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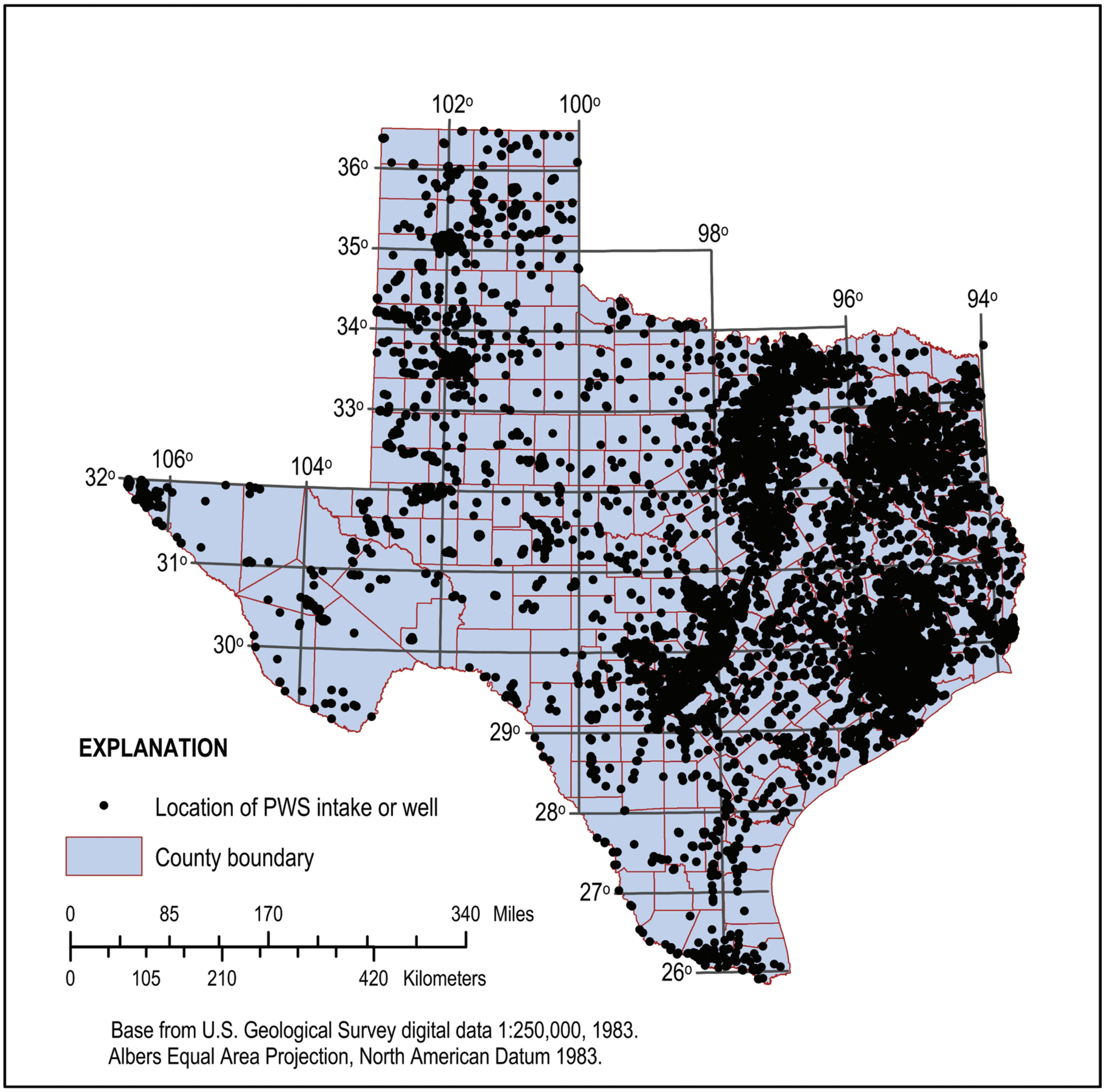
Source-Water Susceptibility Assessment in Texas: Approach and Methodology



Scientific Investigations Report 2011–5197

U.S. Department of the Interior
U.S. Geological Survey

Source-Water Susceptibility Assessment in Texas: Approach and Methodology

By Randy L. Ulery, John E. Meyer, Robert W. Andren, and Jeremy K. Newson

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Suggested citation:
Ulery, R.L., Meyer, J.E., Andren, R.W., and Newson, J.K., 2011, Source-water susceptibility assessment in Texas—Approach and methodology: U.S. Geological Survey Scientific Investigations Report 2011–5197, 64 p.

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Conversion Factors and Abbreviations

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
meter (m)	3.281	feet (ft)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
cubic centimeter (cm^3)	0.0610	cubic inch (in^3)
cubic meter (m^3)	35.3147	cubic feet (ft^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.0012	cubic hectometer (hm^3)
milliliter (mL)	0.0338	ounce, fluid (fl. oz)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.0631	liter per second (L/s)
	Mass	
gram (g)	0.0353	ounce avoirdupois (oz avdp)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
metric ton per square kilometer (ton/km^2)	2.8550	ton per square mile (ton/mi^2)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Application rate	
ton per acre (ton/acre)	0.9072	metric ton per acre

Altitude, as used in this report, refers to distance above the vertical datum.

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L), micrograms per liter (µg/L), or picocuries per liter (pCi/L).

The numbers of some bacteria in water are expressed in colony-forming units per hundred milliliters (CFU/100 mL) or the number of oocysts/100 mL.

Bulk density is expressed as grams per cubic centimeter.

Abbreviations used in this report

ACL – aquifer clay layer, less than 30 feet present attribute.

ADNS – domestic animal population density indicator.

AF – Attenuation factor attribute.

AGRP – Agriculture land-use percent attribute.

All – all susceptible contaminants group.

ANND – mean annual discharge attribute.

ANNRPR – mean annual runoff/precipitation indicator rating.

AOI – area of interest

API – area-of-primary influence susceptibility assessment component.

APIW – area-of-primary influence watershed area attribute.

APSC – weighted area-of-primary influence susceptibility rating for all surface-water sources.

APSW – area-of-primary influence susceptibility rating for a surface-water source.

APK – aquifer properties known attribute.

ATOP – aquifer top altitude attribute.

AQC – aquifer code attribute.

AQP – aquifer present attribute.

b_{gw} – aquifer thickness attribute.

AQT – aquifer type code attribute.

AWC – available water capacity attribute.

BASE – aquifer base altitude attribute.

BMP – best-management practices program in place attribute.

BLKD – soil bulk density attribute.

CLAY – soil clay content attribute.

COC – contaminant of concern.

COGW – contaminant-occurrence-susceptibility rating for a groundwater source.

COSC – weighted contaminant-occurrence-susceptibility component rating.

COSW – contaminant-occurrence-susceptibility rating for a surface-water source.

CPN – Boolean value indicating if a PSOC penetrates a aquifer confining unit.

CPTY – capacity (pumping rate) of well attribute.

CRUD – creation, retrieval, update, or delete.

CZ – source area was successfully delineated attribute.

CZ100 – source area polygon, less than or equal to (<=) 100 years.

CZ50 – source area polygon, <= 50 years.

CZ20 – source area polygon, <= 20 years.
CZ10 – source area polygon, <= 10 years.
CZ5 – source area polygon, <= 5 years.
CZ2 – source area polygon, <= 2 years.
CZA – source area in square miles attribute.
CZFIXED – source area polygon within ½-mile radius.
CZI – image well analysis required attribute.
CZJ – conjunctive delineation required attribute.
CZU – unconfined capture zone present attribute.
CZC – confined capture zone present attribute.
CZS – surface-water capture zone present attribute.
CZR – ½-mile fixed radius capture zone required attribute.
d – average stream depth attribute.
D_g – first-order decay constant attribute.
DAF – Dilution attenuation factor attribute
DBP – disinfection byproduct contaminants group.
DIURON_USE – Diuron application rate percent attribute.
DLND – Agriculture-drained land percent attribute.
DRDN – minimum drawdown constant attribute.
DAF – dilution attenuation factor attribute.
EDNS – permitted effluent-discharge site count indicator.
EPA – U.S. Environmental Protection Agency.
EPT – entry-point susceptibility summary component.
ESRI – Environmental Systems Research Institute.
FCC – final contaminant concentration attribute.
FORP – Forest land-use percent attribute.
GB – gigabytes.
GIS – geographic information system.
GSSC – contaminant-group susceptibility summary rating.
GUI – graphical user interface.
δ_{gw} – groundwater mixing-zone thickness attribute.
H – regional water table or potentiometric surface attribute.
H' – Henry's law constant attribute.
HCON – aquifer hydraulic conductivity attribute.
H_p – pumpage-influenced regional water table or potentiometric surface dataset.
HWTD – average seasonal high water table depth attribute.
HRGN – hydrologic region attribute.
HUC – hydrologic unit code attribute.
HVEL – average velocity at median flow attribute.
HYDG – Average hydrologic soil group attribute.
FALRPR – mean fall season runoff/precipitation indicator rating.
i – water table or potentiometric surface gradient attribute.

I_f – net infiltration rate through soil attribute.
ILK – intake location known attribute.
Inorganic – inorganic contaminants group.
INMP – intake mandatory properties present attribute.
INTK – type of intake attribute.
IPK – intake capacity known attribute.
IRC – intake is compliant with public water system rules flag.
IDGW – identification susceptibility rating for a groundwater source.
IDSC – weighted identification-component rating.
IDSW – identification susceptibility rating for a surface-water source.
ISGW – intrinsic susceptibility rating for a groundwater source.
ISSC – weighted intrinsic-susceptibility component rating.
ISSW – intrinsic susceptibility rating for a surface-water source.
JAD – joint application design.
JRP – joint requirements planning.
k_d – soil-water partition coefficient attribute.
KSAT – soil hydraulic conductivity attribute.
L – distance to the well attribute.
L_{gw} – distance from PSOC to source attribute.
LDF – lateral dilution factor attribute.
LK – leakance attribute.
LOAD – permitted load (mass) attribute.
LPST – leaking petroleum storage tank dataset.
MAI – mean annual inflow volume attribute.
MCS – main channel slope attribute.
Microbial – microbial contaminants group.
MJWA – multijurisdictional watershed area attribute.
MCL – main channel length attribute.
MDI – multiple document interface.
MRLC – multi-resolution landscape characterization.
MRRD – ratio of average reservoir depth to mean annual runoff susceptibility indicator.
MRRS – ratio of average reservoir storage to mean annual runoff susceptibility indicator.
MSI – mean summer inflow volume attribute.
MVC – model-view-controller software architecture pattern.
n – aquifer porosity attribute.
α_x – longitudinal dispersivity attribute.
NITR – application rate of fertilizer and manure nitrogen percent attribute.
NPGW – nonpoint-source susceptibility rating for a groundwater source.
NPSC – weighted nonpoint-source-susceptibility component rating.
NPSM – nonpoint-source method attribute.
NPSW – nonpoint-source susceptibility rating for a surface-water source.
NWIS – USGS National Water Information System.

OGWD – oil and gas well density indicator.

OMAT – soil total organic materials percent attribute.

p – probability of contaminant detection above threshold attribute.

P – mean annual precipitation attribute.

ρ_b – soil bulk density attribute.

ρ_s – soil particle density attribute.

P21 – MRLC 21 – low intensity residential land-use percent attribute.

P31 – MRLC 3 – bare rock, sand, gravel land-cover percent attribute.

P42 – MRLC 42 – evergreen forest land-cover percent attribute.

P51 – MRLC 51 – shrub land land-cover percent attribute.

P71 – MRLC 71 – grasslands/herbaceous land-cover percent attribute.

P81 – MRLC 81 – pasture/hay land-cover percent attribute.

P82 – MRLC 82 – row crops land-cover percent attribute.

Physical – regulated physical properties group.

PIPE – pipeline locations dataset.

PCNT – count of PSOCs within source area attribute.
PDF – portable document format
PERM – soil permeability attribute.
PDNS – pipeline density indicator.
PORS – aquifer porosity attribute.
POTS – aquifer potentiometric surface attribute
PPEN – penetrates confining unit attribute
PSOC – potential source of contamination.
PTGW – point-source susceptibility rating for a groundwater source.
PTSC – weighted point-source-susceptibility component rating.
PTSW – point-source susceptibility rating for a surface-water source.
PTYPE– potential source of contamination type and subtype attribute.
PWS – public water system.
Q – well discharge attribute.
Q- – alluvial-well discharge attribute.
Q+ – image-well recharge attribute.
r – drawdown distance from well attribute.
Radiochemical – radiochemical contaminants group.
RD – mean reservoir depth rating.
Regulated – all regulated contaminants group.
R_i – constituent retardation factor attribute.
s – drawdown depth from well attribute.
SB – screen bottom altitude attribute.
STOR – aquifer storage coefficient attribute.
SDI – single document interface.
SDNS – possible source of contamination site density indicator.
SDWIS – Texas Safe Drinking Water Information System
SER – soil erodibility indicator rating.
SITES – outfall locations dataset.
θ_T – soil porosity attribute.
STO – mean annual reservoir storage attribute.
SLP – land-surface slope attribute.
SNET – gridded representation of stream location attribute.
SPRRPR – mean spring season runoff/precipitation indicator rating.

SOC – synthetic organic contaminants group.
SQL – structured query language.
SSC – susceptibility-summary rating for a public water system.
SSGW – summary susceptibility rating for a groundwater source.
SSSW –summary susceptibility rating for a surface-water source.
ST – screen top altitude attribute.
STHK – aquifer saturated thickness attribute.
STATSGO – state soil geographic database.
STOR – storage coefficient/specific yield attribute.
SUMD – mean summer discharge attribute.
SUMM – summary susceptibility rating for a public water system.
SUMRPR – mean summer season runoff/precipitation indicator rating.
SWAP – source water assessment program.
SWAP-DSS – source water assessment program-decision support system.
SWSA – source-water susceptibility assessment.
t – pumping days constant attribute.
TCC – theoretical contaminant concentration.
TCEQ – Texas Commission on Environmental Quality.
TDNS – transportation density indicator.
THCK – aquifer thickness attribute.
THR – contaminant threshold value.
TOT – traveltime to groundwater source attribute.
TRACS – Texas Regulatory Activities and Compliance System.
TRAN – transportation locations dataset.
α_y – transverse dispersivity attribute.
TRNS – aquifer transmissivity attribute.
TTAT – accumulated time of travel attribute.
TTAD – accumulated distance of travel attribute.
TTAV – instantaneous velocity attribute.
TDWA – truncated watershed source-area in square miles attribute.
TGWA – truncating watershed area attribute.
TRS – total reservoir storage attribute.
TTL – 2-hour traveltime stream distance attribute.
TPL – permitted load (mass) of contaminant attribute.
TWA – total contributing watershed area attribute.
TXPDES – Texas Pollutant Discharge Elimination System.
U_{gw} – Darcian velocity attribute.
URBP – Urban land-use percent attribute.
USGS – U.S. Geological Survey.
v_{COC} – contaminant velocity attribute.
v_w – groundwater seepage velocity attribute.
V – seepage velocity attribute.
α_z – vertical dispersivity attribute.
α_v – vertical groundwater dispersivity attribute.
VOC – volatile organic contaminants group.
θ_{ws} – volumetric water content of vadose-zone soils attribute.
θ_{as} – volumetric air content of vadose-zone soils attribute.
W_s – lateral width of affected vadose zone in direction of groundwater flow attribute.
WAC – annular cement present attribute.
WELL_DENSITY – wells per unit area attribute.
WINRPR – mean winter season runoff/precipitation indicator rating.
WLK – well location known flag.
WMP – well mandatory properties known attribute.

WPK – well pumping rate known attribute.
WRC – well compliant with public water system rules attribute.
WRGN – watersheds region attribute.
WSAR – watershed slope/area indicator rating.
WSHD – source watershed area in square miles attribute.
WSI – screen interval known attribute.
WTAB – aquifer regional water table altitude.
WS – watershed slope attribute.
WSAR – ratio of watershed slope to watershed area susceptibility indicator.
W – real-well location attribute.
Wi – image-well location attribute.
XML – extensible markup language.

Source-Water Susceptibility Assessment in Texas: Approach and Methodology

By Randy L. Ulery[1], John E. Meyer[2], Robert W. Andren[2], and Jeremy K. Newson[1]

Abstract

Public water systems provide potable water for the public's use. The Safe Drinking Water Act amendments of 1996 required States to prepare a source-water susceptibility assessment (SWSA) for each public water system (PWS). States were required to determine the source of water for each PWS, the origin of any contaminant of concern (COC) monitored or to be monitored, and the susceptibility of the public water system to COC exposure, to protect public water supplies from contamination. In Texas, the Texas Commission on Environmental Quality (TCEQ) was responsible for preparing SWSAs for the more than 6,000 public water systems, representing more than 18,000 surface-water intakes or groundwater wells. The U.S. Geological Survey (USGS) worked in cooperation with TCEQ to develop the Source Water Assessment Program (SWAP) approach and methodology. Texas' SWAP meets all requirements of the Safe Drinking Water Act and ultimately provides the TCEQ with a comprehensive tool for protection of public water systems from contamination by up to 247 individual COCs. TCEQ staff identified both the list of contaminants to be assessed and contaminant threshold values (THR) to be applied. COCs were chosen because they were regulated contaminants, were expected to become regulated contaminants in the near future, or were unregulated but thought to represent long-term health concerns. THRs were based on maximum contaminant levels from U.S. Environmental Protection Agency (EPA)'s National Primary Drinking Water Regulations. For reporting purposes, COCs were grouped into seven contaminant groups: inorganic compounds, volatile organic compounds, synthetic organic compounds, radiochemicals, disinfection byproducts, microbial organisms, and physical properties.

Expanding on the TCEQ's definition of susceptibility, subject-matter expert working groups formulated the SWSA approach based on assumptions that natural processes and human activities contribute COCs in quantities that vary in space and time; that increased levels of COC-producing activities within a source area may increase susceptibility to COC exposure; and that natural and manmade conditions within the source area may increase, decrease, or have no observable effect on susceptibility to COC exposure. Incorporating these assumptions, eight SWSA components were defined: identification, delineation, intrinsic susceptibility, point- and nonpoint-source susceptibility, contaminant occurrence, area-of-primary influence, and summary components. Spatial datasets were prepared to represent approximately 170 attributes or indicators used in the assessment process. These primarily were static datasets (approximately 46 gigabytes (GB) in size). Selected datasets such as PWS surface-water-intake or groundwater-well locations and potential source of contamination (PSOC) locations were updated weekly. Completed assessments were archived, and that database is approximately 10 GB in size.

SWSA components currently (2011) are implemented in the Source Water Assessment Program-Decision Support System (SWAP-DSS) computer software, specifically developed to produce SWSAs. On execution of the software, the components work to identify the source of water for the well or intake, assess intrinsic susceptibility of the water-supply source, assess susceptibility to contamination with COCs from point and nonpoint sources, identify any previous detections of COCs from existing water-quality databases, and summarize the results. Each water-supply source's susceptibility is assessed, source results are weighted by source capacity (when a PWS has multiple sources), and results are combined into a single SWSA for the PWS. SWSA reports are generated using the software; during 2003, more than 6,000 reports were provided to PWS operators and the public. The ability to produce detailed or summary reports for individual sources, and detailed or summary reports for a PWS, by COC or COC group was a unique capability of SWAP-DSS.

In 2004, the TCEQ began a rotating schedule for SWSA wherein one-third of PWSs statewide would be assessed annually, or sooner if protection-program activities deemed it necessary, and that schedule has continued to the present. Cooperative efforts by the TCEQ and the USGS for SWAP software maintenance and enhancements ended in 2011 with the TCEQ assuming responsibility for all tasks.

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Introduction

Public water systems provide potable water for the public's use. The Safe Drinking Water Act amendments of 1996 (http://water.epa.gov/lawsregs/guidance/sdwa/theme.cfm) required each State to prepare a source-water susceptibility assessment (SWSA) for each public water system (PWS). States were required to determine the following:

- the source of water for each PWS,
- the origin of any contaminant of concern (COC) monitored or to be monitored, and
- the susceptibility of the PWS to COC exposure.

In Texas, the Texas Commission on Environmental Quality (TCEQ) was responsible for preparing SWSAs for the more than 6,000 public water systems, representing more than 18,000 groundwater wells or surface-water intakes. The TCEQ, working cooperatively with the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency, 1997a), developed the Texas Source Water Assessment Program (SWAP), designed to protect public water supplies from contaminant exposure. TCEQ's goals for the SWAP were to:

- focus protection on sources that were more susceptible to contaminant exposure,
- potentially reduce monitoring costs associated with ensuring safe, public drinking water,
- provide the public an improved understanding of the source of their water supply, and
- support implementation of best-management practices to protect drinking water.

The TCEQ was responsible for administering the SWAP for Texas (Texas Natural Resource Conservation Commission, written commun., 1999), and part of that responsibility was to explain how the goals of SWAP are accomplished. The purpose of this report is to help the TCEQ meet that responsibility by describing the approach and methods used to assess susceptibility. Several reports referenced herein document supplemental work completed to support the SWAP, and the reader is encouraged to consult those references for more detailed information. The TCEQ definition of susceptibility (Texas Natural Resource Conservation Commission, written commun., 1999) is the basis of the SWAP approach and methods summarized here.

- Susceptibility is defined as the potential for a surface-water intake or a groundwater well to withdraw water that has been exposed to a listed contaminant(s) at a concentration that would pose concern, through any of the following pathways: direct injection or discharge; soils; geologic strata including faults, fissures, or other types of secondary porosity; overland flow; upgradient water or streamflow; and through cracks in a well casing or intake pipe.
- Susceptibility of an intake or well to contaminant exposure is related to the physical integrity of the well or intake and the pipe transmitting water from the well or intake to the treatment plant/distribution system; the natural or man-altered physical, geologic, hydrologic, chemical, and biological characteristics of the areal extent of the zone of contribution to a discharging well (source area) or surface-watershed area over which, or matrix through which, water and contaminants can move to the supply point; the type and number of potential sources of contamination (PSOC) and land use within the source area or watershed of a supply well, spring, or intake; and the nature and quantity of contaminants that have been or potentially could be released within a source area, as well as measures in place to prevent such releases.

Since 1997, the USGS worked in collaboration with TCEQ to provide technical assistance in the development of the SWSA approach and methods, to compile data, and to develop computer software named Source Water Assessment Program-Decision Support System (SWAP-DSS), versions 1.8.7 (V1) and 2.1.1 (V2), which are used to produce SWSAs (Ulery, 2000). An initial approach focused on assessing the susceptibility to nonpoint- or point-sources—for example, agricultural land use or gas stations—without specifying the particular associated COCs. This would have yielded an SWSA result, for example, "High Susceptibility to Gas Stations," which would not have been as useful for protection purposes because it did not directly identify specific COCs to be be monitored. A second approach that focused on assessing susceptibility to individual COCs was chosen, because this supported the TCEQ goal to use SWSAs to tailor specific SWAP protection programs on a by-contaminant basis or to provide monitoring waivers for specific COCs. TCEQ staff compiled a list of 247 contaminants of concern and contaminant threshold values (THR) (appendix 1). COCs were chosen because they are regulated contaminants, were expected to become regulated contaminants in the near future, or were unregulated but thought to represent long-term health concerns. THRs are based on maximum contaminant levels from EPA National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1996), which are legally enforceable standards that protect public health by limiting the levels of COCs in drinking water. When a COC is not regulated, the minimum detection level is used for the THR. For reporting purposes, COCs are grouped into seven contaminant groups: inorganic compounds, volatile organic compounds, synthetic organic compounds, radiochemicals, disinfection byproducts, microbial organisms, and physical properties.

Science-based methods, applied to the most accurate, readily available hydrologic, hydrogeologic, land use/cover, point-source, and other natural-resource and environmental data, enable the TCEQ to meet SWAP goals, yet these methods are mainly subjective—that is, they are based on prior experience or best professional judgment, rather than on the collection and analysis of data that can objectively define the degree of susceptibility of a PWS to contamination. Focazio and others (2002) provide a definition of subjective methods that might be used in assessing groundwater susceptibility and advise that the term "subjective" should not infer a concept of inferior or potentially incorrect analysis. SWSA methods are conservative in that protection of the PWS is the primary consideration. SWSA methods are "works in progress" designed to be flexible in order to accommodate new data as acquired and new procedures as developed. Cooperative efforts have begun to address data needs through targeted sampling for pesticides and volatile organic compounds in public water-supply source waters (Mahler, 2000, and Mahler, Canova, and others, 2002) and for pesticides and volatile organic compounds in public water-supply reservoirs and wells (Mahler, Gary, and others, 2002). The reader is encouraged to consult these publications for more information. During 2003, the TCEQ completed initial assessments of all PWS and disseminated results to PWS operators and the public. In 2004, the TCEQ began a rotating schedule for SWSA wherein one-third of public water systems statewide are assessed annually.

Approach

Program goals and constraints of the SWAP first were identified (table 1), then TCEQ and USGS staff formulated SWSA evaluation criteria, determined SWSA indicators to represent the criteria, defined SWSA indicator classification and range values, and defined rules and guidelines for implementing SWAP. Three main assumptions of the approach formulated were that: both natural processes and human activities contribute COCs to source areas in quantities that vary in space and time; increased levels of COC-producing activities within a source area may increase susceptibility to COC exposure; and natural and manmade conditions within the source area may increase, decrease, or have no observable effect on susceptibility to COC exposure.

Some COCs are intentionally applied in agricultural or urban pest-management programs and others are produced during accidental events such as spills, yet COCs from both activities may be carried to streams in stormwater runoff. Some COCs are applied in commercial or residential areas, some along transportation and pipeline corridors, and some may be carried to streams in stormwater runoff or may infiltrate into soils and shallow groundwater. Other activities involve the storage and use of COCs as well as the production of waste products at specific locations, for example gas stations or dry cleaners. The presence of these point- and nonpoint-sources in the source area indicate potential susceptibility to COC exposure, but the degree of susceptibility is uncertain. One approach to address this uncertainty might be to estimate the probability that a COC might be released and transported in the source area based on results from ambient water-quality sampling of source waters, and then to equate susceptibility to the probability of detection. Unfortunately, insufficient water-quality data exist for the majority of COCs for either surface-water or groundwater sources precluding the use of rigorous risk analysis-based SWSA methods for most COCs. In general, a large amount of ambient water-quality data have been collected for various purposes and those data were used whenever possible. However, sufficient data to develop predictive equations for only 67 COCs were available for use in surface-water SWSAs and only 5 for groundwater SWSAs. For some, more "exotic" COCs, highly specific information was collected at known contamination sites, and models were available to simulate movement of contaminants in the environment, yet these data did not represent "average" or background conditions. This level of detailed analysis was beyond the scope of this effort to provide SWSAs for more than 6,000 PWSs within a very short time frame and would work against the TCEQ goal of using standardized methods for all assessments.

Table 1. Goals and constraints of the Source Water Assessment Program.

Goal	Constraint
Develop a conservative approach, where protection of the public water system is the primary consideration.	Use existing data.
Develop a flexible approach that can be modified if new data or knowledge is acquired.	Minimal published literature or guidance on source-water susceptibility assessment approaches and methods was available.
Develop a standardized approach that can be uniformly applied to all sources.	Limited small-scale datasets were available.
Develop assessment methods that are scientifically defensible and reproducible.	Critical datasets were not in a readily usable form.
Complete assessments for over 18,000 public water-supply sources by mandated deadlines.	Water-quality sample data were insufficient.
Provide susceptibility-assessment reports to more than 6,000 water systems and to the public.	To meet deadlines computerized source-water susceptibility assessment capabilities were required, but not available.

Although specific COC concentration data were used when available, it was decided that solubility of a COC in water would be used as the initial quantity of a contaminant that might be introduced to the source area. Water solubility is the maximum amount of a substance that can dissolve in water at equilibrium at a given temperature and pressure and is expressed as mass of solute per volume of water (milligrams per liter). SWSA components associate a COC with nonpoint- and/or point-source activities in the source area, assume an infinite supply of the COC, and use the COC water-solubility value as an initial theoretical contaminant concentration (TCC). The use of a COC water solubility as the initial concentration was thought to be conservative because it represents the maximum concentration that might be present in the source area—representing a "worst-case" situation. A COC TCC value then is simulated as transported through the source area to the intake or well, taking into account dilution, attenuation, and dispersion along the flow path and resulting in an estimated final contaminant concentration (FCC). The COC FCC value then is compared to the COC THR value to assign a susceptibility rating for the COC.

