Investigations and Reports Concerning Surfacewater-Groundwater Interactions in Texas

Created and maintained by Raymond Slade, Jr.,
Certified Professional Hydrologist

Please report any errors or additions to Raymond at rs40@txstate.edu

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Introduction

Most of the reports, data, and information presented or referenced in this report are available on the World Wide Web (Internet). Where identified, a hyperlink to the data or digital version of the report or report reference is presented. References are presented for reports not available on the Web.

Overview

Traditionally, management of water resources has focused on surface water or ground water as if they were separate entities. As development of land and water resources increases, it is apparent that development of either of these resources affects the quantity and quality of the other. Nearly all surface-water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with ground water. These interactions take many forms. In many situations, surface-water bodies gain water and solutes from ground-water systems and in others the surface-water body is a source of ground-water recharge and causes changes in ground-water quality. As a result, withdrawal of water from streams can deplete ground water or conversely, pumpage of ground water can deplete water in streams, lakes, or wetlands. Pollution of surface water can cause degradation of ground-water quality and conversely pollution of ground water can degrade surface water. Thus, effective land and water management requires a clear understanding of the linkages between ground water and surface water as it applies to any given hydrologic setting (from USGS Circular 1139: entitled Ground Water and Surface Water: A Single Resource on the Web at http://water.usgs.gov/pubs/circ/circ1139/).

Texas Background

As concluded later in this report, during low flow conditions most large streams in Texas, except for most stream reaches on the Edwards aquifer, exhibit discharge gains rather than losses. Although some of the discharge gains could represent perched subsurface water, temporary stream bank storage, streambed underflow, or a combination of these factors, most of the gains are attributed to shallow groundwater discharge. Many if not most tributaries to large streams, however, exhibit discharge losses.

The above characteristics could be explained by the following:
1. Shallow groundwater elevations generally are flatter than topography of overlying land, and
2. Streambeds for major steams generally are topographically lower than those for their tributaries.
As a result, major streambeds often intersect underlying groundwater elevations while tributary streambeds often are above underlying groundwater elevations.

During precipitation runoff conditions the following is a popular general conceptual model for the relations between precipitation, runoff, and recharge for most of Texas.

1. Much of initial precipitation falling on natural land surfaces is directly absorbed by soil and vegetation.
2. After the ground becomes saturated, some of any additional precipitation directly infiltrates to the subsurface while some becomes overland flow.
3. Some of the overland flow infiltrates to the subsurface while some enters streams.
4. Some of the streamflow infiltrates to the subsurface while some is received by larger streams, reservoirs, or oceans.

During runoff conditions, increased water-surface elevations in large streams can be higher than underlying groundwater elevations, thus storm runoff can recharge aquifers in major streambeds as well as tributary streambeds.
As a result, large streams often provide groundwater discharge during low flow conditions and groundwater recharge during runoff conditions. Tributaries and areas with overland flow often are dry during low flow conditions but provide recharge during runoff conditions.

Although the actual relations between streams and groundwater for most areas is more complex than explained above, the interactions between surfacewater and groundwater vary between locations and change temporally at locations.

The interaction between surfacewater and groundwater are critical to the quantity and quality of water for both sources, but only a few studies in Texas directly document those interactions. The lack of such studies might represent one of the most critical deficiencies of water-resource knowledge in the State.

Many thousands of reports presenting data and information pertinent to surfacewater-groundwater relations have been prepared by State and Federal agencies in Texas. Some of the reports represent Statewide conditions, however, many characterize regional studies such as river basins or aquifers, while most reports present local information or data. Some of the reports are available in digital format on the Internet, however, most of the reports exist in hard copy only and many of those are not readily available.

Also, many State and Federal agencies maintain systematic water-resource databases containing data pertinent to surfacewater-groundwater relations. As is the case with reports, much of the data is available online but much of the data, typically older data contained in reports and field notes, are not on the Internet and not readily available.

