ANCHOR QEA
614 Magnolia Avenue
Ocean Springs, Mississippi 39564
Phone 228.818.9626
Fax 228.818.9631

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integral consulting inc

MEMORANDUM

To:	Gary Miller U.S. Environmental Protection Agency	**Date:**	April 29, 2013
From:	David Keith, Anchor QEA, LLC Jennifer Sampson, Integral Consulting Inc.		
Cc:	Philip Slowiak, International Paper Company		
Re:	Addendum 2 to the Groundwater Study Sampling and Analysis Plan Additional Groundwater Sampling South of Interstate Highway 10, San Jacinto River Waste Pits Superfund Site		

INTRODUCTION

This memorandum is Addendum 2 to the Groundwater Study Sampling and Analysis Plan (SAP) for the San Jacinto River Waste Pits (SJRWP) Superfund Site (Site) (Anchor QEA and Integral 2011). The sampling described in this addendum addresses U.S. Environmental Protection Agency's (USEPA) requirement for additional groundwater sampling south of Interstate Highway 10 (I-10) in the vicinity of Soil Investigation Area 4 (Figure 1). This SAP Addendum was prepared pursuant to discussions culminating in an electronic mail transmission from USEPA (Miller 2013 pers. comm.), wherein USEPA requires additional groundwater investigations in the vicinity of Soil Investigation Area 4. USEPA initially conveyed these requirements in a telephone conversation on January 10, 2013 (Miller 2013a pers. comm. with David Keith), followed by discussion in a conference call on February 13, 2013 and submission of an email summary (Keith 2013 pers. comm. with G. Miller) of the conceptual plan on February 27, 2013. USEPA approved the conceptual plan on February 28, 2013.

The investigation described in this Addendum will be conducted south of I-10 (Figure 1). This Groundwater Study SAP Addendum is submitted on behalf of International Paper Company (IPC) only, pursuant to the requirements of Unilateral Administrative Order (UAO), Docket No. 06-03-10, which was issued to IPC and McGinnes Industrial Maintenance Corporation

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(MIMC) on November 20, 2009 (USEPA 2009). The 2009 UAO requires IPC and MIMC to conduct a Remedial Investigation/Feasibility Study (RI/FS) for the Site.

In addition to addressing the data quality objectives (DQOs) for groundwater sampling south of I-10, this Addendum describes the anticipated monitoring well design and installation methods, and sample analytes. It also identifies the quality assurance and quality control (QA/QC) procedures that will be applied during the groundwater sampling, chemical analysis, data validation, and reporting. The work described in this Addendum will be conducted in full compliance with the approved Groundwater Study SAP (Anchor QEA and Integral 2011) and related appendices (including the Field Sampling Plan, which is Appendix A to the Groundwater Study SAP) and the Groundwater Study SAP Addendum 1 (Anchor QEA and Integral 2012). Only those aspects of the work unique to the additional groundwater sampling, which is anticipated to be conducted during the spring of 2013, are addressed in this document.

STATEMENT OF THE PROBLEM

In comments on the draft Preliminary Site Characterization Report (PSCR) (Integral and Anchor QEA 2011), USEPA indicated that uncertainties about the potential for groundwater to transport chemicals from soil in the south impoundment area to the surface water environment needed further clarification (Miller 2011b pers. comm.). In separate communications, USEPA required IPC to conduct additional soil and groundwater sampling south of I-10 (Miller 2011a pers. comm.), and to analyze a broad suite of chemicals, including volatile organic compounds (VOCs) and semivolatile organic compounds (SVOC) not previously considered chemicals of potential concern, in groundwater (Miller 2011c pers. comm.). Further, USEPA indicated in discussions in January and February 2013 that uncertainties exist regarding groundwater quality in the southern portion of Soil Investigation Area 4, and below the Beaumont Clay confining layer, which is present throughout the region. To address these uncertainties, USEPA is requiring collection of groundwater in transmissive fill materials above native soils in one location (SJMW004S; Figure 2).

If concentrations of one or more chemical analytes in a groundwater sample from this location exceed USEPA maximum contaminant levels (MCLs) or applicable State water quality criteria if an MCL is not available for a specific chemical, additional sampling will be conducted, as follows:

- From just below the Beaumont Clay at SJMW004S (i.e., potential well SJMW004D).
- In transmissive fill materials above native, undisturbed soil to the west of SJMW004S (i.e., potential well SJMW005), equidistant between SJMW004S and the shoreline of the San Jacinto River.

Well SJMW004S will be installed and sampled first and the validated analytical results from that well will be used to determine if potential wells SJMW004D and SJMW005 are required. In addition to obtaining groundwater sample from SJMW004S, sustainable well yield information will be obtained during the initial field effort using procedures outlined in Texas Commission on Environmental Quality (TCEQ) Regulatory Guidance RG-366/TRRP-8 (TCEQ 2010) from the shallow existing wells (SJMW001, 002, and 003) and new shallow well(s) (SJMW004S) to determine the appropriate groundwater classification, in regards to groundwater resource potability. Groundwater elevation data will also be collected from new and existing wells to define hydraulic gradients and groundwater flow direction in the area of investigation, within the upper transmissive zone.

USEPA requires that groundwater samples to be collected under this addendum be analyzed for all of the chemicals required for analysis in its December 8, 2011 letter (Miller 2011a pers. comm.). These analytes are listed in Table 1.

PROJECT ORGANIZATION, METHODS, AND QUALITY ASSURANCE PROCEDURES

Groundwater sampling and analyses described in this Addendum will be conducted in full compliance with the Groundwater Study SAP and SAP Addendum 1 (Anchor QEA and Integral 2011, 2012), including Appendix A (Field Sampling Plan), and in the context of the objectives and sampling locations relevant to this task. The Groundwater Study SAP describes the means to achieve all QA/QC requirements and documentation articulated by USEPA's guidance for preparation of quality assurance project plans, and field sampling plans (USEPA 1998, 2001); these specifications will be applied to the collection, analysis, QA review, data management, validation, and reporting of the information generated, as described in this Addendum. Sampling personnel will comply with the overall Health and Safety Plan (HASP)

(Anchor QEA 2009) and Addendum 3 to the overall HASP that is provided in the Soil SAP Integral 2010, Appendix A, Attachment A-3), and Addendum 4 to the overall HASP that is provided in the Soil SAP Addendum 1 (Integral 2011, Appendix A, Attachment A2).

The groundwater analytes, method reporting limits, and method detection limits are listed in Table 1. For this sampling effort, dioxin and furan concentrations will be determined on unfiltered and filtered samples (0.45 micron effective pore size filter) to determine the degree those chemicals may be associated with particulate materials in the sample water. Table 2 provides laboratory analytical methods. Table 3 provides sampling location data. Table 4 provides sample container, preservation, and holding time information. These tables are analogous to tables presented in the Groundwater Study SAP.

DATA QUALITY OBJECTIVES

This section provides a summary of the DQOs for the required groundwater sampling inclusive of the objective of the task, analytical approach, and sampling locations.

USEPA regards there to be uncertainty as to whether groundwater in the south impoundment area could transport dioxins and furans or other chemicals in Table 1 from soils to the aquatic environment (Miller 2011b pers. comm.). The classification of the groundwater resource under TCEQ guidance is also unconfirmed. Additional data on the concentrations of chemicals in Table 1 and total dissolved solids (TDS) in groundwater that could occur above native soils in Soil Investigation Area 4, and well tests information are required to address these uncertainties. Groundwater elevation data will also be collected to reduce the uncertainty associated with hydraulic gradients and groundwater flow direction.

Sample Collection Design

In the initial sampling effort, groundwater will be collected for chemical analyses, water elevation data will be collected, and sustainable well yield information will be obtained from well SJMW004S. Water elevation data and sustainable well yield information will also be collected from existing wells (SJMW001, 002, and 003) in the initial sampling effort. If a second sampling event is needed based on the results of chemical analysis of the sample from

SJMW004S, then sampling for chemical analyses will be conducted at two additional wells, as described below. This section describes methods for each type of data collection.

Assessment of Groundwater Elevation

Prior to sampling for chemical analyses, and after water levels in any newly installed well stabilize, a complete round of potentiometric water level data will be collected from the well set elsewhere in Soil Investigation Area 4 (SJMW001 through SJMW003 and SJMW004S, SJMW004D, through SJMW005 [as installed]). Water levels will be collected consistent with the 2011 Groundwater SAP procedures.

Groundwater Chemistry Sampling

Groundwater samples will be collected from monitoring well SJMW004S in fill above the native, undisturbed soil (Figures 2 and 3). The estimated total depth of SJMW004S based on existing boring data will be less than 30 feet. Groundwater samples will be collected to further determine whether chemicals are present in groundwater from the upper transmissive zone at the location of SJMW004S, and to determine the concentrations of any chemicals that are detected.

Following potentiometric data collection, the well at SJMW004S will be developed in accordance with procedures previously set forth in the Groundwater Study SAP (Anchor QEA and Integral 2011) for chemical sampling. After development activities, each well will be purged and sampled for the chemicals listed in Table 1, also in accordance with the Groundwater Study SAP. Analytical methods for the groundwater sample are listed in Table 2. Samples will be collected on a total (i.e., unfiltered) basis for all chemicals except metals and dioxins and furans. Samples for metals and dioxin and furan analyses will be collected on a filtered and unfiltered basis. Conventional groundwater parameter data (turbidity, dissolved oxygen, specific conductance, temperature, pH, and oxidation/reduction potential) will be obtained during well development, purging, and sampling.

If analytical results from SJMW004S exceed USEPA MCLs (or applicable State drinking water quality criteria where MCLs are not available) (Table 1), two additional monitoring wells will be installed. A deep well (SJMW004D) will be installed with a screened interval below the Beaumont Clay aquitard adjacent to SJMW004S (Figure 2 and 3). A shallow well (SJMW005) will be installed west of SJMW004S, equidistant between SJMW004S and the San Jacinto River (Figure 2). This shallow well will be constructed using the same well design as SJMW004S (Figure 3).

Wells will be installed using hollow stem auger, sonic, or other common environmental drilling methods, depending on contractor availability and the contracting process, as described initially in Groundwater SAP Addendum 1. The construction of shallow wells will be consistent with the shallow well design presented in the Groundwater Study SAP, and as modified by USEPA. The deep well, if required, will be installed and constructed consistent with the deep wells installed north of I-10.

The shallow well sampling design originally presented in the Groundwater SAP has been modified by USEPA (Miller 2011a pers. comm.) such that the wells "shall be screened above the native, undisturbed soil material." Shallow wells will be screened from the bottom of the fill towards the surface, with the screened interval intercepting the observed potentiometric surface by at least 1 foot, and with the top of the screen at least 5 feet below the ground surface, unless field conditions dictate otherwise.

Monitoring wells have been located in part to assess groundwater quality near soil sampling data that has been or will be collected. Well SJMW004S is located between SJSB019 and SJSB023, as determined by USEPA. Similarly, the locations of potential wells SJMW004D and SJMW005 are also determined by USEPA. Soil samples in any well will only be collected for core logging purposes – no additional soil samples will be collected for laboratory analysis from these well borings.

Groundwater Resource Productivity Evaluation

Sustainable well yield information will be obtained during the initial field sampling event using procedures outlined in TCEQ RG-366/TRRP-8 (Attachment 1; TCEQ 2010) from the shallow existing wells (SJMW001, SJMW002, and SJMW003) and new shallow well(s) SJMW004S and potentially SJMW005.

Specifically, Method 2c (Direct determination of well yield by equilibrium discharge) or Method 2d (Direct determination of Class 2/Class 3 yield boundary by constant discharge) will be used to evaluate the sustainable well yield. Each method includes pumping the target well at a constant rate to determine sustainable well yield. These direct measurement methods are deemed most appropriate in low transmissivity settings; initial development efforts in May 2012 indicate the setting is a low transmissivity groundwater bearing unit (GWBU).

Analytical Approach

The work described in this SAP Addendum is being conducted to address Remedial Investigation Study Element 3, Physical Conceptual Site Model, and Fate and Transport Evaluation. Groundwater samples will be collected to determine if chemicals required for analysis by USEPA (Miller 2011c pers. comm.) are present at concentrations greater than MCLs, or State drinking water standards for chemicals lacking MCLs (Table 1) in groundwater from SJMW004S. TDS will be collected to assist in groundwater classification according to TCEQ (2010), if necessary. Conventional groundwater parameters and water level data will be collected to assess general groundwater quality and behavior (i.e., flow gradients).

Results of groundwater analyses will be compared with USEPA MCLs and State drinking water quality criteria. If results are below applicable standards, no additional groundwater work is anticipated. If results exceed standards, wells SJMW004D and SJMW005 will be installed and sampled, consistent with the Groundwater SAP.

Soil extracted from all three well borings will be visually inspected and logged to characterize subsurface stratigraphy.

Timing of Sampling and Reporting

Sampling will be conducted following approval of this SAP Addendum. Sampling is estimated to take place in mid-May 2013.

Field work, data validation, and reporting are subject to certain factors outside of IPC's control. These factors include, but are not limited to timely review and approval of this and related documents by USEPA, property access, weather, and availability of qualified contractors. Unvalidated data from the first well (SJMW004S) are expected to be available within approximately 2 weeks of sampling, and validated data will be available electronically within approximately 2 weeks following delivery of preliminary chemistry data. If sampling is completed in this timeframe, and all groundwater samples are in the laboratory on or about May 15, 2013, validated analytical results are expected to be available and loaded to the project database on or about June 15, 2013. If wells SJMW004D and SJMW005 are required based on the analytical results of SJMW004S, those wells would be installed by mid-July 2013, assuming property access issues, weather, and availability of qualified contractors to perform the work are aligned.

A table with results of chemical analyses and a map showing sample locations will be provided to USEPA, as soon as practicable, after validated data are available. It is anticipated that the data from this sampling event will be presented to USEPA and evaluated as an addendum to the RI report.

LIST OF ACRONYMS AND ABBREVIATIONS

DQO	data quality objective
HASP	Health and Safety Plan
GWBU	groundwater bearing unit
I-10	Interstate Highway 10
IPC	International Paper Company
MCL	maximum contaminant level
MIMC	McGinnes Industrial Maintenance Corporation
PSCR	Preliminary Site Characterization Report
QA/QC	quality assurance and quality control
RI/FS	Remedial Investigation/Feasibility Study
SAP	Sampling and Analysis Plan
SITE	San Jacinto River Waste Pits Superfund Site
SJRWP	San Jacinto River Waste Pits
SVOC	semi-volatile organic compound
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solid
TRRP	Texas Risk Reduction Program
UAO	Unilateral Administrative Order
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

REFERENCES

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Miller, M.G., 2011b. Personal communication (letter to D. Keith, Anchor QEA, Ocean Springs, MS, dated December 8, 2011, regarding the draft Preliminary Site Characterization report for the San Jacinto River Waste Pits Superfund Site). U.S. Environmental Protection Agency, Dallas, TX.

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USEPA, 1998. USEPA Guidance for Quality Assurance Project Plans. EPA QA/G-5. U.S. Environmental Protection Agency, Washington, DC.

USEPA, 2001. USEPA Requirements for Quality Assurance Project Plans. EPA QA/R-5. EPA/240/B-01/003. U.S. Environmental Protection Agency, Office of Environmental Information, Washington, DC.

USEPA, 2009. Unilateral Administrative Order for Remedial Investigation/Feasibility Study. U.S. EPA Region 6 CERCLA Docket No. 06-03-10. In the matter of: San Jacinto River Waste Pits Superfund Site Pasadena, Texas. International Paper Company, Inc. & McGinnes Industrial Management Corporation, respondents.

TABLES

Table 1
Analytes, Screening Criteria, Method Reporting Limits (MRL), and Method Detection Limits (MDL) for Groundwater Samples
COPCs and EPA-Required VOCs and SVOCs

Analyte	CAS Number	Screening Criteria (ug/L)[a]		MRL	MDL
Metals					
Aluminum	7429-90-5	50-200	c	50	40
Arsenic	7440-38-2	10	b	10	4
Barium	7440-39-3	2000	b	5	0.5
Cadmium	7440-43-9	5	b	5	0.9
Chromium	7440-47-3	100	b	5	2
Cobalt	7440-48-4	7.3	e	1	0.4
Copper	7440-50-8	1300	b, d	10	5
Lead	7439-92-1	15	b, d	10	4
Magnesium	7439-95-4	NA		20	0.4
Manganese	7439-96-5	1100	e	5	0.7
Nickel	7440-02-0	490	e	20	3
Thallium	7440-28-0	2	b	0.02	0.005
Vanadium	7440-62-2	44	e	0.2	0.03
Zinc	7440-66-6	5000	c	10	2
Mercury	7439-97-6	2	b	0.2	0.02
Organics					
EPA Required non-COPC VOCs					
Acetone	67-64-1	22000	e	20	2.5
Benzene	71-43-2	5	b	0.5	0.045
Bromobenzene	108-86-1	200	e	2	0.027
Bromochloromethane	74-97-5	980	e	0.5	0.091
Bromodichloromethane	75-27-4	15	e	0.5	0.036
Bromoform	75-25-2	120	e	0.5	0.080
Bromomethane	74-83-9	34	e	0.5	0.072
2-Butanone	78-93-3	15000	e	20	3.8
n-Butylbenzene	104-51-8	1200	e	2	0.056
sec-Butylbenzene	135-98-8	980	e	2	0.036
tert-Butylbenzene	98-06-6	980	e	2	0.038
Carbon disulfide	75-15-0	2400	e	0.5	0.045
Carbon tetrachloride	56-23-5	5	b	0.5	0.068
Chlorobenzene	108-90-7	1	b	0.5	0.045
Chloroethane	75-00-3	9800	e	0.5	0.13
Chloroform	67-66-3	240	e	0.5	0.042
Chloromethane	74-87-3	70	e	0.5	0.053
2-Chlorotoluene	95-49-8	490	e	2	0.035
4-Chlorotoluene	106-43-4	490	e	2	0.025
1,2-Dibromo-3-chloropropane	96-12-8	0.2	b	2	0.22
Dibromochloromethane	124-48-1	11	e	0.5	0.057
1,2-Dibromoethane	106-93-4	0.05	e	2	0.084
Dibromomethane	74-95-3	120	e	0.5	0.089
1,2-Dichlorobenzene	95-50-1	6	b	0.5	0.044
1,3-Dichlorobenzene	541-73-1	730	e	0.5	0.041
1,4-Dichlorobenzene	106-46-7	75	b	0.5	0.054
Dichlorodifluoromethane	75-71-8	4900	e	0.5	0.083
1,1-Dichloroethane	75-34-3	4900	e	0.5	0.042
1,2-Dichloroethane	107-06-2	5	b	0.5	0.073
1,1-Dichloroethene	75-35-4	7	b	0.5	0.10
cis-1,2-Dichloroethene	156-59-2	70	b	0.5	0.045
trans-1,2-Dichloroethene	156-60-5	100	b	0.5	0.048
1,2-Dichloropropane	78-87-5	5	b	0.5	0.042
1,3-Dichloropropane	142-28-9	9.1	e	0.5	0.032
2,2-Dichloropropane	594-20-7	13	e	0.5	0.050
1,1-Dichloropropene	563-58-6	9.1	e	0.5	0.051
cis-1,3-Dichloropropene	10061-01-5	1.7	e	0.5	0.038
trans-1,3-Dichloropropene	10061-02-6	9.1	e	0.5	0.041
Ethylbenzene	100-41-4	700	b	0.5	0.042
Hexachlorobutadiene	87-68-3	12	e	2	0.19
2-Hexanone	591-78-6	120	e	20	2.9
Isopropylbenzene	98-82-8	2400	e	2	0.031
4-Isopropyltoluene	99-87-6	2400	e	2	0.044
4-Methyl-2-pentanone	108-10-1	2000	e	20	3.0

Table 1
Analytes, Screening Criteria, Method Reporting Limits (MRL), and Method Detection Limits (MDL) for Groundwater Samples
COPCs and EPA-Required VOCs and SVOCs