Given a relatively large number of datasets, attributes, indicators, and ratings required to produce a comprehensive SWSA, a component-based framework was considered the most reasonable organizational structure. The component-based framework breaks the problem into smaller components, which represent the natural boundaries of the problem. This, in turn, facilitates translation to modern object-based computer code that attempts to represent real-world objects through properties and behaviors. The component-based framework first is organized based on the source of water (ground, surface, or conjunctive) on intrinsic characteristics of the source area, including soil and climatological characteristics and land surface slope, and second on the origin of assessed COCs (nonpoint- or point-source-associated COCs). SWSA criteria include: physical integrity of an intake or well; intrinsic characteristics of the source area; point and nonpoint sources of COCs within the source area; COCs associated with the area-of-primary influence (API) for surface-water intakes; occurrence of COCs at water-quality monitoring sites within the source area; and a source susceptibility summary component, which combines the results from the various components into ratings of high, medium, low, or no susceptibility to each of the 247 COCs. The content of an SWSA varies depending on the number of groundwater wells or surface-water intakes, on their capacities, and on the type and location of each source. During execution of the assessment, SWSA components are applied as necessary; for example, a groundwater well screened in the confined portion of an aquifer (appendix 2) is expected to be isolated from COCs that might be introduced at land surface, therefore the intrinsic and nonpoint-source components are not applied. The point-source component is applied only if the confining unit is known to be penetrated, perhaps by an oil or gas well or other PSOC, such that COCs could be introduced to the aquifer. The contaminant occurrence component is applied regardless of the source type. Appendixes 3*A*–3*F* illustrate, by flowchart, applicable components and processing steps for the various source types.

The EPA specified that a SWSA for a PWS should represent all source wells or intakes that provide source water, enabling the SWSA to be independent of any particular "mix" of PWS source wells or intakes (U.S. Environmental Protection Agency, 1997a). TCEQ further specified that an individual SWSA would be produced and maintained, so that details of the SWSA could be referenced if necessary. If a PWS consists of a single well or intake source, the SWSA for the PWS is the SWSA of the source. If a PWS consists of multiple wells or intakes, the SWSA is a capacity-weighted average of all source SWSAs. The capability to provide susceptibility ratings for individual contaminants enables the TCEQ to tailor specific SWAP protection programs for the PWS on a by-contaminant basis and is thought to be unique to the Texas SWAP, as is the flexibility to provide both a detailed source assessment for each intake or well and a system assessment for the PWS. These capabilities provide a range of outputs suitable for a variety of stakeholder purposes.

The SWSA is output in report form by executing a computer model, which during execution first identifies the source of water for each well or intake, and then uses inputs based on natural and manmade conditions within the source area to assess susceptibility to contamination by COCs. A SWSA consists of up to eight components, each with a specific objective as shown in table 2.

SWSA ratings are based on (1) intrinsic characteristics, (2) comparison of point-source, nonpoint-source, and API-associated COC concentrations with COC THRs, or (3) detection of COCs above the THR in ambient or finished water-quality samples from the source area. Indicator ratings from each SWSA component for each COC are combined to produce a summary susceptibility rating for a groundwater source (SSGW) or for a surface-water source (SSSW). If no known COC sources exist, then no susceptibility rating is produced for the COC. When a PWS contains more than one surface-water intake or groundwater well, a system susceptibility summary component combines all source susceptibility summaries into a system susceptibility summary (SSC). An entry point is a unique grouping of one or more surface-water intakes or groundwater wells employed by the water suppliers to support different water-mixing strategies. An entry-point SWSA combines selected source summaries into an entry point summary (EPT).

Source-Water Susceptibility Assessment Methodology

Descriptions of SWSA methods are grouped by component and include methods that identify surface-water intake or groundwater well properties; delineate the source area; compute indicator values for the source area; provide details on computation of weighted values and indicator-ratings; and methods that combine all component ratings into a summary assessment rating.

Table 2. Source-water susceptibility assessment rating names, component names, and descriptions.

[IDGW, identification susceptibility rating for a groundwater source; —, not applicable; IDSW, identification susceptibility rating for a surface-water source; ISGW, intrinsic susceptibility rating for a groundwater source; ISSW, intrinsic susceptibility rating for a surface-water source; NPGW, nonpoint-source susceptibility rating for a groundwater source; NPSW, nonpoint-source susceptibility rating for a surface-water source; PTGW, point-source susceptibility rating for a groundwater source; PTSW, point-source susceptibility rating for a surface-water source; APSW, area-of-primary influence susceptibility rating for a surface-water source; COGW, contaminant occurrence susceptibility rating for a groundwater source; COSW, contaminant occurrence susceptibility rating for a surface-water source; SSGW, summary susceptibility rating for a groundwater source; SSSW, summary susceptibility rating for a surface-water source; SUMM, summary susceptibility rating for a public water system; EPT, summary susceptibility rating for an entry point; COC, contaminant of concern; TCEQ, Texas Commission on Environmental Quality; GSSC, contaminant-group summary rating, IDSC, weighted identification-component rating; ISSC, weighted intrinsic-susceptibility component rating; PTSC, weighted point-source-susceptibility component rating; NPSC, weighted nonpoint-source-susceptibility component rating; COSC, weighted contaminant-occurrence-susceptibility component rating; SSC, system-susceptibility component summary rating]

Susceptibility rating name	Susceptibility component name	Description
IDGW, IDSW	Identification.	Obtains the source location and the hydrogeologic or hydrographic properties used to delineate the source area(s) for the intake or well. Produces susceptibility ratings for each assessed COC for the well or intake.
—	Delineation.	Delineates water source area(s) based on hydrogeologic or hydrographic properties identified under the identification component. No susceptibility ratings are produced by this component.
ISGW, ISSW	Intrinsic susceptibility.	Estimates the degree to which intrinsic factors such as climatological, soils, and topographic factors that cause the intake or well to be more or less susceptible to contamination. Produces susceptibility ratings for each assessed COC for the well or intake.
NPGW, NPSW	Nonpoint-source susceptibility.	For selected COCs, evaluates nonpoint sources as potential sources of contaminant exposure based on the probability of detection given selected land use and other explanatory indicators of the source area. For other COCs, land-use-associated contaminants are input into a simplified COC-flux/attenuation model. Produces susceptibility ratings for each assessed COC for the well or intake.
PTGW, PTSW	Point-source susceptibility.	Utilizes a simplified flux/attenuation/decay model to estimate whether potential sources of contamination or permitted discharge-associated COCs are likely to be attenuated before reaching the well or intake based on physical properties of the COC and of the aquifer or contributing watershed. A susceptibility determination is made by comparing the estimated final concentration at the well or intake from all point/area sources, after COC attenuation, to the TCEQ-established COC threshold. Produces susceptibility ratings for each assessed COC for the well or intake.
APSW	Area-of-primary influence susceptibility.	For emergency response purposes, identifies proximity and density of threatening activities and associated COCs within the immediate area of the intake. Indicator ratings are applied to the associated COC and susceptibility to contaminant exposure from activities within the area of primary influence is determined. Produces susceptibility ratings for each assessed COC for the intake.
COGW, COSW	Contaminant occurrence.	At water-quality monitoring and finished water sites near the intake or well, identifies COC detections above TCEQ-threshold values. If COCs are detected above the threshold, a “High” susceptibility rating is assigned. Produces susceptibility ratings for each assessed COC for the well or intake.
SSGW, SSSW	Source susceptibility summary.	Combines all component ratings into a summary assessment for the intake or well. Produces susceptibility ratings for each assessed COC.
APSC	Area-of-primary influence.	Weighted-susceptibility rating for all surface-water sources.
COSC	Contaminant occurrence.	Weighted-susceptibility rating for all sources.
EPT	Entry-point susceptibility summary.	Combines all source summary component ratings into a summary assessment for the entry point. Produces susceptibility ratings for each assessed COC.
GSSC		Contaminant-group-susceptibility rating.
IDSC		Weighted-susceptibility rating for all sources.
ISSC		Weighted-susceptibility rating for all sources.
PTSC		Weighted-susceptibility rating for all sources.
NPSC		Weighted-susceptibility rating for all sources.
SSC	System susceptibility summary.	For a public-water system with multiple intakes or wells, combines all source summary component ratings into a summary assessment for the system. Produces susceptibility ratings for each assessed COC.

Identification Component

Groundwater Sources

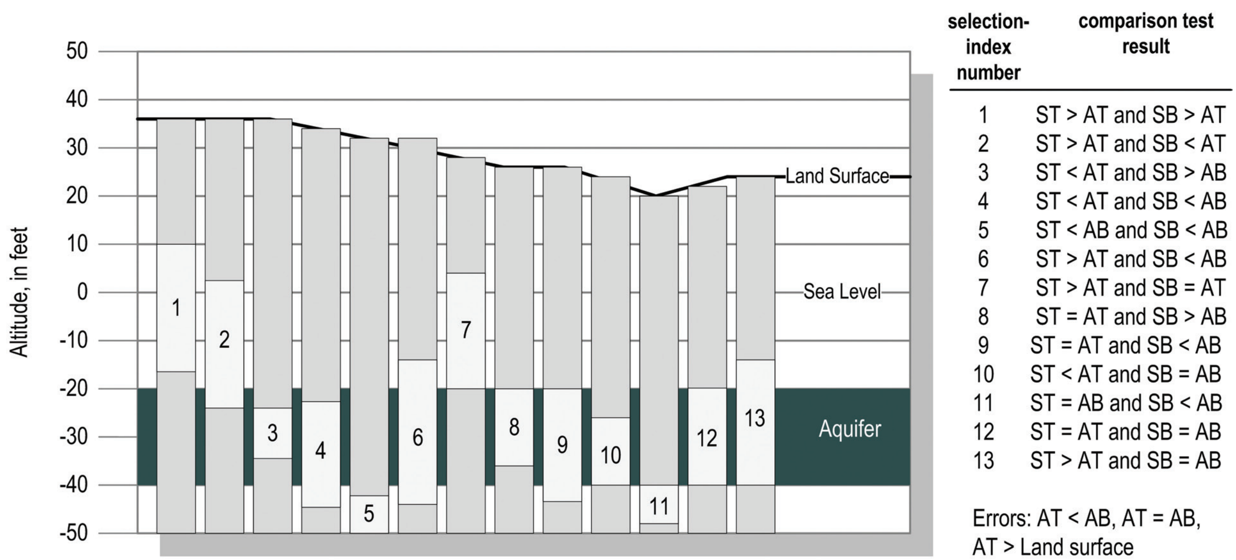
Identification-component methods are concerned with database retrieval, verification, and testing of selected well properties, such as capacity (pumping rate), well depth, screen interval, aquifer confinement, well integrity to determine if the source is assessable; if properties of the source reduce or eliminate susceptibility to contaminant exposure; which aquifer (if any) the well is screened in; and estimation of aquifer properties at the well. During execution, this component reads well properties such as screen interval, well capacity, and latitude/longitude from TCEQ databases and uses these properties to identify (1) the potential source aquifers at the location, (2) the screened aquifer, and (3) aquifer properties from the spatial database for the screened aquifer identified. Table 3 shows the list of attributes or properties of this component.

The identification component identifies potential aquifers present at the well. Then, well-screen top and well-screen bottom altitudes are compared with each potential aquifer's top altitude and base altitude to determine if the screen intersects the potential aquifer. A unique selection-index number (1–13) is assigned based on the comparison results (fig. 1) and this selection-index number is stored in the database. A potential

Table 3. Attributes of aquifer or well or indicators of contaminant susceptibility, descriptions, and units used to compute the susceptibility rating of the identification component of the source-water susceptibility assessment for a groundwater source (IDGW).

[>, greater than; —, not applicable; TCEQ, Texas Commission on Environmental Quality]

Attribute or indicator	Description	Unit
ACL	Aquifer clay layer, >30 feet is present.	True or false.
APK	Aquifer properties known.	True or false.
ATOP	Aquifer top altitude.	Feet above mean sea level, at well.
AQC	Aquifer code.	1–50 (see appendix 2).
AQP	Aquifer present.	True or false.
AQT	Aquifer type code.	Unconfined = 1, confined = 2, alluvial = 3, Edwards/conjunctive = 4, other = 5.
BASE	Aquifer base altitude.	Feet above mean sea level, at well.
BMP	Best-management practices program in place.	True or false.
COC	Contaminant of concern.	—
CPN	Confining unit penetrated.	True or false.
CPTY	Capacity (pumping rate) of well.	Gallons per minute, TCEQ database.
HCON	Aquifer hydraulic conductivity.	Feet per day, at well.
IDGW	Susceptibility rating, based on well integrity.	True = 1, false = 0.
PORS	Aquifer porosity.	Unitless, at well.
SB	Screen bottom altitude.	Feet above mean sea level, from TCEQ database. Note that in the case of a well with multiple screens, the deepest screen altitude is used.
ST	Screen top altitude.	Feet above mean sea level, from TCEQ database. Note that in the case of a well with multiple screens, the shallowest screen altitude is used.
STHK	Aquifer saturated thickness.	Feet, at well.
STOR	Aquifer storage coefficient.	Unitless, at well.
THCK	Aquifer thickness.	Feet, at well.
TRNS	Aquifer transmissivity.	Square feet per day, at well.
WAC	Annular cement is present.	True or false.
WLK	Well location is known.	True or false.
WMP	Well mandatory properties are known.	WLK, WPK, APK are known, True = 1 or false = 0.
WPK	Well pumping rate is known.	True or false.
WRC	Well is compliant with public water system rules.	True or false.
WSI	Screen interval is known.	True or false.
WTAB	Aquifer regional water-table altitude.	Feet, at well.



[<, less than; >, greater than; ST, Screen top; SB, Screen bottom; AT, Aquifer top; AB, Aquifer base, selection-index number uniquely identifies the comparison test result used to identify the screened aquifer.]

Figure 1. Example of aquifer selection by comparison of screen and aquifer geometries.

aquifer is selected if at least 50 percent (or 20 ft) of the screen is within the potential aquifer. If more than one potential aquifer meets the criteria, the most shallow aquifer is chosen. In some cases, required aquifer properties were not available and were estimated; for example, aquifer properties were estimated for wells screened in the Edwards North BFZ (aquifer code 11, appendix 2), where sufficient data exist for development of a water-table dataset but other properties were not available. Saturated thickness and depth of unsaturated-soil zone, required for attenuation of COCs, is estimated using the water-table dataset. No water-table dataset is available for Edwards South BFZ (aquifer code 43, appendix 2) wells; therefore, saturated thickness is estimated to be 25 percent of aquifer thickness and depth of unsaturated-soil zone is estimated to be 75 percent of aquifer thickness.

During execution, this component assigns one of five TCEQ-defined aquifer types based on well location and well screen relative to aquifer geometry. The aquifer types assigned are:

- unconfined isotropic aquifers,
- confined isotropic aquifers,
- alluvial sediment aquifers along major rivers,
- Edwards aquifer/conjunctive (anisotropic karst), and
- other aquifers.

If a screened aquifer is assigned, the identification component determines hydrogeologic properties (table 2) at the well location. If well-screen information is not known or cannot be assigned to a specific aquifer, the aquifer-type assessment property is assigned “Other.” The aquifer-type property is used in all subsequent components to specify methods for source-area delineation and assessment.

The groundwater identification component assigns a susceptibility rating (IDGW) for all assessed COCs based on the physical integrity of the well and selected properties of the source aquifer thought to isolate the well from contaminant exposure. The susceptibility rating value is set to zero by default, meaning that the PWS well is likely isolated from possible contaminant exposure. If isolating properties are not present, the well may be susceptible to contaminant exposure and the indicator is set to one unless a SWSA protection plan has been instituted. The susceptibility rating (table 2) produced under this component is based on properties of the PWS (table 3) or the source aquifer that might affect susceptibility to contaminant exposure. This assignment has the effect of raising the susceptibility summary ratings by a small amount, a subjective decision based on best professional judgment. Based on testing of well and aquifer properties, the IDGW susceptibility rating may be reassigned. The susceptibility associated with well integrity is assigned as follows (see table 3 for identification of terms):

$$IDGW = 1, \text{ if } WRC \text{ or } WAC \text{ or } ACL \text{ or } WLK \text{ or } WSI \text{ or } WPK = \text{False} \quad (1)$$

$$IDGW = 1, \text{ if } AQT = 3 \text{ or } AQT = 5, \text{ if } CPN = \text{True or if } BMP = \text{False} \quad (2)$$

During execution of the point-source susceptibility component (described in a subsequent section), discovery of a penetrating PSOC in the source area having assessed COCs will cause the value of CPN (confining unit penetrated flag) to be updated to true and, consequently, the IDGW will be assigned a one, indicating a low susceptibility to all associated PSOC COCs, rather than a zero, which previously indicated no susceptibility.

Surface-Water Source

Surface-water identification-component methods are concerned with database retrieval, verification, and testing of selected surface-water intake properties including major river basin name, hydrologic region, hydrologic unit, and other attributes listed in table 4. During execution of this component, the susceptibility indicator (IDSW) initially is assigned a zero, meaning that the PWS intake is thought to be isolated from contaminant exposure. The component assigns a susceptibility rating for all assessed COCs based on the physical integrity of the surface-water intake and selected properties of the source watershed thought to isolate the intake from contaminant exposure.

The susceptibility rating produced under this component is based on properties that might affect susceptibility to contaminant exposure. The IDSW is computed as follows (see table 4 for identification of terms):

$$IDSW = 1 \text{ if } ILK \text{ or } IRC \text{ or } IPK \text{ and } BMP = \text{False} \quad (3)$$

If these isolating properties are not present, the surface-water intake may be susceptible to contaminant exposure and the indicator is reset to one; however, if an SWSA protection plan has been instituted the indicator is not reset.

Table 4. Attributes of watershed or indicators of contaminant susceptibility, descriptions, and units used to compute the identification susceptibility rating of the identification component of the source-water susceptibility assessment for a surface-water source (IDSW).

[—, not applicable]

Attribute or indicator	Description	Unit
COC	Contaminant of concern.	—
CPTY	Intake capacity.	Gallons per minute.
BMP	Protection plan instituted.	True or false.
HRGN	Hydrologic region.	Region number (1–11).
HUC	Hydrologic unit code.	8-digit code.
IDSW	Susceptibility rating.	1 or 0
ILK	Intake location known.	True or false.
INMP	Intake mandatory properties present.	True or false.
INTK	Type of intake.	Reservoir, stream, or spring.
IPK	Intake capacity known.	True or false.
IRC	Intake is compliant with public water system rules.	True or false.

Delineation Component

Groundwater Source

Delineation of the source area for a specific groundwater well field or spring is complicated by geologic structure, groundwater/surface-water interaction, heterogeneous aquifer-matrix material resulting from the depositional environment of the aquifer, and a general lack of site-specific aquifer information required for delineation (table 5). For the purposes of susceptibility assessment, a source area is the projection of the three-dimensional aquifer space within which a volume of water flows to a discharge well onto a two-dimensional map under steady-state conditions. EPA guidance for delineation of source-water areas (U.S. Environmental Protection Agency, 1997a) listed methods for estimation of the source area including: (1) deterministic numerical models; (2) analytical boundary-element computations; (3) image-well analysis; or (4) use of observed data in the development of a two-dimensional flownet surface. A flownet-surface analysis was used to delineate groundwater-source areas for Texas, because all aquifers are evaluated on a regional scale and the length of most aquifers is several orders of magnitude longer than the aquifer thickness. Because the dip (slope) of most aquifers in Texas is very slight (less than 40 ft/mi), flow in the aquifer can be approximated as two-dimensional along the length of the aquifer and can be considered horizontal. Flownet-surface analysis also assumes that an aquifer is homogeneous in composition, horizontally isotropic (the Edwards aquifer is an exception), laterally extensive on a regional scale, and flow in the aquifer is laminar (that is, Darcy's law is valid). For flownet-surface analysis, a regional water-table map for unconfined aquifers or a potentiometric-surface map for confined aquifers was developed. Water-table contours for unconfined isotropic media represent the flownet surface and the lines perpendicular to the water-table surface represent flow paths (E.L. Kuniansky, U.S. Geological Survey, written commun., 1999, and Freeze and Cherry, 1979).

Using hydrogeologic data created during execution of the identification component, the groundwater delineation component delineates the 100-year traveltime area or a ½-mi fixed-radius source area that is expected to contribute water to a PWS well. No susceptibility rating is produced by this component. For other than fixed-radius source areas, the delineation component creates time-of-travel and source-area datasets associated with selected travel-endtimes. Two types of public-supply wells may be under the influence of surface water requiring a conjunctive delineation—that is, the integrated

Table 5. Attributes of aquifer or well or indicators of contaminant susceptibility, descriptions, and units used to delineate a source area for a groundwater source.

[<=, less than or equal to]

Attribute or indicator	Description	Unit
CZ	Flag indicating whether a source area was successfully delineated.	True = 1, false = 0.
CZ100	Source area <= 100 years.	Square miles. Surface-area polygons, estimated for selected travel-endtimes, or surface-area-polygon for ½-mile fixed-radius delineation.
CZ50	Source area <= 50 years.	
CZ20	Source area <= 20 years.	
CZ10	Source area <= 10 years.	
CZ5	Source area <= 5 years.	
CZ2	Source area <= 2 years.	
CZFIXED	Source area = ½-mile radius.	
CZI	Flag indicating if an image well analysis was required.	True = 1, false = 0.
CZJ	Flag indicating if conjunctive delineation was required.	
CZU	Flag indicating if an unconfined capture zone is present.	
CZC	Flag indicating if a confined capture zone is present.	
CZS	Flag indicating if a surface-water capture zone is present.	
CZR	Flag indicating if a ½-mile fixed radius capture zone was required.	
d	Average stream depth.	Feet, used in alluvial-delineation method.
DRDN	Minimum drawdown constant.	0.1 ft. At the edge of the drawdown cone, a minimum drawdown is achieved ensuring that only drawdown that appreciably affects the regional water-level surface is included.
H	Regional water table or potentiometric surface.	Feet, at well.
Hp	Pumpage-influenced regional water table or potentiometric surface.	Feet, at well.
i	Water table or potentiometric surface gradient.	Unitless, change in height divided by change in length along the steepest flow path.
K	Aquifer hydraulic conductivity.	Feet per day, at well.
L	Distance to the well.	Feet.
n	Aquifer porosity.	Unitless, at well.
Q	Well discharge.	Cubic feet per day.
Q-	Alluvial-well discharge.	Cubic feet per day.
Q+	Image-well recharge.	Cubic feet per day.
r	Drawdown distance.	Distance at which drawdown is less than or equal to DRDN.
s	Drawdown.	Feet, at well.
S	Storage coefficient/specific yield.	Unitless, at well.
SNET	Grid representation of stream location.	Stream = 1, not stream = 0.
t	Pumping days constant.	Constant 100 days. A sufficiently large number to allow the shape of the drawdown cone to grow to its maximum potential size, for all practical purposes a steady state, within 100 days.
T	Aquifer transmissivity.	Square feet per day, at well.
TTAT	Accumulated time of travel.	Years, estimated for source area of well.
TTAD	Accumulated distance of travel.	Feet.
TTAV	Instantaneous velocity.	Feet per day (27 for Edwards Aquifer wells).
V	Seepage velocity.	Feet per second.
W	Real-well location.	X, Y location coordinates in meters, used in alluvial-delineation method.
Wi	Image-well location.	X, Y location coordinates in meters, used in alluvial-delineation method.

delineation of groundwater- and surface-water contributing areas. These types include:

- wells screened in a karst aquifer system, most notably the Edwards aquifer,
- wells screened in unconfined hydrogeologic settings where the source area of the well intersects a surface-water body.

For these types of wells, the resultant SWSA includes assessments for both surface water and unconfined groundwater. The surface-water assessment represents the upstream-source area contributing flow to the most downstream river location within the groundwater-capture zone and the groundwater assessment represents the unconfined-source area.

During execution of the delineation component, grid-cell-based methods specifically developed for this purpose are used to estimate the portion of the flownet surface that defines the source area of the well or spring. Computations are made to determine traveltime and resultant areas that contribute flow to the well for specific endtimes. The vertical movement of water to the water table is not approximated, only the horizontal movement. The assumption is that the source area to a well in an unconfined system is that area directly above the flow paths for a specified endtime (2, 5, 10, 20, 50, and 100 years). In a confined system, the source area is that area terminating in the outcrop of the aquifer for similarly specified endtimes. Activities such as well drilling or oil/gas exploration may penetrate or breach a confining unit above a confined aquifer. These wells may be poorly constructed or deteriorated and could allow vertical flow from the land surface through the confining unit into the water-supply aquifer. Therefore, the area directly above flow paths that extend to a 2-, 5-, 10-, 20-, 50-, and 100-year traveltime from the well or spring is included in the source area even if this area is not within the outcrop of the confined aquifer.

The groundwater delineation component uses a drawdown computation for both confined and unconfined aquifers that is based on a modified Theis equation (Cooper and Jacob, 1946):

$$s = \frac{0.183Q}{T} \times \log_{10}\left(\frac{2.25Tt}{r^2 S}\right) \quad (4)$$

where

s is drawdown,
Q is pumping rate,
T is transmissivity,
t is pumping time interval,
S is storage coefficient,

and

r is radius.

Aquifer datasets (table 3) used as input in the delineation component have been specially prepared in such a way that storage coefficient (S) values are present in confined areas, and specific-yield values are present in unconfined areas. Transmissivity (T) is computed from hydraulic conductivity (K) and saturated thickness (STHK). Pumping time (t) is set to 100 days which is assumed sufficient for the cone of depression to reach a steady state. Initially, regional-drawdown computations were made for the aquifer-extent area within an area of interest (AOI) defined by the area within a circle of radius (r) equal to about 4 mi from the well. This AOI placed a limit on the number of cells to be processed within the aquifer extent and was satisfactory for most aquifers; however, for a few aquifers the AOI was too small and source areas up to 100 years could not be delineated, yet, enlarging the fixed radius would result in many more cells than necessary being processed for many aquifers. Eventually, it was recognized that an optimally sized AOI could be created by testing increasing r distances while holding aquifer properties constant. During execution, successive drawdowns (s) are computed at increasing r distances until s is less than (<) 0.1 ft. Next, the radius r equal to the associated distance is used to define the radius AOI and s is computed. Within the AOI, s is subtracted from the regional water-table surface to produce a new water-table surface, which represents the influence of the source well. Next, gradient, direction, and distance are computed between the processing cell and the neighboring cells. Flow length and time of travel are summed along the flow path from each cell to the well, yielding continuous surfaces of total accumulated length and total accumulated traveltime. Next, the maximum gradient between the processing cell and the neighboring cells (or the change in water-surface altitude (ΔH) divided by the travel distance (ΔL)) is recorded as the value for the processing cell. When all cells are processed, pore water or seepage velocity (V) is computed by multiplying the gradient (i) at a grid cell by the hydraulic conductivity (K) divided by the effective porosity (n). Traveltime (t) is computed by dividing the accumulated distance (L) by velocity and multiplying by the reciprocal number of days in 1 year as in

$$i = \frac{\Delta H}{\Delta L},\ V = \frac{K \times i}{n},\ \text{and}\ t = \frac{L}{V} \times \frac{1}{365.25} \quad (5)$$

Source-area polygons CZ2, CZ5, CZ10, CZ20, CZ50, and CZ100 (table 5), which enclose the 2-, 5-, 10-, 20-, 50-, and 100-year traveltimes to the well screen are created from the continuous traveltime dataset. The 100-year polygon (fig. 2) is used to represent the groundwater SWSA source area when assessing susceptibility to all except microbial COCs. The 2-year traveltime is used to assess susceptibility to microbial COCs. If required data are not available, a ½-mi-radius circular polygon CZFIXED is delineated (fig. 2) and centered on the source well to represent the source area for a groundwater SWSA.