Texas Investigations Relevant to Surfacewater-Groundwater Relations

Streamflow Gain-Loss Studies

Streamflow gain-loss studies probably represent the easiest, cheapest, and most direct method to document interactions between surfacewater and groundwater. Since 1918, the USGS has conducted streamflow gain-loss studies on streams throughout much of Texas. The objective for most of the studies was to obtain data that could be used to estimate discharge from, or recharge to, shallow aquifers.

Based on the studies, with the exception of most stream reaches on the Edwards aquifer, most large streams in Texas display gains rather than losses in low flow discharges. Therefore, groundwater discharges dominate base flow characteristics throughout most of Texas.

The streamflow data, along with the flow gain or loss to each subreach is presented online at http://water.usgs.gov/pubs/of/ofr02-068/. The report presents the results of 366 gain-loss studies involving 249 unique reaches of streams throughout Texas, and provides channel gains and losses for 2,872 subreaches. A detailed summary of the data and associated analyses are presented in appendix 1 at the end of this report.

Along with the flow data, water temperature and other limited water-quality data were documented for some of the flow studies. References for all identified reports containing these data are presented in the next section. References for selected gain-loss study reports are presented in appendix 2.

In 1960, the Texas Water Development Board published a report containing data for all flow studies done at that time. A reference for the report is: Bulletin 5807D “Channel Gain and Loss Investigations, Texas Streams, 1918-1958”, April 1960. This report presents two sections: (1) low-flow investigations, including tabulation of measurements, text, and substantiating information;
and (2) delivery of water investigations, (releases from reservoirs) including discussion of purpose and scope, summary of results, and presentation of results in hydrographs and time-of-travel curves for delivered water.

**Low Flow Characteristics**

Base flow discharges for streams typically are void of direct surface runoff and generally represent groundwater discharges to streambeds. Therefore, documentation of the quantity and water-quality of low-flow characteristics is an important tool for establishing surfacewater-groundwater relations.

A Texas report providing base flow characteristics as determined from streamflow hydrograph-separation analysis in West-Central Texas is online at [http://pubs.er.usgs.gov/pubs/wri/wri884218](http://pubs.er.usgs.gov/pubs/wri/wri884218). Although other similar reports could not be identified for Texas, many Texas studies documenting flow and water-quality characteristics during low-flow conditions have been identified for many streams.

Thirty-one USGS and TWDB reports containing the words “low-flow” or “base flow” in the title were identified and presented below. The online (digital) reports are available as digital files in the links provided below and the reports not online are identified in the following section. The studies involve relations between flow in channels and aquifers, characteristics for low-flow discharges, and presentation of streamflow discharge and water-quality data.

These reports provide direct or indirect information about relations between streamflow and groundwater, and should be used in the development of any additional studies to document such relations. A USGS report presenting methods to collect and analyze data for low-flow investigations is online at [http://water.usgs.gov/pubs/twri/twri4b1/](http://water.usgs.gov/pubs/twri/twri4b1/).