Analyte	CAS Number	Screening Criteria (ug/L)[a]		MRL	MDL
Methylene chloride	75-09-2	5	e	2	0.23
Naphthalene	91-20-3	490	e	2	0.10
n-Propylbenzene	103-65-1	980	e	2	0.037
Styrene	100-42-5	100	b	0.5	0.039
1,1,1,2-Tetrachloroethane	630-20-6	35	e	0.5	0.047
1,1,2,2-Tetrachloroethane	79-34-5	4.6	e	0.5	0.064
Tetrachloroethene	127-18-4	5	b	0.5	0.077
Toluene	108-88-3	1000	b	0.5	0.048
1,2,3-Trichlorobenzene	87-61-6	73	e	2	0.10
1,2,4-Trichlorobenzene	120-82-1	70	b	2	0.13
1,1,2-Trichloroethane	79-00-5	5	b	0.5	0.061
1,1,1-Trichloroethane	71-55-6	200	b	0.5	0.050
Trichloroethene	79-01-6	5	b	0.5	0.061
Trichlorofluoromethane	75-69-4	7300	e	0.5	0.086
1,2,3-Trichloropropane	96-18-4	0.03	e	0.5	0.14
1,2,4-Trimethylbenzene	95-63-6	1200	e	2	0.037
1,3,5-Trimethylbenzene	108-67-8	1200	e	2	0.042
Vinyl chloride	75-01-4	2	b	0.5	0.071
o-Xylene (total xylenes)	95-47-6	10000	b	0.5	0.037
m,p-Xylenes (total xylenes)	179601-23-1	10000	b	0.5	0.078
Dioxins/Furans					
Dioxins and Furans (as 2,3,7,8 TCDD)	1746-01-6	3.00E-05	b	1.00E-05	3.70E-07
Total PCBs	1336-36-3	0.5	b	0.2	0.049
Semivolatile Organic Compounds					
Carbazole	86-74-8	46	e	10	0.364
Phenol	108-95-2	7300	e	10	0.324
Bis(2-ethylhexyl)phthalate	117-81-7	6	b	1	0.13
EPA Required non-COPC SVOCs					
2,4,5-Trichlorophenol	95-95-4	2400	e	0.5	0.031
2,4,6-Trichlorophenol	88-06-2	24	e	0.5	0.058
2,4-Dichlorophenol	120-83-2	73	e	0.5	0.047
2,4-Dimethylphenol	105-67-9	490	e	4.0	2.2
2,4-Dinitrophenol	51-28-5	49	e	4.0	0.17
2,4-Dinitrotoluene	121-14-2	1.3	e	0.2	0.018
2,6-Dinitrotoluene	606-20-2	1.3	e	0.2	0.033
2-Chloronaphthalene	91-58-7	2000	e	0.2	0.041
2-Chlorophenol	95-57-8	120	e	0.5	0.054
2-Methyl-4,6-dinitrophenol	534-52-1	2.4	e	2.0	0.025
2-Methylnaphthalene	91-57-6	98	e	0.2	0.026
2-Methylphenol	95-48-7	1200	e	0.5	0.11
2-Nitroaniline	88-74-4	7.3	e	0.2	0.024
2-Nitrophenol	88-75-5	49	e	0.5	0.063
3,3'-Dichlorobenzidine	91-94-1	2	e	2.0	0.428
3-Nitroaniline	99-09-2	7.3	e	1.0	0.029
4-Bromophenyl phenyl ether	101-55-3	0.06	e	0.2	0.026
4-Chloro-3-methylphenol	59-50-7	120	e	0.5	0.037
4-Chloroaniline	106-47-8	4.6	e	0.2	0.025
4-Chlorophenyl phenyl ether	7005-72-3	0.06	e	0.2	0.027
4-Methylphenol	106-44-5	120	e	0.5	0.12
4-Nitroaniline	100-01-6	46	e	1.0	0.019
4-Nitrophenol	100-02-7	49	e	2.0	0.28
Acenaphthene	83-32-9	1500	e	0.2	0.026
Acenaphthylene	208-96-8	1500	e	0.2	0.015
Anthracene	120-12-7	7300	e	0.2	0.024
Benz[a]anthracene	56-55-3	1.3	e	0.2	0.018
Benzo[a]pyrene	50-32-8	0.2	b	0.2	0.031
Benzo[b]fluoranthene	205-99-2	1.3	e	0.2	0.017
Benzo[ghi]perylene	191-24-2	730	e	0.2	0.019
Benzo[k]fluoranthene	207-08-9	13	e	0.2	0.024
Benzoic acid	65-85-0	98000	e	5.0	1.1
Benzyl alcohol	100-51-6	2400	e	5.0	0.073
Bis(2-chloroethoxy)methane	111-91-1	0.83	e	0.2	0.024

Table 1
Analytes, Screening Criteria, Method Reporting Limits (MRL), and Method Detection Limits (MDL) for Groundwater Samples
COPCs and EPA-Required VOCs and SVOCs

Analyte	CAS Number	Screening Criteria (ug/L)[a]		MRL	MDL
Bis(2-chloroethyl) ether	111-44-4	0.83	e	0.2	0.035
Bis(2-chloroisopropyl) ether	39638-32-9	13	e,f	0.2	0.026
Bis(2-ethylhexyl) phthalate	117-81-7	6	b	1.0	0.13
Butyl benzyl phthalate	85-68-7	480	e	0.2	0.018
Chrysene	218-01-9	130	e	0.2	0.028
Dibenz[a,h]anthracene	53-70-3	0.2	e	0.2	0.017
Dibenzofuran	132-64-9	98	e	0.2	0.018
Diethyl phthalate	84-66-2	20000	e	0.2	0.012
Dimethyl phthalate	131-11-3	20000	e	0.2	0.021
Di-n-butyl phthalate	84-74-2	2400	e	0.2	0.023
Di-n-octyl phthalate	117-84-0	980	e	0.2	0.018
Fluoranthene	206-44-0	980	e	0.2	0.020
Fluorene	86-73-7	980	e	0.2	0.027
Hexachlorobenzene	118-74-1	1	b	0.2	0.022
Hexachlorocyclopentadiene	77-47-4	50	b	1.0	0.19
Hexachloroethane	67-72-1	17	e	0.2	0.024
Indeno[1,2,3-cd]pyrene	193-39-5	1.3	e	0.2	0.021
Isophorone	78-59-1	960	e	0.2	0.016
Nitrobenzene	98-95-3	49	e	0.2	0.028
N-Nitrosodi-n-propylamine	621-64-7	0.13	e	0.2	0.037
N-Nitrosodiphenylamine	86-30-6	190	e	0.2	0.048
Pentachlorophenol	87-86-5	1	b	1.0	0.34
Phenanthrene	85-01-8	730	e	0.2	0.022
Phenol	108-95-2	7300	e	0.5	0.063
Pyrene	129-00-0	730	e	0.2	0.019
Conventional					
Total Suspended Solids	none	500,000	c	5000	5000
Total Dissolved Solids	none	--		5000	5000

Notes:

MRLs/MDLs for Vanadium and Naphthalene may be revised during laboratory evaluation.

Additional conventional data consisting of turbidity, dissolved oxygen, specific conductance, temperature, pH and oxidation/reduction potential will be collected with field instruments during development, purging and sampling activities.

Method detection limits are updated periodically by the laboratories. MDLs that are in effect at the laboratory at the time of analysis will be used. These may differ slightly from the MDL shown in this table.

a. ACGs were selected from the following tiered sources:

Tier 1: Primary MCL

Tier 2: Secondary MCL

Tier 3: PCL for residential groundwater ingestion.

b. Primary MCL (USEPA 2009d)

c. Secondary MCL (USEPA 2009d), The Secondary Maximum Contaminant Level (SMCL) for aluminum indicates an acceptable range between 0.05 mg/l - 0.20mg/l. While EPA encourages utilities to meet a level of 0.05mg/l for aluminum where possible, the Agency still believes that varying water quality and treatment situations necessitate a flexible approach to develop the SMCL. What may be appropriate in one case may not be appropriate in another. Hence, a range was developed for the aluminum SMCL (56 FR 3526, 3573; January 30, 1991).

d. Primary MCL is an Action Level defined as the level of lead or copper which, if exceeded in over 10% of the homes tested, triggers treatment for corrosion control.

e. PCL for residential groundwater ingestion (TCEQ 2012)

f. The CAS number for this chemical in the PCL tables is 108-60-1, or dichloroisopropyl ether . It therefore is unclear whether the PCL is for this chemical or for bis(2-chloroisopropyl) ether.

NA = Not available

CAS = Chemical Abstract Service

MCL = Maximum Contaminant Level

PCL = Protective Concentration Level

TCEQ = Texas Commission on Environmental Quality

TRRP = Texas Risk Reduction Program

USEPA = United States Environmental Protection Agency

References:

USEPA. 2009d. 2009 Edition of the Drinking Water Standards and Health Advisories. EPA 822-R-09-011. Office of Water. United States Environmental Protection Agency. Washington, DC. Available at: http://water.epa.gov/action/advisories/drinking/drinking_index.cfm#dw-standards. Used as primary source.

TCEQ. 2012. TRRP PCLs. Tables 3. Texas Commission on Environmental Quality. Available at: http://www.tceq.state.tx.us/remediation/trrp/trrppcls.html

Table 2
Proposed Laboratory Methods for Samples

Matrix	Parameter	Laboratory	Sample Preparation		Quantitative Analysis	
			Protocol	Procedure	Protocol	Procedure
Water (Groundwater)	**Metals (Filtered and Unfiltered)**					
	Aluminum, arsenic, barium, cadmium, chromium, cobalt, copper, lead, magnesium, manganese, nickel, thallium, vanadium, zinc	ALS Environmental	EPA 3050	Strong acid digestion	EPA 6010B/6020	ICP/ICP-MS
	Mercury	ALS Environmental	EPA 7470A	Acid digestion/oxidation	EPA 7470A	CVAA
	Organics (Unfiltered)					
	Dioxins /Furans	ALS Environmental	EPA 1613B	Separatory funnel/Soxhlet/solid phase extraction	EPA 1613B	HRGC/HRMS
	PCB Aroclors	ALS Environmental	EPA 3510C/3520C/3535A	Separatory funnel/continuous liquid-liquid/solid phase extraction	EPA 8082	GC-ECD
	VOCs	ALS Environmental	EPA 8260B	Purge and trap	EPA 8260B	GC/MS
	SVOCs	ALS Environmental	EPA 3510C/3520C/3535A	Separatory funnel/continuous liquid-liquid/solid phase extraction	EPA 8270C	GC/MS
	Conventional					
	TDS	ALS Environmental	SM2540 C	Filter, evaporate filtrate and dry	SM2540 C	Weigh residue

Notes:

All VOCs and many SVOCs are required by USEPA, see Table 1.
CVAA = cold vapor atomic absorbtion spectrometry
EPA = U.S. Environmental Protection Agency
GC/ECD = gas chromatograpthy/electron capture detector
GC/MS = gas chromatography/mass spectrometry
HRGC = high-resolution gas chromatography
HRMS = high-resolution mass spectrometry
ICP = inductively coupled plasma-atomic emission spectrometry
ICP/MS = inductively coupled plasma/mass spectrometry
NA = not applicable
SVOC = semivolatile organic compound
TBD = to be determined
TDS = total dissolved solids

Table 3
Number of Locations Sampled-Soil Investigation Area 4

Sample Group	Sampling Method	Number of Locations	Approximate Coordinates[a]	Sample Locations	Analytes	Study Elements
Groundwater, COPCs[b], TSS, TDS, VOCs[c], SVOCs[c]	Low flow sampling techniques, screened zone of wells	1 shallow well (one shallow and one deep contigent upon results of initial sample)	3215482, 13856025 (TBD, TBD)	Monitoring well installed in one location (two additional wells contingent) to allow groundwater quality and flow characterization	COPCs[b], TSS, TDS, VOCs[c], SVOCs[c]	Physical CSM and Fate and Transport Evaluation

Notes:

COPC = chemical of potential concern (see Table 1).

[a] Three sampling locations are planned, consisting of shallow monitoring wells required by USEPA/TCEQ. See Figures 2 and 3. Coordinates are x,y NAD 1983 State Plane Texas South Central (Feet). Locations are approximate; as-built locations will be surveyed following field work.

[b] See Table 1.

[c] All VOCs and many SVOCs are required by USEPA, see Table 1.

Table 4
Sample Containers, Preservation, and Holding Time Requirements

Matrix	Container[a] Type	Container[a] Size	Laboratory	Parameter	Preservation	Holding Time	Sample Size[b]
Water (Groundwater)							
	HDPE	500 mL	TBD	Metals (total and dissolved)	4±2°C, HNO_3 to pH<2	6 months	100 mL
	HDPE	500 mL	TBD	Mercury (total and dissolved)	4±2°C, HNO_3 to pH<2	28 days	100 mL
	AG	1L	TBD	Dioxins/Furans (total)	4±2°C	1 year/1 year[c]	1L
	AG	4x1L	TBD	Dioxins/Furans (filtered)	4±2°C	1 year/1 year[c]	4L
	Glass	3x40 mL VOA Vials	TBD	Volatile Organic Compounds[d]	4±2°C, HCl to pH<2	14 days	5 mL
	AG	1L	TBD	Semivolatile Organic Compounds[d]	4±2°C	7 days	500 mL
	AG	1L	TBD	PCBs	4±2°C	7 days	500 mL
	HDPE	1L	TBD	Total Suspended Solids	4±2°C	7 days	1L
	HDPE	1L	TBD	Total Dissolved Solids	4±2°C	7 days	1L
Equipment Filter Wipe Blanks							
	HDPE	4 oz.	TBD	Metals	4±2°C	6 months	1 wipe
	HDPE	4 oz.	TBD	Mercury	4±2°C	28 Days	1 wipe
	AG	4 oz.	TBD	Dioxins/Furans	4±2°C	1 year/1 year[c]	1 wipe
	AG	4 oz.	TBD	PCBs	4±2°C	14 days/40 days[c]	1 wipe
	AG	4 oz.	TBD	Semivolatile Organic Compounds[d]	4±2°C	14 days/40 days[c]	1 wipe

Notes:

AG = amber glass
HDPE = high density polyethylene
NA = not applicable
TBD = to be determined
WMG = wide mouth glass
[a] The size and number of containers may be modified by the analytical laboratory.
[b] Sample sizes may be modified once laboratory selection is made.
[c] Holding time for samples prior to extraction/ holding time for extracts.
[d] All VOCs and many SVOCs are required by USEPA, see Table 1.

FIGURES

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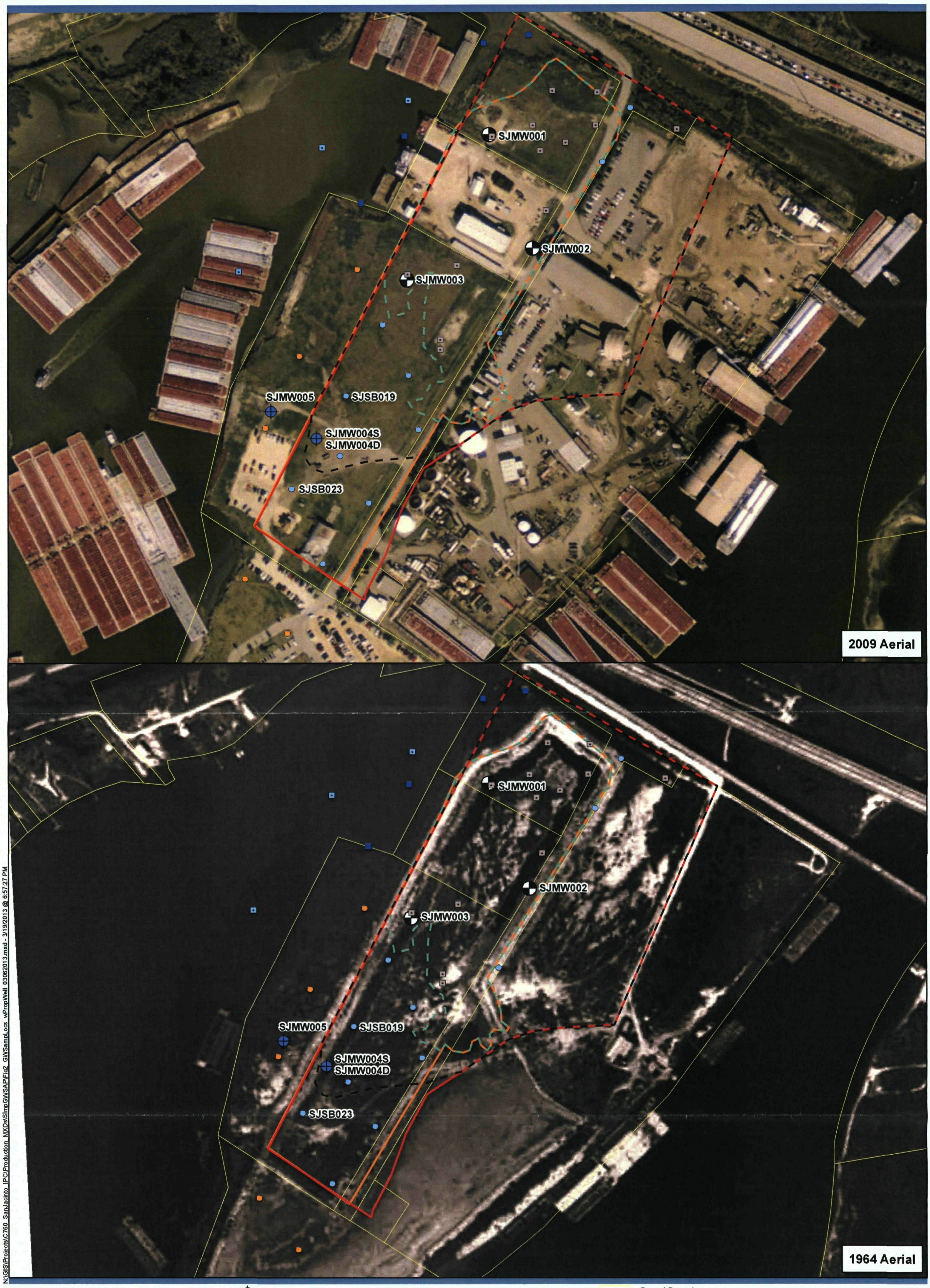
integral consulting inc.

- Approximate impoundment boundary derived from historical TSDH drawings.
- Boundary of a flooded area that is visible in a 1966 aerial photograph.
- The smaller of two approximate impoundment boundaries proposed by EPA on the basis of a 1964 aerial photograph.
- The larger of two approximate impoundment boundaries proposed by EPA on the basis of historical drawings by the TSDH.
- Soil Investigation Area 4

0 400
Feet

Figure 1
Overview South Impoundment
SJRWP Groundwater Study SAP Addendum 2
SJRWP Superfund/IPC



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ANCHOR QEA integral consulting inc.

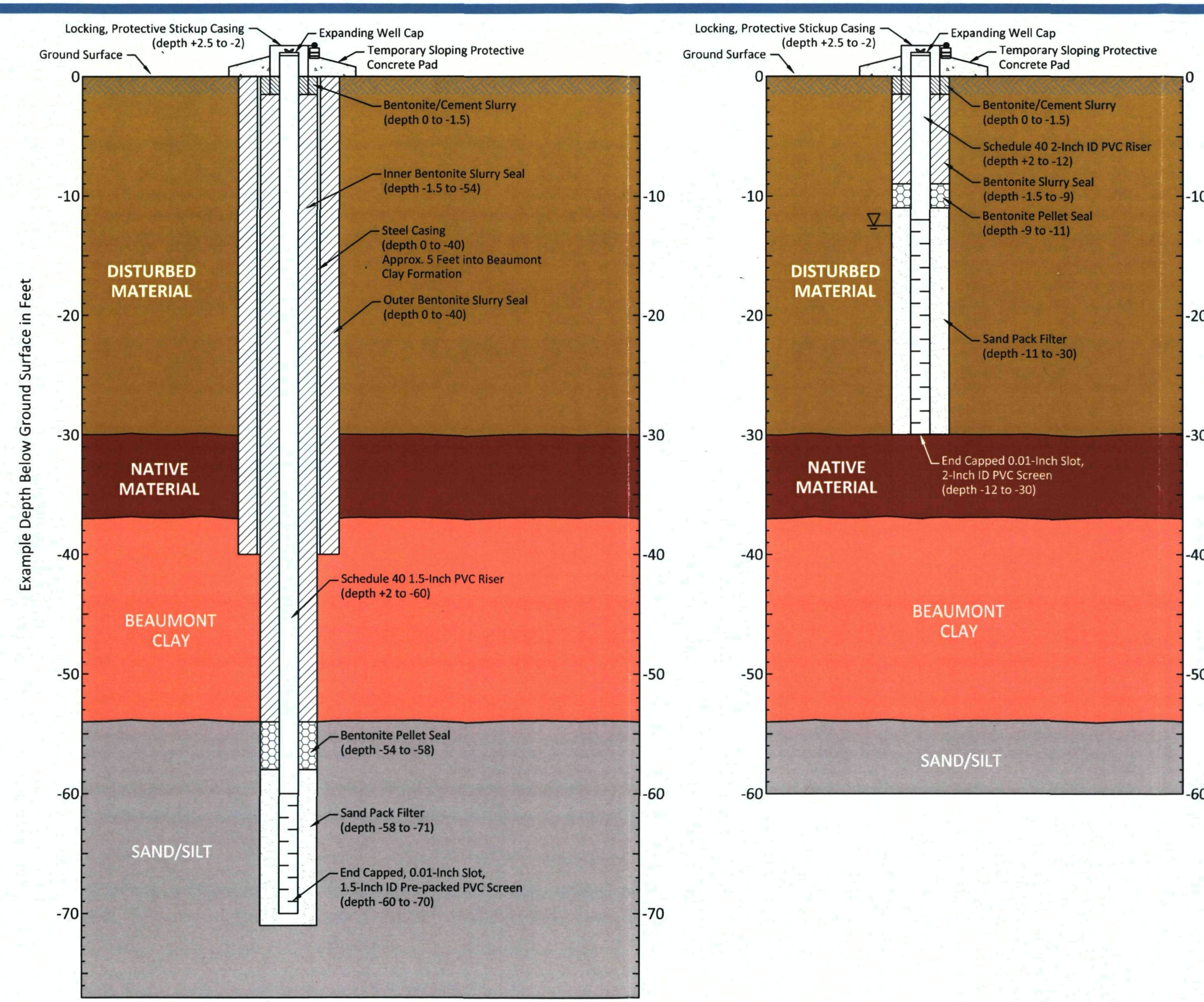
0 400 Feet

- Proposed Monitoring Well
- Existing Monitoring Well
- Soil Core at 2 Ft Intervals with All COPCs Analyzed in Every Other Interval **
- Soil Core at 2 Ft Intervals, Dioxins and Furans Only
- Sediment Sample Location
- Existing Sediment Sample Location
- Existing Soil Boring Sample Location
- Approximate impoundment boundary derived from historical TSDH drawings.
- Boundary of a flooded area that is visible in a 1966 aerial photograph.
- The smaller of two approximate impoundment boundaries proposed by EPA on the basis of a 1964 aerial photograph.
- The larger of two approximate impoundment boundaries proposed by EPA on the basis of historical drawings by the TSDH.
- Parcel Boundary

Figure 2
Sampling Locations
SJRWP Groundwater Study SAP Addendum 2
SJRWP Superfund/IPC

FEATURE SOURCES:
Parcel Boundaries: Harris County Appraisal District

NOTES:
** The upper 2 feet will be divided into 0-6, 6-12 and 12-24 inch increments. All of these will be analyzed for COPCs.