Estimating source areas for wells deriving water from the Edwards aquifer is complex and characterized by significant uncertainty owing to its karst nature. Six numerical models have been developed over time and all have limitations inherent in numerical models; that is, they are simplifications of

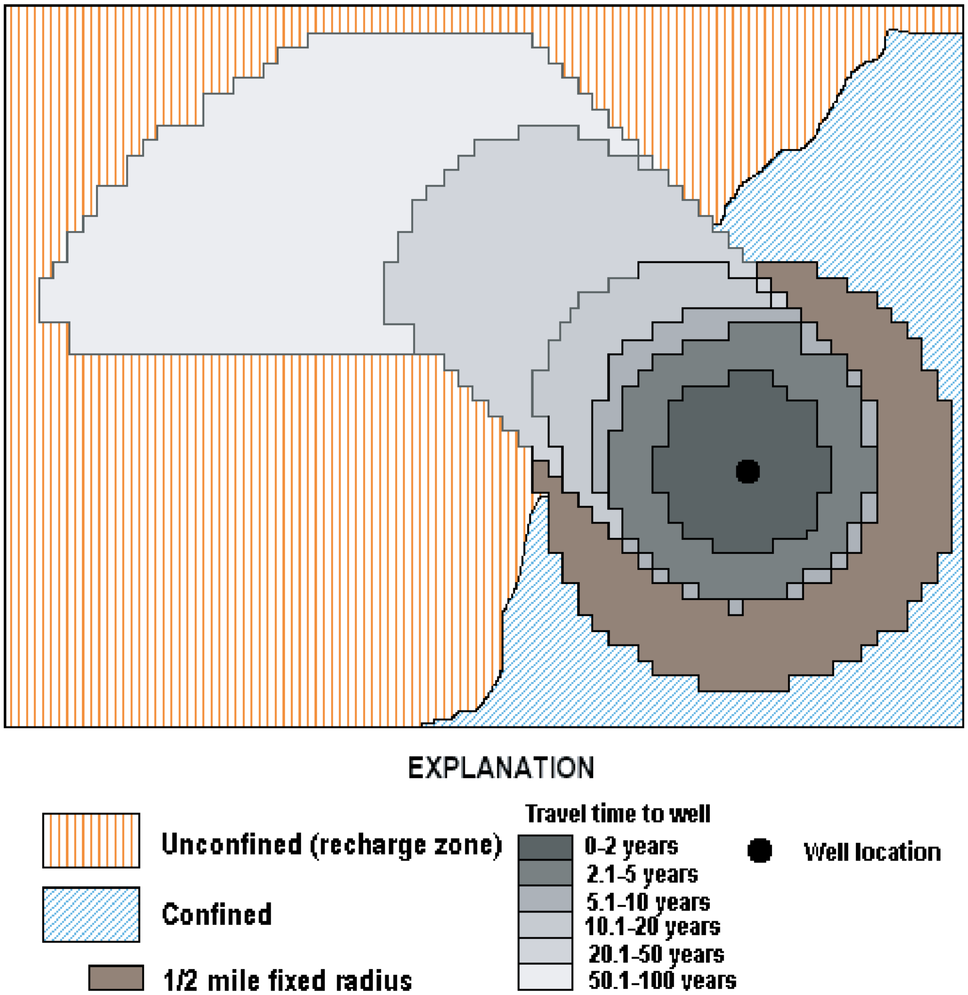


Figure 2. Example of delineated source areas for wells screened in unconfined and confined aquifers.

the real system. All of the models are limited in relation to the quantity and quality of input data, the scale at which the model can be applied, and the assumptions used to develop the model (Lindgren and others, 2009). The surface-watershed source area(s) are delineated at the most downstream end of all streams crossing the unconfined (recharge) area within the source area (fig. 3) of the well delineated, because the flow of groundwater in the Edwards aquifer is closely related to flow of surface water and traveltimes potentially can be very short (Lindgren and others, 2009).

The complex karst hydrology of the Edwards aquifer and the potential for multiple porosities to take effect at various water levels (for example, the intersection of a conduit as water levels increase) introduces additional uncertainty particularly regarding dilution and attenuation potential of the aquifer. Three methods have been used to determine the source area for the wells screened in the Edwards aquifer and all have been minimally satisfactory. The USGS has published groundwater-flow models of the Edwards aquifer (Lindgren and others, 2009). Using output datasets from that model, a grid was created that contained estimated flow directions. In the first of three methods used to delineate the source area for wells screened in the Edwards aquifer, the model grid was used to identify source cells contributing flow to the public-supply well and traveltime was estimated by calculating flow length from each contributing model cell to the well using a literature estimated constant of 27 ft/d average flow velocity in the aquifer

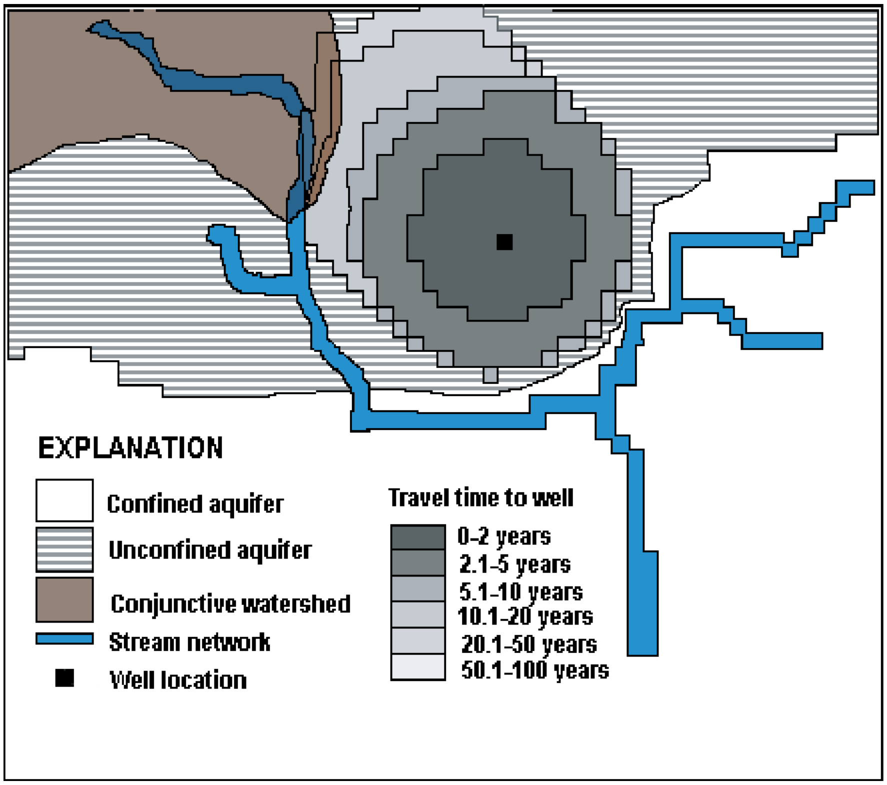


Figure 3. Example of delineated conjunctive-source areas for wells screened in Edwards aquifer.

(E. Baker, U.S. Geological Survey, oral commun., 2003). Conjunctive watersheds then were delineated at the most downstream location(s) where major streams cross the unconfined boundary (fig. 3). A second method, which uses an updated model grid and data, applies the modified Theis method (eq. 4) as is done for wells screened in unconfined aquifers. In a third method, a fixed-radius area is delineated around the well, and conjunctive watersheds are delineated at the most downstream major stream-crossing locations within the fixed-radius area.

Edwards aquifer wells are assessed for susceptibility to contamination using SWAP methods for confined aquifers within the confined part of the aquifer, methods for unconfined aquifers in the unconfined part of the aquifer, and methods for surface water within the source area supplying recharge to the PWS (conjunctive watershed). No surface-water area-of-primary influence component (described later in the report) is applicable, and up to three assessments are combined into a single assessment for the PWS, representing source-water contributions from the various zones.

Conjunctive source-area delineation for wells screened in alluvial aquifers (fig. 4) is complicated by the boundary conditions imposed by the river (a source of water). A technique known as method of images (Ferris and others, 1962) is used to simulate the effects of the river (fig. 5) on the drawdown observed in the discharging well. The river is a constant-head source of water, and its effects on drawdown are simulated using a recharging image well with the recharge rate equal to the rate of the pumping well (real well) but with the opposite (−) sign.

A drawdown surface is produced by adding the discharge and recharge surfaces that result from the pumping and recharging wells. Flow path and time-of-travel datasets then are created as previously described for unconfined and confined aquifers. In alluvial aquifer settings, the capture zone of the well typically includes the stream and there may be appreciable groundwater and surface-water interaction; hence, the SWSA includes a surface-water assessment of the upstream-source area contributing flow to the most downstream point on the stream within the groundwater-source area.

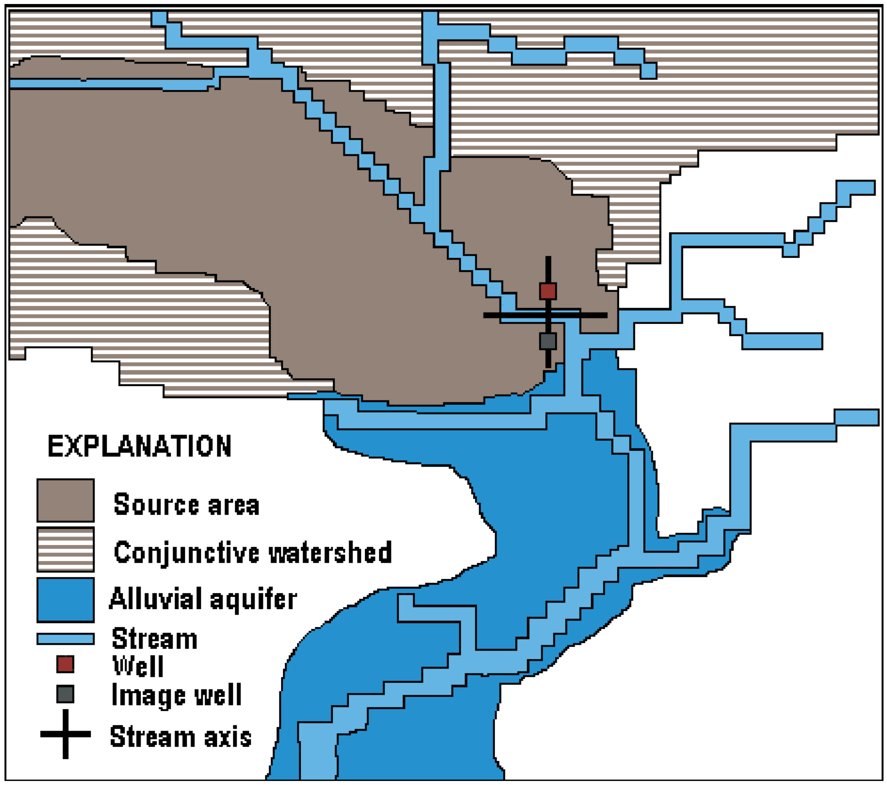


Figure 4. Example of delineated conjunctive-source areas for wells screened in alluvial aquifers.

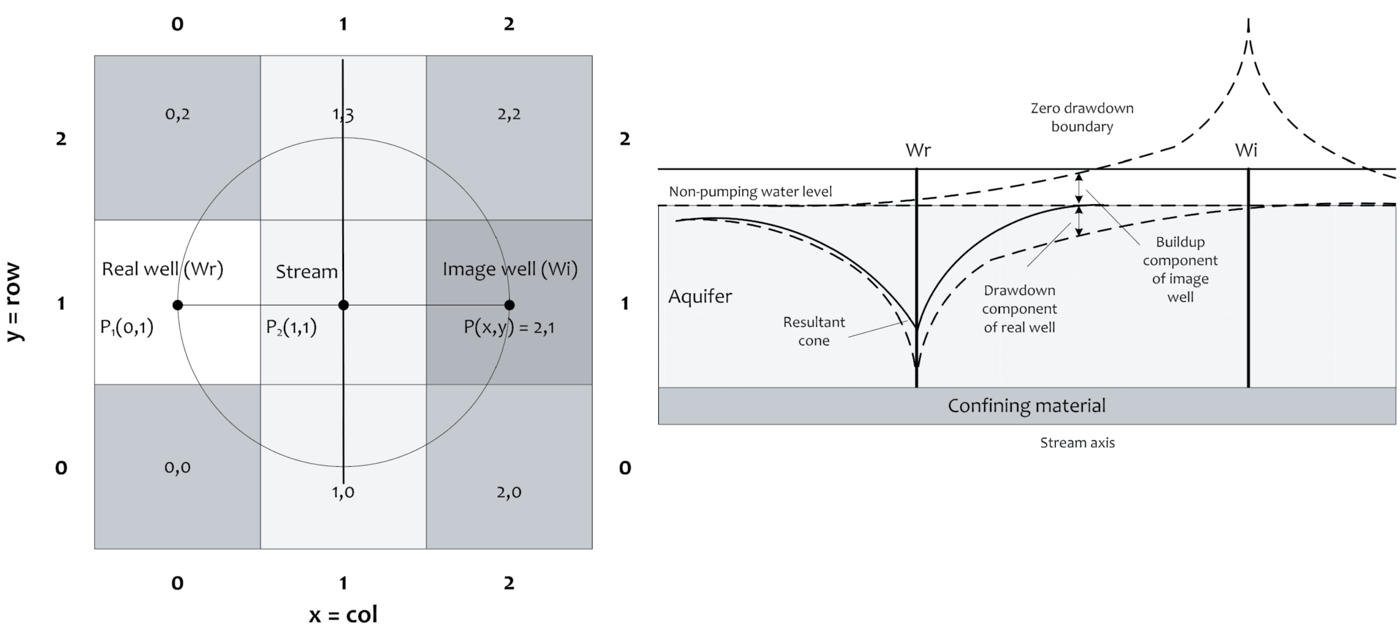


Figure 5. Example of method of images used to delineate conjunctive-source areas for wells screened in alluvial aquifers (modified from Ferris and others, 1962).

Surface-Water Source

The delineation component for surface-water sources is concerned with delineation of source areas (fig. 6) and determination of watershed attributes and indicators of contaminant susceptibility (table 6) for surface-water intakes. Types of source-area watersheds used in SWSAs for surface-water intakes include:

- contributing watershed to a surface-water intake (delineated at the public water-supply reservoir outlet or at the mapped location of a surface-water intake on the stream).
- monitored watersheds (as required)—the contributing area to a water-quality monitoring site on a stream, reservoir, or municipal stormwater site,
- contributing watershed to water-supply reservoirs with normal storage capacity of greater than 1,000 acre-ft, located within the truncated watershed area of a surface-water intake,
- truncated watershed—the area that contributes flow to a surface-water intake excluding contributing watersheds of water-supply reservoirs with normal storage capacity of greater than 1,000 acre-ft,
- area-of-primary influence (API)—the area within 1,000 ft of a reservoir boundary, and, for all streams discharging directly to the reservoir, the area within 1,000 ft of the center of the stream reach within a 2-hour traveltime immediately upstream from the reservoir. For surface-water intakes on streams, the API is the area within 1,000 ft of the stream reach within a 2-hour traveltime immediately upstream from the surface-water intake, and
- multijurisdictional area—a contributing watershed that crosses Texas state boundaries and includes areas that lie in adjacent states or Mexico, such as the Red River and Rio Grande.

Base datasets used in the delineation of surface-water source areas include elevation, flow direction, flow accumulation, and hydrography (streams and reservoirs). The source-area delineation process is a computer resource-intense activity, and the largest watersheds required several hours of computer-processing time; therefore, approximately 600 surface-water intakes were delineated outside of the SWAP-DSS software, although the software is capable of performing the watershed delineation process.

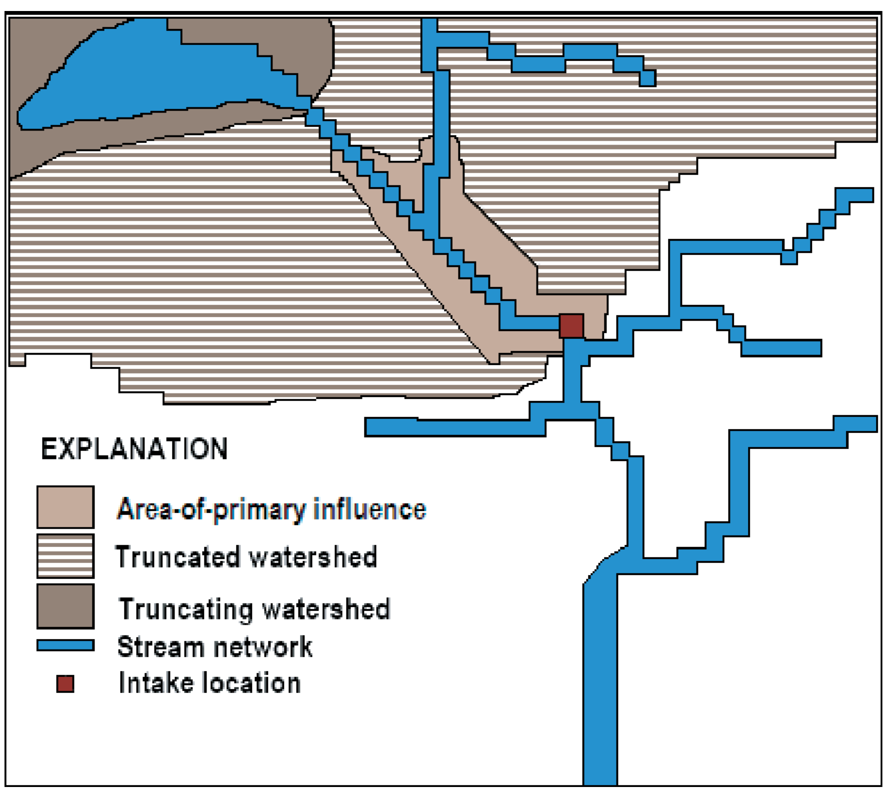


Figure 6. Example of delineated source areas for surface-water intakes.

Table 6. Attributes of watershed, descriptions, and units used to delineate a source area for a surface-water source.

Attribute	Description	Units
APIW	Area of primary influence watershed area.	Square miles.
MCL	Main channel length.	Mile.
MCS	Main channel slope.	Feet per mile.
MJWA	Multijurisdictional watershed area.	Square miles.
TDWA	Contributing watershed area.	Square miles.
TGWA	Truncating watershed area.	Square miles.
TTL	2-hour traveltime stream distance.	Mile.
TWA	Total contributing watershed area.	Square miles.
WRGN	Watersheds region dataset.	Region number (1–11).
WS	Watershed slope.	Percent.

During execution, the SWAP-DSS software delineates all required watersheds for any new surface-water intakes and replaces existing watersheds if higher resolution base datasets are available. Watershed delineations for small reservoirs located within the contributing areas of public-supply reservoirs were delineated as were initial API watersheds. For each of twelve recognized Texas hydrologic regions (Asquith and Slade, 1995), a mean 2-year peak flow velocity value was calculated from selected observations at USGS gaging stations located in each region (R.M. Slade, U.S. Geological Survey, written commun., 1999). These regional mean values are used to estimate the 2-hr travel distance along the main channel. A 1,000-ft buffer is established along the channel, includes the reservoir perimeter, and extends upstream a distance that represents the 2-hour traveltime.

Intrinsic-Susceptibility Component

The intrinsic-susceptibility component is applicable to the unconfined-source area for a well, conjunctive ground-water-plus-surface-water source areas, and the surface-water source area for a surface-water intake on a stream or in a reservoir. The names and sources of spatial databases used to obtain intrinsic and anthropogenic attributes during execution of the intrinsic component of the SWSA are located in appendix 4. Intrinsic-attribute-indicator classification scales (table 7) were developed from observed breaks in the frequency distribution of the statewide indicator using a classification method known as the Jenks Optimization (Jenks, 1967), which is based on maximization of goodness-of-variance fit of the distribution. Indicator ratings for COCs under assessment components (where M is a weighted-average indicator value compared to the statewide indicator scale) are assigned as follows:

- high if M greater than (>) 66th percentile on indicator scale,
- medium if 33rd less than or equal to (≤) M ≤ 66th percentiles on indicator scale,
- low if M < 33rd percentile on indicator scale, or
- none if no known COC sources.

The numerical rating is translated to a categorical rating based on TCEQ ranges.

Groundwater Source

Intrinsic susceptibility of a groundwater source is characterized by a number of unsaturated-zone, soil, and land-surface indicators, which are thought to influence the movement of water from the land surface through soils to the aquifer, and potentially to the source. During execution of the groundwater intrinsic susceptibility component, indicator values, as shown in table 7, are determined for the source area. Next, indicator values are compared against the TCEQ indicator-rating scales and numerical-indicator ratings are assigned for each COC. Numerical-indicator ratings are combined to create a single intrinsic susceptibility rating, ISGW, representing intrinsic susceptibility of the source. The resultant numerical rating is translated to a categorical rating based on TCEQ-established ranges. This component is applicable to the unconfined portion of all aquifers, alluvial aquifers, and the surface-watershed area of a conjunctive delineation.

For unconfined aquifers, a higher leakance-indicator value (LK) indicates that the PWS is more susceptible to contaminant exposure owing to shorter transport time through soils. A high land-surface-slope (SLP) indicator value indicates that the PWS is less susceptible to contaminant exposure owing to lower recharge, assuming shorter residence time and, hence, less infiltration is likely to occur on steeper slopes. A high available-water-capacity (AWC) indicator value indicates that the PWS is more susceptible to contaminant exposure, assuming a higher rate of transmittal of contaminants through soil water. A high high-water-table-depth (HWTD) indicator value indicates that the PWS is less susceptible to contaminant exposure owing to proximity to land surface. A high bulk-density (BLKD) indicator value indicates that the PWS is less susceptible to contaminant exposure owing to reduced transport through soil. A high clay-content (CLAY) indicator value indicates that the PWS is less susceptible to contaminant exposure owing to reduced transport through soil and aquifer materials. A high

Table 7. Attributes of source area soils and slope, descriptions, and units used to compute the intrinsic susceptibility rating of the source-water susceptibility assessment for a groundwater source (ISGW).

[—, not applicable; <, less than; >, greater than]

Attribute or indicator	Description	Unit
AWC	Available water capacity.	Depth-weighted mean inches per inch, < 0.31 = 1, 0.31 to 0.51 = 2, > 0.51 = 3.
BLKD	Soil bulk density.	Depth-weighted mean grams per cubic centimeter, < 0.57 = 3, 0.57 to 0.96 = 2, > 0.96 = 1.
CLAY	Soil clay content.	Depth-weighted mean percent, < 14.62 = 3, 14.62 to 26.30 = 2, > 26.30 = 1.
COC	Contaminant of concern.	—
CZA	Source area.	Square miles.
HWTD	Average seasonal high water-table depth.	Depth-weighted mean feet, < 2.94 = 3, 2.94 to 5.11 = 2, > 5.11 = 1.
ISGW	Intrinsic susceptibility component rating.	1 = Low, 2 = Medium, 3 = High.
KSAT	Saturated hydraulic conductivity.	Assumed equal to soil permeability.
LK	Leakance (soil permeability/soil thickness).	Inches per hour per foot $< 1.16\text{x}10^{-4} = 1$ $1.16\text{x}10^{-4}$ to $2.02\text{x}10^{-4} = 2$ $> 2.02\text{x}10^{-4} = 3$.
OMAT	Soil total organic materials.	Depth-weighted mean percent, < 36.8 = 3, 36.8 to 71.7 = 2, > 71.7 = 1.
PERM	Soil permeability.	Depth-weighted harmonic mean inches per hour.
SLP	Land-surface slope.	Percent, < 2.0 = 3, 2.0 to 6.0 = 2, > 6.0 = 1.

organic-material-content (OMAT) indicator value indicates that the PWS is less susceptible to contaminant exposure owing to potential attenuating effect of organic carbon. ISGW is computed as follows:

$$ISGW = \frac{LK + SLP + AWC + HWTD}{N} \quad \frac{+ BLKD + CLAY + OMAT}{N} \tag{6}$$

where

N is the count of valid indicators.

Intrinsic-susceptibility indicator ratings are assumed to be additive in that each contributes equally to susceptibility. Indivdual intrinsic ratings for each valid indicator are combined into a single average component rating and then translated to a categorical rating as follows:

- high, if an ISGW > 2.33
- medium, if 1.66 ≤ ISGW ≤ 2.33
- low, if an ISGW < 1.66, or
- none, if there are no known COC sources.

Surface-Water Source

Indicator values for the intrinsic-susceptibility component for surface-water sources (table 8) are determined for the source area using spatial-overlay techniques. Indicator values then are compared against the TCEQ indicator-rating scales and each COC is assigned a numerical-indicator rating. Numerical-indicator ratings are combined to create a single intrinsic susceptibility rating, ISSW. The resultant numerical rating is translated to a categorical rating based on TCEQ-established ranges.

To varying degrees, all surface-water supplies are intrinsically susceptible to contaminant exposure because the source area is open to the environment and COCs potentially can reach surface-water intakes in a very short time. Several factors affect the degree of susceptibility. Geology, soils, and vegetative cover affect the amount of runoff and potential attenuation of contaminants in watersheds. Eroded soil may carry (adsorbed on the surface of the sediment particles) organic chemicals and pesticides, nutrients, and heavy metals. The dilution capacity and the contaminant-degradation capability of a stream or reservoir each affect the fate and transport of contaminants. If the watershed is large, has a low slope, and (or) has one or more reservoirs between source areas and the

Table 8. Attributes of watershed or reservoir or indicators of contaminant susceptibility, descriptions, and units used to compute the intrinsic susceptibility component rating of the source-water susceptibility assessment for a surface-water source (ISSW).

[<, less than; >, greater than; —, not applicable; STATSGO, State Soil Geographic Database; KFFACT, soil erodibility]

Attribute or indicator	Description	Unit
ANNRPR	Mean annual runoff/precipitation indicator rating.	Dimensionless, < 0.11 = 1, 0.11 to 0.22 = 2, > 0.22 = 3.
COC	Contaminant of concern.	—
FALRPR	Mean fall season runoff/precipitation indicator rating.	Dimensionless, < 0.016 = 1, 0.016 to 0.028 = 2, > 0.028 = 3.
ISSW	Intrinsic susceptibility rating.	1 = Low, 2 = Medium, 3 = High.
MRRD	Mean reservoir depth to mean annual runoff ratio indicator rating.	Dimensionless, > 0.66 = 1, 0.33 to 0.66 = 2, < 0.33 = 3.
MRRS	Total reservoir storage to mean annual runoff indicator rating.	Dimensionless, < 0.33 = 1, 0.33 to 0.66 = 2, > 0.66 = 3.
RD	Mean reservoir depth (volume/surface area).	Meters (m)
SER	Soil erodibility indicator rating.	STATSGO KFFACT, < 0.2 = 1, 0.2 to 0.4 = 2, > 0.4 = 3.
SPRRPR	Mean spring season runoff/precipitation indicator rating.	Dimensionless, < 0.091 = 1, 0.091 to 0.22 = 2, > 0.22 = 3.
SUMRPR	Mean summer season runoff/precipitation indicator rating.	Dimensionless, < 0.009 = 1, 0.009 to 0.057 = 2, > 0.057 = 3.
TRS	Total reservoir storage.	Cubic meters (m^3)
WINRPR	Mean winter season runoff/precipitation indicator rating.	Dimensionless, < 0.007 = 1, 0.007 to 0.124 = 2, > 0.124 = 3.
WSAR	Watershed slope/area indicator rating.	Feet per mile per square mile ($ft/mi/mi^2$), < 0.51 = 1, 0.51 to 1.38 = 2, > 1.38 = 3.
WSHD	Source watershed area.	Square miles (mi^2)

intake or sampling site, traveltime is longer, dilution would be greater, and instream and intrareservoir processes, including uptake, conversion, and breakdown of the contaminant and volatilization would be greater. These factors can attenuate the COC load as the COC is transported through the watershed. For reservoirs, the trapping of sediment and associated contaminants is an additional factor that reduces the transport of contaminants downstream (Smith and others, 1997; Van Metre and Reutter, 1995). In areas with low rainfall and high soil permeability, little rain actually becomes runoff; hence, relatively small amounts of land-surface contaminants reach the stream in runoff but could be present in baseflow from groundwater at some time in the future.

Three broad indicators—precipitation-runoff relations, soil erodibility, and the effects of reservoirs—were developed to assess the degree of intrinsic susceptibility of a surface-water source to contamination.

Precipitation-Runoff Relations—Generally speaking, more runoff increases suscepbility due to increased potential for contaminants to be washed from the land surface during storm events. Under a separate project task, an analysis of streamflow records was conducted to determine the base period for estimating long-term flow. The results of that analysis indicated that runoff for the period 1961–90 is a better representation of long-term flow than runoff for the 1951–80 period; therefore, the 1961–90 period was used in the computations that produced predictive runoff equations used in SWSA (Lanning-Rush, 2000).

Variability of mean annual streamflow can be attributed partly to seasonal variability in climate over the State. To assess intrinsic susceptibility associated with surface runoff, the ratio of the mean annual runoff to mean annual precipitation, ANNRPR, is computed. A high ANNRPR indicates that the PWS is more susceptible to contaminant exposure owing to increased transport of contaminants. A low ANNRPR indicates that the PWS is less susceptible to contaminant exposure. Precipitation quantity and intensity, as well as the subsequent surface runoff generated, vary by season. To assess intrinsic susceptibility associated with the seasonal variability of surface runoff, indicators based on the ratios of mean seasonal runoff to mean seasonal precipitation—SPRRPR, SUMRPR, FALRPR, and WINRPR—are computed. A high seasonal runoff/precipitation-ratio value indicates that a source is more susceptible to COC exposure owing to increased transport of COCs, particularly pesticides, and other agricultural chemicals applied during that season. A low seasonal runoff/precipitation ratio indicates that the source is less susceptible to contaminant exposure during that season.