**Online Reports**

**Stream name and report link**


**Cibolo Creek**  


**Upper Guadalupe River**  

**Pecos River**  

**Prairie Dog Town Fork of the Red River**  
Sabine and Old Rivers  


Southeast Texas - http://pubs.er.usgs.gov/pubs/wri/wri884154

Southeast Texas - http://pubs.er.usgs.gov/pubs/fs/fs12299

West Central Texas - http://pubs.er.usgs.gov/pubs/wri/wri884218


Reports not Online

Stream name and report reference

Barton Creek (Colorado River basin) - http://pubs.er.usgs.gov/pubs/ofr/ofr7015
Big Elkhart and Little Elkhart Creek (Trinity River basin) - TWDB, Report 026, Quantity and Quality, 1966
Cibolo Creek - TWDB, Bulletin 6511, Quantity and Quality, 1965
Guadalupe River - TWDB, Bulletin 6503, Comal County, Quantity, 1965
Leon and Lampasas Rivers - TWDB, Report 097, Quantity and Quality, 1969
Lampasas River - TWDB, Bulletin 6506, Quantity and Quality, 1965
Little Cypress Creek - TWDB, Report 025, Upshur, Gregg, and Harrison Counties, Texas, Quantity and Quality, 1966
Llano River - TWDB, Bulletin 6505, Quantity and Quality, 1965
Pecos River below Girvin, Tx - TWDB, Report 107, Quantity and Quality, 1970
Pedernales River - http://pubs.er.usgs.gov/pubs/ofr/ofr5656, and
  TWDB, Bulletin 6407, Quantity and Quality, 1964
San Gabriel River - TWDB, Bulletin 6510, Quantity and Quality, 1965
San Jacinto - http://pubs.er.usgs.gov/pubs/ofr/ofr70124
San Antonio River - TWDB, Report 142, Reconnaissance of the Oxygen Balance and the Variation of Selected Nutrients in the San Antonio River During Low Flow

Stream Basin Studies

The water-resource characteristics for stream basins dictate the quantity and water-quality for streamflow and recharge to underlying aquifers, thus is important in assessing surfacewater-groundwater relations.

Basin-wide studies involving various water-resource subjects have been conducted for major river basins in Texas (presented below). Most of the studies involve assessment of surfacewater quality but many involve streamflow discharges or sources of contaminants to streamflow. Eight online reports representing small basins are presented after the section below.
Additionally, from 1964-1974, a series of 14 reports presenting the reconnaissance of water-quality for each major river basin in Texas was published by the TWDB. Those reports are presented in appendix 3 at the end of this report. Most of these reports provide historic background data or information that could be valuable in documenting changes to current or more recent streamflow-groundwater relations.

### Large Basins

<table>
<thead>
<tr>
<th>Basin name</th>
<th>Year of publication</th>
<th>Subject of publication</th>
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<tbody>
<tr>
<td></td>
<td>(1964) water quality assessment</td>
<td><a href="http://pubs.er.usgs.gov/pubs/wri/wri884216">http://pubs.er.usgs.gov/pubs/wri/wri884216</a></td>
</tr>
<tr>
<td></td>
<td>TWDB Report 168, Woody Phreatophytes Along the Brazos River and Selected Tributaries Above Possum Kingdom Lake.</td>
<td></td>
</tr>
<tr>
<td>Nueces</td>
<td>(1965) base flow study</td>
<td><a href="http://pubs.er.usgs.gov/pubs/ofr/ofr65134">http://pubs.er.usgs.gov/pubs/ofr/ofr65134</a></td>
</tr>
<tr>
<td>Pecos</td>
<td>(1928) water quality assessment</td>
<td><a href="http://pubs.er.usgs.gov/pubs/wsp/wsp596D">http://pubs.er.usgs.gov/pubs/wsp/wsp596D</a></td>
</tr>
</tbody>
</table>

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Red River

Rio Grande
http://pubs.er.usgs.gov/pubs/fs/fs09897 (1997) trace elements and organic compounds

Sabine

San Antonio

San Jacinto

Trinity River
http://pubs.er.usgs.gov/pubs/fs/fs974057 (1997) organochlorine compounds

Wichita
Additionally, two other reports representing multiple river basins are referenced below.


Small Basins

Basin name and report link

Comal River (Guadalupe River basin)
http://pubs.er.usgs.gov/pubs/fs/fs09997

Cow Bayou (Brazos River basin)

Escondido Creek (San Antonio River basin)

Little Elm Creek (Trinity river Basin)

Pin Oak Creek (Trinity River basin)

Richland and Chambers Creek (Trinity River basin)
http://pubs.er.usgs.gov/pubs/wri/wri974132

San Marcos River (Guadalupe River basin)
http://pubs.er.usgs.gov/pubs/fs/fs05997

Seco Creek (San Antonio basin)
http://pubs.er.usgs.gov/pubs/ofr/ofr98627
Regional Aquifer Studies

As concluded in the “Streamflow Gain-Loss Studies’ section earlier, with the exception of most stream reaches on the Edwards aquifer, most large streams in Texas display gains rather than losses in low flow discharges. Therefore, the water-resource characteristics for aquifers dictate the quantity and water quality of base flows throughout much of Texas.