NOTES:
1. Presence and depths of lithology and components are estimated and may vary based on field conditions.

0 10
Vertical Scale in Feet
Horizontal: Not to Scale

ANCHOR QEA

Figure 3
Typical Shallow and Deep Well Construction Details
SJRWP Groundwater Study SAP - Addendum 2
SJRWP Superfund Site/IPC

ATTACHMENT 1
TCEQ RG-366/TRRP-8

Groundwater Classification

Objectives: This document provides recommended procedures for classifying groundwater and documenting the classification under the Texas Risk Reduction Program.

Audience: Regulated Community and Environmental Professionals

References: The Texas Risk Reduction Program (TRRP) rule, together with conforming changes to related rules, is contained in 30 Texas Administrative Code Chapter 350. The TRRP rule was initially published in the September 17, 1999 Texas Register (24 TexReg 7413-7944). The rule was amended in 2007 (effective March 19, 2007; 32 TexReg 1526-1579) and 2009 (effective March 19, 2009; 34 TexReg 1861-1872).

Find links for the TRRP rule and preamble, Tier 1 PCL tables, and other TRRP information at: <www.tceq.state.tx.us/remediation/trrp/>.

TRRP guidance documents undergo periodic revision and are subject to change. Referenced TRRP guidance documents may be in development. Links to current versions are at: <www.tceq.state.tx.us/remediation/trrp/guidance.html>.

Contact: TCEQ Remediation Division Technical Support Section: 512-239-2200, or <techsup@tceq.state.tx.us>.

For mailing addresses, refer to: <www.tceq.state.tx.us/about/directory/>.

1.0 Introduction

This document discusses the rule requirements for groundwater classification and provides a recommended process for completing groundwater classifications.

1.1 Applicable Regulatory Requirements

Under the Texas Risk Reduction Program (TRRP) rule, all groundwater-bearing units affected by, or reasonably anticipated to be affected by, chemicals of concern (COCs) having concentrations at or above residential groundwater assessment levels must be characterized with regard to the applicable groundwater resource classification, in accordance with §350.52. Under §350.4(a)(40), a *groundwater-bearing unit* is defined as *a saturated geologic formation, group of formations, or part of a formation that has a hydraulic conductivity equal to or greater than 1 x 10^{-5} cm/sec.*

TRRP at §350.52 establishes three categories of groundwater resources, designated Class 1, Class 2, and Class 3, based upon a site-specific evaluation of the current use of the groundwater-bearing unit (GWBU), as well as its potential use, as defined on the basis of natural water quality and well yield (see Table 1).

Saturated geologic units can be identified most readily during assessment by their capability to transmit water to an open borehole. Only saturated geologic units with hydraulic conductivities of $K \geq 1 \times 10^{-5}$ $^{cm}/_{sec}$ meet the definition of groundwater bearing unit (GWBU) in §350.4(a)(40) and must be classified as Class 1, Class 2, or Class 3 groundwater. Saturated geologic units with hydraulic conductivities of $K < 1 \times 10^{-5}$ $^{cm}/_{sec}$ are *not* subject to the classification requirements of §350.52.

1.2 Key Acronyms and Abbreviations

APAR	Affected Property Assessment Report
ASTM	American Society for Testing and Materials
COC	Chemical of concern
gpd	Gallons per day
GWBU	Groundwater-bearing unit
K	Hydraulic conductivity
PCL	Protective concentration level
PDWS	Primary Drinking Water Standards
PWS	Public water supply
Q	Well yield (*e.g.*, from well)
RAL	Residential assessment level
TDS	Total dissolved solids
TCEQ	Texas Commission on Environmental Quality
TRRP	Texas Risk Reduction Program
USCS	Unified Soil Classification System

1.3 Effect of Groundwater Resource Classification on TRRP Response Objectives

For each affected GWBU, the applicable groundwater response objectives, including the types of response measures that may be applied (removal/decontamination *vs* control) and the associated residential assessment level and groundwater protective concentration level (PCL), depend upon the groundwater resource classification of that GWBU and any other GWBUs which may be hydraulically-interconnected with it (See Sections 2.1.2 and 2.4) to the degree that it potentially can be impacted.

Applicable remedy standards and exposure pathways for Class 1, Class 2, and Class 3 groundwater resources are described below.

1.3.1 Applicable Remedy Standards

Under TRRP, the person conducting the response action may implement either Remedy Standard A (requiring removal or decontamination of affected media such that COC concentrations are less than or equal to applicable PCLs) or Remedy Standard B (requiring removal, decontamination, or control of affected media so as to prevent exposure to COCs at levels exceeding applicable PCLs). The applicability of removal/decontamination or control often is dictated by the groundwater resource classification, as follows:

1.3.1.1 Class 1 Groundwater.

For Class 1 groundwater resources, affected groundwater must be removed and/or decontaminated to the critical PCL; control options are not permitted by §350.33(b).

1.3.1.2 Class 2 or 3 Groundwater.

For affected Class 2 or Class 3 groundwater resources, affected groundwater must be removed and/or decontaminated to the critical PCL, *unless*: a plume management zone is approved *per* Remedy Standard B (§350.33), *or* such remediation is demonstrated by the person to be technically impracticable, in which case a plume management zone is required.

1.3.1.3 Groundwater Classification using Table 1.

Table 1 summarizes the TRRP Groundwater Resource Classification System by regulatory citation. Classification of a groundwater resource may be based on its *potential use* and/or its *current use*. A GWBU is assigned the highest water-quality classification for which *all of a citation's applicable potential use and current use conditions are true*. However, different classifications can apply to different portions of a single GWBU. For example, a GWBU can transition laterally from Class 2 to Class 3. Additionally, response objectives for each affected GWBU must be adjusted as needed to be protective of any hydraulically-interconnected GWBUs to which COCs could migrate such that the pathway can be reasonably anticipated to be complete (§350.71(c)).

1.3.2 Applicable Groundwater Exposure Pathways and PCLs

Under TRRP, a set of groundwater PCLs apply, at a minimum, to affected groundwater contained within GWBUs. The applicable groundwater exposure pathways and associated groundwater PCLs depend upon the site-specific groundwater resource classification and applicable exposure conditions, as follows:

> **Discussion Box**
> This discussion addresses *GWBUs* only. In some cases, additional response objectives may apply to soil strata based on other relevant soil PCLs, or non-aqueous phase liquids. Refer to the TCEQ document *Affected Property Assessment Requirements* (RG-366/TRRP-12) for additional discussion of applicable soil exposure pathways.

1.3.2.1 Class 1 and 2 Groundwater Ingestion Pathways.

All Class 1 and Class 2 groundwater resources are considered usable, or potentially usable, drinking water supplies. Therefore, under TRRP, the groundwater ingestion exposure pathway ($^{GW}GW_{Ing}$) is applicable to Class 1 or Class 2 groundwater.

1.3.2.2 Class 3 Groundwater Resource Protection Pathways.

Class 3 groundwater resources are not considered usable as drinking water and are not subject to groundwater ingestion PCLs. Rather, Class 3 groundwater is subject to the $^{GW}GW_{Class\ 3}$ PCL, which is equal to 100 x $^{GW}GW_{Ing}$.

A decision-logic flowchart for determining groundwater resource classification is provided on Figure 1.

1.3.2.3 Additional Exposure Pathways.

For Class 1, Class 2, or Class 3 groundwater resources, if either the groundwater-to-surface water exposure pathway (^{SW}GW) or the groundwater-volatilization-to-ambient air exposure pathway ($^{Air}GW_{Inh\text{-}V}$) is determined to be complete, the PCL for the additional pathway(s) will apply.

NOTE: ***If a GWBU meets the criteria for more than one groundwater classification, then the GWBU shall be assigned the higher (quality) classification (§350.52).***

Table 1. TCEQ Groundwater Resource Classification System

Groundwater Classification	**TRRP Citation**	**Potential Use of GWBU Based on Aquifer Characteristics - Well Yield Criteria**	**Potential Use of GWBU Based on Aquifer Characteristics - Water Quality Criteria**	**Current Use of GWBU**
Class 1 Groundwater Resource	§350.52(1)(A)			Affected GWBU is within 0.5 miles of an existing public water supply well and COCs could impact the groundwater production zone for the well.
	§350.52(1)(B)	> 5,000 gpd (from 4-inch diameter well or equivalent)	TDS < 1,000 mg/L	GWBU is the only reliable source of water in vicinity (i.e., no public water system available) and depth to unit ≤ 800 feet bgs.
	§350.52(1)(C)	≥ 144,000 gpd (from 12-inch diameter well or equivalent)	TDS ≤ 3,000 mg/L and water meets PDWS	No current use required
Class 2 Groundwater Resource	§350.52(2)(A)			Affected GWBU is groundwater production zone for an existing well (other than public water supply well) located within 0.5 miles of affected groundwater and used either for human consumption, agriculture, or other purpose that could result in human or ecological exposure.
	§350.52(2)(B)	< 144,000 gpd (from 12-inch diameter well or equivalent) **and** ≥ 150 gpd (from 4-inch diameter well or equivalent)	TDS ≤ 10,000 mg/L	No current use required
Class 3 Groundwater Resource	§350.52(3)(A)	< 150 gpd (from 4-inch diameter well or equivalent)		Groundwater from affected GWBU is *not* used within 0.5 miles in a manner resulting in human or ecological exposure.
	§350.52(3)(A)		TDS > 10,000 mg/L	Groundwater from affected GWBU is *not* used within 0.5 miles in a manner resulting in human or ecological exposure.

bgs = below ground surface.

COC = chemical of concern.

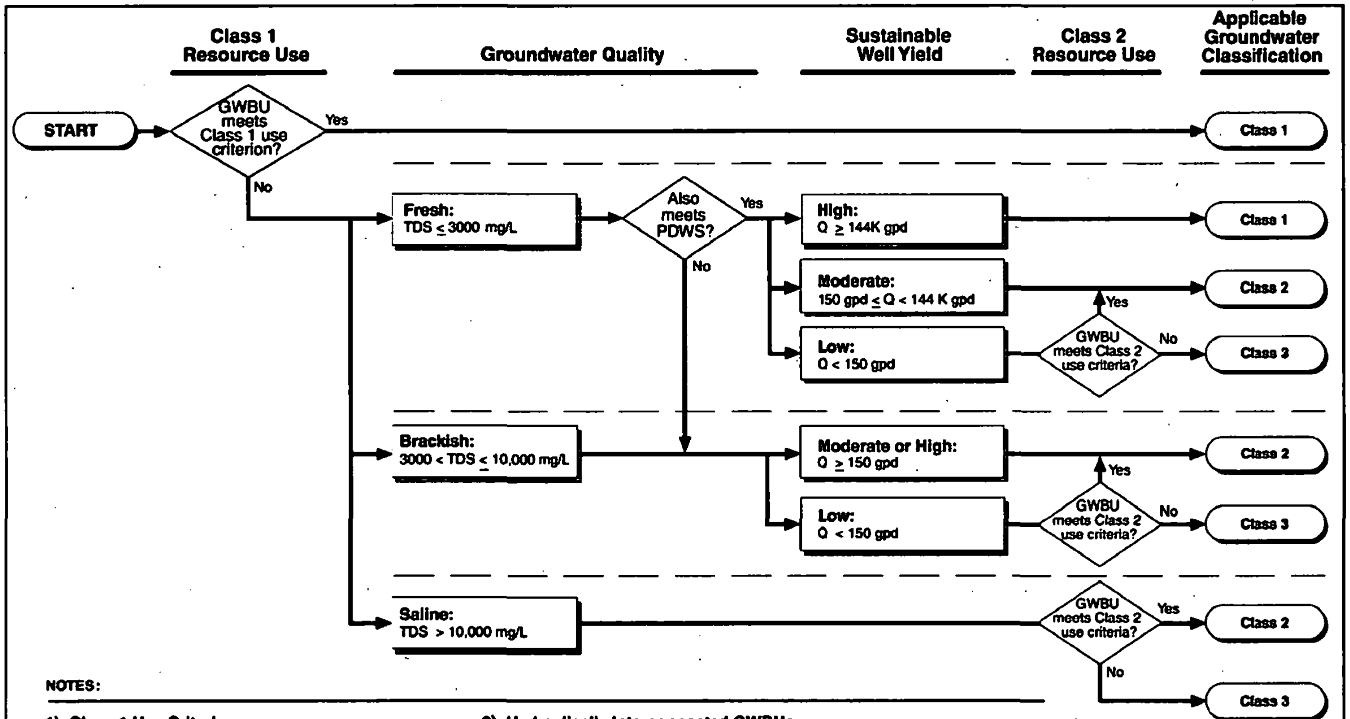
gpd = gallons per day.

GWBU = Groundwater-Bearing Unit.

PDWS = Primary Drinking Water Standards per 40 CFR Part 141.

TDS = Total Dissolved Solids.

Groundwater Production Zone – the groundwater-bearing unit(s) which contributes water to a well (see Section 2.5.2.1)



NOTES:

1) Class 1 Use Criteria:

- Affected groundwater zone is within 0.5 miles of public water supply well and COCs could migrate to well production zone; or
- GWBU is only reliable source of water in area, with depth < 800 ft below grade, TDS < 1000 mg/L, and sustainable well yield > 5000 gpd.

2) Class 2 Use Criteria:

- GWBU is production zone for existing water supply well (other than PWS well) within 0.5 miles which is used for human consumption, agriculture, or other purpose which could result in human or ecological exposure.

3) Hydraulically Interconnected GWBUs

If affected GWBU is hydraulically interconnected with unaffected units, the groundwater response objectives for the affected unit must serve to prevent impacts on hydraulically interconnected unit in excess of applicable assessment levels.

4)

gpd	= Gallons per day	PWS	= Public water supply
GWBU	= Groundwater-bearing unit	Q	= Well yield for GWBU
PDWS	= Primary Drinking Water Standards, 40 CFR 141 as amended	TDS	= Total dissolved solids per USEPA Method 160.1/160.2

Figure 1. TCEQ Groundwater Resource Classification Logic Diagram.

1.4 Use of this Guide for Classifying Groundwater Resources

The following sections of this guide present step-by-step procedures to determine the appropriate groundwater classification for each GWBU. *In general, the level of effort required for this classification process will depend upon the type of classification to be demonstrated.*

> **Early Concurrence**
> Persons are encouraged to seek concurrence for groundwater classification prior to full completion and submission of the APAR in order that the completed assessment and APAR are based on the approved groundwater classification.

1.4.1 Known or Default Class 1 Groundwater Resource

By default, a GWBU has a Class 1 designation unless it can be demonstrated otherwise using the classification process described herein. If the affected GWBU is known to be a public drinking water supply aquifer (e.g., Edwards, Ogallala, Evangeline, etc.), then the applicable resource designation is probably Class 1 and no further evaluation of the resource classification is necessary *unless* the person intends to demonstrate that the affected portion of that GWBU is a zone of lower productivity or water quality. However, assessment and characterization of all affected or threatened GWBUs should be submitted via the APAR. Similarly, if the affected GWBU is not a producing zone for a public drinking water supply well, but the person is prepared to conduct the response action consistent with the response objectives applicable to a Class 1 groundwater resource, then a Class 1 designation may be assumed without further demonstration. Table 2 summarizes the criteria by which a Class 1 groundwater resource designation is made.

> **Well Surveys**
> Field reconnaissance and a records survey are required to identify surrounding water wells per *§350.51(i) even if a Class 1 designation is assumed* (*see* Section 2).

Reclassification of a groundwater resource to a lower classification (e.g., reclassify from Class 1 to Class 2) may be appropriate in instances when: 1) site conditions change, 2) when the person wishes to amend a Class 1 default classification, or 3) any other circumstance under which reclassification is appropriate. However, reclassification to a lower classification resource shall require submittal of all commensurate data associated with the amended classification (see Section 2.9).

Table 2. Class 1 Groundwater Resource Criteria

	Resource Use	Groundwater Quality	Well Yield (Productivity)[1]
Case 1	Class 1 designation assumed by default	*N/A*	*N/A*
Case 2	*Class 1 Use Criteria* Affected GWBU is within 0.5 miles of PWS well **and** COCs could migrate to groundwater production zone	*N/A*	*N/A*
Case 3	*Class 1 Use Criteria* GWBU is only reliable source of water in area **and** Depth < 800 feet	TDS <1,000 mg/L	Q > 5,000 gpd
Case 4	*Class 1 Use Criteria* No required use	TDS ≤ 3,000 mg/L	Q ≥ 144,000 gpd

gpd = gallons per day **mg/L** = milligrams per liter

PDWS = primary drinking water standard **PWS** = public water supply

Q = well yield **TDS** = total dissolved solids

[1]Well yield determined via Methods 1 and 2 (see Section 2.7).

1.4.2 Class 2 Groundwater Resource

To show that an affected GWBU is a Class 2 groundwater resource, the person need only demonstrate that the unit does not currently qualify as a Class 1 resource. This demonstration requires, at a minimum, an accurate and thorough water well survey that identifies all water wells within 0.5 miles of the extent of affected groundwater, and if the survey reveals there is no use within 0.5 miles:

1. an evaluation of water quality, or
2. an estimate of well yield for the affected GWBU.

As indicated in Figure 1, a Class 2 designation may be applied to GWBUs that do not meet the Class 1 criteria. Table 3 summarizes the criteria by which a Class 2 groundwater resource designation is made.

Table 3. Class 2 Groundwater Resource Criteria

	Resource Use	Groundwater Quality	Well Yield (Productivity)[1]
Case 1	*Class 2 Use Criteria* Production zone for existing water supply well (other than PWS well) w/in 0.5 mile & used for human consumption, agriculture, *etc.*	*N/A*	*N/A*
Case 2	No use within ½ mile	*Brackish* 3,000 mg/L < TDS ≤ 10,000 mg/L (*and* may **not** meet PDWS)	Moderate or High Q ≥ 150 gpd
[1]Well yield determined via Methods 1 and 2 (see Section 2.7).		gpd = gallons per day	
PDWS = primary drinking water standard		PWS = public water supply	
Q = well yield		TDS = total dissolved solids	

1.4.3 Class 3 Groundwater Resource

To show that an affected groundwater-bearing unit is a Class 3 groundwater resource, the person must demonstrate that the unit does not currently qualify either as a Class 1 or Class 2 resource. *This demonstration comprises a more rigorous site-specific evaluation than is required for a Class 1 or Class 2 designation*. At a minimum, the person must provide all site-specific data required for a Class 2 groundwater determination *plus* the following supporting information:

1. site-specific natural TDS of the affected groundwater-bearing unit > 10,000 mg/L, *or*
2. determination that the sustainable daily rate of withdrawal from a properly completed well is less than 150 gpd using Method 1 or Method 2 (*see* Section 2.7 and 2.8).

Table 4 summarizes the criteria by which a Class 3 groundwater resource designation is made. As shown, well yield is the critical classification criterion for Case 1 and Case 2. Groundwater quality is the critical criterion for Case 3, Case 4, and Case 5.

1.4.4 Saturated Soils

As defined by the TRRP rule, saturated geologic units with a hydraulic conductivity $K < 1 \times 10^{-5}\ {}^{cm}/_{sec}$ do not qualify as GWBUs for purposes of requisite GWBU classification. At a minimum, the person must provide the following supporting information:

1. site-specific evaluation of hydraulic conductivity (required), *and*
2. *laboratory*-determined USCS soil classification.