Soil Erodibility—The quality of surface-water runoff is affected by soil-forming processes or reactions that occur within the soil zone. Sediment reduces the storage capacities of reservoirs and carries adsorbed organic chemicals and pesticides, nutrients, and heavy metals. The processes of soil erosion and sediment transport by rain and runoff are selective in terms of grain size and weight. In general, the coarser particles settle out of suspension first and the fine particles are transported further downstream. Consequently, suspended sediments tend to contain more of the finer, less dense particles. It follows that an enrichment of any sorbed chemical in eroded sediment would be an important consideration in an assessment of surface-water susceptibility because these fine particles may contain adsorbed chemicals. A soil-erodibility indicator (SER) is used to represent these processes and is computed using KFACTOR, which is the average soil loss in tons per acre for a particular soil, a value obtained from the State Soil Geographic (STATSGO) database (U.S. Department of Agriculture, 1994). In this case, the SER indicator is a measure of the likelihood of soil particles to detach and be transported by rainfall and runoff. Texture is the principal factor affecting KFACTOR, but soil structure, the amount of organic matter, and soil permeability also affect the magnitude of this value. A high SER indicator value indicates that the source is more susceptible to contaminant exposure from soil and soil-adsorbed contaminants. A low SER indicates that the PWS is less susceptible to contaminant exposure from soil-associated contaminants.

Effects of Reservoirs—Studies (Smith and others, 1997; Van Metre and Reutter, 1995) document that reservoirs can integrate and mitigate the variable water quality of their contributing streams. The effectiveness of a reservoir's integrating capacity is a function of the reservoir's storage characteristics. COCs enter a reservoir either as intermittent inflows of runoff from nonpoint sources or as relatively continuous inflows from point sources. Within a reservoir, the processes of adsorption, absorption, volatilization, dispersion, dilution, sedimentation, chemical/biological conversion and degradation, and biological uptake can work together or individually to reduce the concentration of a COC or convert/degrade the COC to a less threatening form. To assess the potential effects of reservoirs within a watershed, the ratio of total reservoir storage in the watershed to its runoff (MRRS) and the ratio of average reservoir depth to runoff (MRRD) are used to represent the processes listed above. There are more than 4,500 reservoirs in Texas with a normal storage capacity ranging from 200 to 5,000 acreft, but only public-supply reservoirs with a normal storage capacity greater than 1,000 acre-ft (about 176) were used to compute the MRRS indicator. A higher MRRS value indicates longer residence times and higher potential for attenuation; hence, the source has lower susceptibility to COC exposure (for example, they are beneficial processes). A lower MRRS value indicates shorter residence times and lower potential for attenuation, indicating higher susceptibility. A high MRRD value indicates that the source is less susceptible to contaminant exposure owing to lower erosive velocities that could resuspend contaminants associated with bottom sediments.

Given sufficient time, dispersion, dilution, sedimentation, chemical/biological conversion and degradation, and biological uptake processes within a stream can work to reduce the concentration of a COC or convert/degrade the COC to a less threatening form. There is less potential for the concentration of a contaminant to be reduced when there is a shorter traveltime between the point where the contaminant enters the stream and the surface-water intake point. Intrinsic susceptibility associated with traveltime is estimated using an indicator based on the ratio of watershed slope to watershed area (WSAR). A high WSAR value represents shorter traveltime across steep slopes and indicates higher relative susceptibility to contaminant exposure; a low WSAR value indicates longer traveltimes across low slopes and lower susceptibility. Intrinsic susceptibility ratings for each COC are computed as follows (see table 8 for explanation of terms):

$$ISSW = \frac{ANNRPR + SPRRPR + SUMRPR}{N} \frac{+ FALRPR + WINRPR + MRRS}{N} \frac{+ MRRD + WSAR + SER}{N} \quad (7)$$

where

N is the count of valid indicators.

Intrinsic ratings for each indicator are combined into a single average component rating, translated to a categorical rating, and assigned as follows:

- high, if an ISSW > 2.33
- medium, if 1.66 ≤ ISSW ≤ 2.33
- low, if an ISSW < 1.66, or
- none, if there are no known COC sources.

Point-Source Susceptibility Component

Groundwater Source

The point-source susceptibility component for groundwater sources determines susceptibility to COC exposure from PSOC. For wells screened in confined aquifers, an important indicator affecting susceptibility is whether or not the PSOC is known to penetrate the confining unit. A second important indicator is whether or not the PSOC is located at a depth below the confining unit or the soils zone. Each PSOC is tested to estimate if the associated COCs could affect a supply well. This component is applicable to all aquifer types; however, attenuation is not applied when properties of the aquifer are not available and cannot be estimated. It is applicable to wells screened in confined aquifers when a penetrating PSOC is present. The TCEQ and its predecessor agencies developed and maintain a number of computerized PSOC databases that provide data for the various categories listed in appendix 5. There are records for more than 1.2 million known PSOC sites in the various databases. Although location information for the majority of these sites is available from the databases, the information was not initially accessible with computer software in a format required for spatial analysis.

Approximately 9,000 PSOCs, which previously had no computerized location information (latitude/longitude), were georeferenced. Location information for these sites was available from a physical review of paper files maintained by the TCEQ. In some cases, the locations of PSOCs may have been identified on photocopies of USGS topographic maps; in other cases, only paper engineering reports, site drawings, or field sketches existed. In still other cases, only street-address information was available in the file. A large amount of work was required to provide accurate location data for PSOCs that could affect contributing source waters to a supply well. Interviews were conducted with TCEQ PSOC program staff to determine data type, attributes, locations, quality, availability, and documentation. For PSOCs requiring location data, files were physically pulled, reviewed, and pertinent information was extracted to allow the PSOC to be located on USGS topographic maps or equivalent. In some cases, out-of-date USGS topographic maps did not show streets where a PSOC could be located by address. Supplemental maps or commercial databases with address/location information were required to locate some PSOCs. Once the location information was obtained, a geographic information system (GIS) database was developed. The database provided a variety of information on the PSOCs including the TCEQ program that collected and managed the PSOC data, the source material for the data, descriptions of data quality, and minimal-accuracy standards (or needs) for PSOC locations. The database was linked to regulated COCs (and COC groups) and Standard Industrial Codes. Additional databases were acquired by TCEQ and reformatted for program use and placed in TCEQ files. Inclusion of this database as well as other TCEQ-program databases resulted in more than 2 million PSOC records searched during the assessment process. The digitizing of PSOC records continues to date (2011), and databases are updated 2 to 3 times per year. Contaminant information (table 9) is associated with each PSOC during the compilation process.

Two techniques were used to associate COCs with a PSOC site. One technique was based on the knowledge that COCs are related to particular PSOC types; for example, each gas station likely will have the COCs benzene, xylene, toluene, lead, methyl-tertiary-butyl-ether etc. This assumption may not have been correct for each gas station; however, time constraints and limited digital data did not allow for a survey of each of the 60,000 gas stations at that time. The second technique was based on known sampling or reporting of COCs at a specific site. Examples included a Superfund site with chromium contamination or an industrial facility that had registered specific COCs with the TCEQ through the waste-registration process. This information was contained in relational databases supporting rapid-query capability. The point-source susceptibility component includes attenuation

Table 9. Examples of the types of potential sources of contamination, contaminants of concern, sources, numbers of sources, summed final contaminant concentrations, and point-source susceptibility ratings for groundwater sources identified in the source area.

[FCC, final contaminant concentration; PSOC, potential sources of contamination, COC, contaminant of concern; PTGW, point-source susceptibility rating for a groundwater source; mg/L, milligrams per liter; LPST, leaking petroleum storage tank; —, not applicable]

PSOC type	COC	Source name	Source count	Summed FCCs for all PSOCs (mg/L)	PTGW
LPST	Benzene	Gas station/ mini-mart	3	0.2	Low.
LPST	Toluene	Gas station/ mini-mart	2	.4	Medium.
LPST	Methyl tertiary-butyl ether	Gas station/ mini-mart	2	.6	High.

methods that output FCCs for each COC associated with all PSOCs occurring in the source area. A dilution attenuation factor (DAF) for each COC is applied to the TCC in order to estimate the final concentration. The DAF is estimated based on a model of physical attenuation (Strassberg, 2003), which utilizes first-order decay equations, a timeof-travel estimate, and selected soil and aquifer attributes (table 10) to simulate the physical processes of sorption, decay, volatilization, advection, dispersion, and dilution that may occur during travel from the COC source to the PWS. This component also assesses susceptibility to PSOC areas—including landfills, known COC plumes, confined animal-feeding operations, and so forth—where the source of COCs is modeled as a two-dimensional area rather than a point.

Depending on the traveltime along the flow path from the PSOC to the source, the environment may act to attenuate the FCC, possibly below the THR level. Attenuation cannot be used when aquifer properties are unknown or when time of travel is not available and cannot be estimated. FCCs from all sources are compared to the THR, and the categorical rating is assigned:

- high, if FCC > THR,
- medium, if one-half THR ≤ FCC ≤ THR,
- low, if FCC < one-half THR, or
- none, if there are no known COC sources.

Table 10. Attributes of aquifer or source-area soils or indicators of contaminant susceptibility, descriptions, and other information used to compute the point-source susceptibility rating of the source-water susceptibility assessment for a groundwater source (PTGW).

[—, not applicable; PSOC, potential sources of contamination; STATSGO, State Soil Geographic Database; TCEQ, Texas Commission on Environmental Quality; COC, contaminant of concern]

Attribute or indicator	Description	Unit	Data source	Variables needed	Default value
AF	Attenuation factor.	Dimensionless.	—	—	—
COC	Contaminant of concern.	—	TCEQ-defined.	—	—
CZA	Source area.	Square miles.	—	—	—
PTGW	Point-source susceptibility.	1 = Low, 2 = Medium, 3 = High	—	—	—
PTYPE	PSOC	Type/subtype.	Various.	—	—
PCNT	PSOC count.	Number.	—	—	—
PPEN	PSOC penetrates confining unit.	1 = True, 0 = False.	—	—	—
DAF	Dilution attenuation factor.	Dimensionless.	—	—	—
FCC	Final contaminant concentration.	Milligrams per liter.	—	—	—
POTS	Aquifer potentiometric surface.	Feet.	Aquifer-potentiometric-surface dataset.	—	—
θ_{ws}	Volumetric water content of vadose-zone soils.	Cubic centimeter of water per cubic centimeter of soil.	STATSGO soils dataset.	—	0.16
θ_{as}	Volumetric air content of vadose-zone soils.	Cubic centimeter of air per cubic centimeter of soil.	STATSGO constant.	—	.21
k_d	Soil-water partition coefficient.	Cubic centimeter of water per gram of soil.	Chemical database (Strassberg, 2003).	—	—
ρ_b	Soil bulk density.	Grams of soil per cubic centimeter of soil.	STATSGO soils dataset.	—	1.67
ρ_s	Soil particle density.	Grams per cubic centimeter.	STATSGO constant.	—	2.65
θ_T	Soil porosity.	Cubic centimeter pore space per cubic centimeter of soil.	Computed.	ρ_b, ρ_s	.65
H'	Henry's law constant.	Dimensionless.	Chemical database (Strassberg, 2003).	—	—
LDF	Lateral dilution factor.	Dimensionless.	Computed.	δ_{gw}, U_{gw}, b_{gw}, I_f, W_s	—
U_{gw}	Darcian velocity.	Centimeters per year.	Velocity dataset.	—	—
δ_{gw}	Groundwater mixing-zone thickness.	Meters.	Computed.	U_{gw}, b_{gw}, I_f, W_s, α_v	—
b_{gw}	Aquifer thickness.	Meters.	Aquifer-thickness dataset.	—	—
α_v	Vertical groundwater dispersivity.	Meters.	Computed.	L_{gw}	—
I_f	Net filtration rate through soil.	Centimeters per year.	Computed.	P	—
P	Mean annual precipitation.	Centimeters per year.	Mean annual precipitation dataset (Lanning-Rush, 2000).	—	—
W_s	Lateral width of affected vadose zone in direction of groundwater.	Meters.	TCEQ-defined.	Variable, based on average base area of PSOC.	—
L_{GW}	PSOC distance to source.	Meters.	Flow-length dataset.	—	—
α_x	Longitudinal dispersivity.	Meters.	Computed.	L_{gw}	—
α_y	Transverse dispersivity.	Meters.	Computed.	L_{gw}	—
α_z	Vertical dispersivity.	Meters.	Computed.	L_{gw}	—
D_g	First order decay constant.	Day^{-1}.	Chemical database (Strassberg, 2003).	—	—
V_{COC}	COC velocity.	Meters per day.	Computed.	V_w, R_i	—
V_w	Groundwater-seepage velocity.	Meters per day.	Computed.	TOT, L_{gw}	—
R_i	Constituent retardation factor.	—	Computed.	k_d, ρ_b, ρ_s	—
TCC	Theoretical contaminant concentration	Milligrams per liter.	Solubility (Strassberg, 2003).	Various.	—
THR	Contaminant threshold value	Milligrams per liter.	TCEQ-defined.	—	—
TOT	Traveltime to source.	Days.	Time-of-travel dataset.	—	—

Surface-Water Source

The point-source-susceptibility component for surface-water sources determines the susceptibility of a surface-water intake to COCs that are associated with permitted discharges within the upstream (truncated) watershed. The component methodology is based on accumulation of mass over the traveltime from the outfall of the point source to the PWS. To estimate the point-source susceptibility of a surface-water intake to the permitted discharge sites, the discharge-sites dataset is overlaid on the truncated watershed to determine the presence of any discharge sites upstream from the PWS. Selected properties are identified (table 11) and stored in database tables.

Next, the TCEQ Texas Pollutant Discharge Elimination System (TXPDES) database is queried to identify permit information such as permitted contaminants and effluent limits of contaminants (pounds per year). The TXPDES permit number is used to relate the contaminant loads to at least one location (the facility outfall closest to the stream channel). During execution, for each permitted COC, the PTSW component uses the contaminant location and contaminant loads in conjunction with a regional average 2-year peak-flow velocity to estimate traveltime from the outfall location to the PWS location. COCs are assumed to degrade at a constant rate over the traveltime and FCCs are estimated by the in-stream decay function:

$$FCC = TCC \times e^{(-kt)} \tag{8}$$

where

- e is 2.71828, the base of natural logarithms.
- k degradation rate, in milligrams per liter per day
- t is time, in days

FCC then is compared to the THR, and the categorical rating for point-source susceptibility (PTSW) is assigned as follows:

- high, if FCC > THR,
- medium, if one-half THR ≤ FCC ≤ THR,
- low, if FCC < one-half THR, or
- none, if there are no known COC sources.

Nonpoint-Source Susceptibility Component

The nonpoint-source susceptibility component is applicable to unconfined-source areas of SWAP aquifers, fixed-radius

Table 11. Attributes of watershed or indicators of contaminant susceptibility, descriptions, and units used to compute the point-source susceptibility rating or the source-water susceptibility assessment for a surface-water source (PTSW).

[—, not applicable; TXPDESID, Texas Pollutant Discharge Elimination System unique identification number]

Attribute or indicator	Description	Unit
ANND	Mean annual discharge.	Cubic feet per second (ft^3/s)
COC	Contaminant of concern.	—
FCC	Final contaminant concentration.	Milligrams per liter (mg/L)
HVEL	Average velocity at median flow, by region.	Feet per second (ft/s)
LOAD	Permitted load (mass).	Liter (L)
MAI	Mean annual inflow volume.	L
MSI	Mean summer inflow volume.	L
PTSW	Point-source susceptibility.	1 = Low, 2 = Medium, 3 = High.
TCC	Theoretical contaminant concentration.	mg/L
TDWA	Truncated watershed source-area.	Square mile (mi^2)
THR	Contaminant threshold value.	—
TPL	Permitted load (mass) of contaminant.	mg
SITES	Outfall locations spatial dataset.	TXPDESID
SUMD	Mean summer discharge.	ft^3/s
STO	Mean annual reservoir storage.	L

(other) source areas, conjunctive surface-watershed areas associated with Edwards or alluvial aquifers, and surface-watershed source areas for surface-water intakes. Nonpoint-source susceptibility is related to presence of COC-producing activities within a source area upstream (Saunders and Maidment, 1996) or upgradient (Thomas and others, 2001) from a PWS, and to hydrologic factors that affect the potential transport of nonpoint-source contaminants over the land surface to streams or through soils to aquifers. Most COCs are manmade organic compounds whose occurrence in the environment is enhanced by human activities and is largely controlled by land use. For example, the occurrence of pesticides in wells is greater in urban and agricultural settings than in rangeland, forest, or other relatively undeveloped areas as demonstrated in a number of studies in Texas (Ulery and Brown, 1994, and Land and Brown, 1996). Human factors that are correlated with the occurrence of contaminants in wells include population density; percentage of urban, agricultural, range, forest, and wetland; agricultural crop acreage; urban- and agricultural-pesticide use; domestic animal densities on agricultural land; presence of oil and gas wells; and road and railroad densities.

For selected COCs, nonpoint-source susceptibility is estimated using results from logistic-regression models Battaglin and others, 2003) that were developed to estimate the probability of contaminant detection above TCEQ-designated THR for COCs using the percentages of selected land-use types and other characteristics of the source area (table 12). Sources of data used to derive values for these susceptibility indicators were obtained from various sources (appendix 4).

Table 12. Attributes of source area or indicators of contaminant susceptibility, descriptions, and units used to compute the nonpoint-source susceptibility rating of the source-water-susceptibility assessment for a groundwater source (NPGW) or a surface-water source (NPSW).

[—, not applicable; COC, contaminant of concern; MRLC, Multi-resolution land characterization; TCEQ, Texas Commission on Environmental Quality]

Attribute or indicator	Description	Unit
AGRP	Agriculture land use.	Percentage of source area.
COC	Contaminant of concern.	—
CZA100	Source area within 100-year traveltime.	Square miles (mi^2)
DIURON_USE	Diuron application rate in source area.	Metric tons per square kilometer.
DLND	Agriculture-drained land.	Percentage of source area.
FCC	Final contaminant concentration.	Milligrams per liter (mg/L)
FORP	Forest land use.	Percentage of source area.
HYDG	Average hydrologic soil group.	Average group number, 1= low, 2 = medium, 3= high.
NPGW,NPSW	Nonpoint-source susceptibility.	Low, medium, high.
NITR	Application rate of fertilizer and manure nitrogen in source area.	Ton per square kilometer (ton/km^2)
NPSM	Nonpoint-source method.	Equation or land use associated.
P	Probability of COC detection above threshold.	0.0 to 1.0
P21	MRLC 21 – low intensity residential land use.	
P31	MRLC 3 – bare rock, sand, gravel land cover.	
P42	MRLC 42 – evergreen forest land cover.	
P51	MRLC 51 – shrub land cover.	Percentage of source area.
P71	MRLC 71 – grasslands/herbaceous land cover.	
P81	MRLC 81 – pasture/hay land cover.	
P82	MRLC 82 – row crops land cover.	
PIPE	Pipeline locations, associated COCs.	Mile (mi)
TCC	Theoretical contaminant concentration.	mg/L
THR	Contaminant threshold value.	mg/L
TRNS	Transportation includes highways and railroads, associated COCs.	mi
URBP	Urban land use.	Percentage of source area
WELL_DENSITY	Density of wells in source area.	$Wells/mi^2$

In order to develop the logistic-regression models, a multiagency water-quality database was assembled, which contained approximately 1.25 million water-quality-sample analyses collected from both surface-water and groundwater sites during more than 20 years. A summary of COC detections was prepared, which included the number of analyses for each COC, the number of detections above the threshold, and other data for quality-assurance purposes. The summary was reviewed and a list of COCs was prepared that contained at least 50 water-quality analyses with detections above the TCEQ-specified THR. This criterion was considered a minimum requirement for a statistically valid equation for the COC. Regression models were not considered valid or not developed under the following conditions.

- When less than 50 sample analyses at groundwater sites for a particular aquifer, or less than 50 sample analyses at surface-water sites for a particular watershed, were available.
- When there were less than 10 percent of groundwater sites for a particular aquifer, or less than 10 percent of surface-water sites for a particular watershed, with analytical data.
- When more than 50 samples total, at more than 32 sites, were available, but the target contaminant was detected at or above the threshold value at less than 15 percent of those sites.
- When more than 50 samples total, at more than 32 sites, were available, and the target contaminant was detected at or above the threshold value at more than 15 percent of those sites, but a statistically significant model still could not be developed using the available independent variables.

When sufficient data were available, logistic-regression models were developed as well as measures of the relative goodness-of-fit of the models. Six regression models were developed for data obtained from groundwater-sampling sites for the following COCs—aluminum, manganese, nitrate, nitrite, nitrate plus nitrite, and sulfate. Sixty-three regression models were developed for data obtained at surface-water sampling sites.

If a model exists for a contaminant, nonpoint-source susceptibility is determined by computing a probability of exceeding a contaminant THR. For example, the variables—quantity of the pesticide Diuron used (*DIURON_USE*), percentage of land-use type (*P21*-low intensity residential), and number of wells per unit area (*WELL_DENSITY*)—were determined to be statistically significant explanatory variables for the equation that was developed to predict susceptibility of a groundwater PWS to contamination by the COC, Diuron. During execution of the assessment, values for these variables are obtained for the source area from GIS databases and substituted into the logistic-regression model to obtain the probability (*p*) that the concentration of Diuron will exceed the THR at the source:

$$p = \frac{e^{-1.81 + 0.98 \bullet DIURON\_USE + 0.127 \bullet P21 + 0.544 \bullet WELL\_DENSITY}}{1 + e^{-1.81 + 0.98 \bullet DIURON\_USE + 0.127 \bullet P21 + 0.544 \bullet WELL\_DENSITY}} \quad (9)$$

where

- *p* is probability of detecting contaminant above the threshold value and
- *e* is 2.71828, the base of natural logarithms.

Next, *p* was compared to the attribute-rating scale, and the nonpoint-source susceptibility rating (NPGW for groundwater or NPSW for surface water) was assigned and converted to a categorical rating for reporting purposes as follows:

- high, if $p > 0.66$.
- medium, if $0.33 \leq p \leq 0.66$.
- low, if $p < 0.33$, or
- none, if there are no known COC sources.

If a logistic regression model did not exist, the nonpoint-source susceptibility rating was based on land-use type within the source area and any land-use-associated COCs. This is a conservative method such that a land-use-associated COC's water-solubility values are used as the TCCs for all land-use-associated COCs. During execution of the nonpoint-source susceptibility component, land-use types, pipelines, and transportation corridors were identified within the source area; then a table was created that contained a TCC value for each land-use or pipeline-and-transportation corridor cell. For groundwater sources, the FCC then was estimated using the same transport/attenuation/dilution model as was used in the PTGW component; however, rather than a PSOC site, each cell of the model was treated as a point source of the COC and attenuated over the traveltime to yield an estimated FCC value at the well and the FCC/THR ratio was computed.

For surface-water sources, daily mass loads were first estimated from the land-use-associated COC TCC value for the source area. Next, mean daily runoff for the source area was obtained by dividing mean annual runoff by the number of days per year and then average daily concentration was obtained by dividing total daily load by total daily runoff. Finally, using estimated traveltimes for overland and channel flow, the first-order decay function was applied, the FCC was computed at the source location, and the FCC/THR ratio was computed. The NPGW or NPSW was assigned as follows based on the FCC/THR ratio:

- high, if ratio > 1,
- medium, if $0.5 \leq$ ratio ≤ 1,
- low, if ratio < 0.5, or
- none, if there are no known COC sources.

These methods operated under the assumption that a COC was always present at the solubility-defined TCC value if the land-use types were present within the source area and that the contaminant is transported and attenuated over time.

Area-of-Primary-Influence Component

The proximity of a surface-water intake to a point-source discharge, a transportation corridor, or a pipeline can be a determining factor in the source water being susceptible to COC exposure during flood events or emergency situations. A relatively short traveltime of a chemical spill to the surface-water intake reduces the ability of a stream to attenuate COC concentrations by dilution or degradation to a less threatening form. To address this possibility, the API susceptibility component was added to the SWAP. The API source area is delineated based on the estimated 2-hour traveltime in the stream channel at a regionally-averaged peak-flow velocity. The API susceptibility component determines density of COC-associated activities within the API-source area upstream of a surface-water intake or reservoir inlet.

The API component assigns a susceptibility rating (APSW) for all COCs associated with activities within the API. These activities are domestic animal population density (ADNS), pipeline density (PDNS), oil well and gas well density (OGWD), highway and railroad density (TDNS), PSOC density (SDNS), and number of permitted effluent-discharge sites (EDNS) (table 13). High densities or counts indicate increased susceptibility to activity-associated contaminants. The final APSW ratings for each COC are assigned the maximum indicator rating among all applicable indicator ratings for each contaminant as follows:

$$APSW = Max[ADNS,PDNS,OGWD,\\ TDNS,EDNS,SDNS] \qquad (10)$$

Next, each numerical rating is assigned a categorical rating as follows:

- high, if APSW > 2.33.
- medium, if $1.66 \leq$ APSW ≤ 2.33.
- low, if APSW < 1.66. or
- none, if there are no known COC sources.

Contaminant-Occurrence Component

During execution, spatial-overlay techniques were used to obtain water-quality sites and associated attributes (table 14) within the source area. Next, using these lists, the contaminant-occurrence component searched two specially prepared databases containing more than 2 million water-quality records for any samples associated with the list of sites in either of the two lists. The first database was selected from the Texas Safe Drinking Water Information System (SDWIS) database (USEPA, 1997b and USEPA, 1998), which contains information about public water systems and any violations of

Table 13. Attributes of watershed or indicators of contaminant susceptibility, descriptions, and units used to compute the area of primary-influence susceptibility rating of the source-water susceptibility assessment for a surface-water source (APSW).

[>, greater than;—, not applicable; PSOC, potential sources of contamination]

Attribute or indicator	Description	Unit
APIW	Area-of-primary influence watershed.	Area, in square miles.
APSW	Area-of-primary influence susceptibility.	1 = Low, 2 = Medium, 3 = High.
ADNS	Domestic animal population density.	Animal count per square mile, 0.1 to 27.25 = 1, 27.25 to 77.74 = 2, > 77.74 = 3.
COC	Contaminant of concern.	—
EDNS	Permitted effluent-discharge sites.	Count, 1 = Low, 2 = Medium, 3 = High.
OGWD	Oil and gas well density.	Well count per square mile, 0.1 to 6.43 = 1, 6.43 to 42.3 = 2, > 42.3 = 3.
PDNS	Pipeline density.	Miles per square mile, 0.1 to 2.0 = 1, 2.0 to 3.0 = 2, > 3.0 = 3.
SDNS	PSOC density.	PSOC count per square mile, 0.01 to 9.4 = 1, 9.4 to 38.4 = 2, > 38.4 = 3.
TDNS	Transportation density includes highways and railroads.	Miles per square mile, 0.1 to 2.0 = 1, 2.0 to 3.0 = 2, > 3.0 = 3.

Table 14. Attributes of source area or indicators of contaminant susceptibility, descriptions, and units used to compute the contaminant occurrence susceptibility rating of the source-water susceptibility assessment for a groundwater source (COGW) or a surface-water source (COSW).

[—, not applicable; <=, less than or equal to]

Attribute	Description	Unit
COC	Contaminant of concern.	—
COGW	Contaminant-occurrence susceptibility for groundwater source.	3 or 0.
COSW	Contaminant-occurrence susceptibility for surface-water source.	3 or 0.
CZ100	Source area within 100-year traveltime of well.	Square miles.
Detected	Contaminant detection above threshold.	True = 1, false = 0.
TDWA	Truncated watershed area.	Square miles.

drinking-water regulations during the period 1990–2010; it is called the compliance-monitoring database. The second database is compiled from three separate databases—the TCEQ Regulatory Activities and Compliance System (TRACS) surface-water quality database (TCEQ, 2003), the Texas Water Development Board's groundwater-quality database (Texas Water Development Board, 2010), and the USGS National Water Information System (NWIS) water-quality database (USGS, 1998); it is called the ambient-monitoring database. During execution of the SWSA, the ambient-monitoring database was checked for COC detections above the THR in water samples from sites within the upstream or upgradient-source area(s) of the surface-water intake or groundwater well. Next, the compliance-monitoring database was checked for COC detections above the THR in treated water actually being delivered to the public. Currently (2011), this component utilizes Web services provided by the USGS to retrieve data from the USGS NWIS database. The component will retrieve data from a Web service developed by the TCEQ when the service becomes available. Use of these Web services reduces overhead associated with storing large databases on each client workstation and ensures that the latest data are being queried. The historical databases are archived and available if the Web services are inaccessible during execution of the component.

An exceedence of the THR in water-quality samples from either database causes the source susceptibility summary rating for the COC to be set to high susceptibility, even if the source is deemed not susceptible to the COC by other SWSA components. The detection of a COC from samples at the source or from sites within the source area weighs heavily in the overall assessment. It indicates that the PWS is likely to experience COC exposure unless other intervening conditions are present; therefore, increased water-quality sampling may be necessary.