Many regional reports have been prepared for Texas aquifers and many of those are available online (links below). The reports referenced below without links are not available as digital files. Although the reports primarily present data and information concerning groundwater hydrology, hydraulics, and water quality, many also present direct or indirect information about the relations between streamflow and groundwater. In addition, many TWDB reports present groundwater resources by aquifer, county, or other geographic area, can be identified by word search in the TWDB Publication Catalog file, and obtained as hard copies.

The TWDB publication catalog is at
Many of the reports in the catalog also are available online as digital files in four separate catalogs identified as
TWDB Groundwater Bulletins at
http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/bulletins/Bulletins.asp;
TWDB Groundwater numbered reports at
http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/GWreports.asp; and
TWDB contracted reports at
http://www.twdb.state.tx.us/RWPG/rpgm_rpts.asp.
A few such reports are presented in TWDB limited publications at
http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/LimitedPublications/LimitedPublications.asp

Aquifer and report link or reference

Carrizo Wilcox Aquifer

Carrizo Wilcox Aquifer

Carrizo Wilcox and Gulf Coast Aquifers
http://pubs.er.usgs.gov/pubs/wri/wri994233

Central High Plains Aquifer Water Quality
http://pubs.er.usgs.gov/pubs/wri024112

Cretaceous Aquifers in North Central Texas

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Cretaceous Aquifers in Texas Panhandle
BEG, Geological Circular 8803, Hydrogeology and Hydrochemistry of Cretaceous Aquifers, Texas Panhandle.

Docum


Edwards Aquifer (Barton Springs segment)
http://pubs.er.usgs.gov/pubs/wri/wri864036

Edwards aquifer (northern segment)


Edwards Aquifer (San Antonio area)
http://pubs.er.usgs.gov/pubs/sir/sir20045277


Edwards Plateau

http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R360AEPC/AEPCindex.htm

Edwards-Trinity (Plateau) Aquifer

Edwards and Trinity Aquifers
http://pubs.er.usgs.gov/pubs/sir/sir20045201

Gulf Coast Aquifers Hydrology
http://pubs.er.usgs.gov/pubs/ofr/ofr9164

High Plains

High Plains Water Quality
http://pubs.er.usgs.gov/pubs/ofr/ofr03345
Lower Rio Grande Valley
http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/Individual%20Report%20htm%20files/Report%20316.htm and
http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/bulletins/Bull.htm/B6014.htm

Ogallala Aquifer


South Central Texas Water Quality
http://water.usgs.gov/pubs/circ/circ1212/

Southern High Plains Water Quality
http://pubs.er.usgs.gov/pubs/ofr/ofr03345

Texas Counties boarding the Rio Grande

Trinity River basin aquifers (Trinity, Carrizo-Wilcox, and Gulf Coast aquifers)
http://pubs.er.usgs.gov/pubs/wri/wri994233

West Texas Aquifers

Groundwater Vulnerability

Investigations of groundwater vulnerability from surface contamination require knowledge of surfacewater-groundwater relations and represent a valuable resource for protecting and managing aquifers. Although many groundwater vulnerability reports have been done in other states, only a few such reports have been identified in Texas.


The EPA has a publication presenting methods to assess aquifer vulnerability to surface contamination at http://www.epa.gov/cgi-bin/claritgw?op-Display&document=clserv:OW:0182;&rank=4&template=epa
Time of Travel for Contaminants

Time of travel studies involve use of dye to document the time of travel of water or waterborne solutes between two points in a stream or aquifer. By sampling over the time that a dye cloud is detected at a sampling point, the time of travel and dispersion characteristics of the stream or aquifer can be documented. Although primarily used to document travel time of solutes in streams, these studies have documented surfacewater-groundwater interactions for many areas outside Texas. Although a few time of travel studies have been conducted in Texas, most document travel for streams rather than the interaction of streams and groundwater.