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Table 4. Class 3 Groundwater Resource Criteria

	Resource Use	Groundwater Quality	Well Yield (Productivity)[1]
Case 1	*No well use*	*N/A*	Q<150 gpd
Case 2	*No well use*	TDS ≤ 10,000 mg/L	Q<150 gpd
Case 3	*No well use*	TDS > 10,000 mg/L	Q>150 gpd
Case 4	*No well use*	TDS > 10,000 mg/L	Q>50 gpd
Case 5	*No well use*	TDS > 10,000 mg/l	N/A

[1]Well yield determined via Methods 1 and 2 (see Section 2.7). gpd = gallons per day

PDWS = primary drinking water standard Q = well yield

TDS = total dissolved solids

2.0 Principal Steps in Groundwater Resource Classification Process

To establish the appropriate groundwater resource classification, the person must first identify the GWBUs that have been affected (or could reasonably be expected to be affected) by a COC in excess of the applicable residential assessment level (RAL). See TCEQ guidance document *Affected Property Assessment Requirements* (RG-366/TRRP-12) for information on COC assessment. Since the applicable RAL is determined on the basis of the groundwater classification, the groundwater COC assessment and groundwater classification procedures often will be iterative. However, a preliminary evaluation of background information on local hydrogeology and groundwater use may give the person an indication of the likely GWBU classification before initiating a drilling program. Since the assessment level is the same for Class 1 and Class 2 groundwater, but is different for Class 3 groundwater, the critical consideration is whether the GWBU is likely Class 3.

Therefore, before following the steps outlined in this section, it is recommended that the on-site groundwater COC assessment be completed at a minimum. Particular attention should be given to recognition of any natural preferential groundwater transport pathways for the COCs as these indicate zones that should be focused upon when characterizing a GWBU. Note that even if the on-site COC assessment indicates that groundwater is not yet affected, the upper-most GWBU still must be classified in order to set soil PCLs that are protective for that upper-most GWBU. Alternatively, the unaffected upper-most GWBU can be presumed to be Class 1.

2.1 Overview of Classification Process

A *groundwater-bearing unit* is defined as *a saturated geologic formation, group of formations, or part of a formation that has a hydraulic conductivity equal to or greater than 1 x 10-5 cm/sec.*

Groundwater resource classifications are determined on a site-specific basis, requiring hydrologic and geologic information for the GWBU under investigation. Available information from nearby sites may be used to augment the site-specific evaluation – *but typically will not be acceptable as a substitute for requisite site-specific information.*

In each step of the groundwater resource classification process, care must be taken to demonstrate that all information provided is *representative* of that GWBU. *Significant lithologic and stratigraphic heterogeneities, and variability of measured aquifer parameters and water chemistry, should be considered and reconciled for the purpose of delineating GWBUs whose physical, chemical, geologic, and hydraulic properties are internally consistent with and representative of that unit.*

> **Use of Existing Aquifer Test Data**
> Aquifer test data from an adjacent (or nearby) site may be accepted by the TCEQ in lieu of site-specific test data if the hydrostratigraphy from which the data originate can be *properly correlated* to the same hydrostratigraphic unit whose groundwater resource is being classified.

For each affected GWBU, determination of the appropriate groundwater resource classification is achieved through an orderly progression of steps. Depending on the actual classification, some steps may be optional (*see* Section 2.2). Table 5 summarizes the steps for determination of the groundwater resource classification on a site-specific basis.

The Classification Steps are summarized as follows:

2.1.1 Step 1: Describe Affected Groundwater-Bearing Unit(s)

Identify groundwater-bearing units by:

1. characterizing the *site-specific* stratigraphy and relevant water-saturated units with soil borings and USCS soil classification; and
2. grouping the saturated stratigraphic units into the fewest number of GWBUs that is reflective of hydrogeologic conditions.

Depositional environment and hydrostratigraphic considerations should factor into these evaluations (*see* Sec 2.3).

2.1.2 Step 2: Determine Hydraulic Interconnectivity

Determine any hydraulic interconnectivity with other GWBUs by using:

1. stratigraphic methods, including detailed site stratigraphy, levels at which water is first encountered, and static water levels;
2. hydraulic methods to determine if water levels in one GWBU respond to pumping stresses in the other GWBU, and/or
3. water chemistry methods, including affected groundwater and natural water quality tracers.

Table 5. Summary of Steps in Groundwater Resource Classification

		Procedures	Section	Notes	Required and Optional Classification Steps			
					Class 1	Class 2	Class 3	Sat. Soil
Step 1	Describe Affected GWBUs or Saturated Soil	Identify and define GWBU	2.3		■	■	■	■
Step 2	Determine Hydraulic Interconnectivity	Stratigraphic method	2.4	Important if proving no threat to groundwater production zone	■	■	■	■
		Water chemistry method			□	□	□	□
		Hydraulic method			□	□	□	□
Step 3	Determine Current Groundwater Use	Field reconnaissance	2.5		■	■	■	■
		Records search *			■	■	■	■
Step 4	Evaluate Natural Groundwater Quality	Determination of TDS	2.6	Important if not assuming Class 1	□	□	□	N/A
Step 5	Evaluate GWBU Productivity	Determine GWBU aquifer parameters or well yield	2.7		□	□	□	■
Step 6	Evaluate GWBU Sustainability	Ephemerality of saturation	2.8.1	Important if classification not based on wells or TDS	N/A	□	N/A	N/A
	Evaluate GWBU Sustainability	Hydrostratigraphic extent of GWBU	2.8.2	Important if classification not based on wells or TDS	N/A	□	N/A	N/A
Step 7	Document Results	Reporting requirements	2.9		■	■	■	■

*** Not required if GWBU is unaffected and assuming Class 1.**

■ = Required Step □ = Optional Step

2.1.3 Step 3: Determine Current Groundwater Use

Identify current use of affected and interconnected GWBUs using:

1. field reconnaissance surveys within 500-foot radius of affected property; and
2. record searches for existing water supply wells within 0.5 miles in any direction from the affected groundwater zone.

Affected Property
Affected Property is defined as the extent of environmental media containing COCs in excess of residential assessment levels. Affected Property **is not** defined by a property boundary. See *Affected Property Assessment Requirements* (RG-366/TRRP-12) for discussion of affected property.

2.1.4 Step 4: Evaluate Natural Groundwater Quality

Characterize natural water quality of GWBU(s) based on:

1. background TDS concentration, and
2. PDWS criteria (see *40 CFR Part 141*) (optional).

2.1.5 Step 5: Evaluate GWBU Productivity

Determine aquifer and yield parameters of relevant GWBUs, including:

1. installation of fully-penetrating test wells appropriately screened and developed;
2. determination of GWBU hydraulic conductivities;
3. single- and multiple-well aquifer tests (optional for Class 1/Class 2 GWBUs); and
4. well yield tests (optional for Class 1/Class 2 GWBUs).

2.1.6 Step 6: Evaluate GWBU Sustainability

Characterize the sustainability of each GWBU to be classified, based on:

1. demonstration of historical or predicted permanence of saturation; and/or
2. analysis of the geologic extent and hydrologic character of GWBU.

2.1.7 Step 7: Document Results

Prepare for submittal all supporting documentation for the information upon which all groundwater resource classifications are determined. Submit the information and the results of the groundwater classification

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effort for TCEQ review as part of the *Affected Property Assessment Report* (APAR). Consider submitting the groundwater classification documentation for TCEQ approval prior to submitting the full APAR.

The appropriate content and format of the APAR is addressed in TCEQ Form No. 10325/APAR (*see* www.tceq.state.tx.us/remediation/trrp/guidance.html).

2.2 Required and Optional GWBU Classification Steps

Some steps in the groundwater resource classification process may be optional depending on the site-specific conditions or whether the Class 1 default is assumed. Table 5 summarizes the general minimum effort required for the classification of all affected GWBUs by indicating which classification steps are required or optional for completing the groundwater classification process.

For example, the classification process can conclude upon determination by the person that the affected GWBU could impact the groundwater production zone of a public water supply well or is the only reliable water supply source (i.e., Class 1 resource designation applies).

2.3 STEP 1: Describe Affected Groundwater-Bearing Units

Upon completion of a sufficient COC assessment, a site-specific hydrogeologic evaluation must be completed in order to characterize the stratigraphy over the depth and areal extent that soil and groundwater impacts have occurred, or could be expected to occur, and define GWBUs that must be classified. The stratigraphy should be evaluated in the context of the depositional environment in order that an appropriate hydrogeologic conceptual model is considered when defining the GWBUs.

Sealed Geoscience Work
The description and interpretation of geologic units described herein qualifies as geoscience work (22 TAC §851.10). All boring logs, cross-sections, stratigraphic sections and maps depicting geoscience work must be individually sealed by a licensed professional geoscientist (P.G.) pursuant to 22 TAC §851.156.

Sampling locations and data collection methods must be sufficient to characterize the following:

1. depth of occurrence, lateral continuity, thickness, and geometry of soil or rock type of affected GWBUs;
2. saturated thickness; and
3. lateral extent and continuity of affected and interconnected GWBUs.

2.3.1 Site Stratigraphy

The principal goal of the stratigraphic investigation for the affected property assessment is to characterize the occurrence and movement of groundwater affected or threatened by the COC release. The degree to which site stratigraphy is characterized should be based on the level of hydrogeologic complexity present at the location. The person should prepare for such an investigation by being familiar with the local geology prior to initiating an assessment in order to anticipate the full scope of the requisite work.

> **Soils-Only Impact**
> Even when groundwater is not affected by a release in excess of the residential assessment level, the soils must be protective of the groundwater. Therefore, unless a site-specific evaluation demonstrates otherwise, the first (uppermost) GWBU *shall be considered to be Class 1.*

Stratigraphy must be correlated between different locations to define the continuity and thickness variation of each stratum across the site. At each location, the soil and/or rock column penetrated by the borehole should be discretized into individual strata based on variation of soil type, appearance, and apparent hydraulic properties. Standard stratigraphic correlation methods should be employed in constructing strike and dip sections for the site.

For the purpose of consistent stratigraphic characterization *in the field* and for presentation to the agency, soils observed and/or collected at the affected property should be classified according to the Unified Soil Classification System (USCS) per *ASTM Standard Practice D 2488* (field classification method).

Supplemental subsurface information may be developed using cone penetrometer testing (CPT) or geophysical logging methods to generate continuous stratigraphic logs, based on appropriate correlation to actual soil or rock core samples from the site. *Data from CPT and other logging methodologies can be used to supplement, but not replace, standard geologic log information (e.g., ASTM Standard Guide D 5434).*

> **Photo Documentation**
> Photographic documentation of prepared split-spoon, core-barrel, Shelby tube, and/or other undisturbed representative subsurface soil samples may be used in conjunction with other required soil information to support a GWBU Class determination.

The number of borings necessary to satisfy a complete subsurface investigation should be commensurate with the size of the affected area(s) and the complexity of the hydrogeologic setting. *The minimum number of borings is that necessary to satisfy the requirements of Section 2.3.*

Various drilling and sampling methods may be employed for this purpose (e.g., hollow-stem auger, mud rotary, air rotary, etc.) as appropriate for local soil or rock conditions (*see* Attachment A for recommended drilling methods).

2.3.2 Identification of Water-Saturated Units

To qualify as a GWBU, a geologic formation (or a portion thereof) must be water-saturated and have sufficient hydraulic conductivity (i.e., $K \geq 1 \times 10^{-5}$ $^{cm}/_{sec}$).

Water saturation conditions within geologic strata can be confirmed on the basis of drilling observations, existing wells or piezometers, or installation of additional wells or piezometers. The presence of moisture or water seepage from soil cores, or water accumulation in boreholes during or after drilling operations suffices to confirm water saturation in a stratum.

For strata from which the presence of water saturation is difficult to discern during drilling (due either to low water yield rates, use of a wet drilling method, etc.), the presence or absence of water may be determined based upon inspection of an open borehole, piezometer, monitoring well, pore pressure transducer, or other reliable device that is capable of providing hydrologic information from an isolated stratum (or strata) in question and that is allowed to equilibrate for an appropriate time period following drilling or well installation (e.g., minimum 24-hour period for open borehole, piezometer, or monitoring well).

For unconfined saturated units, the depth at which water saturation occurs within the stratum can be defined based on the height of the static water level within the observation device. For confined units, the static water level will occur at or above the top of the permeable stratum, corresponding to fully saturated conditions within the permeable unit.

Perched groundwater is an unconfined zone of saturation formed above a main GWBU and is separated from the main GWBU by an unsaturated zone. Perched groundwater generally is maintained by a *perching bed*, or lens, of low hydraulic conductivity geologic material typically comprised of clay. If the perched groundwater exhibits Class 2 well yield characteristics, the zone may be downgraded to a Class 3 GWBU if it can be demonstrated that the unit has historically or predictably ephemeral saturation (*see about* Class 3 GWBUs, Sec. 1.4.3; *and* resource sustainability, Sec. 2.8).

Monitoring Wells
All activities associated with test well and monitor-ring well construction, open boreholes, and bore hole/well plugging and abandoning must comply with Texas Department of Licensing and Regulation requirements set forth in 16 TAC §76.1000 - §76.1009.

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2.3.3 Saturated Thickness

For *unconfined* GWBUs, the saturated thickness (b) at each location is the vertical distance from the static water level elevation to the base of the saturated unit. If static water level measurements are available for an extended time period for an unconfined GWBU, the static water elevation used for calculation of saturated thickness should be matched to the estimated mean annual static water level for the unit.

For *confined* GWBUs, the saturated thickness at each location is equal to the stratigraphic thickness of the GWBU, itself (i.e., the distance from the upper surface of the permeable stratum to its base).

Groundwater level measurements performed in accordance with ASTM Standard Test Method D 4750 are acceptable to the TCEQ.

If the GWBU is heterogeneous (e.g., consists of multiple soil types of variable hydraulic properties), refer to Section 2.3.4 for methods of organizing heterogeneous sediments into hydrogeologically coherent units.

The thickness of the saturated zone(s) beneath the affected property is recorded on geologic/soil boring logs and well logs, and should include *both* the level at which water was encountered *and* static water level measurements obtained from site monitoring wells, piezometers, or other appropriate measurement devices.

Groundwater levels that are observed to fluctuate over time should be measured over a period of time with a frequency sufficient to provide a statistically valid *mean water level* for each applicable GWBU.

Additional guidance on the collection, preparation, and presentation of groundwater-level information can be found in *ASTM Standard Guide D 6000.*

2.3.4 Characterization of Groundwater-Bearing Units

The characterization of GWBUs comprises: 1) the recognition of separate hydrostratigraphic units which possess contrasting hydraulic properties, and 2) the definition of the boundaries of hydraulically-distinct and separate GWBUs. Hydrostratigraphic units are comprised of geologic units grouped together on the basis of similar hydraulic conductivity (Fetter, 1988). The combination or separation of varied geologic materials into single, hydraulically-coherent GWBUs includes methodologies to:

1. *delimit* the boundaries of separate GWBUs based on hydraulic properties and the depositional environment which control the geometry of those geologic deposits, and
2. *organize* heterogeneous, anisotropic, rhythmic, or otherwise variable saturated geologic materials into GWBUs.

The delineation of separate GWBU sediments, performed in fulfillment of site characterization requirements for understanding COC distributions, should be placed within the context of their depositional environment and their applicable hydraulic properties. Guidelines for accomplishing the task of appropriately defining the boundaries of sedimentary GWBUs include the following:

1. Ensure the interpreted geometries of sediment bodies associated with zone(s) of saturation at the affected property are consistent with the general geologic framework.
2. Analyze site stratigraphy and assign all sediments associated with the zone(s) of saturation to an appropriate hydrostratigraphic unit.
3. Designate as a separate GWBU each saturated hydrostratigraphic unit that possesses unique bulk hydraulic properties.
4. Delineate the three-dimensional hydrostratigraphic boundaries comprising the *affected or potentially impacted* portion of each identified GWBU for the affected property.
5. Document the three-dimensional location and geometry of all identified and interconnected GWBUs and all intervening units (i.e., subsurface discontinuities, etc.) associated with the affected property.

Small-scale stratigraphic variations, such as thin alternating fine-grained/coarse-grained sequences may exist *within* a given GWBU (*e.g.*, fluvial overbank deposits, coastal back-bay deposits, *etc.*). Since the coarse-grained sediments typically possess higher hydraulic conductivities and often act as the preferential COC transport pathways, it is necessary to group them appropriately when *significant occurrences* are observed. Small-scale sequences of interbedded sediment should be *organized together into a single hydraulically-coherent GWBU* when the following conditions are met:

1. the individual layers are too thin to practicably resolve their individual hydraulic properties using available aquifer testing methods; *and*
2. the bulk hydraulic property of a sub-section of the interlayered sequence is otherwise indistinguishable from the bulk hydraulic property of a different sub-section in the same sequence.

Large-scale stratigraphic units, such as homogeneous channel sand and beach sand bodies, which are sufficiently thick to practicably perform aquifer tests upon and which can yield meaningful measurements of aquifer hydraulic properties are designated as separate GWBUs.

Geoscience work performed in Step 1 should be conducted by a licensed professional geoscientist (P.G.) who is familiar with the recognition, delineation and organization of sediments from common depositional systems. The resulting geoscience work products should be sealed by the P.G. pursuant to 22 TAC §851.156.

2.3.5 Minimum Number of GWBUs at an Affected Property

The minimum number of GWBUs that are required to be reported at an affected property are the following:

1. any delimited GWBUs into which a direct COC release has occurred, *and*
2. any interconnected GWBUs which potentially can be impacted by the affected GWBUs.

However, note that application of the rule in terms of setting assessment levels, demonstrating sufficient assessment, development of PCLs, defining PCLE zones and determining the appropriate response objectives will be more complicated as the number of proposed GWBUs and classifications increase. This is particularly true if multiple GWBUs and groundwater classifications are laterally distributed across the affected property. It may be more practical to assume the same higher-quality classification (e.g., Class 2 is higher than Class 3) for all GWBUs at the affected property.

2.4 STEP 2: Determine Hydraulic Interconnectivity of GWBUs

For purposes of groundwater classification, consider an affected GWBU to be hydraulically interconnected with another GWBU if flow from one GWBU may potentially cause an exceedence of a critical PCL in a receiving GWBU. The evaluation of *hydraulic interconnection* must consider the potential groundwater flow that can be induced between separate hydrostratigraphic units as a result of pumping in the unaffected unit. Such flow may occur as a result of 1) stratigraphic connections, 2) the presence of artificial penetrations, or 3) leakage through intervening confining layers. For the purpose of this evaluation, assume that the groundwater production zone of the hypothetical pumping well is screened only within the unaffected groundwater-bearing unit and is not assumed to interconnect multiple strata. Where the hydraulic interconnection is so pronounced that the two units hydraulically behave as one, consider them one GWBU.

Table 6 summarizes some methodologies and example diagnostics that can be applied to a *line of evidence* demonstration concerning the determination of GWBU interconnectivity.

General lines of evidence that indicate the potential for hydraulic interconnection of groundwater-bearing units, or the lack thereof, are listed on Table 6. In many cases, evaluation of hydraulic interconnection may be based upon a qualitative assessment of the type, thickness, and continuity of the intervening strata, in combination with evaluation of hydraulic head elevations and water quality data. If such data are inconclusive, the TCEQ may require additional field measurements to address potential interconnections, such as 1) *in-situ* hydraulic conductivity tests for intervening confining layers, 2) an aquifer pumping test within the unaffected groundwater-bearing unit to detect the presence or absence of a hydraulic response in the affected unit, or 3) other appropriate investigations.

The applicable groundwater resource classification for a given hydraulically-interconnected GWBU will be determined based upon consideration of the current use, water quality, and well yield of that individual GWBU only. Response objectives for affected GWBUs must serve to prevent impacts to hydraulically-interconnected unaffected GWBUs in excess of the applicable assessment levels for the unaffected GWBU.

Table 6. Lines of Evidence for Hydraulic Interconnectivity of GWBUs

Type of Information	Example Line-of-Evidence Conditions for Use in Determining Hydraulic Interconnection	
	Not Interconnected	***Interconnected***
1) **Stratigraphic Data** Thickness, continuity, and hydrologic properties of intervening confining layer.	• Homogeneous, unfractured, continuous clay stratum $\geq$ 20 ft in thickness.	• Confining unit is laterally discontinuous, highly fractured, or composed of permeable material.
2) **Static Water Levels (SWL)** Relative hydraulic head elevations in separate GWBUs.	• Significant SWL difference between wells screened above and wells screened below confining unit.	• SWLs are identical above and below confining unit.
3) **Affected Groundwater** Presence or absence of affected groundwater in GWBUs.		• Affected groundwater present in all GWBUs.
4) **Natural Water Quality** Contrast in natural water quality characteristics (e.g., Total Dissolved Solids (TDS), major ion distribution, etc.)	• Separate GWBU is not affected and exhibits significantly different TDS and/or major ion distribution from affected unit.	
5) **Field Hydraulic Conductivity Test** In-situ field hydraulic conductivity tests performed on intervening confining unit.	• Confining unit is laterally continuous with vertical hydraulic conductivity $\leq 10^{-7}$ cm/sec.	• Confining unit exhibits vertical hydraulic conductivity $\geq 10^{-5}$ cm/sec.
6) **Aquifer Pumping Test** Field test conducted to evaluate effect of pumping from unaffected unit on SWL in affected unit.	• No measurable SWL drop (*e.g.*, < 0.01 ft corrected for barometric variations) observed in affected unit within 24-hour period of continuous pumping from unaffected unit.	• Measurable SWL drop observed in affected unit as a result of pumping in unaffected unit.