If a COC has been detected above the THR at a water-quality site within the source area, then the contaminant occurrence susceptibility rating for a groundwater source (COGW) or for surface-water source (COSW) is assigned as follows.

$$\text{If COC concentration} > \text{THR then COGW} = 3 \text{ and COGW} = \text{high} \quad (11)$$

$$\text{If COC concentration} > \text{THR then COSW} = 3 \text{ and COSW} = \text{high} \quad (12)$$

Source-Susceptibility-Summary Component

The source-susceptibility summary component produces a summary COC susceptibility rating for the source based on the output of all applicable components. For a well screened in a confined aquifer, susceptibility is assessed only for COCs associated with PSOCs known to penetrate the confining unit. These COCs are attenuated, and susceptibility is assigned based on the results of attenuation. For a well screened in an unconfined aquifer, alluvial aquifer, or the Edwards aquifer, or wells classified as other, the well is assumed to be susceptible to all COCs associated with point- and nonpoint-source activities present within the source area of the well, including a surface-water truncated watershed where applicable. Surface-water sources are assumed to be susceptible to all COCs associated with point- and nonpoint-source activities present within the truncated and API watersheds. The source-susceptibility summary rating is assigned the maximum rating computed from the possible combinations of applicable SWSA components. The groundwater identification component susceptibility rating IDGW or the surface-water identification component susceptibility rating IDSW is set equal to 1 (that is, the identification component is applicable and therefore is included in the summary rating) if the well or surface-water intake does not meet the TCEQ-established minimum criteria for well integrity. The inclusion of IDGW or IDSW in the summary rating increases the resultant susceptibility rating slightly to reflect the additional susceptibility based on well or intake integrity. If there are no known point- or nonpoint-contaminant sources, no susceptibility rating is assigned for the contaminant. If the identification component is applicable, then ratings are computed as follows:

$$SSGW = Max\left[\frac{IDGW + ISGW + NPGW}{2}\right] \text{ or } Max\left[\frac{IDGW + ISGW + PTGW}{2}\right] \quad (13)$$

$$SSSW = Max\left[\frac{IDSW + ISSW + NPSW}{2}\right] \text{ or } Max\left[\frac{IDSW + ISSW + PTSW}{2}\right] \text{ or } Max\left[\frac{IDSW + ISSW + APSW}{2}\right] \quad (14)$$

If the identification component is not applicable, then ratings are computed as follows:

$$SSGW = Max\left[\frac{ISGW + PTGW}{2}\right] \text{ or } Max\left[\frac{ISGW + PTGW}{2}\right] \quad (15)$$

$$SSSW = Max\left[\frac{ISSW + NPSW}{2}\right] \text{ or } Max\left[\frac{ISSW + PTSW}{2}\right] \text{ or } Max\left[\frac{ISSW + APSW}{2}\right] \quad (16)$$

Under the contaminant occurrence component, if a COC is identified as having been detected in at least one sample and the detected value was at or above the THR, then the summary rating is set to 3.0. Each numerical rating is assigned a categorical rating as follows:

- high, if SSGW or SSSW > 2.33,
- medium, if 1.66 ≤ SSGW or SSSW ≤ 2.33,
- low, if SSGW or SSSW < 1.66, or
- none, if there are no known COC sources.

System-Susceptibility Summary Component

The system-susceptibility summary component determines the susceptibility to COC exposure for a PWS with multiple wells or intakes; the summary value is based on ratings for all assessed water-supply sources. During execution of this component, each active water-supply source belonging to the PWS is assessed. A PWS may contain a number of water-supply sources that are temporarily or permanently inactive, but only active or emergency sources are included in a system assessment.

System susceptibility summary (SSC) ratings are prepared for all COCs to which a water-supply source has been determined to be susceptible. SSC ratings are weighted according to the capacity of each source, if available, as a percentage of the source's contribution to the total PWS capacity (table 15). The SSC rating for each COC is determined as the maximum value computed from among all applicable components for all active water-supply sources.

If a capacity value for each water-supply source is available, then the summary rating is a weighted average of the ratings computed for each water-supply source. If a capacity value for each source is not available, then a weight of 1 is used for each source missing a capacity value. Weighted-susceptibility ratings are computed for each SWSA component for each COC as follows

$$IDSC = \frac{\sum_{i=1}^{n} IDGW_i w_i \text{ or } IDSW_i w_i}{\sum_{i=1}^{n} w_i} \quad (17)$$

$$ISSC = \frac{\sum_{i=1}^{n} ISGW_i w_i \text{ or } ISSW_i w_i}{\sum_{i=1}^{n} w_i} \quad (18)$$

$$PTSC = \frac{\sum_{i=1}^{n} PTGW_i w_i \text{ or } PTSW_i w_i}{\sum_{i=1}^{n} w_i} \quad (19)$$

$$NPSC = \frac{\sum_{i=1}^{n} NPGW_i w_i \text{ or } NPSW_i w_i}{\sum_{i=1}^{n} w_i} \quad (20)$$

$$APSC = \frac{\sum_{i=1}^{n} APSW_i w_i}{\sum_{i=1}^{n} w_i} \quad (21)$$

$$COSC = High \text{ if } COGW_i \text{ or } COSW_i = 3 \quad (22)$$

where

n is the number of sources,
i is the individual intake or well, and
w is the source-capacity weight.

Table 15. Example of a capacity weight table for a public water system having two water-supply sources.

Source identification	Capacity (gallons per minute)	Weight
1	1,100	0.3548
2	2,000	.6452
Total	3,100	1.0

Next, the component susceptibility ratings are combined into an SSC rating for each COC. If the IDSC is 1, then ratings are computed for each COC as follows:

$$SSC = Max\left[\frac{IDSC + ISSC + NPSC}{2}\right] \text{ or } Max\left[\frac{IDSC + ISSC + PTSC}{2}\right] \text{ or } Max\left[\frac{IDSC + ISSC + APSC}{2}\right] \quad (23)$$

If IDSC is 0, then ratings are computed for each COC as follows:

$$SSC = Max\left[\frac{ISSC + NPSC}{2}\right] \text{ or } Max\left[\frac{ISSC + PTSC}{2}\right] \text{ or } Max\left[\frac{ISSC + APSC}{2}\right] \quad (24)$$

SSC ratings for each COC are reassigned based on numerical ratings as follows:

- high, if SSC > 2.33,
- medium, if 1.66 ≤ SSC ≤ 2.33.
- low, if SSC < 1.66, or
- none, if there are no known COC sources.

Source and system-susceptibility-summary components determine susceptibility for contaminant groups based on results of detailed source or system summaries. Contaminant-group-susceptibility summary results are reported to the public and are critical to achieving the goals of the SWAP program. Contaminant groups as defined by the TCEQ are listed in table 16.

Table 16. Contaminant group names, descriptions, and representative contaminants used in the source-water susceptibility assessment.

Contaminant group	Description	Representative contaminant
Regulated	All regulated contaminants.	1, 1, 1-Trichloroethane.
All	All susceptible contaminants.	1, 2, 4-Trichlorobenzene.
DBP	Disinfection byproduct contaminants.	Bromomethane.
Inorganic	Inorganic contaminants.	Aluminum.
Microbial	Microbial organisms.	*Cryptosporidium* Parvum.
Physical	Regulated physical properties.	pH.
Radiochemical	Radiochemical contaminants.	Radium-226.
SOC	Synthetic organic contaminants.	Aldicarb.
VOC	Volatile organic contaminants.	Acetone.

A contaminant-group-susceptibility rating (GSSC) can be computed for a water-supply source, for groups of sources, or for a system. An entry point is defined as a particular group of water-supply sources, and a GSSC rating can be computed for an entry point as well. For each source, or entry point, or for the system within each contaminant group, the GSSC is set to the maximum of the COC's SSC ratings for all contaminants in the contaminant group as follows:

$$GSSC = Max\left[COC_{SSC1} \text{ or } COC_{SSC2} \ldots COC_{SSCn}\right] \quad (25)$$

where subscripts SSC1, SSC2, and SSCn represent the different COCs.

Next, GSSC ratings for each contaminant group are reassigned based on numerical ratings as follows:

- high, if GSSC > 2.33,
- medium, if 1.66 ≤ GSSC ≤ 2.33,
- low, if GSSC < 1.66, or
- none, if there are no known COC sources.

SWAP-DSS Software

The execution of a SWSA is a technically complex activity involving specialized computer databases and computer programs. SWSAs are dependent on spatial-analysis techniques consisting of one or more lower level computer algorithms, some of which are available in commercial software but require specialized knowledge in order to combine them into usable software components capable of performing the various higher level analyses of SWSA. Commercial GIS software also utilizes complex data structures and formats requiring specialized expertise to design and use.

On execution of SWAP-DSS, through either interactive or batch-process methods, each water-supply source's susceptibility is assessed, and source assessment results are weighted by source capacity, combined into a single SWSA for the public water system (PWS), and stored on computer disk. During 2003, more than 6,000 reports (representing over 18,000 individual source-water-susceptibility assessments) were printed and mailed to PWS operators (appendix 6). The length of the single largest report, for a system comprising over 190 wells, was over 900 pages. The ability to produce detailed or summary reports on individual water-supply sources, and detailed or summary SWSA reports for the PWS by individual COC or COC group, is thought to be a unique capability of Source Water Assessment Program-Decision Support System (SWAP-DSS).

Decision rules utilized in SWSA are encoded so that they may be applied to data derived from spatial analysis, as well as to data from internal and external TCEQ databases. In some cases, these rules are simple Boolean (true or false) tests; in other cases, a series of complex queries involving several relational-database files are executed, and the results analyzed. An easy-to-use software system for staff charged with assessing public water supplies enables the staff to make assessments without special training or experience in using GIS technology. Owing to the volume and variety of required data and the level of technical detail of SWSA, the TCEQ staff executing SWSA require access to software documentation and help files, metadata describing the databases, references to external publications, and background or other supplementary information. A most-efficient system places these data files and a reference at the fingertips of the analyst in the form of context-sensitive help or in easily accessible files.

Software that supports batch or unattended execution enables staff to complete the large number of SWSAs within tight time constraints; however, an interactive version is preferred in cases where a single assessment (a new PWS or a new water source added to an existing PWS) or a small number of assessments are to be completed, a review of a completed assessment is needed, or printing of a SWSA report is required.

SWSA software specifically designed to meet the above requirements did not exist; therefore, a major work element of the SWAP project involved the design and creation of the SWAP-DSS software. The work had to be completed in time to execute assessments for all Texas PWS by EPA-mandated deadlines, and, with the scope of the effort, with the uncertanties about many elements of the program and the constraints outlined previously, completing all tasks on time turned out to be a significant challenge. Major tasks included designing, creating, and testing of the following database and software.

- SWAP database—based on a data model defining overall database structure, data tables, data elements within tables, and data-entity relations, including a data dictionary.
- Software used to retrieve records from, to manage, and to interact with the various spatial and non-spatial databases required for SWSA components.
- Software modules used to display input and (or) output datasets, and allow user interaction with these datasets; for example, for dataset-coverage display, database query, hardcopy output, or report generation.
- Software modules to execute spatial-analysis methods such as delineation of contributing areas; calculation or determination of indicator variables, characteristics, threshold values, and so forth, based on the results of the analysis; or other analysis as required for the various SWSA components.
- Software modules to apply appropriate decision rules for determining susceptibility within the various SWSA components and determining overall susceptibility once the required components have been completed.

- Software modules to provide help or documentation for the SWSA.
- Software modules to manage asynchronous execution of SWSA.

To the extent possible, the development approach conformed to the general principles of information engineering in that joint requirements planning (JRP) sessions and joint application design (JAD) sessions for requirements definition and systems design were held at a series of review points during the development process.

The specific approach for SWSA software was development of a custom Microsoft Windows application using Environmental Systems Research Institute (ESRI) ArcObjects software components and Visual Studio (V 6.0 and .Net V 3–10) licensed from Microsoft Corporation for object and user-interface programming. Microsoft ActiveX Data Object components are used to support creation, retrieval, update, or delete (CRUD) of Microsoft Access format database files. The executable program and databases reside on desktop computers running the Windows operating system. The software license for ESRI ArcObjects is obtained on the local desktop or over standard network protocols.

SWAP-DSS V1 implements a three-tier component object framework: User Services, Business Services, and Database Services tiers, which were developed as separate, but integrated, components consisting of software functions supporting use and reuse in a flexible manner. SWAPDSS V2 incorporates a model-view-controller (MVC) component object framework, which serves to separate software functions even further. This version is based on Microsoft.Net technologies, which support a full object inheritance model. This greatly simplified the development process and reduced the number of lines of source code by approximately one-half. SWAP-DSS V1 and V2 satisfy the functional requirements outlined above and allow for maintenance, upgrade, and enhancement of software. SWAP-DSS integrates the extensive database information and maps required for SWSA on the analyst's desktop by use of ESRI ArcObjects software components. Additionally, SWAP-DSS provides fast tabular-data search and spatial-analysis capabilities, without incurring the typical overhead penalties associated with running scripts against ESRI desktop Arc/Info or ArcMap applications. To the extent possible, SWAP-DSS is compatible with anticipated software and hardware directions at the TCEQ. Conversion of SWAP databases to databases residing outside of the SWAP program is facilitated using Structured Query Language (SQL) and Extensible Markup Language (XML). Access to SWAP databases is provided to other applications using SQL and XML. SWAP-DSS is capable of producing reports in a number of output formats including Microsoft Word, Portable Document Format (PDF), and XML.

Support for interactive-assessment sessions is provided through the graphical user interface (GUI). The user is able to execute a single interactive assessment or multiple interactive assessments sequentially. This capability is based on Multiple Document Interface (MDI) (Microsoft Corporation, 1999) framework. An example of the MDI, as implemented in commercial software, is the ability of users of Microsoft Office applications to open and simultaneously work on multiple documents. This design was closely coordinated with TCEQ staff and conforms to TCEQ requirements. In SWAP-DSS V1, the number of interactive assessments open is limited only by the hardware on which the SWSA software is run; however, only one assessment may be executed at a time (no batch processing). In SWAP-DSS V2, owing to limitations of using ESRI ArcObjects software components in an asynchronous process, one interactive assessment may be open for review and an unlimited number of assessment tasks may be processed sequentially in a queue. Batch execution is provided through a user-interface queue (represented by a table) called the batch processor. The assessment task, represented by an entry in the table, represents the assessment task waiting in the queue or executing. The assessment task status is continuously updated and displayed while the task is executing is under way and the user is notified when processing is complete.

Appendix 7 shows selected SWAP-DSS software objects created to represent various objects from the SWSA problem domain such as assessment components, utility objects that make up the user interface, objects that display and interact with GIS datasets and maps, database query objects, custom views of various data objects, and reports or summaries objects produced for a particular public water-supply susceptibility assessment. The SWSA data produced are stored in SWAP program workspaces, allowing users to open previously completed assessments for review.

The SWAP-DSS software is one of a number of software systems used by TCEQ staff. Discussions within a data-management workgroup focused on how the SWSA software interacts with other TCEQ software and with TCEQ corporate-database structures. Every effort was made to ensure that the SWSA software is compatible with existing systems at the TCEQ, primSarily through SQL-compliant access to databases and by enabling the user to "cut and paste" the various maps, tables, reports, etc., produced with SWSA software to other desktop applications. Presented here are summaries of the tasks completed during software design and development.

Acquire and Install Application Development, Professional GIS, and Database Software and Licenses—Under this task, software used to design, develop, and run SWSA software were obtained. Commercial software and licenses for Microsoft Windows operating systems, Visual Studio, and Arc/Info 8.x software, including ArcObjects, were obtained from commercial sources. Additional development tools or components such as help/documentation tools or graphics/statistics modules were obtained as needed. The software was set up and tested, and logs of the procedures followed were kept and provided to the TCEQ upon request.

Database-Requirements Analysis—Requirements analysis focused on database and database software needs for SWAP components. A series of JRP sessions were held in order to identify relevant processes and data entities within the

SWAP program. A high-level object-data model was developed describing SWSA database requirements for various components. The model included a data dictionary, which defines data elements used in SWSA, data elements associated with GIS coverages, and descriptions with data-flow diagrams for software modules. Standardized database field names, directory-tree structures, and specifications for geographic standards, such as scale and projection, to be used throughout SWSA databases were created according to exchange standards for GIS and relational data tables described in the Spatial Data Transfer Standard (U.S. Geological Survey, 1999). The data dictionary was used to create database-table templates, which were populated with SWSA data as data became available. The tables were named according to conventions specified in the data dictionary, and the tables were located in specified directory-tree structures. A GIS database structure that complies with established principles of GIS-database design also was developed under this task. The tiling structure of the database was defined and documented under this task, and content standards for digital geospatial metadata (Federal Geographic Data Committee, 1998) were created for all GIS coverages. Unique identifier numbers for relating water supplies to their contributing-recharge- or watershed-areas were established. Standard projection files, coordinate-control points (.tic files), standard boundary coordinates, and so forth, were developed under this task. Supplemental cartography (key files, symbol sets, and so forth) developed specifically for SWSA also were prepared.

Design and Develop Software for Public Water-Supply Assessment Components—Software classes, methods, and events used to support SWSA of groundwater supplies were designed and developed from specifications outlined in the detailed work plans. Subtasks included documenting, testing, and debugging of code. JAD sessions were held as necessary in order to accomplish this task.

Design and Develop Graphical User Interface—The GUI can be thought of as the glue that binds together the various assessment components, databases, GIS coverages, business rules, and documentation into a cohesive application. A primary goal of this development task was to provide the analyst with an easy to use yet powerful environment in which to execute susceptibility assessments. Several tasks were accomplished with the creation of the GUI. First, standard software functions such as menus including file, edit, copy/paste, view, etc. were created and added to the GUI. Next, graphic elements such as tabs, data controls, status bars, scroll bars, data grids, and other elements were added to the GUI. Finally, underlying code was developed to respond to software-, user-, or system-initiated events or messages that initiate the opening of files or databases, loading/unloading software components, obtaining licenses, printing reports, saving files or databases, modifying the graphic display, and other actions. In the appendixes, two versions of the SWAP-DSS GUI are shown as screen captures: appendix 8*A* shows SWAP-DSS V1, based on an MDI framework using Visual Basic Versions 5 and 6; and appendix 8*B* shows SWAP-DSS V2, based on an SDI framework, using Visual Basic.Net Versions 3–9+. SWAP-DSS V1 supports opening several documents at once, similar to other Windows desktop software. SWAP-DSS V2 supports the opening of a single assessment for interactive viewing and an unlimited number of assessments running sequentially in an asynchronous batch processor. SWAP-DSS capabilities for batch SWSA (asynchronous processing) are fully integrated into the application through a task manager. The software could be easily modified to run from a system command line, rather than the GUI with user-supplied parameters such as an input file name of water supplies to be assessed, an output file name, and so forth.

Quality-Assurance Plan—To the extent possible, the software-development process followed established software-programming principles as well as additional requirements of the TCEQ. During development, all software modules were tested to determine proper function and their proper interaction with other software modules. Software developed was tested and submitted for internal and (or) external peer review as required. All programs were written with sufficient embedded comments in order to fully document the thought process behind the programming. At a minimum, each computer program contains the following elements:

- name of program,
- author,
- purpose,
- date created,
- calls, routines, or arguments within program or script.
- type of program and version.
- date modified and
- specific-system dependencies.

Maintenance/Enhancements and Support Requirements—It was anticipated that software and databases developed will be fully compatible with the future TCEQ computing environment and that maintenance of software and databases will be no more than will be required for other areas of the TCEQ. Because of the close collaboration of TCEQ and USGS staff on this program, TCEQ staff is familiar with the software and database structures developed and is capable of maintaining and enhancing SWAP-DSS.

Summary

The TCEQ and the USGS have worked in cooperation for more than 14 years to develop and implement the Texas Source Water Assessment Program (SWAP). During the project, extensive databases were created to represent more than 100 data themes, providing a legacy for continued TCEQ activities, and serving as core databases for many

Texas programs both internal and external to the TCEQ. The SWAP-DSS computer software developed incorporates the source-water-susceptibility assessment (SWSA) approach and methods and provides a useful tool for assessing public water-system susceptibility to exposure to contaminants of concern. To date (2011), no other State is known to have developed a more complete or comprehensive program. The approach, methods, and software are works in progress flexible enough to enable enhancements or modifications to support evolution of the SWAP.

On execution of SWAP-DSS, through either interactive or batch-process methods, each water-supply source's susceptibility is assessed, and source assessment results are weighted by source capacity, combined into a single SWSA for the public water system (PWS), and stored on computer disk. During 2003, more than 6,000 reports (representing over 18,000 individual source-water-susceptibility assessments) were printed and mailed to PWS operators. The length of the single largest report, for a system comprising over 190 wells, was over 900 pages. The ability to produce detailed or summary reports on individual water-supply sources, and detailed or summary SWSA reports for the PWS by individual COC or COC group, is thought to be a unique capability of Source Water Assessment Program-Decision Support System (SWAP-DSS).

In 2004, the TCEQ began a rotating schedule when approximately one-third of PWSs statewide were assessed at least annually and more frequently if required by protection-program activities. The TCEQ and the USGS cooperative agreement ended in 2011 with the TCEQ assuming full responsibility for all tasks.