A manual presenting methods to conduct these studies is presented at http://water.usgs.gov/pubs/twri/twri3-a9/ and a manual presenting methods to analyze water samples for the tracers is presented at http://water.usgs.gov/pubs/twri/twri3-a12/.

The USGS has conducted only eight time-of-travel studies for Texas streams. Report references for the studies are presented below. The first four of these reports and the seventh report below are available as digital files.

Stream name and report link or reference

Buffalo Bayou and tributaries - http://pubs.er.usgs.gov/pubs/wri/wri004236
Trinity River from Dallas to Trinidad - http://pubs.er.usgs.gov/pubs/ofr/ofr89614


The report determines the time required for translatory waves to travel through the reach of the Brazos River from Whitney Reservoir to Richmond, and through the Leon, Little, and Brazos Rivers from Belton Reservoir to Bryan.


A limited number of time of travel studies have been conducted on aquifers in Texas—mostly for the Edwards aquifer. A summary of such studies done for the Edwards aquifer associated with Barton Springs is online at http://www.bseacd.org/graphics/Report_Summary_of_Dye_Trace.pdf.
**Springflow**

Springs represent surface discharge of groundwater and dominate the base flow for many Texas streams. Therefore, in many areas the flow rate and water quality of stream base flows are dependent upon the groundwater that provides springflow. Much of the water in these aquifers originates from surface recharge in aquifer outcrop areas, thus springs truly represent the interaction of surfacewater and groundwater. The locations, flow rates, and water quality of springs are perhaps the best direct indicator of surfacewater-groundwater interactions, and trends in the flow and water quality of springs characterize a direct measure of changes in those interactions.

Groundwater withdrawals and changes in land use, along with inundation by reservoirs have caused many springs to cease flowing or have reduced flows. Gunnar Brune (1975, report link below) reported that Texas originally had 281 major and historical springs of which 63 had failed as of 1975. Therefore, surfacewater-groundwater interactions have substantially changed in areas proximate to many Texas springs. Brune also stated that 139 of these springs are in the Edwards aquifer or Edwards-Trinity (Plateau) aquifer thus, at least for those aquifers, springs are an important source for the quantity and quality of stream base flows.


In 1975, the TWDB published a report on major springs in Texas—it is online at [http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/Individual%20Report%20htm%20files/Report%20189.htm](http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/Individual%20Report%20htm%20files/Report%20189.htm). The report, authored by Gunnar Brune, presents detailed information for each of 281 springs, including the location, geologic setting, historical background, and discharge.

Subsequent investigations for springs, including ongoing investigations, are identified in Appendix 4 near the end of this report.


**Water Budgets and Atmospheric Energy Budgets**

Budgets of inflow and outflow of water volumes for aquifers or watersheds generally provide direct information and data that can be used to assess surfacewater-groundwater relations. Likewise, atmospheric energy budgets document values for evapotranspiration, which can be used in water budgets to assess inflows and outflows often involving interactions between surfacewater and groundwater.

The homepage for a USGS research program for Water, Energy, and Biogeochemical budgets is [http://water.usgs.gov/webb/](http://water.usgs.gov/webb/). The program was initiated in 1991 to document the processes controlling water, energy, and biogeochemical fluxes over a range of temporal and spatial scales and to understand the interactions of these processes, including the effect of atmospheric and climatic variables.

A report presenting methods to conduct watershed studies for water, energy, and biogeochemical budgets is presented at [http://water.usgs.gov/pubs/fs/fs-165-99/](http://water.usgs.gov/pubs/fs/fs-165-99/)
Even though **water budget studies** are important in documenting surfacewater-groundwater relations, few such studies could be identified for Texas. Four such studies are identified below.