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2.5 STEP 3: Determine Current Groundwater Use

> **Records and Field Surveys**
> If the groundwater is not affected above a residential assessment level and a Class 1 groundwater resource designation has been assumed for the purpose of setting ^{GW}Soil, the records survey is not required per §350.51(i). The 500-foot field survey is required in all cases when an affected property assessment is conducted.

For the purpose of groundwater resource classification, the current use of affected GWBUs and any threatened, hydraulically-interconnected units must be characterized. The groundwater-use data support evaluation under §350.52(1)(A) and §350.52(2)(B). As specified in §350.51(i), characterization of current groundwater use will involve the following tasks:

1. **Records Survey:** Conduct a records survey to identify all water wells within a 0.5-mile distance of the limits of groundwater that contains COCs in excess of the residential assessment level (i.e., affected groundwater).
2. **Field Survey:** Conduct a field survey to identify any existing water wells located to at least 500-foot distance of the boundary of the affected property.

Current status and actual condition of wells that result from the above surveys should be determined. Note that the provision "existing well" in §350.52(1)(A) and §350.52(2)(A) means that as water supply wells are put into service or permanently abandoned in the vicinity of the affected property, the groundwater classification can adjust up or down during the life span of the remediation project.

2.5.1 Required Information Regarding Current Water Use

Documentation of the current use evaluation shall include:

1. a scale map showing water supply wells located within 0.5 miles of the affected groundwater, *and*
2. a complete tabulation of available information on a) well use, b) well construction (screened interval, seal, *etc.*), and c) groundwater production zone, as determined from available water well driller's logs, groundwater resource publications (e.g., Texas Water Development Board, United States Geological Survey, University of Texas Bureau of Economic Geology, etc.), and other relevant sources.

If documentation of water well construction/completion (i.e., drilling logs or other well construction records submitted to the State) is not available *assume that the well is completed within the affected GWBU* unless that well is inspected for completion construction details, well casing integrity and potential for cross-communication. Additionally, if the well use is uncertain, *presume the well is used as a drinking water source.*

Identification of monitoring well locations is not the focus of the well surveys required for the groundwater resource classification. However, monitoring wells can provide valuable groundwater classification information (e.g., identify high TDS groundwater).

It is recommended that available groundwater resource publications be reviewed in order to 1) provide insight into and understanding of the subsurface, 2) identify the major groundwater production zones underlying the affected property, and 3) assess their potential interconnection with affected GWBUs.

2.5.2 Applicable Groundwater Resource Classification

A preliminary groundwater resource classification can be determined in this step if any of the following groundwater resource conditions are identified during the groundwater use survey (see *§350.52*):

1. **Proximity to Public Water Supply Well:** Drinking water supply well serving public water system (as defined under *30 TAC §290.38*) is located within 0.5 miles, and the groundwater production zone of this well potentially could be impacted by COCs from the affected GWBU. *Applicable Groundwater Resource Classification*: **Class 1**.
2. **Only Reliable Water Source Affected:** The affected GWBU is the only reliable source of drinking water (i.e., a connection to a public water system is not currently available and will not be provided to the affected property as part of the remedy) located within 800 feet below grade in the area, groundwater TDS < 1,000 mg/L, and well yield for 4-inch diameter well > 5,000 gpd. *Applicable Groundwater Resource Classification*: **Class 1**.
3. **Proximity to Other Water Supply Well:** Domestic (private) water supply well used for drinking water, agricultural supply, or other use (other than a public water supply) that could result in human or ecological exposure is located within 0.5 miles of the affected property and has groundwater production zone within the affected groundwater-bearing unit. *Applicable Groundwater Resource Classification*: **Class 2** (**unless** otherwise Class 1, based on consideration of well yield and natural water quality).

If the results of this evaluation show the affected GWBU to qualify as a Class 1 groundwater resource (based on Conditions 1 or 2, as described above), no further evaluation of the resource classification is necessary. The person can proceed directly to Step 7: Documentation.

The following example explores the subtle distinction between §350.52(1)(A) and §350.52(2)(A) with regard to groundwater production zone. Figure 2 depicts the subsurface conditions for the example. Two GWBUs exist at the affected property. GWBU A is unconfined. GWBU B is confined and is the groundwater production zone for the well in the example. The affected groundwater is less than 0.5 miles from the well. In the example, four separate scenarios are evaluated for the purpose of illustrating how GWBU A should be classified under different conditions. In all of the scenarios, the well is sealed across GWBU A and there is no leakage down the well bore. In the scenarios, the classification of GWBU A is dependent upon whether the well is a public or domestic water supply well, the groundwater production zone, hydraulic interconnectivity between GWBUs A and B, COC transport properties, and the intrinsic characteristics of GWBU A.

1. **Scenario 1:** The well is a public water supply well and based on hydraulic interconnection between GWBUs A and B and the transport characteristics of the COCs, GWBU A **will contribute** COCs to the groundwater production zone (GWBU B) for the well.

   GWBU A Classification: Class 1 in accordance with §350.52(1)(A) since the affected groundwater (GWBU A) is within 0.5 miles of a public water supply well, and GWBU A will contribute COCs to the groundwater production zone (GWBU B) for the public water supply well.

2. **Scenario 2:** The well is a public water supply well and based on lack of hydraulic interconnection between GWBUs A and B and transport characteristics of the COCs, GWBU A **will not contribute** COCs to the groundwater production zone (GWBU B) for the well.

   GWBU A Classification: Class 1, 2, or 3 based on the characteristics of GWBU A. Although the affected groundwater (GWBU A) is within 0.5 miles of the public water supply well, GWBU A is not the groundwater production zone for the well and will not contribute COCs to the groundwater production zone. Therefore, §350.52(1)(A) is not applicable.

3. **Scenario 3:** The well is a domestic water supply well and based on hydraulic interconnection between GWBUs A and B and the transport characteristics of the COCs, GWBU A will contribute COCs to the groundwater production zone (GWBU B) for the well.

   GWBU A Classification: Class 1, 2 or 3 based on the characteristics of GWBU A. Because the well is not a public water supply well, §350.52(1)(A) is not applicable. Although the affected groundwater is within 0.5 miles of the domestic well, because GWBU A is not the groundwater production zone for the well, §350.52(2)(A) is not applicable. However, because GWBU A is contributing COCs to the groundwater production

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zone (GWBU B), the standard response objectives for the applicable classification for GWBU A may need to be modified so that the response objectives for GWBU B can be met.

4. **Scenario 4:** The well is a domestic water supply well and based on lack of hydraulic interconnection between GWBUs A and B and transport characteristics of the COCs, GWBU A will not contribute COCs to the groundwater production zone (GWBU B) for the well.

   GWBU A Classification: Class 1, 2 or 3 based on the characteristics of GWBU A.

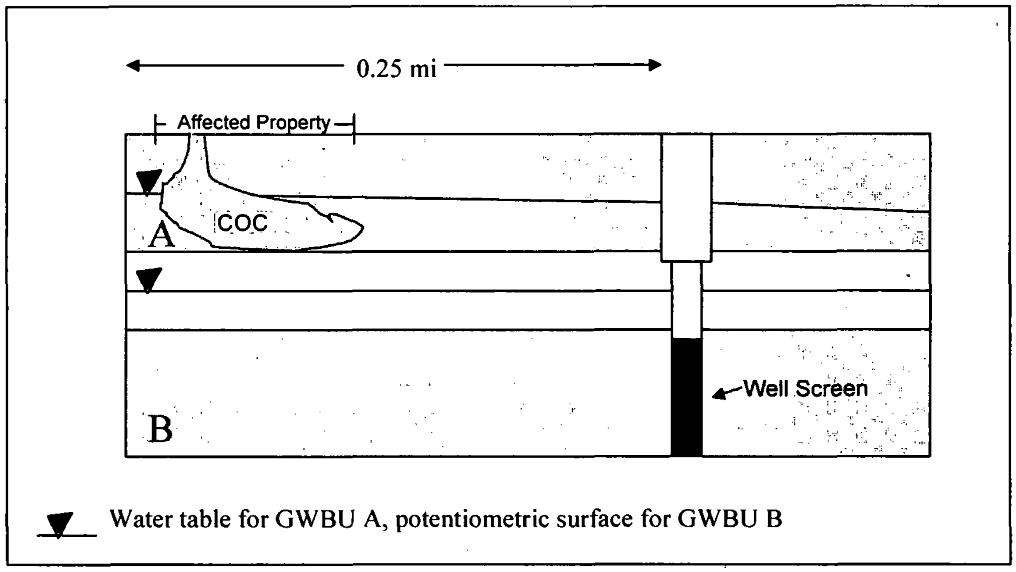

Figure 2. Hydrostratigraphic Scenario for Multiple GWBU Classification Example.

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Table 7 summarizes the conditions and classification results of the example scenarios.

Table 7. Example Classification of GWBU A.

	Production Zone	Well Type	GWBU A Contributes COCs to GWBU B	Classification
Scenario 1	**GWBU B**	**Public Supply Well**	YES	**Class 1** §350.52(1)(A)
Scenario 2	**GWBU B**	**Public Supply Well**	NO	**Class 1, 2, or 3** Based on GWBU A characteristics
Scenario 3	**GWBU B**	**Domestic Supply Well**	YES	**Class 1, 2, or 3** Based on GWBU A characteristics. *But* must meet response objective for GWBU B in GWBU B
Scenario 4	**GWBU B**	**Domestic Supply Well**	NO	**Class 1, 2, or 3** Based solely on characteristics of GWBU A

2.6 STEP 4: Evaluate Natural Groundwater Quality

For the purpose of groundwater resource classification, the natural (*background*, not anthropogenic) water quality of a groundwater-bearing unit is to be characterized on the basis of the background *total dissolved solids* (TDS) content of the groundwater.

2.6.1 Characterization of Natural Water Quality

To characterize natural TDS, groundwater should be collected properly from one or more background well locations in each affected GWBU (and any hydraulically-interconnected GWBU) and submitted for laboratory analysis of TDS content using EPA Method 160.2. All groundwater sample collection, preservation and handling procedures must conform to applicable TCEQ and United States Environmental Protection Agency guidelines. *Composite groundwater samples are not acceptable* for TDS analysis. Estimation of groundwater TDS based on measurement of *specific conductance is not acceptable* for the purpose of groundwater resource classification.

If groundwater samples are collected from multiple sampling locations *within a single GWBU*, the representative TDS value for that unit may be estimated as the *arithmetic mean* of the laboratory test results for the individual samples.

In some instances, an affected property may coincide with a TDS boundary or a transition between two different groundwater classifications within the same GWBU. Before "averaging" across the two different water quality zones, *the person may opt to subdivide a commensurate portion of the GWBU into a lower-quality zone based on a higher TDS content* per §350.52. Otherwise, the person can opt to demonstrate that there is not a portion of the affected property where the higher-quality water would not be degraded by drawing in the lower-quality water during pumping. If there are isolated high-TDS zones, then averaging the higher TDS water in this zone is not appropriate.

2.6.2 Applicable Resource Classification by Natural Groundwater Quality

The classification of groundwater resources based on the measured TDS content of the groundwater *not meeting Class 1 or Class 2 in Step 3* (as summarized in Table 1 and Figure 1) follows:

1. **Representative TDS > 10,000 mg/L:** *AND* the GWBU does not qualify as Class 1 or 2 based on current groundwater use (see Step 3). *Applicable groundwater resource classification*: **Class 3.**
2. **Representative TDS ≤ 10,000 mg/L and > 3,000 mg/L:** *AND* the GWBU does not qualify as Class 1 based on current groundwater use (see Step 3). *Applicable groundwater resource classification*: **Either Class 2 or Class 3**, depending on well yield.
3. **Representative TDS ≤ 3,000 mg/L:** *Applicable groundwater resource classification*: **Either Class 1, Class 2, or Class 3**, depending on use and/or well yield.

If the results of the TDS evaluation show that the affected GWBU qualifies as a Class 3 groundwater resource based on TDS > 10,000 mg/L, no further evaluation of the resource classification is necessary. The person can proceed directly to Step 7: Documentation.

2.7 STEP 5: Evaluate Groundwater Resource Productivity

Aquifer parameters of GWBUs and well yield determinations must be estimated or directly measured from relevant GWBUs using appropriate protocols and methods. Discussion and methodologies that support the activities related to determining groundwater resource productivity include the following:

1. Monitoring/test well installation, development, and/or rehabilitation; and
2. Determination of hydraulic conductivity using single-well tests, multiple-well tests, or direct yield measurements.

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Table 8 summarizes the purpose, applicability, requirements, and some caveats associated with the hydraulic test methods described herein.

Table 8. Methods for Groundwater Classification by Well Yield.

	Purpose	Applicability	Requirements	Caveats
Method 1 Section 2.7.1	Estimate of well yield by known *K* and *b* via calculations or well yield graphs	High to low GWBU transmissivities	Site-specific *K* and *b* (Attachment A)	Direct measurement method required if within 20% of GW class boundary
Method 2a Section 2.7.2.2	Direct determination of well yield by cyclic discharge	High to low GWBU transmissivities	Measure total volume withdrawn and time to recharge	Minimum of three (3) cycles; Recharge cannot exceed 90%
Method 2b Section 2.7.2.3	Direct determination of well yield by equilibrium discharge	Low GWBU transmissivities	Constant discharge rate (pumped or bailed)	Wells should not be pumped dry
Method 2C Section 2.7.2.4	Direct determination of Class 2/Class 3 yield boundary by constant discharge	Low GWBU transmissivities	Constant discharge rate (0.1 gpm)	Discharge rate and water level should be monitored continuously

Figure 3 provides a decision tree to assist the person in the selection of the appropriate productivity method. Figure 3 shows a general framework to aid in selecting appropriate hydraulic testing and a guide to choices inherent in the use of the productivity methods.

Aquifer parameter and well yield determinations should be performed only after the following *caveats* have been addressed:

1. The person should be thoroughly familiar with all standard methods employed in the construction and development of test wells, implementation of test procedures, and reduction of test data. (See Attachment A.)
2. Test wells should be constructed in accordance with 16 TAC §§76.1000 – 76.1009. Additional guidance on appropriate test well depths, placement, development, and rehabilitation (if necessary) can be found in standard methods presented in Table A1 (Attachment A). It is strongly recommended that the use of non-standard methods be pre-approved by the TCEQ.
3. Guidance for multi-well test, single-well test and well yield determination procedures, data collection methods, and data reduction can be found in standard methods summarized in Tables A2, A3 and A4 (Attachment A). It is strongly

recommended that deviations from the standard test methods be pre-approved by the TCEQ.

4. Aquifer parameter and well yield determinations *should be completed in wells that are most likely to produce the greatest yields or optimum flow rates from the GWBU*. Typically, evaluation of the lithologic descriptions for the well borings, evaluation of well design, construction, completion and development, and observation of relative recharge rates following purging preparations for sampling will provide sufficient basis to identify the wells that are most suitable for testing.

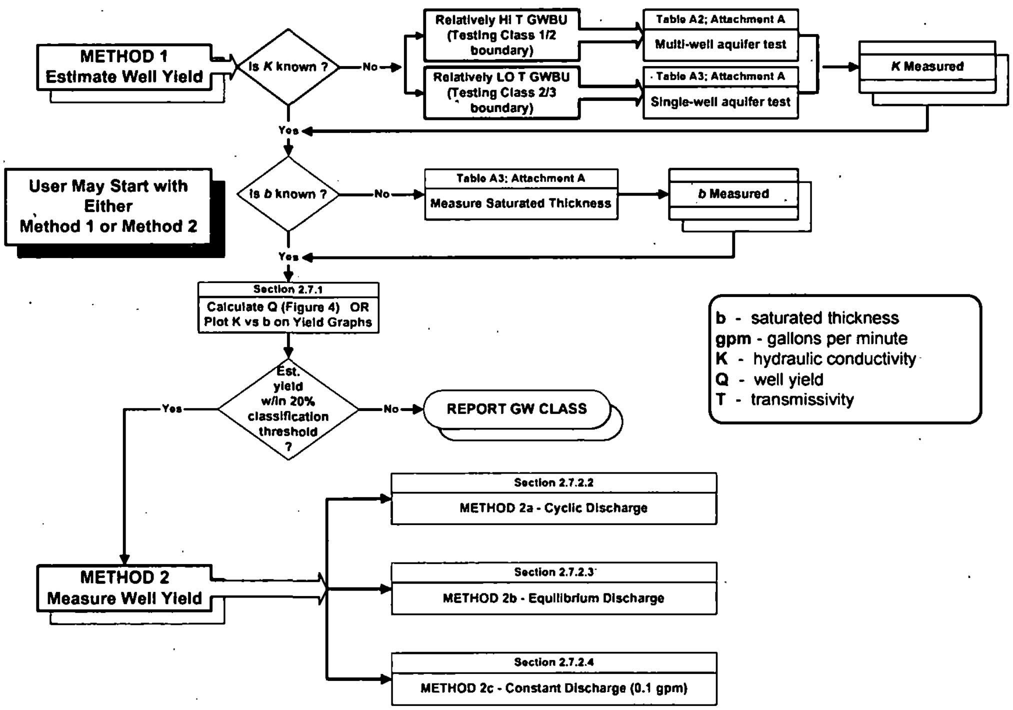


Figure 3. Decision Tree for Guidance in Selecting Productivity Tests.

2.7.1 METHOD 1: Groundwater Classification by Calculation and Yield Graphs

For each location evaluated within a GWBU, the well yield is estimated using the hydraulic conductivity, the saturated thickness (or the confining head, for confined units only) at that location, and the appropriate form of the Method 1 equation (i.e., Equations A or B for

Use of *Confined* Yield Graph. Figure 4 (for *confined units*) is based on a default confining head (hc) of 10 feet. To use the graph, multiply the saturated thickness value (b) at the site by a correction factor equal to the *actual* site-specific confining head (hc) in feet and divide by 10 feet. Then define and plot the (K, b) point for the representative hydraulic conductivity and the adjusted saturated thickness value.

confined units and Equations C or D for unconfined units in Figure 4). For use in evaluation of the Class 3 yield boundary (150 gpd), the default well radius in Equations A and C is set to 2 inches (4-inch diameter well screen). For use in evaluation of the Class 1 yield boundary, Equations B and D assume a default 6-inch well radius (12-inch diameter well screen).

Figure 4 summarizes the Method 1 well yield equations. For convenience, the Q = 150 gpd and the Q = 144,000 gpd well yield curves (and their respective ± 20% envelopes) are plotted on Figure 5 (for confined groundwater) and Figure 6 (for unconfined groundwater).