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Appendixes 1–8

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
	Disinfection byproducts group	
BROMOCHLOROMETHANE	Water treatment disinfection byproducts.	0.08 mg/L
BROMODICHLOROMETHANE		0.08 mg/L
BROMOFORM		0.08 mg/L
BROMOMETHANE		0.08 mg/L
CHLOROFORM		0.12 mg/L
TOTAL TRIHALOMETHANE		0.08 mg/L
DIBROMOCHLOROMETHANE		0.08 mg/L
	Inorganic compounds group	
ALUMINUM	Naturally occurs through mineralization process. Anthropogenic sources include air emission from petroleum, electronic and metal plating/fabrication processes.	0.2 mg/L
ANTIMONY	Petroleum refineries, fire-retardants, ceramics, and electronics-production wastes.	0.006 mg/L
ARSENIC	Naturally occurs through mineralization process. Anthropogenic sources include industrial electronics production and runoff from orchards.	0.01 mg/L
ASBESTOS	Naturally occurs through mineralization process. Anthropogenic sources include deterioration of asbestos cement in water mains.	7 microfibers per liter
BARIUM	Naturally occurs through mineralization process. Anthropogenic sources include discharge of drilling fluid waste, motor vehicle waste-disposal wells, and metal refineries.	2 mg/L
BERYLLIUM	Metal refineries, coal-burning factories and electrical, aerospace and defense industries	0.004 mg/L
BICARBONATE	Natural product of photosynthesis. Many anthropogenic sources.	1,000 mg/L
BORON	Naturally occurs through mineralization process and volcanic activity. Anthropogenic sources include industrial air emissions, fertilizer/herbicide applications, and industrial and municipal wastes.	2.45 mg/L
BROMIDE	Agricultural soil and structural fumigant uses to control pests	50 mg/L
CADMIUM	Naturally occurs through mineralization process and volcanic activity. Anthropogenic sources include corrosion of galvanized pipes, discharge from metal refineries, and runoff from waste batteries and paints.	0.005 mg/L
CALCIUM	Naturally occurs through mineralization process.	1,000 mg/L
CARBONATE	Naturally occurs through mineralization process.	1,000 mg/L
CHLORIDE	Naturally occurs through mineralization process and volcanic activity. Anthropogenic sources include discharge from storage tanks cement/concrete factories, chemical/petroleum processing, and motor vehicle waste-disposal wells.	300 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
CHROMIUM	Naturally occurs through mineralization process. Anthropogenic sources include discharge from steel fabrication/finishing and pulp mills.	0.1 mg/L
COPPER	Naturally occurs through mineralization process. Anthropogenic sources include household pluming and industrial processing and fabrication and runoff from industrial and motor vehicle waste-disposal wells.	1 mg/L
CYANIDE	Metal refineries, plastic, and fertilizer factories.	0.2 mg/L
FLUORIDE	Naturally occurs through mineralization process. Anthropogenic sources include water additives and discharge from fertilizer and aluminum factories.	4.0 mg/L
HYDROGEN SULFIDE	Natural product of decaying organic matter. Anthropogenic sources include agricultural disinfectants and decomposition in sewer or septic systems.	0.05 mg/L
IRON	Naturally occurs through mineralization process. Anthropogenic sources include discharge from steel fabrication/finishing.	0.3 mg/L
LEAD	Naturally occurs through mineralization process. Anthropogenic sources include household plumbing industrial processing and fabrication and runoff from industrial and motor vehicle waste-disposal wells.	0.015 mg/L
MAGNESIUM	Naturally occurs through mineralization process. Anthropogenic sources include discharge from steel fabrication/finishing.	1,000 mg/L
MANGANESE	Naturally occurs through mineralization process	0.05 mg/L
MERCURY	Naturally occurs through mineralization process. Anthropogenic sources include discharge from fabrication/finishing factories and runoff from industrial waste-disposal wells and agricultural lands.	0.002 mg/L
NICKEL	Naturally occurs through mineralization process. Anthropogenic sources include discharge from steel fabrication/finishing.	0.25 mg/L
NITRATE	Naturally occurs through mineralization process. Anthropogenic sources include leaching from septic tanks and fertilizer use.	10 mg/L
NITRATE+NITRITE		10.0 mg/L
NITRITE		1.0 mg/L
PERCHLORATE	Naturally present in environment. Anthropogenic sources include fertilizer refineries, chemical factories, and aerospace and defense industries.	0.004 mg/L
SELENIUM	Naturally present in environment. Anthropogenic sources include chemical/petroleum refineries, and discharge from mines, pulp mills, and industrial waste-disposal wells.	0.05 mg/L
SILVER	Naturally occurs through mineralization process. Anthropogenic sources include medical waste disposal and discharge from mineral mines.	0.1 mg/L
SODIUM	Naturally present in environment. Anthropogenic sources include transportation corridors.	1,000 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
SULFATE	Naturally present in environment. Anthropogenic sources include agricultural range/grazing lands, and decomposition in sewer or septic systems and chemical/petroleum processing.	300 mg/L
TDS	—	1,000 mg/L
THALLIUM	Metal refineries, medical-waste disposal, industrial electronics, and leaching from ore-processing sites	0.002 mg/L
ZINC	Naturally occurring through mineralization process. Anthropogenic sources include petroleum, electronics and metal fabrication/finishing, and industries.	5.0 mg/L
Microbial organisms group		
CRYPTOSPORIDIUM PARVUM	Human and animal waste.	1 oocyst
ESCHERICHIA COLI[1]		CFU/100 mL
FECAL VIRUSES[1]		CFU/100 mL
GIARDIA LAMBLIA[1]		CFU/100 mL
TOTAL COLIFORM		CFU/100 mL
Physical properties group		
ALKALINITY	—	—
HARDNESS	—	—
P-ALKALINITY	—	—
pH	—	6.5–8.5
SPECIFIC CONDUCTANCE	—	—
Radiochemicals group		
GROSS ALPHA	Decay of natural minerals that are radioactive and may emit forms of radiation. Anthropogenic sources include commercial nuclear and research reactors and government weapons-production plants.	15 pCi/L
GROSS BETA		50 pCi/L
RADIUM-226		5.0 pCi/L
RADIUM-228		5.0 pCi/L
RADON		0.5 pCi/L
STRONTIUM-89		0.5 pCi/L
STRONTIUM-90		0.5 pCi/L
TOTAL ALPHA EMIT RADIUM		5 pCi/L
TRITIUM		1 pCi/L
URANIUM		0.001 pCi/L
Synthetic organic compounds group		
2,4,5-T	Residue of discontinued herbicide used to defoliate broad-leafed plants.	0.12 mg/L
2,3,7,8-TCDD	Chemical factories, waste incinerators, and other combustions.	0.0001 mg/L
2,4,5-TP	Residue of discontinued herbicide.	0.0005 mg/L
2,4-D	Runoff from herbicide used on row crops.	0.005 mg/L
3-HYDROXYCARBOFURAN	Runoff from insecticide used to fumigate rice and alfalfa.	0.0005 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
ACENAPHTHENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.75 mg/L
ACENAPHTHYLENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.75 mg/L
ALACHLOR	Runoff/leaching from herbicide used on row crops.	0.002 mg/L
ALDICARB	Runoff from, and byproducts of, a systemic insecticide, acaricide, and nematicide used to control various pests.	0.0005 mg/L
ALDICARB SULFONE		0.0005 mg/L
ALDICARB SULFOXIDE		0.0005 mg/L
ALDRIN	Residue of banned insecticide used to control insects on corn, cotton, and citrus crops, and as a wood preservative for termite control.	0.0000054 mg/L
ANTHRACENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	3.65 mg/L
AROCLOR	Runoff from landfills and discharge of waste Polychlorinated biphenyl chemicals.	0.0005 mg/L
ATRAZINE	Runoff from use on row crops.	0.0002 mg/L
BENTAZON	Runoff from herbicide.	0.01 mg/L
BENZO[A]ANTHRACENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.00013 mg/L
BENZO(A)PYRENE	Leaching from linings of water-storage tanks and distribution lines.	0.0002 mg/L
BENZO[B]FLUORANTHENE	Emission-emitting factories, waste incinerators, and other combustion facilities.	0.00013 mg/L
BENZO[G,H,I]PERYLENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.365 mg/L
BENZO[K]FLUORANTHENE	Emission-emitting factories, waste incinerators, and other combustion facilities.	0.0013 mg/L
BROMACIL	Runoff/leaching from herbicide used for brush control on non-cropland areas.	1.2 mg/L
BUTACHLOR	Runoff/leaching from herbicide used for grass and certain broad-leaved weeds in rice control.	0.0002 mg/L
BUTYL BENZYL PHTHALATE	Rubber and plastic factories, leaching from landfills.	2.45 mg/L
CARBARYL	Runoff/leaching from insecticides used for home gardens; commercial, agricultural, and forestry; and rangeland protection.	1.2 mg/L
CARBOFURAN	Runoff/leaching of soil fumigant used on rice and alfalfa.	0.0005 mg/L
CHLORDANE	Residue of discontinued termiticide.	0.001 mg/L
CHLORDANE (ALPHA-CHLORDANE)	Byproduct of chlordane.	0.0002 mg/L
CHLORDANE (GAMMA-CHLORDANE)	Byproduct of chlordane.	0.0002 mg/L
CHLORDANE (TRANS-NONACHLOR)	Byproduct of chlordane.	0.0002 mg/L
CHRYSENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.013 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
CYANAZINE	Runoff/leaching from herbicide used for grass and certain broad-leaved weeds.	0.00011 mg/L
DALAPON	Runoff/leaching from herbicide used on rights of way.	0.01 mg/L
DCPA DI-ACID DEGRADATE	Residue of Dacthal (DCPA) used as an herbicide for urban, household, and agricultural applications.	0.001 mg/L
DCPA MONO-ACID DEGRADATE	Residue of Dacthal (DCPA) used as an herbicide for urban, household, and agricultural applications.	0.001 mg/L
DDE	Component of DDT, a discontinued synthetic pesticide.	0.00027 mg/L
DI-2-ETHYLHEXYL ADIPATE	Industrial chemical factories.	0.0021 mg/L
DI-2-ETHYLHEXYL PHTHALATE	Rubber and chemical factories.	0.0021 mg/L
DIAZINON	Leaching and runoff of insecticide for urban, household, and agricultural applications.	0.011 mg/L
DIBENZ[A,H]ANTHRACENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.00002 mg/L
DIBROMOCHLOROPROPANE	Residue of discontinued pesticide used to control worms that cause damage to crops and other plants.	0.001 mg/L
DICAMBA	Runoff/leaching from herbicide used to control weeds in grain crops and highlands.	0.0365 mg/L
DIELDRIN	Residue of discontinued insecticide used to control insects on corn, cotton, and citrus crops, and as a wood preservative for termite control.	0.0000057 mg/L
DIETHYL PHTHALATE	Discharge from rubber and plastic factories and leaching from landfills.	10.0 mg/L
DIMETHYL PHTHALATE	Chemicals, plastics, aerospace and defense industries, and runoff/leaching from landfills.	10.0 mg/L
DI-N-BUTYL PHTHALATE	Rubber and plastic factories and leaching from landfills.	1.2 mg/L
DINOSEB	Runoff/leaching from herbicide use.	0.001 mg/L
DIQUAT	Runoff/leaching from herbicide use.	0.02 mg/L
DISULFOTON	Residue of discontinued insecticide.	0.00049 mg/L
DIURON	Runoff/leaching from herbicide used to control a wide variety of broadleaf and grassy weeds.	0.0245 mg/L
ENDOTHALL	Runoff/leaching from herbicide.	0.1 mg/L
ENDRIN	Residue of discontinued insecticide.	0.0002 mg/L
EPTC	Runoff/leaching from herbicide.	0.305 mg/L
ETHYLENE DIBROMIDE	Petroleum refineries.	0.00005 mg/L
FLUORENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.49 mg/L
FONOFOS	Residue from discontinued organophosphate agricultural insecticide.	0.0245 mg/L
GLYPHOSATE	Runoff/leaching from herbicide use.	0.7 mg/L
HEPTACHLOR	Residue of discontinued termiticide.	0.0002 mg/L
HEPTACHLOR EPOXIDE	Residue of discontinued termiticide (breakdown of heptachlor).	0.0002 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
HEXACHLOROBENZENE	Metal refineries and agricultural chemical factories.	0.0002 mg/L
INDENO[1,2,3,CD]PYRENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.00065 mg/L
HEXACHLORO-CYCLOPENTADIENE	Industrial chemical factories.	0.0012 mg/L
LAMBAST	Runoff/leaching from herbicide used for grass and certain broad-leaved weeds in rice control.	0.00005 mg/L
LINDANE	Runoff/leaching from insecticide used on cattle, lumber, gardens.	0.0002 mg/L
LINURON	Runoff/leaching from restricted use herbicide used to control broadleaf grassy weeds on crop and non-crop sites.	0.001 mg/L
METHIOCARB	Runoff/leaching from pesticide used as a bird repellent, insecticide, and molluscicide.	0.005 mg/L
METHOMYL	Runoff/leaching from a broad-spectrum insecticide used as an acaricide to control ticks and spiders.	0.305 mg/L
METHOXYCHLOR	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, and livestock.	0.0002 mg/L
METOLACHLOR	Runoff/leaching from restricted-use herbicide used to control broadleaf and grassy weeds on crop sites.	1.85 mg/L
METRIBUZIN	Runoff/leaching from herbicide used to control broadleaf and grassy weeds on vegetable crop, field, and turf-grass sites.	0.305 mg/L
MOLINATE	Runoff/leaching from herbicide used to control broadleaf and grassy weeds in rice and other crops.	0.0245 mg/L
OXAMYL	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes.	0.005 mg/L
PCBs	Runoff from landfills; discharge of waste chemicals.	0.0002 mg/L
PENTACHLOROPHENOL	Wood preserving factories.	0.00102 mg/L
PHENANTHRENE	Chemical industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.365 mg/L
PICLORAM	Runoff/leaching from herbicide used as a general woody-plant control.	0.005 mg/L
PROMETON	Runoff/leaching from herbicide used to control broadleaf and grassy weeds.	0.185 mg/L
PROPACHLOR	Runoff/leaching from herbicide used to control broadleaf and grassy weeds, generally to sorghum crops.	0.0002 mg/L
PROPAZINE	Runoff/leaching from general-use herbicide used to control broadleaf and grassy weeds.	0.0021 mg/L
PYRENE	Discharge from chemical and research industry that produces dyes, plastics, pesticides, explosives, and (or) pharmaceuticals.	0.365 mg/L
HEXAHYDRO-1,3,5-TRINITRO-1,3,5-TRIAZINE (RDX)	Residue from commonly used military explosive.	0.001 mg/L
SIMAZINE	Runoff/leaching from selective triazine herbicide used to control broadleaf and annual grasses.	0.0002 mg/L
TERBACIL	Runoff/leaching from general-use herbicide used to control broadleaf and grassy weeds.	0.002 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
TERBUFOS	Runoff from an organophosphate insecticide and nematicide used on corn, sugar beets. and grain sorghum.	0.0004 mg/L
TOXAPHENE	Runoff/leaching from insecticide used on cotton and cattle.	0.003 mg/L
TRIAZINES	Runoff/leaching from nonselective herbicide used to control broadleaf, perennial. and annual grasses.	0.0000001 mg/L
TRIFLURALIN	Runoff/leaching from selective, preemergent dinitroaniline herbicide used to control broadleaf and annual grasses.	0.0012 mg/L
ALACHLOR ESA	Residue byproduct of herbicide Alachlor.	0.001 mg/L
ALACHLOR OA	Residue byproduct of herbicide Alachlor.	0.002 mg/L
DIMETHOATE	Runoff/leaching from systemic and contact insecticide used to control mites and various other insects.	0.0007 mg/L
METOLACHLOR ESA	Residue byproduct of herbicide Metolachlor.	0.004 mg/L
METOLACHLOR OA	Residue byproduct of herbicide Metolachlor.	0.002 mg/L
Volatile organic compounds group		
1,1,1,2-TETRACHLOROETHANE	Textile-finishing factories.	0.0035 mg/L
1,1,1-TRICHLOROETHANE	Metal-degreasing sites and other factories.	0.0005 mg/L
1,1,2,2-TETRACHLOROETHANE	Naturally present in environment. Anthropogenic sources include synthesizing for use in chemical processing.	0.00046 mg/L
1,1,2-TRICHLOROETHANE	Industrial chemical factories.	0.0005 mg/L
1,1-DICHLOROETHANE	Rubber, plastic, and chemical industries; leaching from landfills.	1.2 mg/L
1,1-DICHLOROETHYLENE	Industrial chemical factories.	0.0005 mg/L
1,1-DICHLOROPROPENE	Industrial chemical factories.	0.00091 mg/L
1,2,3-TRICHLOROBENZENE	Industrial chemical factories.	0.0365 mg/L
1,2,3-TRICHLOROPROPANE	Fabrication/finishing and cleaning/degreasing factories and runoff/leaching from industrial waste-disposal sites.	0.000013 mg/L
1,2,4-TRICHLOROBENZENE	Textile-finishing factories.	0.0005 mg/L
1,2,4-TRIMETHYLBENZENE	Petroleum and coal refineries.	0.6 mg/L
1,2-DICHLOROETHANE	Industrial chemical factories.	0.0005 mg/L
1,2-DICHLOROPROPANE	Industrial chemical factories.	0.0005 mg/L
1,2-DIPHENYLHYDRAZINE	Residue from industries that use benzene to make various fabric dyes and discharge from medical industries that produce medicines.	0.00011 mg/L
1,3,5-TRIMETHYLBENZENE	Industrial solvent and electronics-production wastes.	0.001 mg/L
1,3-DICHLOROBENZENE	Runoff/leaching from insecticide and fungicide on crops and space deodorizers, and discharge from plastic, dyes, and pharmaceutical industries.	0.001 mg/L
1,3-DICHLOROPROPANE	Runoff/leaching from preplant fumigant and nematicide.	0.001 mg/L
1,3-DICHLOROPROPENE	Runoff/leaching from insecticide used on food and feed crops.	0.00091 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
2,2-DICHLOROPROPANE	Residue from use of insecticide and fungicide on crops and space deodorizers, and discharge from plastic, dyes, and pharmaceutical industries.	0.0013 mg/L
2,4,6-TRICHLOROPHENOL	Residue from use of herbicide and fungicide on crops.	0.0083 mg/L
2,4-DICHLOROPHENOL	Residue from use of herbicide.	0.0365 mg/L
2,4-DINITROPHENOL	Scientific, chemical, and wood preservative industries.	0.0245 mg/L
2,4-DINITROTOLUENE	Chemical industry that produce plastics, foam, and (or) explosives.	0.00013 mg/L
2,6-DINITROTOLUENE	Chemical industry that produce plastics, foam, and (or) explosives.	0.00013 mg/L
2-CHLOROTOLUENE	Residue from use of insecticide and fungicide on crops and space deodorizers, and discharge from plastic, dyes, and pharmaceutical industries.	0.001 mg/L
2-HEXANONE	Emission from chemical/petroleum refineries, and discharge from coal mines, oil shale processing, and pulp mills.	0.75 mg/L
2-METHYLPHENOL	Naturally present in environment. Anthropogenic sources include synthesizing for use in chemical, fabric dye, and household cleaner industries.	0.6 mg/L
4-CHLOROTOLUENE	Chemical industry.	0.245 mg/L
4-ISOPROPYLTOLUENE	Petroleum and crude oil refineries.	1.2 mg/L
4-METHYL-2-PENTANONE (MIBK)	Fabrication/finishing factories and runoff from industrial waste-disposal wells.	1.0 mg/L
ACETOCHLOR	Runoff/leaching from pesticides used in preemergent applications.	0.002 mg/L
ACETONE	Fabrication/finishing factories and runoff from industrial waste-disposal wells.	11.0 mg/L
ACRYLONITRILE	Rubber and plastic factories; leaching from landfills.	0.00017 mg/L
DIBROMOMETHANE	Fabrication/finishing factories and runoff from industrial waste-disposal wells.	0.012 mg/L
DICHLORO-DIFLUOROMETHANE	Emission from aerosol and older vehicle air conditioning leaks.	2.445 mg/L
DICHLOROMETHANE	Drug and chemical factories.	0.0005 mg/L
ETHYL METHACRYLATE	Base material for coatings and adhesives used in resins, solvents, adhesives, and dental products.	1.1 mg/L
ETHYLBENZENE	Petrochemical factories.	0.0005 mg/L
BENZENE	Petrochemical factories and leaching from gasoline-storage tanks and landfills.	0.0005 mg/L
BROMOBENZENE	Chemical plants and other industrial activities.	0.245 mg/L
CARBON DISULFIDE	Runoff/leaching from fumigation of grains and fruit; production of cellophane film.	1.2 mg/L
CARBON TETRACHLORIDE	Chemical plants and other industrial activities.	0.0005 mg/L
CHLOROBENZENE	Chemical and agricultural chemical factories.	0.0001 mg/L
CHLOROETHANE	Emission from aerosol and older vehicle air conditioning leaks.	4.9 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
CHLOROMETHANE	Naturally present in environment. Anthropogenic sources include synthesizing for use in chemicals.	0.007 mg/L
CIS-1,2-DICHLOROETHYLENE	Industrial chemical factories.	0.0005 mg/L
CIS-1,3-DICHLOROPROPENE	Runoff/leaching from pesticides used as a preplanting fumigant and nematicide.	0.00017 mg/L
HEXACHLOROBUTADIENE	Runoff/leaching from pesticide application.	0.001 mg/L
METHYL IODIDE (IODOMETHANE)	Naturally occurring at rice plantations in small amounts. Anthropogenic sources include runoff/leaching from herbicide/fungicide, insecticide, nematicide, and soil disinfectant.	0.017 mg/L
ISOPROPYLBENZENE	Petrochemical factories and crude oil refineries.	0.001 mg/L
M + P XYLENE	Petrochemical factories and leaching from gasoline-storage tanks and landfills.	0.001 mg/L
METHYL ETHYL KETONE	Industrial chemical factories.	7.5 mg/L
METHYL METHACRYLATE	Rubber and plastic factories; leaching from landfills.	17 mg/L
METHYL-TERT-BUTYL ETHER	Petrochemical factories and leaching from gasoline storage tanks and landfills.	0.12 mg/L
MONOCHLOROBENZENE	Component of DDT, a discontinued synthetic pesticide.	0.0005 mg/L
M-XYLENE	Petrochemical factories and leaching from gasoline-storage tanks and landfills.	0.001 mg/L
NAPHTHALENE	Emissions from petroleum and coal refineries.	0.245 mg/L
N-BUTYLBENZENE	Rubber and plastic factories; leaching from landfills.	0.05 mg/L
NITROBENZENE	Chemical and fragrance industries.	0.006 mg/L
N-PROPYLBENZENE	Petrochemical factories.	0.49 mg/L
ORGANOTINS	Rubber, plastic and chemical industries and runoff/leaching from agricultural fungicides and building-material landfills.	0.0001 mg/L
ORTHO-1,2-DICHLOROBENZENE	Industrial chemical factories.	0.0005 mg/L
O-XYLENE	Petrochemical factories and leaching from gasoline storage tanks and landfills.	0.0005 mg/L
PARA-1,4-DICHLOROBENZENE	Industrial-chemical factories.	0.0005 mg/L
P-XYLENE	Petrochemical factories and leaching from gasoline storage tanks and landfills.	0.001 mg/L
S-BUTYLBENZENE	Industrial chemical factories.	0.49 mg/L
STYRENE	Rubber and plastic factories; leachate from landfills.	0.0005 mg/L
T-BUTYLBENZENE	Industrial chemical factories.	0.49 mg/L
TETRACHLOROETHYLENE	Industrial chemical factories and dry cleaners.	0.0005 mg/L
TETRAHYDROFURAN	Industrial chemical factories.	0.012 mg/L
TOLUENE	Petrochemical factories and leaching from gasoline storage tanks and landfills.	0.0005 mg/L
TRANS-1,2-DICHLOROETHYLENE	Industrial chemical factories.	0.0005 mg/L
TRANS-1,3-DICHLOROPROPENE	Industrial chemical factories.	0.0091 mg/L
TRICHLOROETHYLENE	Metal-degreasing sites.	0.0005 mg/L

Appendix 1. Names of contaminants of concern, common uses or sources, and threshold values used in source-water susceptibility assessments.—Continued

[COC, contaminants of concern; mg/L, milligrams per liter; —, not applicable; CFU/100 mL, colony-forming units per hundred milliliters; pCi/L, picocurie per liter]

Name of COC	Common use or source	Threshold value
TRICHLORO-FLUOROMETHANE	Emissions from older vehicle air conditioning leaks.	3.65 mg/L
VINYL ACETATE	Industrial chemical factories.	12 mg/L
VINYL CHLORIDE	Leaching from polyvinyl chloride pipe; discharge from plastic factories.	0.001 mg/L
XYLENES (TOTAL)	Petrochemical factories and leaching from gasoline storage tanks and landfills.	0.001 mg/L
1,3-DINITROBENZENE	Residues from chemical and research industries that produce and use explosives.	0.0009 mg/L
2,2,4,4,5,5-HEXABROMOBIPHENYL (HBB)	Used as flame retardants such as home electrical appliances and laptop cabinets.	0.0007 mg/L
2,2,4,4,5,5-HEXABROMODIPHENYL ETHER (BDE-153)	Brominated flame retardants used as flame-retardant products such as building products, home electrical appliances, airplanes, foams, and laptop cabinets.	0.0008 mg/L
2,2,4,4,5-PENTABROMODIPHENYL ETHER (BDE-99)	Brominated flame retardants used as flame-retardant products such as building products, home electrical appliances, airplanes, foams, and laptop cabinets.	0.0009 mg/L
2,2,4,4,6-PENTABROMODIPHENYL ETHER (BDE-100)	Brominated flame retardants used as flame-retardant products such as building products, home electrical appliances, airplanes, foams, and laptop cabinets.	0.0005 mg/L
2,2,4,4-TETRABROMODIPHENYL ETHER (BDE-47)	Brominated flame retardants used as flame-retardant products such as building products, home electrical appliances, airplanes, foams, and laptop cabinets.	0.0003 mg/L
2,4,6-TRINITROTOLUENE	Residue from commonly used military explosive.	0.0008 mg/L
ACETOCHLOR ETHANE SULFONIC ACID (ESA)	Residue byproduct from herbicide used in preemergent applications.	0.001 mg/L
ACETOCHLOR OXANILIC ACID (OA)	Residue byproduct from herbicide used in preemergent applications.	0.002 mg/L
N-NITROSO-DIETHYLAMINE (NDEA)	Chemical and industry and residue of legacy production of rocket fuel.	0.000005 mg/L
N-NITROSO-DIMETHYLAMINE (NDMA)	Chemical and research industry and residue of legacy production of rocket fuel. Water treatment disinfection byproducts.	0.000002 mg/L
N-NITROSODI-N-BUTYLAMINE (NDBA)	Water treatment disinfection byproducts.	0.000004 mg/L
N-NITROSODI-N-PROPYLAMINE (NDPA)	Water treatment disinfection byproducts.	0.000007 mg/L
N-NITROSO-METHYLETHYLAMINE (NMEA)	Rubber, plastic, and leather-tanning industries, and pesticide and food processing. Water treatment disinfection byproducts.	0.000003 mg/L
N-NITROSO-PYRROLIDINE (NPYR)	Nitrosamines found in cured meat and beer.	0.000002 mg/L

[1] All microbial COC susceptibility ratings are set to the susceptibility rating of total coliform.

Appendix 2. Aquifers used in groundwater source susceptibility assessments.

[SWAP, source water assessment program; —, not applicable; BFZ, Balcones fault zone]

Unique identifier (aquifer code) in SWAP[1]	SWAP aquifer name	Datasets completed	Comments
1	Hueco–Mesilla Bolson	9	
2	West Texas Bolsons	9	
3	Pecos Valley	9	
4	Seymour	9	
5	Brazos River Alluvium	3	Extent, top, base only.
6	Blaine	9	
7	Blossom	9	
8	Bone Spring–Victorio Peak	—	Unable to construct base.
9	Capitan Reef Complex	3	Extent, top, base only.
10	Carrizo–Wilcox	—	Subdivided into 46, 47, 48, and 49.
11	Edwards North BFZ	3	Extent, top, base only. Aquifer dividing line is Colorado River in Travis County.
12	Edwards–Trinity (High Plains)	9	
13	Edwards–Trinity Plateau	9	
14	Ellenburger–San Saba	9	
15	Gulf Coast	—	Subdivided into 31, 32, and 33.
16	Hickory	9	
17	Igneous	9	
18	Marathon	—	Unable to construct base.
19	Marble Falls	7	
20	Nacatoch	9	
21	Ogallala	9	
22	Other	—	Unknown aquifer.
23	Rita Blanca	9	
24	Queen City	9	
25	Rustler	3	Extent, top, base only.
26	Dockum	9	
27	Sparta	9	
28	Trinity	—	Subdivided into 36, 37, 38, 39, 40, 41, and 45.
29	Woodbine	9	
30	Lipan	9	
31	Chicot	9	
32	Evangeline	9	

Appendix 2. Aquifers used in groundwater source susceptibility assessments.—Continued

[SWAP, source water assessment program; —, not applicable; BFZ, Balcones fault zone]

Unique identifier (aquifer code) in SWAP[1]	SWAP aquifer name	Datasets completed	Comments
33	Jasper	9	
34	Jackson Group[2]	9	Includes Whitsett, Manning, Welborn, and Caddell Formations of the Jackson Group
35	Yegua[2]	9	
36	Trinity Upper[3]	9	Includes the Upper Member of the Glen Rose Formation of the Trinity Group.
37	Trinity Middle[3]	9	Includes the Lower Member of the Glen Rose Formation, Hensel Sand/Bexar Shale, and Cow Creek Limestone of the Trinity Group.
38	Trinity Lower[3]	9	Includes the Sycamore Sand/Sligo and Hosston Formations of the Trinity Group
39	Paluxy[4]	9	Paluxy Formation of the Trinity Group
40	Twin Mountain–Travis Peak[4]	9	Twin Mountains/Travis Peak Formations of the Trinity Group
41	Antlers[4]	9	Antlers Formation of the Trinity Group
42	Cypress	—	Includes the Queen City Sand, Recklaw Formation, Carrizo Sand of the Claiborne Group, and the Wilcox Group. Locally in Camp, Franklin, Morris, and Titus Counties these units are hydrologically connected and called the Cypress aquifer. The SWAP project was a regional study and ultimately the local naming convention was not used but is included for completeness.
43	Edwards South BFZ	3	Extent, top, base only. Aquifer dividing line is the Colorado River in Travis County.
44	Alluvial (about 50)	3	Extent, top, base only.
45	Glen Rose[4]	9	Glen Rose Formation of the Trinity Group (North of the Colorado River).
46	Carrizo[5]	9	Carrizo Sand of the Claiborne Group
47	Wilcox[5]	9	Winter Garden area.
48	Simsboro[5]	9	Simsboro Formation of the Wilcox Group (Colorado River to Trinity River).
49	Wilcox	9	North and east of the Trinity River to Sabine uplift.
50	Edwards	9	Barton Springs segment (northern area of Edwards South BFZ).

[1] Historically, 9 major and 20 minor aquifers have been recognized in Texas (Ashworth and Hopkins, 1995, George and others, 2011). The aquifers have been segmented into 450 aquifer codes (Rein and Hopkins, 2008), each having unique geologic, hydrogeologic, and water-quality characteristics. The aquifer codes were developed to support multiple uses including public drinking water but the 29 major and minor aquifers did not provide sufficient detail for SWAP purposes. Data requirements for 450 aquifers were beyond the scope of this work therefore agreement was reached between the various stakeholders, including representatives of Texas Commission on Environmental Quality, Texas Water Development Board, and U.S. Geological Survey, on a list of 50 aquifers for which sufficient data might be available. A literature review then was conducted in order to determine status and availability of reports and maps describing these aquifers. Source materials were acquired and digitized, and selected aquifer datasets were published (Houston and others, 2003a–2003f and Strom and others, 2003a–2003c).

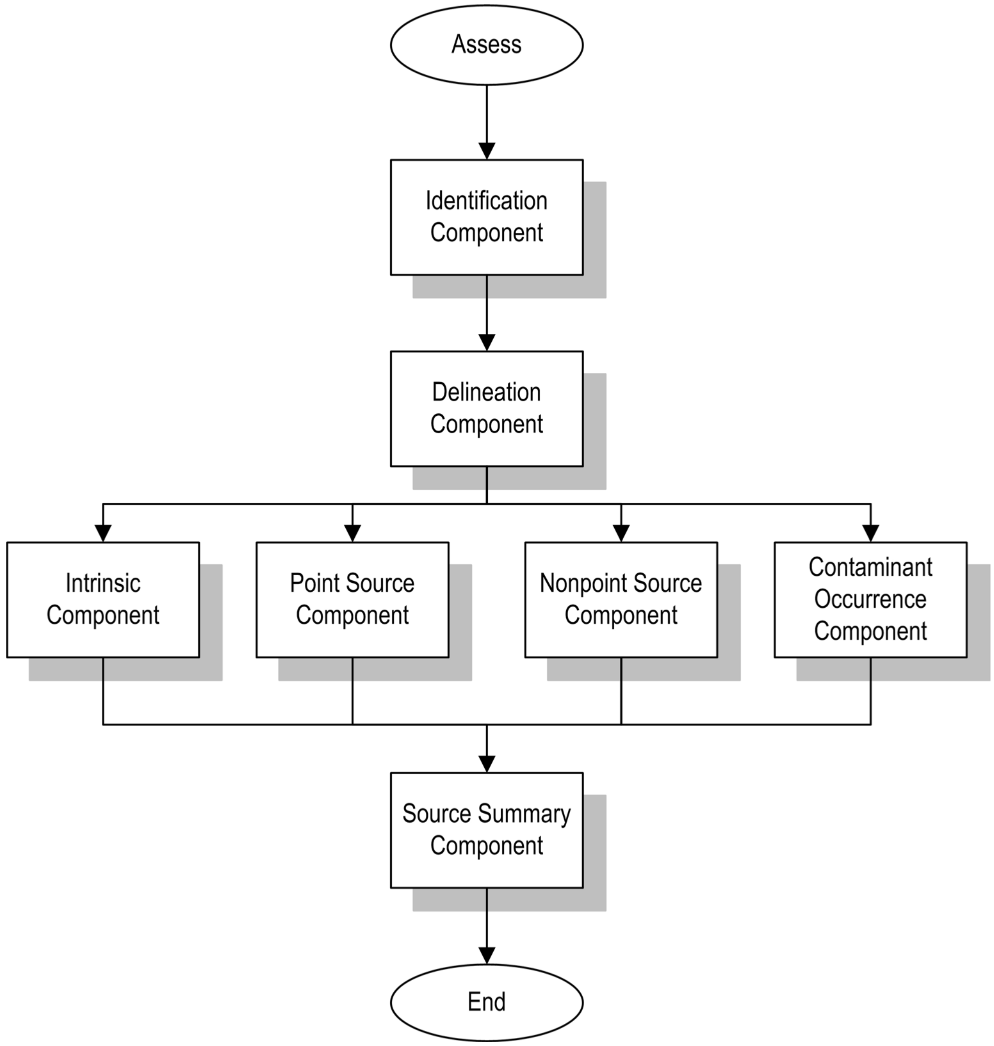
[2] The State of Texas recognizes these as the Yegua-Jackson aquifer.

[3] The State of Texas refers to these as the Upper, Middle and Lower zones of the Hill Country portion of the Trinity aquifer (Barker and Ardis, 1996, Jones and others, 2011).