A water budget to document evapotranspiration was performed for the Edwards aquifer, referenced at: “Woodruff, C.M., Jr., Water budget analysis for the area contributing recharge to the Edwards aquifer, Barton Springs segment: *in* Woodruff, C.M., Jr., and Slade, R.M., Jr., eds., Hydrogeology of the Edwards aquifer-Barton Springs segment: Austin Geological Society Guidebook no. 6, p. 36-42.”


A water budget for **Hubbard Creek Reservoir** is referenced as TWDB, Report 151, Water Budget and Quality of Water Studies of Hubbard Creek Reservoir, Texas, 1963-67.

Lack of **evapotranspiration data** probably represent the main reason that few water budget analyses are done. However, the technology to document evaporation and transpiration has dramatically improved over the last few decades and the data needed for such documentation is becoming readily available. For example and regional scale evapotranspiration of Texas from NOAA satellite was reported at: [http://twri.tamu.edu/reports/2002/2002-005/2002-005.pdf](http://twri.tamu.edu/reports/2002/2002-005/2002-005.pdf).

The “**Water Use and Evapotranspiration**” heading within the section “Statewide Reports Relevant to Surfacewater-Groundwater Relations” below present many Texas reports and investigations that document data for evaporation and transpiration from crops, rangeland, and brush. Also, research is now being conducted that uses atmospheric energy data to document evapotranspiration values.

### Variations and Trends in Hydrologic Conditions

Because of its location in a semi-arid region of the United States, Texas frequently experiences short and long durations of drought conditions for local and regional areas. However, Texas also experiences some of the most substantial flood volumes in the Nation. Therefore, Texas experiences substantial variations in water-resource conditions. Information on droughts and floods in Texas is presented at [http://onlinelaminemeks.usgs.gov/lizardtech/iserv/browse?cat=WSP&item=%2Fwsp_2375.djvu&page=525&cp=0.5%2C0.5&lev=0&wid=750&hei=600&props=imag%28name%2Cdescription%29&style=simple%2Fview-dhtml.xsl&bg=ff%2Cff%2Cff%x=32&y=7](http://onlinelaminemeks.usgs.gov/lizardtech/iserv/browse?cat=WSP&item=%2Fwsp_2375.djvu&page=525&cp=0.5%2C0.5&lev=0&wid=750&hei=600&props=imag%28name%2Cdescription%29&style=simple%2Fview-dhtml.xsl&bg=ff%2Cff%2Cff%x=32&y=7).

During low-flow conditions, changes probably occur in interactions between surfacewater and groundwater. For example, other than most stream reaches on the Edwards aquifer, most streams display gains rather than losses in low flow discharges. However, this characteristic is likely to change as springs fail and groundwater levels decrease during sustained droughts—increases in groundwater withdrawals could have the same affect. During such conditions, waste and permitted discharges into streams could dominate base flow conditions.

Also, many reports have concluded that El Nino Southern Oscillation (ENSO) causes variations in precipitation and hydrologic conditions. However, other than a preliminary analysis produced as part of the project producing this report, other reports documenting the relation of ENSO to hydrologic conditions in Texas could not be identified.
Studies that document recent and current hydrologic conditions in comparison to past conditions would be important in predicting water availability and surfacewater-groundwater interactions. Especially beneficial would be a comprehensive Texas study documenting the relation between ENSO and hydrologic conditions.


**Texas Reports Relevant to Surfacewater-Groundwater Relations**

Many reports presenting statewide scope contain information pertinent to surfacewater-groundwater relations. Most of the reports are available on the Internet. Below are subjects for such reports and Web links or references to the reports.