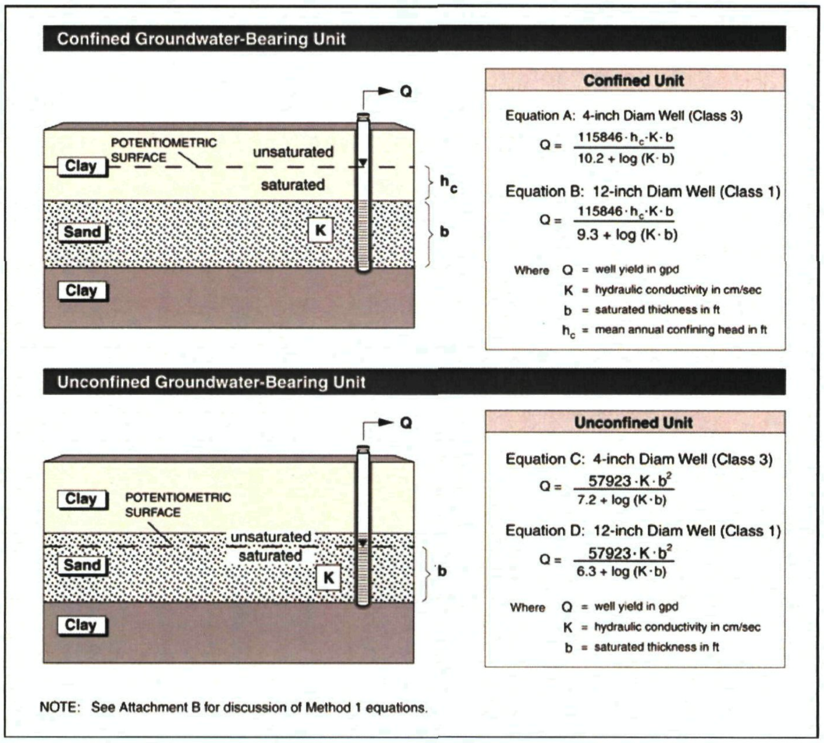
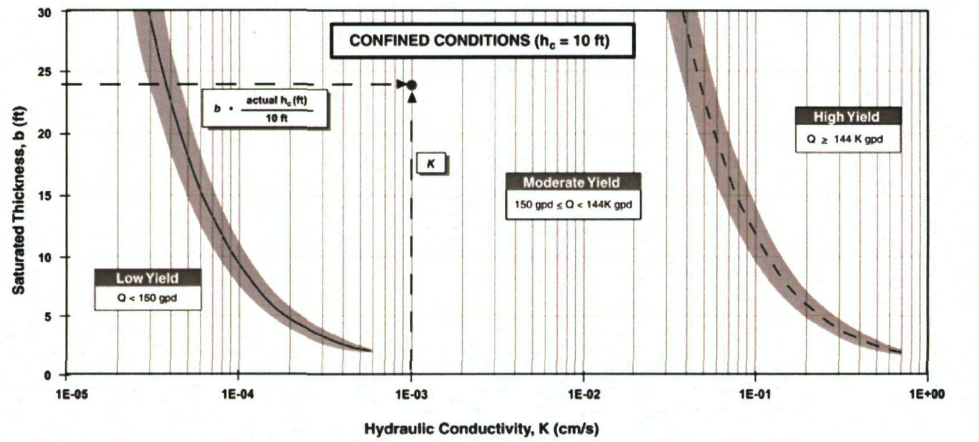


Figure 4. Method 1 Equations for Estimating Well Yield.

To use Figures 5 and 6, find the intersection of the saturated thickness value (b) and the hydraulic conductivity value (K) to define a point on the plot. The location of this (K, b) point on the plot indicates whether the well yield (Q) at that location falls in the Low (Q < 150 gpd), Moderate (150 gpd ≤Q < 144,000 gpd), or High (Q ≥ 144,000 gpd) yield range.

Derivation of the Method 1 equations and **full-scale reproductions of Figures 5 and 6** (for use in plotting actual data) **are provided in Attachment B** of this guide.

NOTE: ***If a GWBU meets the criteria for more than one groundwater classification, then the GWBU shall be assigned the higher (quality) classification (§350.52).***



NOTE:

1) To use chart, align representative saturated thickness and hydraulic conductivity values to define (x,y) point on plot. Location of (x,y) point defines sustainable well yield category (low, moderate, or high). Note that this plot applies ONLY to confined units with confining head h_c = 10 ft. To match actual confining head, multiply saturated thickness (b) by ratio of (actual h_c in ft) / (10 ft) before plotting (x,y) point. For example, if actual h_c = 20 ft, b = 12 ft, K = 1.0E-3, then correction ratio = 20 ft / 10 ft = 2. Plot point is b = 2 x 12 ft = 24 ft; K = 1.0E-3 cm/s. Yield = moderate (Class 2).

2) If a confined unit is expected to reach an unconfined condition during pumping (due to water level drawdown), the yield calculation should be based on the unconfined unit equation (see Figure 4).

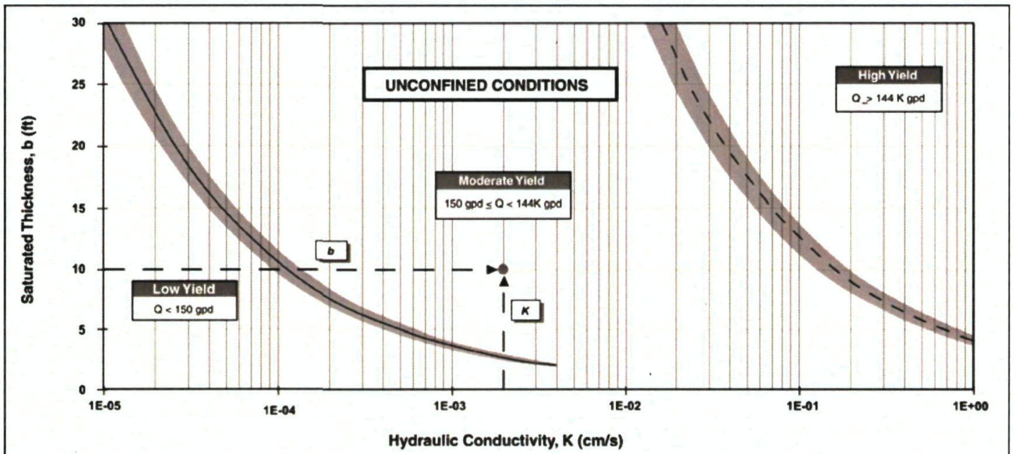
3) If Method 1 yield estimate falls within +/- 20% of Class 1 or Class 3 yield boundary (grey zone), Method 2 direct well yield test required to confirm proper classification.

4) gpd = Gallons per day; GWBU = Groundwater-bearing unit; Q = Well yield; b = Saturated thickness (ft); K = Hydraulic conductivity (cm/sec); h_c = Confining head (ft)

Legend

- ——— Class 3 yield boundary (Q = 150 gpd)
- - - - Class 1 yield boundary (Q = 144K gpd)
- ± 20% zone

Figure 5. Method 1 Estimate of Well Yield for Confined GWBUs.



NOTES:

1) To use chart, align saturated thickness (b) and hydraulic conductivity (K) values to define (x,y) point on plot. Location of (x,y) point defines sustainable well yield category (low, moderate, or high). For example, if K = 2 x 10^{-3} cm/sec and b = 10 feet, then yield = moderate (Class 2).

2) If Method 1 yield estimate falls within +/- 20% of Class 1 or Class 3 yield boundary (grey zone), Method 2 direct well yield test required to confirm proper classification.

4) gpd = Gallons per day; GWBU = Groundwater-bearing unit; Q = Well yield; b = Saturated thickness (ft); K = Hydraulic conductivity (cm/sec)

Legend

- ——— Class 3 yield boundary (Q = 150 gpd)
- - - - Class 1 yield boundary (Q = 144K gpd)
- ± 20% zone

Figure 6. Method 1 Estimate of Well Yield for Unconfined GWBUs.

2.7.2 METHOD 2: Direct Well Yield Determination

If the representative well yield (Q) estimated from Method 1 indicates that the well yield is within ±20% (shaded area around boundary curves) of the Class 1 or Class 3 yield boundaries (Figure 5 or 6) and the resource classification is not otherwise dictated by current use or water quality (per Steps 3 and 4), then a Method 2 direct determination of well yield is required to confirm the appropriate groundwater resource classification. The use of Method 2 determinations is required for the following two conditions:

> **Use of Method 2.** In all cases, the person conducting the affected property assessment may choose in advance to use Method 2 rather than Method 1 to define the representative well yield for the GWBU

1. **Fresh Water, Class 1 Yield Boundary:** GWBU contains fresh water (water meets PDWS and TDS ≤3000 mg/L), and Method 1 well yield estimate (using Figure 4 Equations B or D, as appropriate) falls within ±20% of the Class 1 yield boundary (i.e., 115,200 gpd ≤ Q ≤ 172,800 gpd).
2. **Non-Brackish Water, Class 3 Yield Boundary:** GWBU has representative TDS content that is ≤ 10,000 mg/L, and Method 1 well yield estimate (using Figure 4 Equations A or C, as appropriate) falls within ±20% of the Class 3 yield boundary (i.e., 120 gpd ≤ Q ≤180 gpd).

> **Well Diameter Conversions.** Conversions to equivalent 4-inch or 12-inch diameter test well discharges from other test well diameters can be accomplished by using Table C1 in *Attachment C*.

Method 2 is particularly useful for *low transmissivity GWBUs* and could be useful for high transmissivity units, but can generate high volumes of wastewater in the latter. Method 2 comprises three different techniques by which a direct measurement of well yield can be obtained from a test well completed within a GWBU. If more than one test well is employed in these field measurements, they must be: 1) constructed with similar specifications, 2) located such that they are *testing only the same GWBU* (*see* Section 2.3.4), and 3) representative of the flow rate of water the GWBU is capable of transmitting to that well. If more than one test well location is used to test a single GWBU, the representative well yield should be determined as the geometric mean of the individual well test results.

Results from field tests previously conducted at the affected property can be used to evaluate well yield if the well construction and test procedures used in the prior tests are documented to conform to Method 2 guidelines, as detailed above.

NOTE: ***If a GWBU meets the criteria for more than one groundwater classification, then the GWBU shall be assigned the higher (quality) classification (§350.52).***

2.7.2.1 *METHOD 2: Discharge Methods.*

The discharge method (e.g., hand bailing, suction pump, submersible pump, etc.) used in the yield test must be selected to meet the requirements of the test procedure and ensure that the measured well yield is not "pump-limited". In all cases, the pump curve should show that the pump has sufficient power to produce water at the desired test flow rate, under the applicable suction intake and discharge pressure. The water intake point for the pump (i.e., pump intake for submersible pumps, suction hose for suction pumps, etc.) should be positioned below the lowest depth to water anticipated for the test.

> **Withdrawal in Method 2.** Suction pumps (such as centrifugal pumps, jet pumps, or peristaltic pumps) are typically limited to a practical suction-lift capacity of 25 feet below the pump intake, and may result in reduced discharge if the pumping water level falls below this depth during the test. In low-yield units, hand-bailing methods may be sufficient to evacuate the well, so long as bail-out speed does not cause limitations to test.

2.7.2.2 *METHOD 2a: Well Yield by Cyclic Discharge.*

Primarily used to test the Class 2/Class 3 150 gpd yield boundary in relatively *low-yield GWBUs* (defined as hydrostratigraphic units whose hydraulic conductivity can not be practicably measured using the techniques described in Attachment A).

Method 2a comprises a cyclic *bail down – recovery* test. Method 2a is performed using the following procedure:

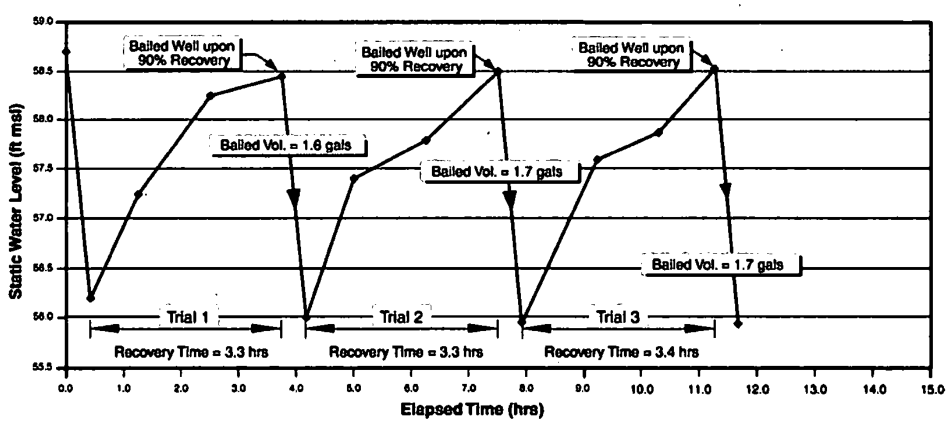
1. **Well Construction:** Test well must be *fully-penetrating*, have a minimum diameter of 2 inches, and be completed with construction details consistent with requirements of 16 TAC §§76.1000 - 76.1009.
2. **Initial Water Level:** Measure static water level in well.
3. **Water-Level Bail-Down:** Use bailer, pump, or other device to effectively evacuate *all* water from the well. Contain all discharged water and measure total volume (*V1*). Measure static water level in well immediately upon completion of water removal.
4. **Time for Water-Level Recovery:** Monitor static water level in well and measure elapsed time (*t1*) from completion of water removal until static water level in well recovers to the *same specified level, up to, but not greater than 90%* of height to initial static water level.
5. **Repeat Bail-Down and Recovery:** Repeat Steps 2 and 3 above twice. *This procedure requires a* ***minimum of three*** *bail-*

down/recovery cycles. Record total volume of water (*V1 ... Vn*) removed from well during each successive bail-down and the elapsed time (*t1 ... tn*) from completion of water removal until water level in well recovers to the same specified level used in prior cycle(s) (*i.e., up to, but not greater than 90%* of height to initial static water level).

The maximum well yield corresponds to the total bailed water volume ($\sum V_n$) divided by the combined recovery time ($\sum t_n$) measured during *at least* three bail-down/recovery cycles (*see* Equation 1).

$$\text{Well Yield} = \frac{\sum_{i=1}^{n} V_i}{\sum_{i=1}^{n} t_i} \qquad \textbf{[EQ 1]}$$

Figure 7 provides an example of a bail-down test calculation performed for a well with approximately 3 feet of available drawdown. In such case, the well yield should be calculated as the total bailed water volume divided by the cumulative recovery time for all cycles and presented in units of *gallons per day* (gpd).



Well Yield Calculation

$$Q_{well} = \frac{V_{bail}}{t} \cdot \frac{(24\ \text{hrs})}{(\text{day})}$$

where:

V_{bail} = Volume of water bailed after the 90 % recovery time for Trials 1, 2, and 3 in gallons.

t = Recovery time for Trials 1, 2, and 3 in hrs.

Q = Estimated daily flowrate for well based on baildown yield test.

$$Q_{well} = \frac{(1.6 + 1.7 + 1.7)\ \text{gals}}{(3.3 + 3.3 + 3.4)\ \text{hrs}} \cdot \frac{(24\ \text{hrs})}{(\text{day})}$$

Q_{well} = 12.0 gallons/day

FINDING:
Maximum well yield < 150 gpd.

Figure 7. Example of Cyclic Bail-Down and Recovery Well Yield Test

2.7.2.3 METHOD 2b: Well Yield by Equilibrium Water Level Test.

To determine if a test well is capable of producing a yield of 150 gpd, the well may be pumped continuously at a discharge rate equivalent to well recharge rate (well yield). In this Method, the well is pumped at a rate such that the pumping water level is maintained as near as practical to the base of the well screen. Test procedures are as follows:

1. **Well Construction:** Test well must be fully-penetrating, be a minimum diameter of 2 inches, and be completed with construction details consistent with requirements of 16 TAC §§76.1000 - 76.1009.
2. **Initial Water Level:** Measure static water level in well.
3. **Pump Installation:** Equip well with pump capable of maintaining a constant drawdown elevation near bottom of well.
4. **Water Level Equilibrium:** After pump and hose installation, monitor static water level in well until water has re-equilibrated to initial water level.
5. **Well Pumping:** Activate pump and set discharge rate to achieve a pumping water level as near as practicable to the base of well screen. Adjust pump discharge rate until it is equivalent to well recharge rate (i.e., water level near the bottom of well remains constant and is lower than static water level).
6. **Measure Equilibrium Discharge Rate:** Once the new water-level equilibrium has been established in the test the pump discharge rate is determined. The pump discharge rate is then converted to units of gallons per day (gpd). Test is complete when a total water volume of 50 gallons has been produced or pumping has been underway for 8 hours, whichever comes first.
7. (**Optional:** The person may choose to perform the test for a longer period of time. There is no limit on the maximum length of the test period. However, if the test period extends beyond 24 hours, bear in mind the results need to be evaluated and conclusions must be presented in a manner consistent with the per day yield criteria of the rule.)

2.7.2.4 METHOD 2c: Well Yield by Constant Discharge (0.1 gpm) Test.

To determine if a test well is capable of producing a yield of 150 gpd, the well may be pumped continuously at a discharge rate equivalent to 0.1 gallons per minute (gpm), or 150 gpd. In this Method, the well is pumped as near as practicable to the base of the well screen at a rate equal to 0.1 gpm. If the well's water level does not fall to the pump inlet level during the test, the well is considered capable of producing a minimum yield of 150 gpd. Test procedures are as follows:

1. **Well Construction:** Test well must be *fully-penetrating*, have a minimum diameter of 2 inches, and be completed with

construction details consistent with requirements of 16 TAC §§76.1001-76.1005.

2. **Initial Water Level:** Measure static water level in well.
3. **Pump Installation:** Equip well with pump capable of maintaining a **constant** *discharge rate of 0.1 gpm* and a pump inlet placement near bottom of well.
4. **Water Level Equilibrium:** If the test well water level remains constant during test, or if the test well water level falls to a new *static* equilibrium water level elevation, the well yield is 150 gpd or greater.
5. **Well Pumping:** The pumping should be monitored continuously and the discharge rate corrected for deviations due to changes in hydrostatic pressure when test well water level falls.
6. **Test Termination:** Test is complete when a total water volume of 150 gallons has been produced, when test well water level falls to bottom of well (no re-equilibrium), or when test duration reaches 8 hours, whichever comes first. The ability to maintain the 0.1 gpd discharge rate indicates Class 2 well yield. The results should be converted to a volume discharged per 24 hour (gpd).
7. (**Optional:** The person may choose to perform the test for a longer period of time. There is no limit on the maximum length of the test period. However, if the test period extends beyond 24 hours, bear in mind the results need to be evaluated and conclusions must be presented in a manner consistent with the *per day* yield criteria of the rule.)

2.7.3 Saturated Soil

Zones of saturation with bulk hydraulic conductivities, $K < 1 \times 10^{-5}$ $^{cm}/_{sec}$ are not classified or regulated as GWBUs. Rather, such zones are regulated as saturated soils.

Demonstrations intended to show that certain saturated geologic strata are *not* GWBUs should be based on the following *minimum* supporting documentation (*see also* Table 5 for additional requirements):

1. data requirements for Class 3 demonstrations (Sec 1.4.3),
2. field measurements showing a representative hydraulic conductivity, $K < 1 \times 10^{-5}$ $^{cm}/_{sec}$ (required); **and**
3. laboratory USCS classification as a clay or silty clay soil stratum (i.e., CH or CL), as confirmed by laboratory testing.

All water-saturated strata or groups of water-saturated strata that are shown not to meet one or more of the exclusion criteria listed below will

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be assumed to be GWBUs for the purpose of the affected property assessment.

Measurements of K. Measurements of hydraulic conductivity for confirming the presence require adherence to the *same protocols* in Step 1. Measurements should be conducted at a sufficient number of locations to provide a representative characterization for each water-saturated unit.

2.7.3.1 Direct Measurement of Hydraulic Conductivity.

To demonstrate that a water-saturated stratum is only a low hydraulic conductivity saturated soil, the person conducting the affected property assessment must obtain a site-specific measurement of hydraulic conductivity, usually by a single-well (slug) test, as described in Section A.3 (Attachment A) of this document. Hydraulic conductivity *estimates* based on laboratory permeability tests or soil grain-size analyses are *not acceptable* for the purpose of classifying a hydrostratigraphic unit as a saturated soil. Test wells used for purposes of measuring hydraulic conductivity must be properly constructed and developed so as to provide an accurate indication of the hydraulic properties of the stratum (*see* Section A.2; Attachment A).

When the saturated unit has a hydraulic conductivity that is too low to test effectively (e.g., no recharge observed during a test period of appropriate length), then an assumption that the hydraulic conductivity is less than 1 x 10^{-5} cm/sec may be appropriate, provided the person can provide a sound and reasoned justification that the inability to effectively test the unit is reflective of the characteristics of the saturated unit and not the design, construction or development of the test well (*e.g.*, insufficient well screen, partial penetration, skin effects, *etc.*). The reasoned justification should include the USCS soil classification referenced in Section 2.7.3.

2.7.3.2 USCS Soil Classification.

Laboratory confirmation, by ASTM Standard Practice D2487, of a CL or CH designation for a homogenous clay stratum is recommended to corroborate the low hydraulic conductivity measurement.

2.7.3.3 Interbedded Soils.

A clay stratum (*i.e.*, CL or CH) containing water-saturated sand or silt seams or partings is classifiable as a GWBU if the *measurable bulk lateral hydraulic conductivity* of the stratum is K $\geq$ 1 x 10^{-5} $^{cm}/_{sec}$. In the instance of the presence of interbedded seams or partings within a clay stratum, additional information will be required to confirm the appropriate hydrologic characterization of the stratum. For example, a more detailed analysis of the stratigraphic profile may be necessary. Field measurements of bulk hydraulic conductivity of small intervals of the greater stratigraphic column *may* be required to demonstrate that the stratum's effective K is less than $1 \times 10^{-5}\ ^{cm}/_{sec}$.

2.7.3.4 Confirmation by COC Transport.

A *confirmation check* should be applied based on the observed patterns of COC migration in the subsurface. If the lateral extent of COCs within the stratum is indicative of an effective $K \geq 1 \times 10^{-5}\ ^{cm}/_{sec}$ (*i.e.*, groundwater or the COC plume has traveled a lateral distance within the stratum from the source with a travel time that indicates an effective $K \geq 1 \times 10^{-5}\ ^{cm}/_{sec}$), then the discrepancy must be resolved and a higher burden of proof may apply to verify that the stratum is not a GWBU. See TCEQ guidance document *Affected Property Assessment Requirements* (RG-366/TRRP-12) for requirements for assessment of COCs in such low permeability saturated soils.

