should be indicated. A comparison to other published or nearby aquifer test values should be included.*

F. **Potential Unreasonable Impacts Analysis** (Tiers 2 and 3 only, except where indicated)

The effects of pumpage on wells and on the aquifer must be evaluated and discussed in this section as they relate to the potential for unreasonable impacts. Aquifer parameters selected for the evaluation should be representative of the potentially impacted area. Discuss the rationale of the parameters selected for the analyses.

Well interference (Tiers 1-3)

i) Discuss and map the estimated extent (area of influence) and magnitude of well interference on existing surrounding wells.
ii) Discuss and consider construction and location of the subject well/well field; target production zone, production capacity, and proposed production rate of the subject well/well field; construction/completion of existing wells in the area of influence; drawdown attributed to drought conditions and seasonal increases in pumping from existing wells; and drawdown attributed to pumping from existing wells and from future domestic and livestock well.
   - *Figure: A plan view map of theoretical maximum drawdown for at least seven years shall be shown on the final maps and cross sections.*
   - *Figure: Chart showing the forecast of distance-drawdown from the pumping well for one week, one year, and seven years. Cooper-Jacob plots are recommended.*
   - *Figure: Hydrogeologic cross section (showing geologic formations and well completions, etc.) showing theoretical drawdown for at least seven years.*

Impacts to regional water resources

i) Discuss the requested production volume in context with the Modeled Available Groundwater (MAG) and the DFC.
ii) Discuss potential short- and long-term impacts from the pumping on freshwater resources including springs and baseflow to surface streams.
iii) Discuss regional numerical or other analytical models and results relevant to the permit.

Changes in water quality

i) Document and discuss any water-quality changes that may have occurred due to pumping during the test.
   - Analytical results from the laboratory should be provided as appendices.
   - *Table: Summary of laboratory water-chemistry results. Should include*

comparison to EPA and TCEQ standards, in addition to other regional averages.

- *Figure: Plots showing water level, temperature, and conductivity during test.*

G. Supplemental Information

Due to the test-specific nature of these investigations, additional information can enhance the results and evaluation of the data. Below are some items that could be considered within the scope of work for the hydrogeologic studies and report:

- *Numerical modeling*
- *Dye tracing*
- *Surface geophysics*
- *Down-hole camera surveys*
- *Other reports or unpublished information or data.*

5.0 Select References

These references are taken from similar guideline documentation on aquifer tests and hydrogeological reports prepared by the Barton Springs/Edwards Aquifer Conservation District.

Alley, William M., 2009, Update on Guidance for the Preparation, Approval, and Archiving of Aquifer-Test Results. U S Geological Survey, Office of Groundwater Technical Memorandum 2009.01 <https://water.usgs.gov/admin/memo/GW/gw09.01.html>

Butler, J., 2009, Pumping Tests for Aquifer Evaluation—Time for a Change? Groundwater, Volume 47, Issue 5, September/October 2009, Pages: 615–617.

Butler, J. and G. Duffield, 2015, Aquifer Testing for Improved Hydrogeologic Site Characterization featuring AQTESOLV and the In-Situ Level TROLL, Course Notes, D. Kelleher (ed), Fort Collins, Colorado, October 27 and 28, 2015, 511 pages.

Cooper, H.H. and C.E. Jacob, 1946, A generalized graphical method for evaluating formation constants and summarizing well field history. Am. Geophys. Union Trans. Vol. 27, pp. 526-534.

Driscoll, F.R., 1986, Groundwater and Wells. Second Edition. Johnson Screens, St. Paul, Minnesota. Pp. 1089.

Hunt, B.B., B.A. Smith, J. Kromann, D. Wierman, and J. Mikels, 2010, Compilation of Pumping Tests in Travis and Hays Counties, Central Texas: Barton Springs Edwards Aquifer Conservation District Data Series report 2010-0701, 12 p. + appendices <http://www.bseacd.org/uploads/BSEACD_DS_2010-0701.pdf>

Kruseman, G.P., and N.A. de Ridder, 1991, Analysis and Evaluation of Pump Test Data, Second Edition, ILRI, Netherlands. Pp. 377

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. Trans. Amer. Geophys. Union, Vol. 16, pp. 519-524.

Appendix A
Guidance for Developing Aquifer Test Work Plans

The District suggests the following content and possible structure for Aquifer Test Work Plans.

1. Initiation, Duration and Pumping Rate

a) Aquifer tests for most aquifers should not be conducted during or immediately after significant rain or recharge events, because of the rapid change in water levels that often follows.
   - *Note: aquifer tests may occur during recharge events for deeply confined aquifers if the pre- and post-test data are sufficient to document trends.*

b) Testing schedules should be coordinated with other area pumping wells to avoid interferences that could result in misleading or uncertain results.