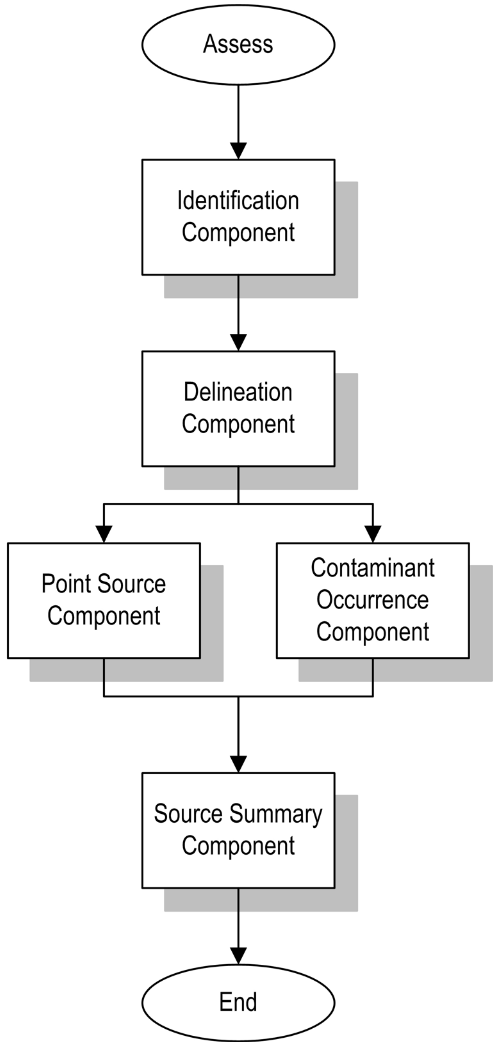
[4] In Central Texas, south of the Trinity River and north of the Colorado River, the Paluxy, Glen Rose, and Travis Peak/Twin Mountains Formations of the Trinity Group, correlate to the Antlers Formation of the Trinity Group. (R.W. Harden and Associates, Inc. and others 2004).

[5] The State of Texas recognizes these units as a major aquifer called the Carrizo-Wilcox aquifer.

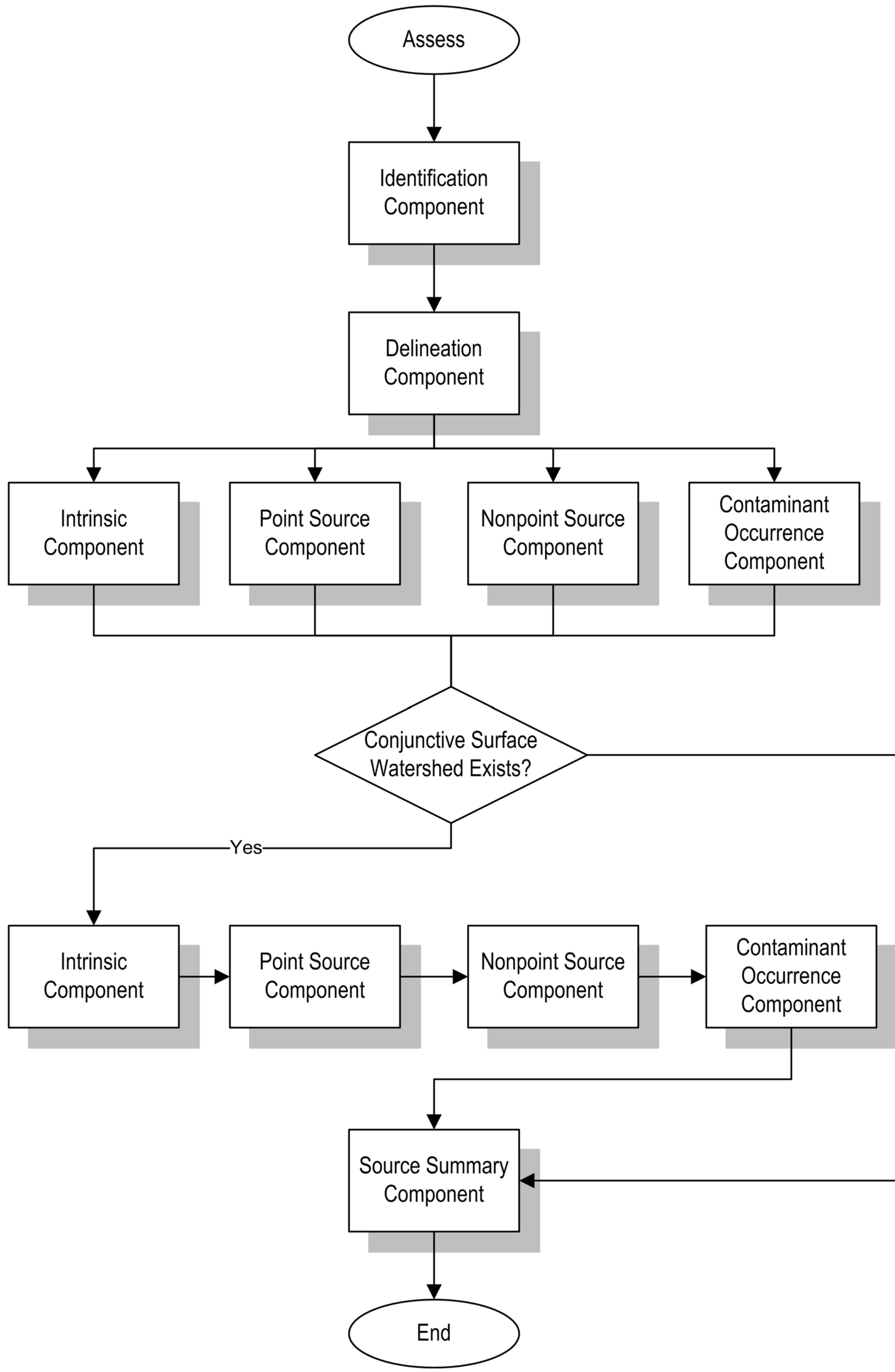
Appendix 3*A*. Process flowchart used in a source-water susceptibility assessment of a well screened in an unconfined aquifer or a well for which the aquifer is unknown.



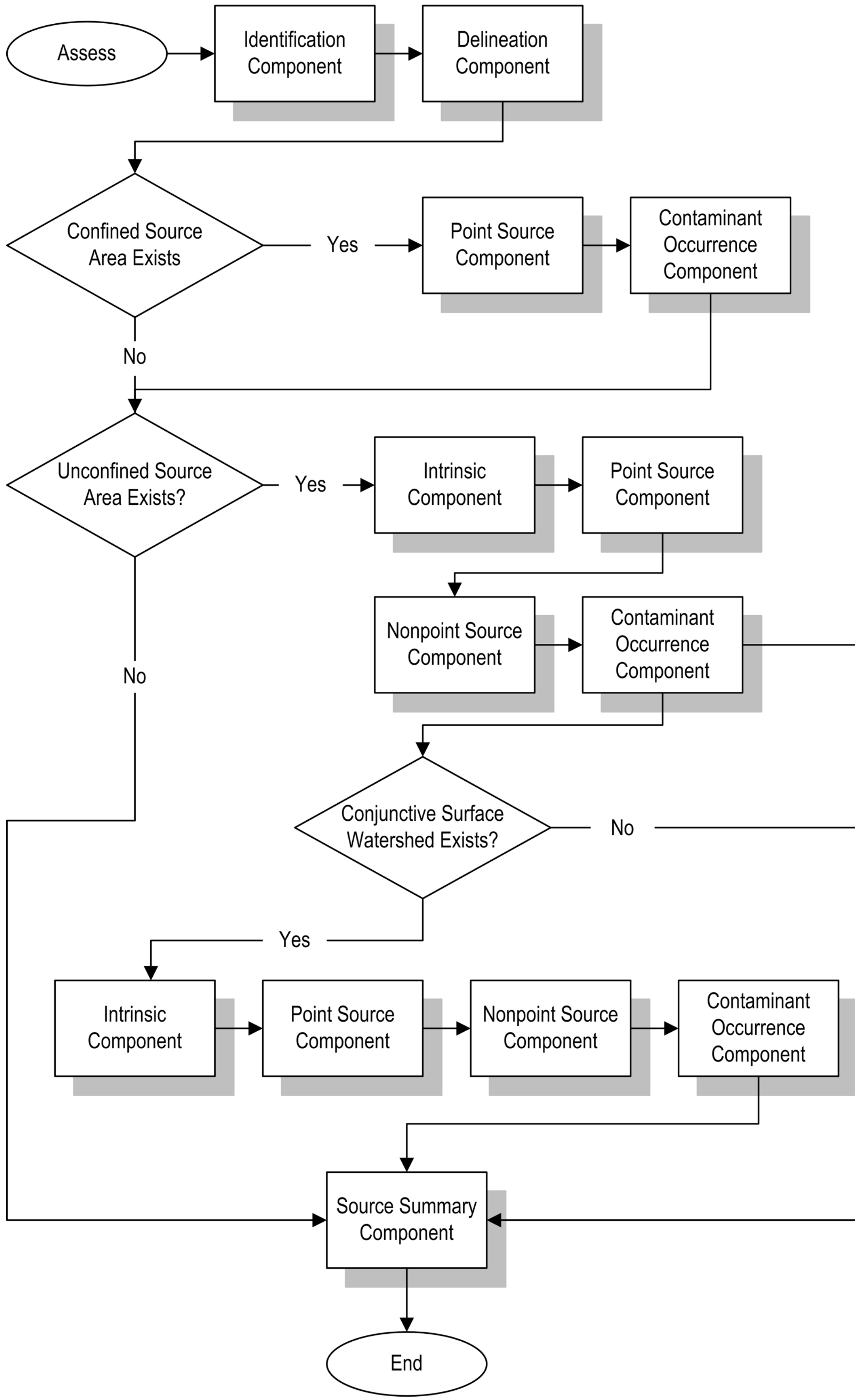
Appendix 3*B*. Process flowchart used in a source-water susceptibility assessment of a well screened in a confined aquifer.



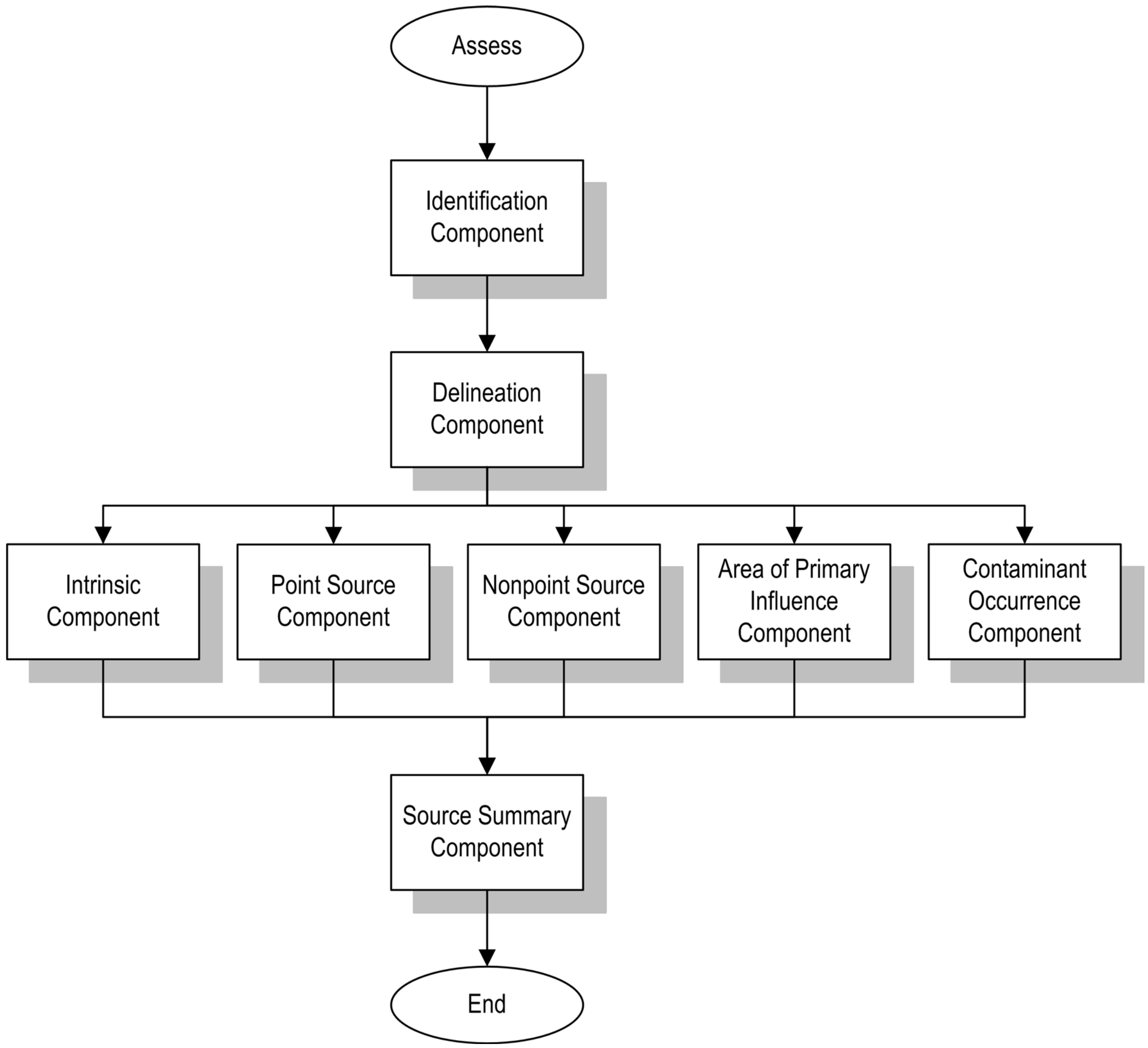
Appendix 3*C*. Process flowchart used in a source-water susceptibility assessment of a well screened in an alluvial aquifer.



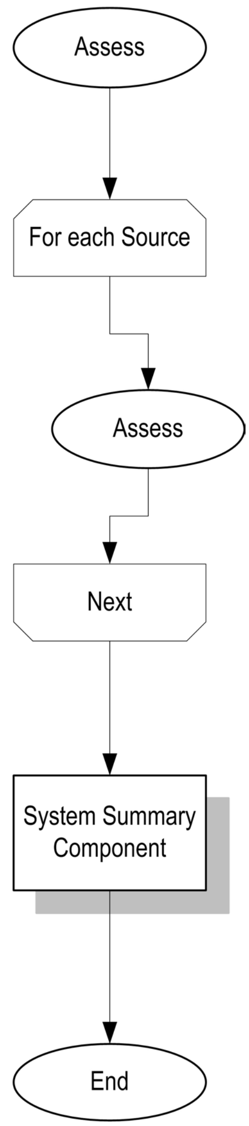
Appendix 3*D*. Process flowchart used in a source-water susceptibility assessment of a well screened in the Edwards aquifer.



Appendix 3*E*. Process flowchart used in a source-water susceptibility assessment of a surface-water intake.



Appendix 3*F*. Process flowchart used in a source-water susceptibility assessment of a public water system.



Appendix 4. Dataset names, descriptions, workspace names, and dataset sources used in source-water susceptibility assessments.

[a_{nn}, unique aquifer identifier, see appendix 3; b_{nn}, unique basin identifier; USDA, U.S. Department of Agriculture; USGS, U.S. Geological Survey; TCEQ, Texas Commission on Environmental Quality; EPA, U.S. Environmental Protection Agency; TXDOT, Texas Department of Transportation; Land cover characteristics are derived from the 2001 Multi-Resolution Landscape Characterization (MRLC) dataset, classified in accordance with the 1992 National Land Cover Dataset land cover definitions (Homer and others, 2004). Population density estimates are computed from 1990 Census blocks (U.S. Census Bureau, 1990), and oil and gas well data density estimates are derived from TCEQ databases. Agricultural chemical use, fertilizer use, and manure production estimates were obtained from various sources (Battaglin and Goolsby, 1994). Land and stream physiography are derived from the National Elevation Dataset (NED) digital elevation model (DEM) data (Brown and others, 2000).]

Dataset name	Description	Workspace name	Dataset source
apop	Animal-population grid (cattle, chickens, hogs, goats, and sheep).	\anth	USDA
annp	Mean annual precipitation.	\clim\	USGS
annr	Mean annual runoff.	\clim\	USGS
annrp	Mean annual rainfall/precipitation ratio.	\clim\	USGS
annq	Mean annual discharge.	\clim\	USGS
athk_g	Aquifer thickness.	\hgol\\a_{nn}\	USGS
atop_g	Aquifer top.	\hgol\\a_{nn}\	USGS
base_g	Aquifer-base grid.	\hgol\\a_{nn}\	USGS
cart	Base cartographic theme (tic, neatline, etc.).	\geog	USGS
cnty	County boundaries.	\admn\	TCEQ
thk_g	Confining-thickness grid.	\hgol\\a_{nn}\	USGS
dptw	Depth-to-water grid.	\phys\	USGS
falp	Mean fall precipitation.	\clim\	USGS
falr	Mean fall runoff.	\clim\	USGS
falrp	Mean fall runoff/precipitation ratio.	\clim\	USGS
falq	Mean fall discharge.	\clim\	USGS
felv	Filled land-surface elevation.	\topo\\b_{nn}\	USGS
flwa	Flow accumulation.	\topo\\b_{nn}\	USGS
flwd	Flow direction.	\topo\\b_{nn}\	USGS
gpws	Public water systems—groundwater.	\anth\	TCEQ
grat	Graticule at 7.5 minutes.	\geog\	USGS
hcon_g	Hydraulic-conductivity grid.	\hgol\\a_{nn}\	USGS
hpop	Human population/density.	\anth	USDC
hunit	Hydrologic units.	\phys\	USGS
hrgn	Texas hydrologic regions.	\phys\	USGS
hvel	Texas 2-year flood-velocity regions.	\hydr	USGS
mac	Master aquifer coverage.	\hgol\\a_{nn}\	USGS
mrlc	Multi-resolution land characterization.	\anth\\b_{nn}\	USGS
neatl	Map neat lines at 7.5 minutes.	\geog\	USGS
nhd	National hydrography streams.	\hydr\\b_{nn}\	USGS
nitr	Nitrogen use grid, fertilizer, and manure.	\anth	USGS
npds	National Pollution Discharge Elimination sites.	\anth\	TCEQ/EPA
obsn	Texas river basins.	\phys\	USGS
pest	Pesticides-use grid, 40 pesticide fields.	\anth	USGS
pipl	Pipelines.	\anth\	USGS
pors_g	Porosity.	\hgol\\a_{nn}\	USGS
pots_g	Potentiometric surface/water table.	\hgol\\a_{nn}\	USGS

Appendix 4. Dataset names, descriptions, workspace names, and dataset sources used in source-water susceptibility assessments.—Continued

[a_{nn}, unique aquifer identifier, see appendix 3; b_{nn}, unique basin identifier; USDA, U.S. Department of Agriculture; USGS, U.S. Geological Survey; TCEQ, Texas Commission on Environmental Quality; EPA, U.S. Environmental Protection Agency; TXDOT, Texas Department of Transportation; Land cover characteristics are derived from the 2001 Multi-Resolution Landscape Characterization (MRLC) dataset, classified in accordance with the 1992 National Land Cover Dataset land cover definitions (Homer and others, 2004). Population density estimates are computed from 1990 Census blocks (U.S. Census Bureau, 1990), and oil and gas well data density estimates are derived from TCEQ databases. Agricultural chemical use, fertilizer use, and manure production estimates were obtained from various sources (Battaglin and Goolsby, 1994). Land and stream physiography are derived from the National Elevation Dataset (NED) digital elevation model (DEM) data (Brown and others, 2000).]

Dataset name	Description	Workspace name	Dataset source
ppt	Intake points and reservoir outlets.	\anth\	USGS
psoc	*See* appendix 5.	\psoc\	TCEQ
finqw, monqw	Multiagency water-quality sites.	\anth\	TCEQ, USGS
rsvr	Reservoirs—storage, depth.	\hydr\	USGS
roads	Roads.	\tran\	TXDOT
rails	Railroads.	\tran\	TXDOT
apiw	Area-of-primary-influence watershed.	\hydr\	USGS
soils	Soil erodibility, total clay content, total organic materials, leakance, permeability, and thickness.	\phys\	USGS
shdr	Shaded relief.	\topo\ b_{nn}\	USGS
slpe	Basin slope.	\topo\ b_{nn}\	USGS
snet	Synthetic hydrography.	\topo\ b_{nn}\	USGS
sprp	Mean spring precipitation.	\clim\	USGS
sprr	Mean spring runoff.	\clim\	USGS
sprrp	Mean spring runoff/precipitation ratio.	\clim\	USGS
sprq	Mean spring discharge.	\clim\	USGS
spws	Public water system—intakes.	\anth\	TCEQ
sthk_g	Saturated thickness.	\hgol\ a_{nn}\	USGS
strg_g	Storage-coefficient grid.	\hgol\ a_{nn}\	USGS
sump	Mean summer precipitation.	\clim\	USGS
sumr	Mean summer runoff.	\clim\	USGS
sumrp	Mean summer runoff/precipitation ratio.	\clim\	USGS
sumq	Mean summer discharge.	\clim\	USGS
trns_g	Transmissivity grid.	\hgol\ a_{nn}\	USGS
winp	Mean winter precipitation.	\clim\	USGS
winr	Mean winter runoff.	\clim\	USGS
winrp	Mean winter runoff/precipitation ratio.	\clim\	USGS
winq	Mean winter discharge.	\clim\	USGS
xtnt_g	Outcrop and subcrop extent.	\hgol\ a_{nn}\	USGS

Appendix 5. Type and description of potential sources of contamination determined in source-water susceptibility assessments (from Texas Commission on Environmental Quality files).

Abandoned Mined Lands—Dataset contains information such as commodity and size (11,929 records).

Airports—Dataset contains information such as airport name, type, and elevation (2,299 records).

Cemeteries—Dataset includes all named features on 7.5-minute U.S. Geological Survey topographic maps. Unnamed cemeteries were added by “heads-up” digitizing (7,595 records).

Class I Injection Wells—Dataset includes names of contaminants injected (365 records).

Class II Injection Wells—Dataset includes names of contaminants injected (37,597 records).

Class III Injection Wells—Dataset includes names of contaminants injected (151 records).

Class V Injection Wells—Dataset includes well type and authorization number (1,799 records).

Corrective Action Sites—Dataset includes site names and generalized description of contaminants (1,228 records).

Candidates for Superfund Sites—Dataset includes names and descriptions of contaminants (1,352 out of 2,688 records with location).

Drycleaners—Dataset includes names and addresses (1,880 records).

Industrial Hazardous Waste Permits—Dataset includes permit information (157 records).

Land Application of Sludge—Dataset includes application acreage and date (193 records).

Marinas—Dataset includes marinas and boat ramp locations and identification information (929 records).

Miscellaneous—Dataset includes location of types (35) such as auto repair, plastic manufacture, and wood preserving (43,425 records).

Municipal Solid Waste (Permitted and Abandoned)—Dataset includes size, type, and contaminants on closed landfills (215 permitted; 2,771 abandoned).

Oil and Gas Wells—Dataset includes oil and gas wells, injection wells, and dry holes (more than 1,063,779 records).

Historical Wellhead/Source-Water Protection Data—Dataset includes information such as septic systems, abandoned wells, and chemical storage tanks (more than 32,696 records).

Petroleum Pipelines—Dataset includes all types of pipelines from crude to refined product and natural gas. (This is a vector database for all 254 counties in Texas.)

Petroleum-Storage Tanks—Dataset includes location and identification information for underground- and aboveground-storage tanks (55,244 records).

Radio-Chemical Sites—Dataset includes sites such as medical facilities and nuclear reactors (2,125 records).

Superfund Locations—Dataset includes names, locations, and associated contaminants (111 records).

Toxic Release Inventory Locations—Dataset includes types of chemicals and types of release (air, water, land, and injection, 5,769 records).

Texas Water Development Board Wells—Dataset includes public, industrial, and private wells, generally pumping more than 100 gallons per minute (125,276 records).

Voluntary Cleanup Program—Dataset includes phase of cleanup, contaminant, and media affected (885 records).

Water-Quality Permits—Dataset includes discharges for municipal, industrial, and agricultural facility (6,749 records).

Appendix 6. Example of a source-water susceptibility assessment report.

This is an example of a source-water susceptibility assessment report prepared for Texas public water systems during 2003, when more than 6,000 reports including more than 18,000 sources were completed and delivered to Texas water systems. The maximum report size was 970 pages, which covered 170 source wells or intakes. An abbreviated report is shown here, and information specific to any particular person or public water system is hidden.

Robert J. Huston, *Chairman*
R.B. "Ralph" Marquez, *Commissioner*
Kathleen Hartnett White, *Commissioner*
Margaret Hoffman, *Executive Director*

PWS ID 1

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY
Protecting Texas by Reducing and Preventing Pollution

April 25, 2003

Dear Water System Manager:

As required by the 1996 Safe Drinking Water Act Amendments, the Texas Commission on Environmental Quality has completed a source water susceptibility assessment (SWSA) for your public water supply (PWS) system. The SWSA methods were produced in a cooperative effort with the United States Geological Survey (USGS) and input from members of the public through regularly held forum discussions. The attached report includes a delineation of areas providing water for each of your PWS system's sources, an inventory of the regulated and unregulated drinking water contaminants within this delineated area, and a determination of the PWS system's relative susceptibility to contamination.

The results of the assessment may provide new insights into the activities near your water source(s) and should be used as a guideline for implementing source water protection. We encourage you to develop measures that can help prevent contamination of your water supply and investigate the source water protection program via the internet at http://www.tceq.state.tx.us/permitting/waterperm/pdw/swap /swp.html where you will find helpful tools, forms and guidance for starting a source water protection program. If you do not have internet access, send your request for information to the address below.

Please read the methodology section of the report and then review the appendices that contain specific results for your water system. If there are any errors or questions you have regarding the report, please provide comments in writing to the address below. We will respond to all written comments once assessments are completed for all PWS in the state.