2.8 STEP 6: Evaluate Groundwater Resource Sustainability

An important aspect of discriminating between Class 2 and Class 3 groundwater resources is the ability for that resource to produce useable water at a *sustainable rate of 150 gallons per day* ... [§350.52(3)]. The capability of a groundwater resource to maintain an annualized *sustainable daily withdrawal rate* of 150 gpd is the basis by which a GWBU is classified in this step. Sustainability is also a consideration for Class 1 groundwater resources, but since most classification efforts are focused on distinguishing Class 2 and 3 groundwater resources, sustainability guidance here emphasizes distinguishing the Class 2/Class 3-classification boundary.

Class 3 by Sustainability
A Class 2 GWBU may be downgraded to a Class 3 designation if the well yield can be demonstrated to be not sustainable.

All well yield determinations are considered to be representative of a sustainable resource. However, in lieu of a short-term hydraulic test that can predict the consequence of long-term sustained withdrawal of water of useable quality from a groundwater resource, alternate methods can be applied to demonstrations that a GWBU does not meet the "sustainable" qualification. These non-hydraulic methods include:

- Ephemeral saturation, and/or
- Limited hydrogeologic extent

Demonstrations can be based on relevant characteristics of the unit. Such demonstrations require *rigorous analysis* and can include characteristics such as geologic extent, ephemeral saturation, *etc.*, and combinations thereof. Content of these demonstrations are described below:

2.8.1 Ephemeral Saturation

GWBUs that can be demonstrated to be: 1) *historically ephemeral (not persistently saturated)* and 2) hydraulically isolated from other GWBUs such that they do not produce *sustainable* yields may be downgraded to Class 3. Demonstrations must be based on *documented* historical water level observations or other unequivocal information that permits a conclusion that the GWBU *is not permanently saturated*, or otherwise *is predictably ephemeral.*

If a GWBU is historically or predictably dry on a seasonal basis, then it meets the criterion for classification as Class 3 unless there is a current use of the GWBU. Such examples can include groundwater accumulations within a perched GWBU, underlain by unsaturated soils, and which diminishes during dry weather periods. If the GWBU goes completely dry at any time during the year, such that no water can be collected within a fully-penetrating monitoring well, then a Class 3 groundwater resource classification applies to the GWBU. The TCEQ may require documentation in the form of periodic water-level monitoring for a minimum of one year to support the classification.

2.8.2 Limited Hydrogeologic Extent

> **Perched Groundwater.** Perched groundwater zones (K > 10^{-5} cm/s), which contain groundwater during all or part of the year, are considered GWBUs (see Section 2.3.2).

Certain GWBUs may be demonstrated to be insufficiently *extensive laterally and/or volumetrically* and/or to be *hydraulically isolated* from other GWBUs and other sources of recharge such that the GWBU can not sustain the required long-term daily withdrawal rate to be a Class 1 or a Class 2 groundwater resource. Demonstrations of limited hydrogeologic extent must be based on both site-specific and regional hydrogeology, including detailed hydrostratigraphic analysis. Hydrogeological analysis of a sedimentary GWBU should include placement of the hydrostratigraphic unit within its overall stratigraphic context. The geometry of the hydrostratigraphic unit must be determined on a site-specific basis and the demonstration must rely on the limited extent of that geometry.

Examples of qualifying hydrostratigraphic units include lobes of permeable alluvial fans isolated by intercalated impermeable units, perched groundwater zones, and other isolated zones of saturation that are not used as groundwater resources.

2.8.3 Additional Lines of Evidence for Non-Sustainability Demonstration

Demonstrations to show that a groundwater resource is non-sustainable by ephemeral saturation and/or limited hydrogeologic extent may be strengthened using supplemental information from regional aquifer studies, groundwater resource assessments, water budget analyses, groundwater-surface water interactions, saline water intrusion studies, *etc.*

2.8.4 Classification of Karst or Fractured Groundwater-Bearing Units

A karst (or karstic) GWBU is defined here as a hydrostratigraphic unit composed primarily of soluble carbonate rock (such as limestone or dolomite) in which water flows appreciably through joints, fractures, faults, bedding-plane partings and/or cavities, any of which have been enlarged by dissolution.

A fractured GWBU is defined here as a hydrostratigraphic unit that exhibits breaks, whether or not caused by displacement, resulting from mechanical failure due to stress and includes cracks, joints, faults and other mechanical discontinuities, and groundwater movement is principally limited to the fractures.

In situations where the karstic or fractured character of a GWBU is the primary control on groundwater flow such that porous media flow is not the dominant character of the GWBU, then all aquifer parameter measurements (e.g., transmissivity) and calculations must be conducted by methods specifically appropriate to usage in *karst* or *fractured* GWBUs, as applicable. However, the direct well yield test methods presented in this guide should be generally applicable provided the test wells are designed and located such that their measurements are representative of the karst or fracture network when karst or fractures are expected to be the principal control on groundwater flow. See Table A4 (Attachment A) for more specialized methods for karst and fractured GWBUs. Also, bear in mind that a GWBU can be so intensely fractured or karsted such that it can mimic porous media flow. Therefore, unless it is clear that porous media flow is not reflective of the GWBU because of its karst or fracture character, the standard tests described in this document can be used.

2.9 STEP 7: Document Results

The results of the groundwater resource classification for all affected GWBUs and threatened hydraulically-interconnected GWBUs shall be submitted for TCEQ review in Section 2.5 of the Affected Property Assessment Report (APAR). The report should provide sufficient explanation and documentation to demonstrate proper classification of the groundwater resource and support TCEQ review. The responsibility is on the person to methodically present a convincing justification that the groundwater is Class 2 or Class 3. Applicable documentation includes the following:

Early Approval of Classification. The person is encouraged to submit to the TCEQ groundwater information used to support a *Class 3* classification *prior to full completion and submittal of the APAR.* Submit information on applicable APAR worksheets and attachments. In some instances, ensuring early TCEQ concurrence with a Class 3 groundwater classification can eliminate delays and remobilizations for additional assessment, revision of portions of the APAR, and duplication of work.

NOTE: All geoscience work submitted must be sealed by a licensed P.G. (per 22 TAC §851.156).

2.9.1 Identification of Groundwater-Bearing Units

Describe stratigraphic conditions, including geologic cross-sections and field and laboratory soil classification results, and provide supporting data related to identification of GWBUs, including soil type, water saturation, and applicable hydraulic conductivity. Evaluate potential hydraulic interconnection of affected GWBUs with other unaffected units.

2.9.2 Current Use and General Hydrogeologic Context

Provide a scaled map showing water supply wells located within 0.5 mile of the affected groundwater area; a tabulation of available information regarding any and all well use; and well construction (screened interval, seal, *etc.*), and the groundwater production zone as determined from available water well driller's logs, groundwater resource publications, and other relevant sources. Identify principal groundwater production zones for any identified wells.

2.9.3 Aquifer Testing

For Method 1, identify the applicable Method 1 equation (confined or unconfined, 4-inch or 12-inch diameter well) and selected calculation locations, and for each location, justify site-specific calculation inputs, including saturated thickness, mean annual confining head (if applicable), and hydraulic conductivity (*i.e.*, results of soil classification tests, rising head slug tests, constant-rate pumping tests, *etc.*).

For Method 2 well yield measurements, provide information on test well location(s) including the reasoning for selecting those test locations, test well construction and development, test procedures, all field data, the calculations used to reduce the data, the results of each calculation, and waste management procedures. Document all calculations of representative well yield for unit.

2.9.4 Natural Water Quality

Provide results of laboratory TDS analyses, including background sampling locations and the basis for assuming they represent natural background TDS, sample collection and handling procedures, and relevant quality assurance/quality control information. Provide information regarding compliance with PDWS criteria, if evaluated.

2.9.5 Groundwater Resource Sustainability

In the circumstance that a GWBU can be demonstrated to be a unit incapable of meeting the sustainability criterion, provide a hydrogeological analysis based on hydrostratigraphy, history of ephemeral saturation, observed ephemeral saturation, or any other site-specific hydrogeologic aspect sufficient to support the contention for a sustainability exemption.

2.9.6 Groundwater Resource Classification

Based on the results of the evaluation, identify the applicable classification in Section 2.5 of the APAR.

NOTE: ***If a GWBU meets the criteria for more than one groundwater classification, then the GWBU shall be assigned the higher (quality) classification (§350.52).***

ATTACHMENT A

Determination of Hydraulic Conductivity in Groundwater-Bearing Units

The determination of hydraulic conductivity in GWBUs may be performed using either multiple-well or single-well methods. Tables A1 through A4 summarize the guidelines useful for determining what drilling and testing methods may be the best for specific site conditions. Acceptable methods are not limited to ASTM methods.

NOTE: *If a GWBU meets the criteria for more than one groundwater classification, then the GWBU shall be assigned the higher (quality) classification (§350.52).*

A.1 Monitoring/Test Well Installation, Development and Rehabilitation

Monitoring wells employed for measurement of hydraulic properties must be screened within the GWBU under investigation and must be designed, constructed, and developed in accordance with 16 TAC §§76.1000-76.1009. For convenience, additional guidance on recommended methods for the design, construction and installation of monitoring/test wells can be found in Tables A1 and A4.

Well Construction. Test results from wells that are not appropriately designed, constructed, and/or developed may not be acceptable for groundwater classification purposes.

Wells used for test purposes should be of conventional construction with a minimum nominal 2-inch diameter (push probes, etc. are *not acceptable*). Some recommended methods for the conventional advancement of borings and drilling methods for geoenvironmental investigations are listed in Table A1.

Prior to Well Installation. It is beneficial to obtain hydro-geologic information of the area in order to advance borings and select proper well construction specifications for future hydraulic testing.

The Class 3 well yield limit (150 gpd) is based on a well with a nominal 4-inch diameter well screen or the equivalent. The Class 1 yield limit (144,000 gpd) is based on a well with a nominal 12-inch diameter well screen or the equivalent. If a well with a screen diameter other than 4-inch or 12-inch is used for the yield test(s), the *equivalent yield* from a 4-inch or 12-inch diameter well can be determined by multiplying the measured yield by the correction factors provided in *Attachment C.*

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A.2 Determination of Hydraulic Conductivity using Multiple-Well Tests

Site-specific values for hydraulic conductivity of GWBUs can be determined by multiple-well aquifer-pumping tests conducted on wells screened within the GWBU. Control wells and observation wells used for this purpose must be constructed and developed in accordance with Section 2.7. The general procedure for a constant-rate pumping test involves:

1. selection of a well array consisting of one control well and two or more observation wells located at various distances from the control well;
2. measurement of initial static water levels in all wells to be used in the test;
3. discharge of groundwater from the control well at a known flow rate for the time period necessary to meet test requirements (i.e., until sufficient time-drawdown or distance-drawdown data are obtained, typically 2 to 24 hours); and
4. measurement of recorded water levels at appropriate time intervals in all test wells during both the period of pumping and during the period of water level rebound after cessation of pumping.

Multiple-well pumping tests provide an estimate of the transmissivity (T), storativity (S) and hydraulic conductivity (K) of the GWBU over the area influenced by the test. A pumping test performed on a GWBU that is *not laterally extensive* requires a modified test method. Additional guidance on testing *areally-bound* GWBUs, such as GWBU with limited lateral extent (e.g., fluvial channels) can be found in ASTM Test Method D 5270.

Methods for selecting multiple-well pumping tests appropriate to site conditions should be conducted in accordance with ASTM Standard Guide D 4043. Procedures for conducting multiple-well pumping tests in *unconfined* GWBUs are contained in ASTM Test Method D 5920. Procedures for conducting multiple-well pumping tests in *extensive confined* GWBUs are provided in ASTM Test Methods D 4106, D 5472, D 5473, and D 5850. Procedures for conducting multiple-well pumping tests in *areally-bounded confined* GWBUs can be found in ASTM Test Method D 5270. Table A2 summarizes various recommended standard methods applicable to multiple-well tests.

Table A- 1. Recommended Methods for Drilling/Installing GWBU Monitoring/Test Wells

Procedure[1]	Application	Recommended Methods
Cable-tool drilling, & soil sampling	Geoenvironmental drilling and well installation	ASTM Guide D 5875
Auger boring for soil investigation	Auger drilling	ASTM Practice D 1452
Hollow-stem auger, soil sampling	Hollow-stem auger drilling	ASTM Practice D 6151
Air-rotary drilling, installation of monitoring wells	Geoenvironmental drilling and well installation	ASTM Guide D 5782
Direct rotary drilling, casing, soil sampling	Geoenvironmental drilling and well installation	ASTM Guide D 5876
Direct rotary drilling w/ water-based drilling fluid	Geoenvironmental drilling and well installation	ASTM Guide D 5783
Dual-wall reverse-circulation drilling, installation of monitoring wells	Geoenvironmental drilling and well installation	ASTM Guide D 5781
Casing advancement for monitoring well installation	Geoenvironmental drilling and well installation	ASTM Guide D 5872
Casing advancement for monitoring well installation (wireline)	Geoenvironmental drilling and well installation	ASTM Guide D 5876
Soil sampling in vadose zone	Geoenvironmental sampling	ASTM Guide D 4700
Split-barrel sampling of soil	Geoenvironmental sampling	ASTM Test D 1586
Thin-walled tube sampling of soil	Geoenvironmental sampling	ASTM Test D 1587
Ring-lined barrel sampling of soil	Geoenvironmental sampling	ASTM Practice D 3550
Rock core drilling and sampling	Geoenvironmental drilling and sampling of rock	ASTM Practice D 2113
Field logging descriptions	Bore log description	ASTM Guide D 5434
Decontamination of field equipment	Decontamination	ASTM Practice D 5088
Monitoring well construction	Well installation/construction	ASTM Practice D 5092
Monitoring well development	Well development	ASTM Guide D 5521
Protecting installed monitoring wells	Monitoring well protection	ASTM Practice D 5787
Monitoring well installation in karst and fractured-rock aquifers	Well installation in karst and fractured rock	ASTM Guide D 5717

[1] Multiple procedures may be applicable at any one affected property.

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The *representative transmissivity* value for a GWBU, appropriately determined, may be calculated as the arithmetic average of the transmissivity values determined for the various monitoring points used in the test (i.e., control well and observation wells). The representative transmissivity value may then be converted to a *representative* hydraulic conductivity (K) by dividing *average* T by the static saturated thickness (b) of the GWBU within the area of influence of the test, or:

$$\overline{K} = \overline{T}/b \qquad \text{(A.1)}$$

where:

$\overline{K}$ = representative hydraulic conductivity

$\overline{T}$ = representative transmissivity

b = aquifer thickness

Control well locations used for the purpose of averaging hydraulic parameters within a GWBU must be confirmed to insure that mean values are not biased low. The USGS (1979) provides additional information on multiple-well pumping tests.

A.3 Determination of Hydraulic Conductivity using Single-Well Tests

Determination of site-specific hydraulic conductivity values may be determined using single-well tests. *Slug tests* (i.e., single-well *instantaneous discharge* head-change tests) must be conducted in wells that are constructed and developed in accordance with the provisions of 16 TAC §76.1000, the requirements in Section A.1 and the recommendations provided in Table A1.

Instantaneous Discharge
Instantaneous discharge in single-well tests requires withdrawal of water from a well sufficiently rapid such that no water is removed from storage (i.e., *gradual* withdrawal by pumping or multiple bailer-loads is *not permitted*).

Special attention to well development efforts is required to ensure that drilling has not caused smearing of the borehole wall, or otherwise decreased the formation hydraulic conductivity, particularly when hollow- and solid-stem auger drilling methods are employed.

Table A- 2. Recommended Methods for Multiple-Well Aquifer Tests.

Procedure	Method Use and Test Results	Test Applicability	Recommended Methods
Selection of appropriate aquifer test	Guidance on selecting multiple-well tests		ASTM Guide D 4043
Field procedures for test wells	Guidance on with-drawal/injection tests		ASTM Test D 4050
Controlling drawdown	Measure h, Q	Constant drawdown, variable discharge	ASTM Practice D 5786
Measuring water levels in observation wells	Measure h (in well)	Observation well	ASTM Test D 4750
Unconfined, anisotropic	Measure T, S, q, and K_h/K_v ratio by Neuman Method	Constant discharge, & fully- or partially-penetrating well	ASTM Test D 5920
Unconfined, radial-vertical aniosotropy	Measure T, S, K_h/K_v	Drawdown << b	ASTM Test D 5473
Unconfined, areally extensive	Measure T, specific capacity	Drawdown < 25% b	ASTM Test D 5472
Unconfined, areally extensive	Measure T, S	Drawdown small *vs* b	ASTM Test D 4106
Unconfined	T by Recovery test	Drawdown small *vs* b	ASTM Test D 5269
Confined, non-leaky	Measure T, S	Fully-penetrating, constant discharge	ASTM Test D 4105
Confined, non-leaky	Measure T, S	Fully- or partially-penetrating, constant discharge	ASTM Test D 4106
Confined, non-leaky, bounded	Measure T, S for GWBU with limited areal extent	Confined unit with linear boundary	ASTM Test D 5270
Confined, radial-vertical aniosotropy	Measure T, S, K_h/K_v	Minimum four (4) partially-penetrating wells	ASTM Test D 5850
Confined, non-leaky, radial-vertical aniosotropy	Measure T, S, K_h/K_v	Partially-penetrating (*vs* fully penetrating)	ASTM Test D 5473
Confined	Measure T, specific capacity (well yield)	Fully penetrating, constant discharge	ASTM Test D 5472
Confined, non-leaky	T, by recovery test	Partially-penetrating	ASTM Test D 5269

b - aquifer thickness	h – head
K - hydraulic conductivity	K_h – horizontal hydraulic conductivity
K_v – vertical hydraulic conductivity	Q – discharge rate
S - storativity	T - transmissivity

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> **Single-Well Test Methods.** The appropriate test method depends both on the hydraulic condition of the GWBU (confined vs unconfined) and the degree of well penetration (fully or partially). See Table A3.

If slug tests are performed to measure hydraulic conductivity for use in the Method 1 Calculation (*see* Section 2.7.1), the tests should be conducted at a **minimum of three locations within each separate identified GWBU** to provide a representative measure of the potential variability. Additionally, a ***minimum of three slug tests should be performed at each well*** to evaluate the possibility that "skin effects" are not dominating the results of the test. Butler *et al.* (1996) recommend using the same head displacement in the first and third test while using another head displacement for the second test.

The representative hydraulic conductivity value for a *single* GWBU is the *geometric mean* of the inter-well results from a single GWBU. The representative hydraulic conductivity value of a *single* well is the *arithmetic mean* of the intra-well results from that single well. The *geometric mean* of inter-well hydraulic conductivity is defined as:

$$\overline{K} = \sqrt[n]{K_1 \cdot K_2 \cdot \ldots \cdot K_n} \qquad \text{(A.2)}$$

where,

$\overline{K}$ = representative hydraulic conductivity

K_n = inter-well average hydraulic conductivity values

n = number of inter-well measurements

The general procedure for a single-well test involves:

1. measuring the initial static water level within the well to be tested;
2. inducing an *instantaneous* positive or negative change of water level; and
3. measuring the recovery towards static water level at appropriate time intervals.

NOTE: *If a GWBU meets the criteria for more than one groundwater classification, then the GWBU shall be assigned the higher (quality) classification (§350.52).*

Recommended field protocols, test procedures and data analysis methods for single-well tests are summarized on Table A-3.

Table A- 3 Recommended Methods for Single-Well Tests.

Procedure[1]	Method Use and Test Results	Test Applicability	Recommended Methods
Selection of appropriate aquifer test	Single-well and multiple-well tests	Properly completed wells	ASTM Guide D 4043
Slugs for instantaneous discharge (head change)	Slug test	Properly completed wells	ASTM Test D 4044
Measuring water levels in observation wells	Slug test	Properly completed wells	ASTM Test D 4750
Unconfined	K	Instantaneous discharge	ASTM Test D 5912
Confined, non-leaky over-damped well response	T	Instantaneous discharge	ASTM Test D 4104
Confined, non-leaky under-damped well response	T	Instantaneous discharge	ASTM Test D 5785
Confined, non-leaky, critically-damped well response	T	Instantaneous discharge	ASTM Test D 5881
Constant head injection	T, S	Packers and pump	ASTM Test D 4630
Pressure pulse	T	Low transmissivity	ASTM Test D 4631

[1] Multiple procedures may be applicable at any one affected property.

K – hydraulic conductivity

S - storativity

T – transmissivity

Table A- 4. Recommended Methods for Drilling and Monitoring Well Installation in Karst and Rock.