**Groundwater**

TWDB, Major and Minor Aquifers of Texas  

USGS, Groundwater atlas of Oklahoma and Texas  

TWDB, Groundwater availability in Texas  

TWDB, Groundwater recharge in Texas  
[http://www.twdb.state.tx.us/rwp/g/pgm_rpts/2000483340.pdf](http://www.twdb.state.tx.us/rwp/g/pgm_rpts/2000483340.pdf)

TWDB, Aquifer storage recovery feasibility  
[http://www.twdb.state.tx.us/rwp/g/pgm_rpts/individualreportpages/91483788.asp](http://www.twdb.state.tx.us/rwp/g/pgm_rpts/individualreportpages/91483788.asp)

TWDB, Geographic areas in Texas suitable for enhanced recharge  
[http://www.twdb.state.tx.us/rwp/g/pgm_rpts/individualreportpages/2001483388.asp](http://www.twdb.state.tx.us/rwp/g/pgm_rpts/individualreportpages/2001483388.asp)

USGS, Texas Groundwater quality  


TWDB, Report 345, Aquifers in Texas, by John B. Ashworth and Janie Hopkins, November 1995  
Discusses lateral extent, composition, water quality, and water-level changes in the nine designated major aquifers and 20 designated minor aquifers. Includes maps of each aquifer, a short list of selected references for each, and schematic cross-sections of the major aquifers.
TWDB, Report 098, Compilation of Results of Aquifer Tests in Texas, by B. N. Myers, July 1969
Presents in graph form results of approximately 480 aquifer tests. Also includes a section on methods of analyzing aquifer tests and a table of transmissibilities estimated from one drawdown measurement for wells on the Southern High Plains.


Surfacewater

TWDB, Geospatial representation of Texas stream channels
http://www.twdb.state.tx.us/RWPG/rpgm_rpts/2002483439.pdf

TWDB, Drainage areas and river miles for Texas streams have been documented in many TWDB reports. A search within the catalog below using "drainage areas" presents many reports with drainage areas and river miles. It is believed that most if not all river miles are done using 1:24,000 scale.
http://www.twdb.state.tx.us/publications/reports/Publications%20Catalog/catalog.pdf. The reports can be found in TWDB Repositories as documented in the “Databases” section of this report.


TWDB, Suspended sediment yields for Texas streams
http://www.twdb.state.tx.us/RWPG/rpgm_rpts/96483148.pdf


TWDB, Limited Publication 098, State of Texas Water Quality Assessment, April 1979
Provides information on segments within 23 river basins including a summary of TDWR surface water monitoring data for each segment.

TWDB, Report 065, Temperature of Texas Streams, by W. H. Goines, November 1967
Presents in tabular form, stream temperature data collected through September 30, 1966.

Water Use and Evapotranspiration

USGS, Water Use in Texas
http://water.usgs.gov/watuse/

TWDB, Surveys of irrigation in Texas
TWDB, Consumptive use of water by major crops

TWDB, Crop consumptive use and free water evaporation
http://www.twdb.state.tx.us/RWPG/rpgm_rpts/95483137.pdf

TWDB, Water yield improvement from rangeland
http://www.twdb.state.tx.us/RWPG/rpgm_rpts/8483437.pdf

TWRI, Effects of brush management on water yields for four basins
http://twri.tamu.edu/reports_abstract.php?number=TR-207

TWRI, Effects of brush management on water yields for eight basin
http://twri.tamu.edu/reports_abstract.php?number=TR-182

TWDB, Effects of brush management on water yield from rangelands on the Edwards Plateau
http://www.twdb.state.tx.us/RWPG/rpgm_rpts/95483134.pdf

TWDB, Effects of brush control on water management strategy
http://www.twdb.state.tx.us/RWPG/rpgm_rpts/99483312.pdf

TWDB, Texas brush control plan,
http://www.twdb.state.tx.us/RWPG/rpgm_rpts/90483751.pdf

USDA Soil Conservation Service, 1985, Texas Brush Inventory: NRCS State Office, Temple, Texas

TWRI, Determination of regional scale evapotranspiration of Texas from NOAA satellite

TWDB, Report 064, Monthly Reservoir Evaporation Rates for Texas, 1940 through 1965, by J. W. Kane, October 1967

**Climatology**

USGS, A summary report on floods and droughts in Texas
http://floodsafety.com/texas/USGSdemo/PDFs/flooddrought.pdf

USGS, An atlas of depth-duration frequency for precipitation in Texas

TWDB, Climatic Atlas of Texas

TWDB, The Climate and Physiography of Texas
Miscellaneous

BEG, Land Resources of Texas, Other Report 0005, 4 figs., 18 tables, 1 map, 4 sheets, scale 1:500,000, 1977.