Sincerely,

Water Supply Division
Public Drinking Water Section
Source Water Assessment and Protection Program, MC 155
P O BOX 13087
Austin, TX 78711-9958

Enclosures: Source Water Assessment Report
cc: Region 4 without enclosures

P. O. Box 13087 Austin, Texas 78711-3087 512/239-1000 Internet address: www.tceq.state.tx.us

TEXAS COMMISSION ON ENVIRONMENTAL
QUALITY SOURCE WATER ASSESSMENT REPORT

Prepared for

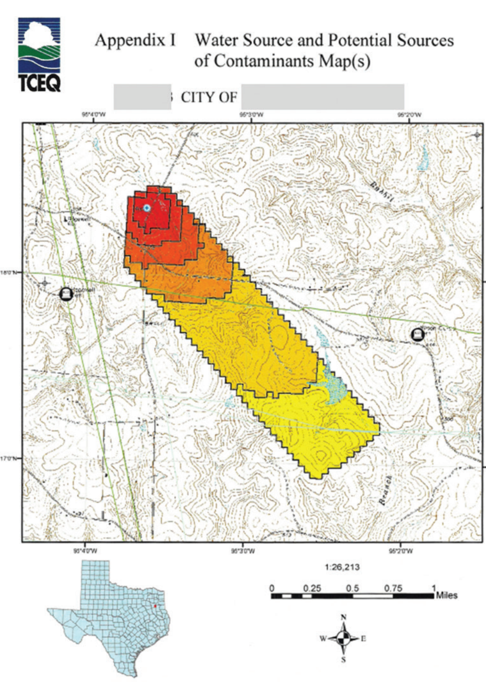
TCEQ

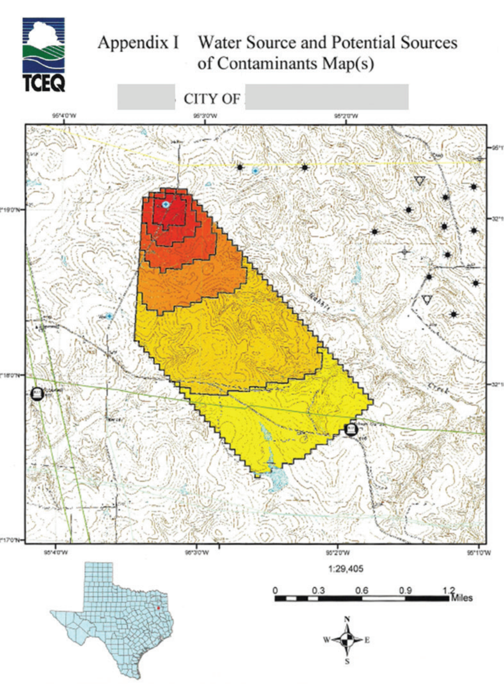
Prepared by

TCEQ's Source Water Assessment and Protection Program

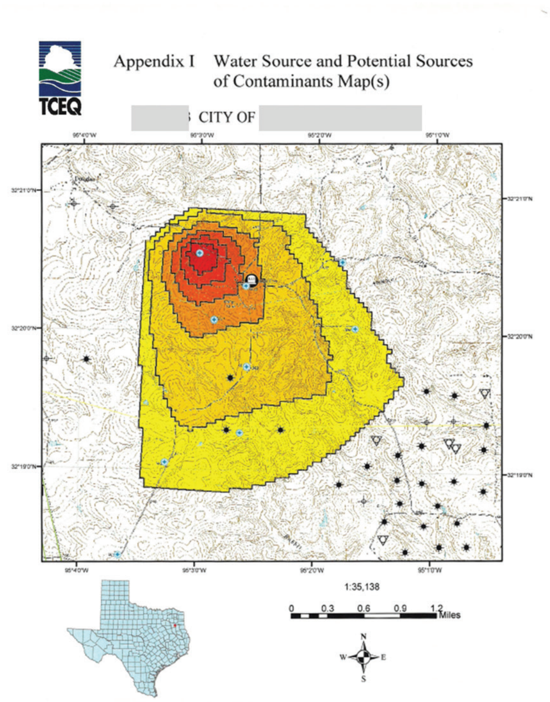
in cooperation with the United States Geological Survey
and the United States Environmental Protection Agency

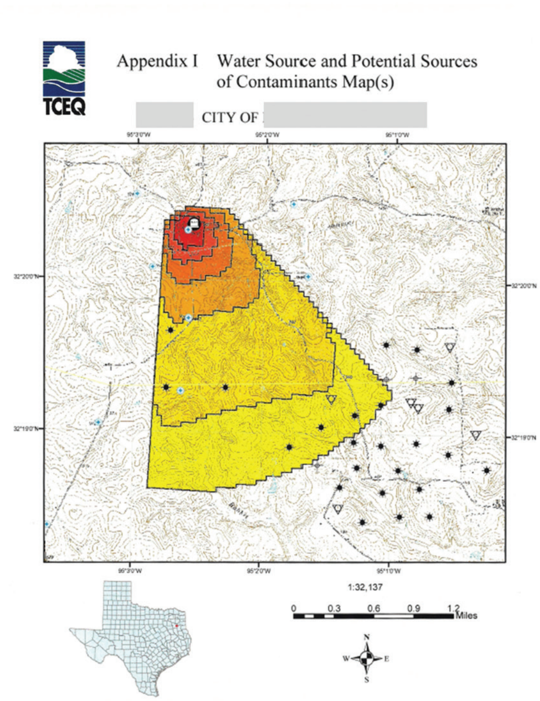
April 25, 2003

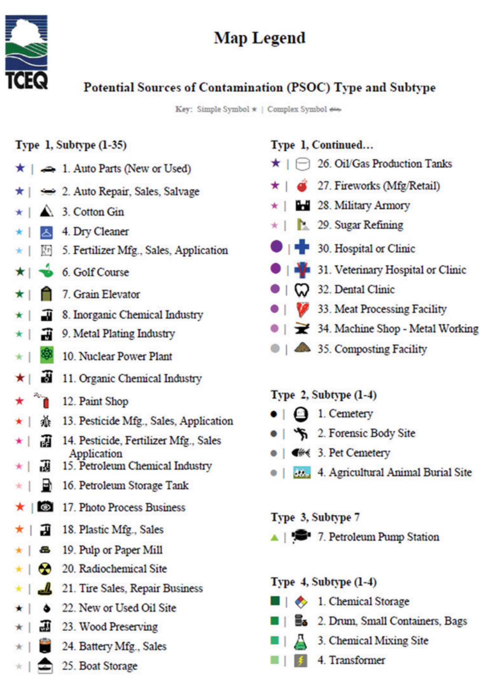




Appendix 6. Example of a source-water susceptibility assessment report.—Continued







TCEQ

Map Legend

Potential Sources of Contamination (PSOC) Type and Subtype

Key: Simple Symbol | Complex Symbol

Type 1, Subtype (1-35)

1. Auto Parts (New or Used)
2. Auto Repair, Sales, Salvage
3. Cotton Gin
4. Dry Cleaner
5. Fertilizer Mfg., Sales, Application
6. Golf Course
7. Grain Elevator
8. Inorganic Chemical Industry
9. Metal Plating Industry
10. Nuclear Power Plant
11. Organic Chemical Industry
12. Paint Shop
13. Pesticide Mfg., Sales, Application
14. Pesticide, Fertilizer Mfg., Sales Application
15. Petroleum Chemical Industry
16. Petroleum Storage Tank
17. Photo Process Business
18. Plastic Mfg., Sales
19. Pulp or Paper Mill
20. Radiochemical Site
21. Tire Sales, Repair Business
22. New or Used Oil Site
23. Wood Preserving
24. Battery Mfg., Sales
25. Boat Storage

Type 1, Continued…

26. Oil/Gas Production Tanks
27. Fireworks (Mfg/Retail)
28. Military Armory
29. Sugar Refining
30. Hospital or Clinic
31. Veterinary Hospital or Clinic
32. Dental Clinic
33. Meat Processing Facility
34. Machine Shop - Metal Working
35. Composting Facility

Type 2, Subtype (1-4)

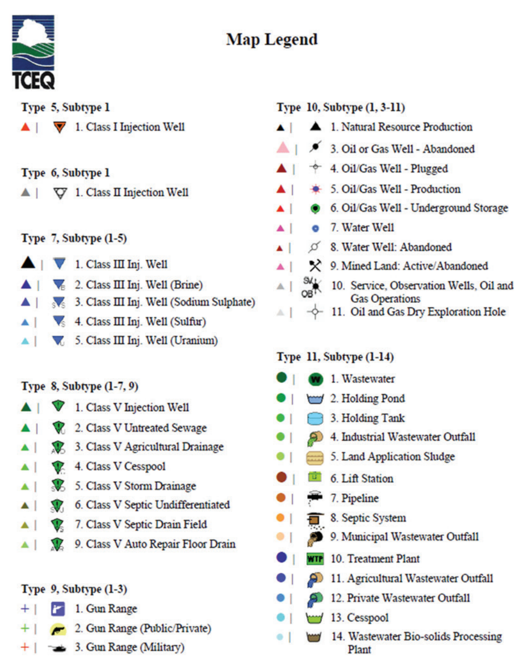
1. Cemetery
2. Forensic Body Site
3. Pet Cemetery
4. Agricultural Animal Burial Site

Type 3, Subtype 7

7. Petroleum Pump Station

Type 4, Subtype (1-4)

1. Chemical Storage
2. Drum, Small Containers, Bags
3. Chemical Mixing Site
4. Transformer



TCEQ

Map Legend

Type 5, Subtype 1

1. Class I Injection Well

Type 6, Subtype 1

1. Class II Injection Well

Type 7, Subtype (1-5)

1. Class III Inj. Well
2. Class III Inj. Well (Brine)
3. Class III Inj. Well (Sodium Sulphate)
4. Class III Inj. Well (Sulfur)
5. Class III Inj. Well (Uranium)

Type 8, Subtype (1-7, 9)

1. Class V Injection Well
2. Class V Untreated Sewage
3. Class V Agricultural Drainage
4. Class V Cesspool
5. Class V Storm Drainage
6. Class V Septic Undifferentiated
7. Class V Septic Drain Field
9. Class V Auto Repair Floor Drain

Type 9, Subtype (1-3)

1. Gun Range
2. Gun Range (Public/Private)
3. Gun Range (Military)

Type 10, Subtype (1, 3-11)

1. Natural Resource Production
3. Oil or Gas Well - Abandoned
4. Oil/Gas Well - Plugged
5. Oil/Gas Well - Production
6. Oil/Gas Well - Underground Storage
7. Water Well
8. Water Well: Abandoned
9. Mined Land: Active/Abandoned
10. Service, Observation Wells, Oil and Gas Operations
11. Oil and Gas Dry Exploration Hole

Type 11, Subtype (1-14)

1. Wastewater
2. Holding Pond
3. Holding Tank
4. Industrial Wastewater Outfall
5. Land Application Sludge
6. Lift Station
7. Pipeline
8. Septic System
9. Municipal Wastewater Outfall
10. Treatment Plant
11. Agricultural Wastewater Outfall
12. Private Wastewater Outfall
13. Cesspool
14. Wastewater Bio-solids Processing Plant

Appendix 6. Example of a source-water susceptibility assessment report.—Continued

TCEQ

Appendix B Description of the Public Drinking Water System and Water Supply Sources

Brief description of the Public Water Supply (PWS) system and its water sources organized by TCEQ's water source identification number. Description of water source includes the system's name for the source, the water source's operational status, TCEQ entry point number and for ground water wells, selected well properties and the aquifer from which the well pumps.

PWS System Information

Address:

Telephone:

PWS Type: COMMUNITY — Population Served: 1536

Total Production: 8.277 million gallons per da — Number Connections: 512

Ground Water Sources

Water Source ID — PWS System Name for Source

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19520300	335	300	003	CARRIZO-WILCOX

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19520600	509	328	003	CARRIZO-WILCOX

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19781025	735	280	003	CARRIZO-WILCOX

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19570000	496	290	003	CARRIZO-WILCOX

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19570717	470	280	003	CARRIZO-WILCOX

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19630418	1050	290	003	CARRIZO-WILCOX

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19650616	810	411	003	CARRIZO-WILCOX

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19670304	800	387	003	CARRIZO SAND

Operational Status	Drill Date (YYYYMMDD)	Well Depth (ft)	Pumpage (GPM)	Entry Point	Aquifer Name
OPERATIONAL	19991200	433	700	003	

Surface Water Sources

Water Source ID — PWS System Name for Source

Operational Status	Entry Point	Surface Waterbody Name	GPM
OPERATIONAL	004	SABINE RIVER	12460

TCEQ

Appendix C PWS System Susceptibility Summary: Contaminants with HIGH Susceptibility

Each water source receives an attribute rating for each contaminant under each of the six components (see raw scores for waters sources under Appendices E and F). For systems with multiple sources, component attribute ratings are averaged and a contaminant susceptibility rating is calculated for an overall system susceptibility (see Sec. 2.7). Listed below are contaminants for which the system has received a high susceptibility rating as well as their component susceptibility ratings. If this page is empty then there are no susceptibility issues for this category.

Inorganics: Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
ALUMINUM	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
ANTIMONY	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
ARSENIC	-----	MEDIUM	LOW	-----	HIGH	HIGH	HIGH
BARIUM	LOW	MEDIUM	HIGH	LOW	HIGH	HIGH	HIGH
BERYLLIUM	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
CADMIUM	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
CHLORIDE	LOW	MEDIUM	LOW	LOW	HIGH	HIGH	HIGH
CHROMIUM	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
COPPER	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
IRON	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
LEAD	-----	MEDIUM	LOW	-----	HIGH	HIGH	HIGH
MANGANESE	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
MERCURY	-----	MEDIUM	LOW	-----	HIGH	HIGH	HIGH
SELENIUM	-----	MEDIUM	LOW	-----	HIGH	HIGH	HIGH
SILVER	-----	MEDIUM	HIGH	LOW	-----	HIGH	HIGH
SULFATE	LOW	MEDIUM	LOW	LOW	HIGH	HIGH	HIGH
TDS	LOW	MEDIUM	HIGH	LOW	HIGH	HIGH	HIGH
THALLIUM	-----	MEDIUM	LOW	-----	-----	HIGH	HIGH
ZINC	-----	MEDIUM	LOW	-----	HIGH	HIGH	HIGH

Inorganics: Un-Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
BORON	-----	MEDIUM	LOW	-----	-----	HIGH	HIGH
NICKEL	-----	MEDIUM	HIGH	-----	HIGH	HIGH	HIGH
SODIUM	LOW	MEDIUM	HIGH	LOW	HIGH	HIGH	HIGH

Volatile Organic Contaminant: Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
1,1,1-TRICHLOROETHANE	-----	MEDIUM	LOW	-----	-----	HIGH	HIGH
CARBON TETRACHLORIDE	-----	MEDIUM	LOW	-----	-----	HIGH	HIGH

Appendix 6. Example of a source-water susceptibility assessment report.—Continued

Appendix D PWS System Susceptibility Summary: Contaminants with MEDIUM Susceptibility

Each water source receives an attribute rating for each contaminant under each of the six components (see raw scores for waters sources under Appendices E and F). For systems with multiple sources, component attribute ratings are averaged and a contaminant susceptibility rating is calculated for an overall system susceptibility (see Sec. 2.7). Listed below are contaminants for which the system has received a medium susceptibility rating as well as their component susceptibility ratings. If this page is empty then there are no susceptibility issues for this category.

Inorganics: Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
CYANIDE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
HYDROGEN SULFIDE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
NITRATE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
NITRATE+NITRITE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
NITRITE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM

Inorganics: Un-Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
BROMIDE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
MAGNESIUM	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM

Volatile Organic Contaminant: Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
1,1,2-TRICHLOROETHANE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
BENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
CIS-1,2-DICHLOROETHYLENE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
DICHLOROMETHANE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
ETHYLBENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
TETRACHLOROETHYLENE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
TOLUENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
TRANS-1,2-DICHLOROETHYLENE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
TRICHLOROETHYLENE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
VINYL CHLORIDE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
XYLENES (TOTAL)	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM

Volatile Organic Contaminant: Un-Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
1,2,4-TRIMETHYLBENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
1,3,5-TRIMETHYLBENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
1,3-DICHLOROBENZENE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
4-ISOPROPYLTOLUENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
ISOPROPYLBENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
M + P XYLENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
METHYL-T-BUTYL ETHER	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
M-XYLENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
NAPHTHALENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
N-BUTYLBENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
N-PROPYLBENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
O-XYLENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
P-XYLENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
S-BUTYLBENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
T-BUTYLBENZENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM

Synthetic Organic Contaminant: Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
2,4,5-TP	-----	MEDIUM	HIGH	-----	HIGH	-----	MEDIUM
2,4-D	-----	MEDIUM	HIGH	-----	HIGH	-----	MEDIUM
ALACHLOR	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
ATRAZINE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
BENZO(A)PYRENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
CHLORDANE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
ENDRIN	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
GLYPHOSATE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
HEPTACHLOR EPOXIDE	-----	MEDIUM	HIGH	-----	-----	-----	MEDIUM
PCBs	-----	MEDIUM	HIGH	-----	-----	-----	MEDIUM
PENTACHLOROPHENOL	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
SIMAZINE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM

Synthetic Organic Contaminant: Un-Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
2,4,5-T	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
ACENAPHTHENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
ALDRIN	-----	MEDIUM	HIGH	-----	HIGH	-----	MEDIUM
ANTHRACENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
BENZO[A]ANTHRACENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
CHRYSENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
DDE	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
DIAZINON	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
DIELDRIN	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
DIURON	-----	MEDIUM	HIGH	-----	-----	-----	MEDIUM
FLUORENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM
PYRENE	LOW	MEDIUM	LOW	LOW	HIGH	-----	MEDIUM

Microbial Organism: Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
TOTAL COLIFORM	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM

Microbial Organism: Un-Regulated

Contaminant Name	Structural Integrity	Aquifer \ Watershed Properties	Nonpoint Source	Point Source	Area Primary Influence	Contaminant Occurrence	SUMMARY
ESCHERICHIA COLI	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM
FECAL VIRUSES	-----	MEDIUM	LOW	-----	HIGH	-----	MEDIUM

Appendix G Counts of Potential Sources of Contamination by Source

Contaminant susceptibility is based on the presence of potential sources of contamination (PSOCs) within the assessed area. For water wells, the PSOCs are located within times of travel which range from 2 to 100 years while PSOCs located within surface water assessment areas may be located within the area of primary influence (API) or the contributing watershed. Listed below are the number of PSOCs located within the various assessment zones for each water source grouped by PSOC type and subtype (refer to Table 2.2 for brief descriptions of PSOC types). If this page is empty then there are no known psocs intersecting the contributing areas.

CLASS II INJECTION WELL

CLASS 2 INJECTION WELL

Time of Travel in Years (Capture Zones)	Number of PSOC sites
50 to 100	1

NATURAL RESOURCE PRODUCTION

OIL OR GAS WELL - PRODUCTION

Time of Travel in Years (Capture Zones)	Number of PSOC sites
20 to 50	3
50 to 100	3

CLASS II INJECTION WELL

CLASS 2 INJECTION WELL

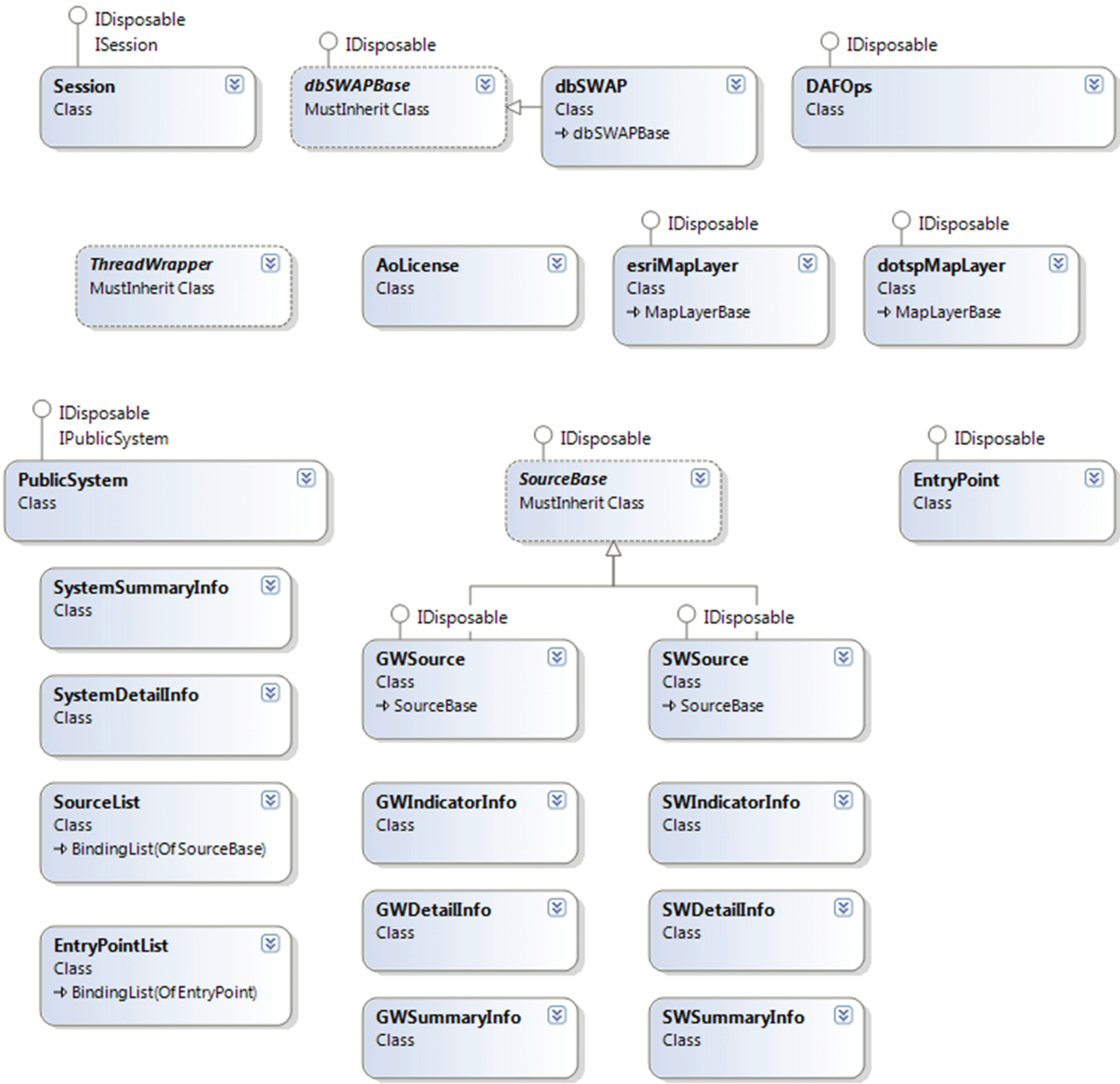
Time of Travel in Years (Capture Zones)	Number of PSOC sites
50 to 100	1

NATURAL RESOURCE PRODUCTION

OIL OR GAS WELL - PLUGGED

Time of Travel in Years (Capture Zones)	Number of PSOC sites
20 to 50	1

Appendix 7. Selected SWAP-DSS software component objects.

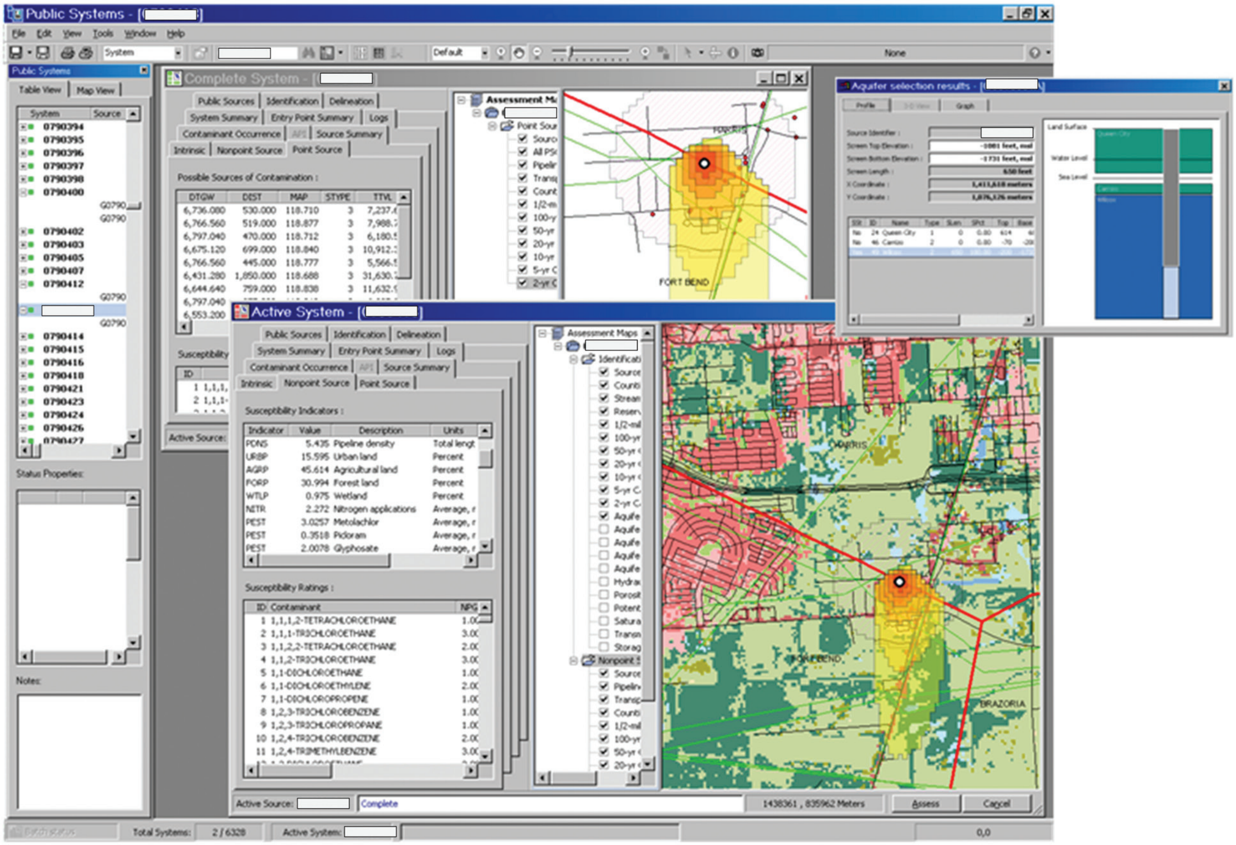


Explanation

Object Name	**Object Purpose**
AoLicense	Handles ArcInfo licensing for the session.
DAFOps	Point- and nonpoint-source component helper methods.
DBSWAP|DBSWAPBase	Data-tier component handles all database creation, retrieval, update, and deletion.
dotspMapLayer	Handles retrieval and display of map data.
Entrypoint	Represents an entrypoint which is a unique collection of wells and/or intakes.
EntryPointList	A collection of entrypoint objects contained by a publicsystem object.
esriMapLayer	Handles datasets used or created during spatial analysis.
GWDetailInfo	Lightweight object used to contain GWSource detail information.
GWIndicatorInfo	Lightweight object used to contain GWSource infdicator information.
GWSource	Object used to contain well or spring properties and behaviors.
GWSummaryInfo	Lightweight object used to contain GWSource summary information.
PublicSystem	Represents a public water system. Contains collections of sources and entrypoints.
Session	Object used to manage the user session and persist user properties.
SourceList	A collection of source objects contained by a publicsystem object.
SWDetailInfo	Lightweight object used to contain SWSource detail information.
SWIndicatorInfo	Lightweight object used to contain SWSource indicator information.
SWSource	Object used to contain intake properties and behaviors.
SWSummaryInfo	Lightweight object used to contain GWSource detail information.
SystemDetailInfo	Lightweight object used to contain System object detail information.
SystemSummaryInfo	Lightweight object used to contain System object summary information.

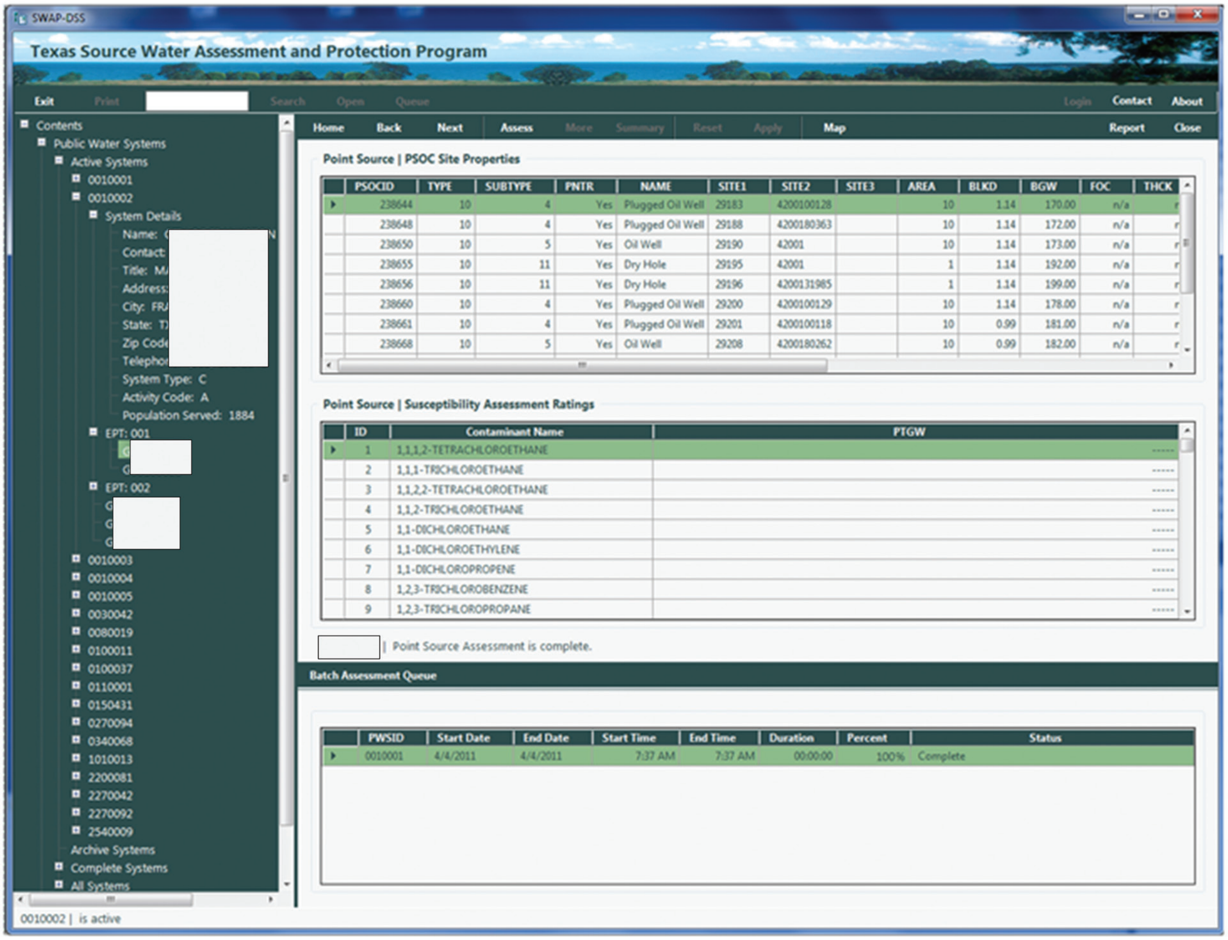
Appendix 8*A*. SWAP-DSS, Version 1.8.7 (V1).

[Information specific to any particular person or public water system is hidden.]



Appendix 8*B*. SWAP-DSS, Version 2.1.1 (V2).

[Information specific to any particular person or public water system is hidden.]



Publishing support provided by
Columbus and Lafayette Publishing Service Centers

Ulery, Meyer, Andren, and Newson—**Source-Water Susceptibility Assessment in Texas: Approach and Methodology**—SIR 2011–5197

ISBN 978-1-4113-3293-5