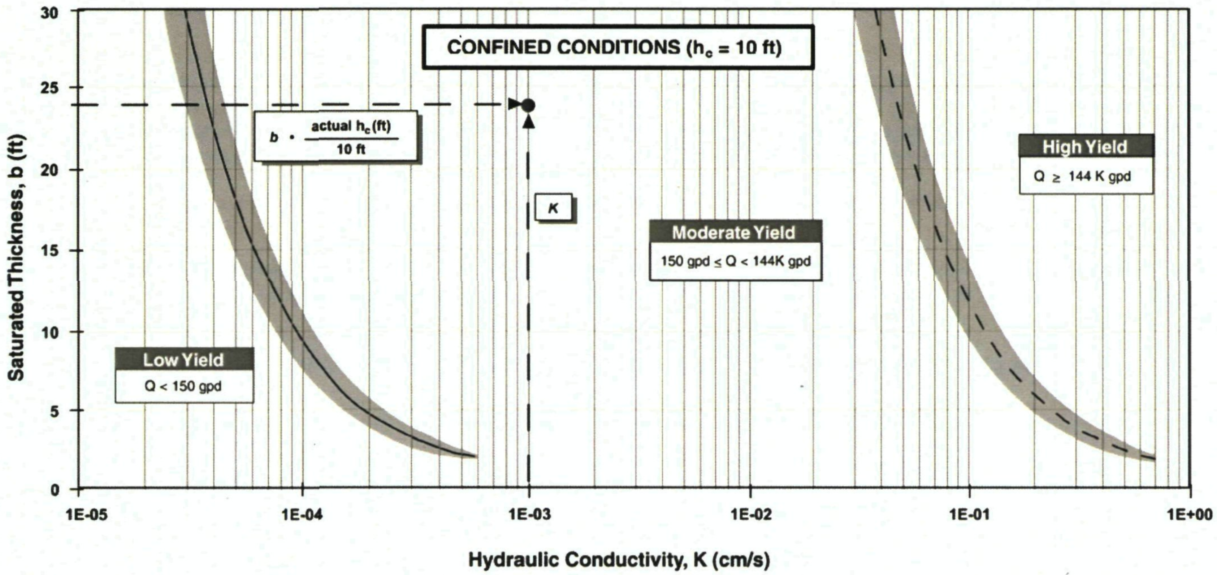
Procedure[1]	Method Use and Test Results	Test Applicability	Recommended Methods
Selection of appropriate aquifer test	Single-well and multiple-well tests	Properly completed wells	ASTM Guide D 4043
Rock core drilling and sampling	Geoenvironmental drilling and sampling of rock	Drilling method for rock	ASTM Practice D 2113
Monitoring well installation in karst and fractured-rock aquifers	Well installation in karst and fractured rock	Monitoring wells in karst/rock	ASTM Guide D 5717

[1] Multiple procedures may be applicable at any one affected property.

K – hydraulic conductivity

S - storativity

T – transmissivity



NOTE:

1) To use chart, align representative saturated thickness and hydraulic conductivity values to define (x,y) point on plot. Location of (x,y) point defines sustainable well yield category (low, moderate, or high). Note that this plot applies ONLY to confined units with confining head h_c = 10 ft. To match actual confining head, multiply saturated thickness (b) by ratio of (actual h_c in ft) / (10 ft) before plotting (x,y) point. For example, if actual h_c = 20 ft, b = 12 ft, K = 1.0E-3, then correction ratio = 20 ft / 10 ft = 2. Plot point is b = 2 x 12 ft = 24 ft; K = 1.0E-3 cm/s. Yield = moderate (Class 2).

2) If a confined unit is expected to reach an unconfined condition during pumping (due to water level drawdown), the yield calculation should be based on the unconfined unit equation (see Figure 4).

3) If Method 1 yield estimate falls within +/- 20% of Class 1 or Class 3 yield boundary (grey zone), Method 2 direct well yield test required to confirm proper classification.

4) gpd = Gallons per day; GWBU = Groundwater-bearing unit; Q = Well yield; b = Saturated thickness (ft); K = Hydraulic conductivity (cm/sec); h_c = Confining head (ft)

Legend

- ——— Class 3 yield boundary (Q = 150 gpd)
- - - - - Class 1 yield boundary (Q = 144K gpd)
- ± 20% zone

Figure 8. Confined Conditions

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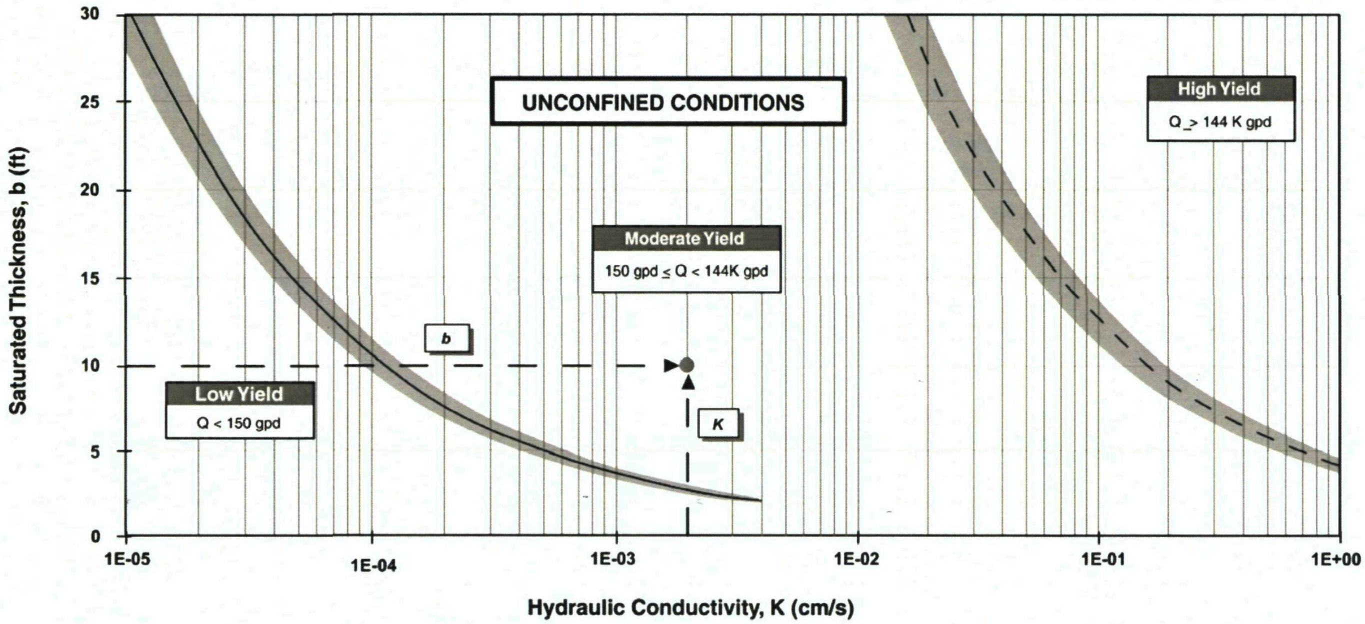

NOTES:

1) To use chart, align saturated thickness (b) and hydraulic conductivity (K) values to define (x,y) point on plot. Location of (x,y) point defines sustainable well yield category (low, moderate, or high). For example, if $K = 2 \times 10^{-3}$ cm/sec and b = 10 feet, then yield = moderate (Class 2).

2) If Method 1 yield estimate falls within +/- 20% of Class 1 or Class 3 yield boundary (grey zone), Method 2 direct well yield test required to confirm proper classification.

4) gpd = Gallons per day
GWBU = Groundwater-bearing unit
Q = Well yield
b = Saturated thickness (ft)
K = Hydraulic conductivity (cm/sec)

Legend

- Class 3 yield boundary (Q = 150 gpd)
- Class 1 yield boundary (Q = 144K gpd)
- ± 20% zone

Figure 9. Unconfined Conditions

ATTACHMENT B

Method 1: Estimation of Well Yield Using Idealized Well Function Equation

Application of NonEquilibrium Well Function Equation

The Cooper and Jacob (1946) approximation to the Theis (1935) solution for radial groundwater flow to a pumping well is as follows:

$$s = \frac{2.3Q}{4\pi T}\left[\log\left(\frac{2.25Tt}{r^2S} \times \frac{ft^3}{7.48gal}\right)\right] \qquad \text{(B.1)}$$

where:

Q = rate of pumping (gallons per day)

T = transmissivity of water bearing unit (gpd/ft)

r = radial distance from well (ft)

S = coefficient of storage (dimensionless)

s = water level drawdown (ft) at pumping rate (Q) and distance (r)

t = time of pumping (days)

The equation is valid for large values of time (t) and/or small values of radial distance (r), such as will occur at a pumping well. For use in estimation of well yield, the equation may be simplified by incorporation of typical default values for less sensitive input parameters, as follows:

r = radius of well (2-inch for TRRP Class 3 yield limit, 6-inch for Class 1 yield limit)

S = 1.0 x 10^{-4} (confined aquifer), 1.0 x 10^{-1} (unconfined aquifer) (see Driscoll, 1986)

t = 7 days

T = K x b,

K = hydraulic conductivity (gpd/ft^2) and

b = saturated thickness of the unit in ft.

Incorporating these default values, well yield Q may be expressed in terms of drawdown (s), hydraulic conductivity (K), and saturated thickness (b).

For a confined aquifer, 12-inch diameter well screen:

$$Q = \frac{5.46(s)(K)(b)}{4.93 + \log(Kb)} \quad \text{(B.2a)}$$

For a confined aquifer, 4-inch diameter well screen:

$$Q = \frac{5.46(s)(K)(b)}{5.88 + \log(Kb)} \quad \text{(B.2b)}$$

For an unconfined aquifer, 12-inch diameter well screen:

$$Q = \frac{5.46(s)(K)(b)}{1.93 + \log(Kb)} \quad \text{(B.2c)}$$

For an unconfined aquifer, 4-inch diameter well screen:

$$Q = \frac{5.46(s)(K)(b)}{2.88 + \log(Kb)} \quad \text{(B.2d)}$$

Estimation of Well Yield Based on Hydrologic Parameters

The Cooper-Jacob equation may be used to calculate an estimate of well yield associated with a pumped water level drawdown (s) equal to the *available drawdown* in the well (i.e., the distance from the static water level to the lowest efficient pumping water level in the well).

In unconfined aquifers, a water level drawdown in excess of two-thirds of the saturated thickness does not significantly increase well yield. Consequently, design guidelines call for screening the lower one-half to one-third of the saturated unit, corresponding to an available drawdown (s_{max}) equal to 50% to 67% of the saturated thickness (Driscoll, 1986). *However*, wells completed in unconfined GWBUs that are used both for COC concentration monitoring *and* hydraulic testing should be *fully penetrating*.

In confined GWBUs, design guidelines call for screening the full saturated thickness of the aquifer, corresponding to an available drawdown equal to 100% of the confining head (h_c).

Based on these design guidelines, available drawdown may be expressed as:

- Confined unit: $s_{max} = (1.0)(h_c)(e)$
- Unconfined unit: $s_{max} = (0.5)(b)(e)$

where:

h_c = confining head

b = saturated thickness

e = well efficiency

Substituting these available drawdown terms into the Cooper-Jacob expression (Equations 2a through 2d above), the well yield (Q) associated with utilization of the full available drawdown (s_{max}) can be calculated based on site-specific values of saturated thickness (b), hydraulic conductivity (K) and (for confined units) confining head (h_c), as follows:

Confined Aquifer

3a) 12-inch diameter well screen:

$$Q = \frac{(115{,}846)(h_c)(K)(b)}{9.25 + \log[(K)(b)]} \qquad \text{(B.3a)}$$

3b) 4-inch diameter well screen:

$$Q = \frac{(115{,}846)(h_c)(K)(b)}{10.2 + \log[(K)(b)]} \qquad \text{(B.3b)}$$

Unconfined Aquifer

3c) 12-inch diameter well screen:

$$Q = \frac{(57{,}923)(K)(b^2)}{6.25 + \log[(K)(b)]} \qquad \text{(B.3c)}$$

3d) 4-inch diameter well screen:

$$Q = \frac{(57{,}923)(K)(b^2)}{7.2 + \log[(K)(b)]} \qquad \text{(B.3d)}$$

where:

b = saturated thickness of water-bearing unit (ft)

h_c = confining head above top of water-bearing unit (ft)

K = hydraulic conductivity of water-bearing unit (cm/s)

Q = well yield (gpd)

e = well efficiency (assumed to be 100%)

Note that, in each of the above expressions, well efficiency (which typically ranges from 70 to 80% in properly designed and developed wells) is assumed to be 100%, providing a theoretical upper-bound yield from an ideal well.

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ATTACHMENT C

Estimation of Equivalent Method 2 Well Yield Based on Alternate Test Well Diameter

Overview of Method 2 Screen Diameter Correction Factors

For the purpose of the TRRP groundwater resource classification process, the person conducting the affected property assessment may estimate the yield from a properly constructed and developed well screened within the GWBU. Under the TRRP classification system, the Class 3 yield limit (150 gpd) is based on a well with a nominal 4-inch diameter well screen *or the equivalent*. The Class 1 yield limit (144,000 gpd) is based on a well with nominal 12-inch diameter well screen or the equivalent.

> **Method 2 Correction Factors.** These correction factors apply *only* to Method 2 direct well yield tests and *do not* apply to slug tests or to any other Method 1 calculations.

These specified well diameters have been incorporated in the Method 1 idealized well function equations presented in this guide (*see* Figures 4, 5, and 6 and *Attachment A*). No adjustment for well diameter is necessary or appropriate when using the Method 1 equations. However, under Method 2, any properly constructed and developed pumping well of nominal well screen diameter of 2 inches or greater may be used for the direct well yield tests. If a well with a screen diameter other than 4-inch or 12-inch is used for the yield test(s), the equivalent yield from a 4-inch or 12-inch diameter well can be determined by multiplying the measured Method 2 yield by the correction factors provided on Table C1. The derivation of the correction factors shown on Table C1 is provided below.

Application of Equilibrium Well Function Equation

The effect of the screen diameter on the well yield of a production well may be estimated using the equilibrium well function (Driscoll, 1986). The equilibrium well function equation (Thiem, 1906) relates well discharge to drawdown assuming two-dimensional radial flow toward the well as follows:

Unconfined Aquifer:

$$Q = \frac{K(H^2 - h^2)}{1{,}055 \log\left(\frac{R}{r}\right)} \qquad \text{(C.1a)}$$

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Confined Aquifer:

$$Q = \frac{Kb(H-h)}{528\log\left(R/r\right)} \qquad \text{(C.1b)}$$

where:

Q = rate of pumping (gpm)

K = hydraulic conductivity of groundwater-bearing unit (gpd/ft^2)

H = static head in well measured from base of the aquifer prior to pumping (ft)

h = pumping head in well measured from base of the aquifer while pumping (ft)

b = saturated thickness of the aquifer (ft)

R= radius of the cone of depression (ft)

r = radius of the well (ft)

Equations C.1a and C.1b are valid when all dynamic conditions in the well and groundwater are assumed to be in equilibrium (i.e., constant discharge, stable water level drawdown and radius of influence, and water flow converging on well at equal rates from all directions). The relationship of well yield to well screen diameter may be defined based on a simplified version of these equations, incorporating a constant term (C), as follows (Driscoll, 1986):

$$Q \approx \frac{C}{\log\left(R/r\right)} \qquad \text{(C.2)}$$

For a 4-inch diameter well (Class 3) and a 12-inch diameter well (Class 1) in either an unconfined or confined aquifer, the well yield (Q) may be expressed in terms of the radius of the cone of depression (R), as follows:

12-inch diameter well screen

$$Q = \frac{C}{\log\left(R/0.5\right)} \qquad \text{(C.3a)}$$

4-inch diameter well screen

$$Q = \frac{C}{\log\left(R/0.17\right)} \qquad \text{(C.3b)}$$

Derivation of Conversion Factors for Equivalent Well Yield from 12 inch or 4 inch Diameter Well Screen

Equations C.3a and C.3b can be used to calculate the equivalent yield from a 12-inch or 4-inch diameter well based on a measured yield from a well of a different diameter (e.g., 2-inch or 6-inch diameter well screen). For this purpose, the measured yield from the test well is multiplied by a correction factor equal to the ratio $Q_{12\text{-in}}/Q_{test}$ for conversion to an equivalent flow from a well with a 12-inch diameter well screen or $Q_{4\text{-in}}/Q_{test}$ for conversion to an equivalent flow from a well with a 4-inch diameter well screen.

For purpose of simplicity, the radius of the cone of depression (R) in Equation C.2 may be set equal to typical values for confined and unconfined groundwater-bearing units (i.e., 1,000 feet and 200 feet, respectively). Derivation of correction factors to estimate equivalent yields from wells with 12-inch or 4-inch diameter screens in either confined or unconfined units is shown below.

Conversion Factors for Confined Unit

12-inch Diameter Well Screen

Correction

$$= \frac{Q_{12-in}}{Q_{test}} = \frac{\log(R/r_{test})}{\log(R/r_{12-in})} = \frac{\log(1000/r_{test})}{\log\left(1000/\left(6/12\right)\right)} = \frac{\log(1000) - \log(r_{test})}{\log(1000/0.5)} = \frac{3 - \log(r_{test})}{3.3} \quad \text{(C.4a)}$$

4-inch Diameter Well Screen

Correction

$$= \frac{Q_{4-in}}{Q_{test}} = \frac{\log(R/r_{test})}{\log(R/r_{4-in})} = \frac{\log(1000/r_{test})}{\log\left(1000/\left(2/12\right)\right)} = \frac{\log(1000) - \log(r_{test})}{\log(1000/0.17)} = \frac{3 - \log(r_{test})}{3.8} \quad \text{(C.4b)}$$

Conversion Factors for Unconfined Unit

12-inch Diameter Well Screen

Correction

$$= \frac{Q_{12-in}}{Q_{test}} = \frac{\log(R/r_{test})}{\log(R/r_{12-in})} = \frac{\log(200/r_{test})}{\log(200/0.5)} = \frac{\log(200) - \log(r_{test})}{\log(200/0.5)} = \frac{2.3 - \log(r_{test})}{2.6} \quad \text{(C.5a)}$$

4-inch Diameter Well Screen

Correction

$$= \frac{Q_{4-in}}{Q_{test}} = \frac{\log(R/r_{test})}{\log(R/r_{4-in})} = \frac{\log(200/r_{test})}{\log(200/0.17)} = \frac{\log(200) - \log(r_{test})}{\log(200/0.17)} = \frac{2.3 - \log(r_{test})}{3.1} \quad \text{(C.5b)}$$

For above Equations C.4a through C.5b:

r_{test} = radius of wellscreen of test well (feet)

R= radius of the cone of depression (feet)

Q = well yield (gallons per day)

Table C1 provides calculated conversion factors for a range of typical well screen diameters. For any given case, the appropriate conversion factor must be selected based upon: 1) the hydraulic condition of the groundwater-bearing unit (confined or unconfined), 2) the well screen diameter of the test well, and 3) the well screen diameter for which an equivalent yield is to be calculated (4-inch or 12-inch). The well yield determined from a Method 2 direct well yield test procedure (Q_{test}) is then multiplied by the appropriate correction factor to obtain the *equivalent yield* from a well with a 12-inch or 4-inch diameter well screen. This equivalent well yield is then used for determining the groundwater resource classification.

Table C- 1. Method 2 Correction Factors for Estimation of Equivalent Yield Based on Alternate Test Well Diameter

Nominal Screen Diameter of Test Well	Correction Factor for Equivalent Yield From:			
	4-inch Diameter Well		12-inch Diameter Well	
	Confined Unit	Unconfined Unit	Confined Unit	Unconfined Unit
2-inch	1.08	1.10	1.24	1.30
4-inch	1.00	1.00	1.14	1.18
6-inch	0.95	0.94	1.09	1.12
8-inch	0.92	0.90	1.05	1.07
10-inch	0.89	0.87	1.02	1.03
12-inch	0.87	0.85	1.00	1.00
16-inch	0.84	0.80	0.96	0.95
24-inch	0.79	0.75	0.91	0.88
Multiply well yield measured in test well by the specified correction factor to obtain the equivalent yield of a well with either a 4-inch diameter screen or a 12-inch diameter screen.				

Example Calculation of Equivalent Well Yield

As an example, a Method 2 direct well yield test conducted on a 2-inch diameter test well determined well yield in a confined aquifer to be 110 gpd. A conversion factor to estimate the equivalent well yield from a 4-inch diameter well can be obtained from Table C1.

For this case, the test well diameter is 2-inches, the equivalent well diameter to be evaluated is 4 inches, and the groundwater-bearing unit is confined, corresponding to a correction factor of 1.08 from Table C1. The well yield determined from a Method 2 direct well yield test procedure (Q_{test}= 110 gpd) is then *multiplied* by the correction to obtain the *equivalent yield* from a well with a 4-inch diameter well screen:

110 gpd x 1.08 = 119 gpd

This equivalent well yield can then used for purposes of evaluating the Class 3 yield boundary. In this example, the well yield of the GWBU (119 gpd) is less than 150 gpd for a 4-inch diameter well (or equivalent), corresponding to a Class 3 groundwater resource.

ATTACHMENT D

References

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