c) The test shall be designed to pump a minimum of three times the daily equivalent of the requested annual permitted volume (see table below). Longer duration pumping tests (four to five times the daily equivalent) are encouraged and could be required where the risk of impacts, or encountering aquifer boundaries, is high.
   - *Note: the duration of the test, rather than the pumping rate, increases the scale of the test (distance of measurable drawdown). The pumping rate has less of an effect on the scale of the test but increases the ability to distinguish water-level fluctuation noise. In addition, unconfined aquifers generally result in slower response and need longer pumping durations for measured responses in monitor wells (Butler and Duffield, 2015). Longer test durations and larger pumping volumes should be considered if it is anticipated the permit would increase sometime in the future, such that the test would not need to be repeated.*

Table - Example duration calculation of aquifer test

Annual Permit Request (gal)	Daily equivalent (gal)	Pumping target volume (gal)	Testing Rate 380 gpm	Testing Rate 285 gpm
100,000,000	274,000	3 x 274,000 = 822,000	36 hour	48 hour

d) The aquifer test should be a constant-rate test. Well testing (step tests) should be performed prior to the aquifer test (allowing for recovery) in order to properly size the pump and estimate the optimal well yield for the test. Well testing should ideally be done prior to the

final work plan.

- *Note: Pumping rates should be measured frequently to verify that a constant discharge rate is being achieved. If a flow meter is used to measure flow, it should be calibrated prior to the test and verified using another calculation method such as an orifice weir, or by the time required to fill a storage vessel of known volume.*

e) Waste of the discharge should be avoided as much as possible, particularly during low water-level conditions in the aquifer and should be routed to storage tanks or to other water systems when possible. If the water must be discharged to surface drainages off-site, the pumped water should be routed so that it does not recharge into the tested aquifer in the vicinity of the pumping or monitor wells during the test. Discharge onto adjoining properties needs to be considered and avoided if possible, especially when it involves flooding and/or poor-quality water. The applicant shall discuss the fate of discharged water in the work plan.

2. Aggregate Well Fields

If the study involves the assessment of two or more pumping wells, each well may be pumped separately to measure their combined effects. If the wells are sufficiently close, it may be possible to pump the wells simultaneously.

3. Well Completion

a) All proposed pumping wells must be completed and equipped for the ultimate planned use or, at minimum, completed and equipped to isolate the target production zone for the ultimate planned use and production rate. Observation wells may be required. The applicant is responsible for all cost associated with the design, engineering, well construction, and other related expenses. The use of test wells must be approved by the District by completing a Production Authorization application and receiving a Test Well General Permit by Rule.

- *Note: If the conversion of the test wells to final production involves significant modifications (well diameter, acidization, etc.), then a special condition of the permit, if granted, may be included to require a re-test of select wells after final completion to demonstrate the data can be reproduced. If the test of wells after final completion results in significant differences in aquifer parameters and measured response to surrounding wells, the full aquifer test may need to be repeated and the permit subject to staff-initiated amendments based on a new aquifer test.*

4. Number and Location of Monitor Wells

a) Monitor wells should be selected radially around the pumping well and include wells completed in the same aquifer.
   - *Provide a detailed map of pumping, monitor, and area wells.*
   - *Use analytical models (Cooper-Jacob) to help forecast distance and potential magnitude of drawdown to monitor wells using published aquifer parameters.*

b) For Tiers 2 and 3, some monitor wells may be selected that are in different aquifers to evaluate the potential for inter-aquifer communication.

c) Ultimately, it may be necessary for the Tier 2 testing, which have a significant risk of unreasonable impacts, to install one or more monitor wells in the absence of existing well-suited monitor wells.

d) For Tier 3, the aquifer test work plan shall also include a monitoring well network that shall be established by installing one or more new monitor wells and identifying a sufficient number of existing wells adjacent to the well or well field prior to the commencement of the aquifer test in accordance with the District- approved monitoring well network plan. The final monitoring well network plan and aquifer test work plan must be approved by the District (Appendix B).

5. Water-Level Data

a) Pre-aquifer test water-level measurements should be collected starting at least one week prior to pumping.

b) Post-test data collection in all wells should continue through the recovery phase, which should be about as long as the pumping phase.
   - *Note: recovery data often results in the best data for parameter estimation as head loss due to well construction is minimized (Butler and Duffield, 2015).*

c) Select monitor wells should be measured beyond the recovery period of the pumping phase to establish regional and local water-level trends and to observe any delayed response to pumping.
   - *Note: It is preferable that recovery lasts two to three times the duration of the pumping for complete recovery and also to measure trends.*

d) All water-level measurements should be within 0.1 feet precision. The use of automated data loggers and vented pressure transducers should be used whenever possible. The automated data should be calibrated/verified with manual e-line measurements if the risk of hanging up the e-line is low.

e) Other means such as airlines or sonic meters, are generally discouraged from use but may be allowed as backup measurements.

f) All water-level data must be submitted in the report and made

available in digital format (spreadsheet).

g) Care should be exercised to prevent (bacterial) contamination of monitor wells.
   - *Note: The District may be able to designate relevant existing monitor wells, and provide logistical support to identify, make introductions, and possibly assist with monitoring if time and resources allow.*

6. Water Quality Data

a) Samples for major ions, nutrients, and other trace elements at the end of the test.
   - *Note: the list of parameters should be provided in the work plan.*

b) Field parameters (temperature, conductivity, pH) should be monitored throughout the test with tabular results provided in the appendices.