TWDB, The State Water Plan for Texas

TWDB, Computer program to create Stiff Diagrams for characterization water quality

Methods and Models to Document Surfacewater-Groundwater Interactions


The USGS also operates a National Research Program concerning “Hydrologic and Chemical Interactions Between Surface Water and Ground Water” at http://water.usgs.gov/nrp/jharvey/site/index.html. The program presents reports (http://water.usgs.gov/nrp/jharvey/site/bibcomplete.html) and methods (http://water.usgs.gov/nrp/proj.bib/jharvey.html) to document surfacewater-groundwater relations and is testing new field methods (http://water.usgs.gov/nrp/jharvey/site/tnfmmt.html) and models (http://water.usgs.gov/nrp/models.html) to evaluate such relations.


Proceedings from a conference sponsored by the American Water Resources Association in 2002 entitled Surfacewater-Groundwater Interactions can be purchased as identified at http://www.awra.org/proceedings/paper.html#groundwater.


Methods

An overview of many methods and tools for understanding and documenting interactions between surfacewater and groundwater is presented online at http://www.agu.org/revgeophys/winter01/winter01.html.
An overview of such methods are identified below.

**Analytical methods** [http://www.agu.org/revgeophys/winter01/node4.html#SECTION00040000000000000000]

**Numerical methods** [http://www.agu.org/revgeophys/winter01/node5.html#SECTION00050000000000000000]

**Field methods** [http://www.agu.org/revgeophys/winter01/node6.html#SECTION00060000000000000000]

**Chemical methods** [http://www.agu.org/revgeophys/winter01/node7.html#SECTION00070000000000000000]

**Biological indicators** [http://www.epa.gov/safewater/swp/bioind.pdf]

Books presenting **general methods** to assess interactions include:


Selected **field methods recommended** for use in documenting interactions are presented below.

A report presenting methods to compute the rate and volume of *stream depletion by wells* is at [http://water.usgs.gov/pubs/twri/twri4d1/](http://water.usgs.gov/pubs/twri/twri4d1/).


A simple device for **measuring differences in hydraulic head** between surfacewater and groundwater is at [http://pubs.usgs.gov/fs/fs-0077-00/](http://pubs.usgs.gov/fs/fs-0077-00/).


Use of **temperature profiles** beneath streams to determine rates of vertical ground-water flow and vertical hydraulic conductivity are presented at [http://pubs.er.usgs.gov/pubs/wsp/wsp2337](http://pubs.er.usgs.gov/pubs/wsp/wsp2337).


An indicator of interaction using **microscopic particle analysis** is at [http://yosemite.epa.gov/water/owrcatalog.nsf/9da204a4b4406ef885256ae0007a79c7/55e72db4e0b0321c85256b06007232f6?OpenDocument&CartID=948-020750](http://yosemite.epa.gov/water/owrcatalog.nsf/9da204a4b4406ef885256ae0007a79c7/55e72db4e0b0321c85256b06007232f6?OpenDocument&CartID=948-020750).

Application of **surface geophysics** to groundwater investigations is presented at [http://water.usgs.gov/pubs/twri/twri2-d1/](http://water.usgs.gov/pubs/twri/twri2-d1/).
Many reports throughout the Nation have documented surfacewater-groundwater interactions—a few of them are presented below.

http://sofia.usgs.gov/publications/ofr/00-483/
http://sofia.usgs.gov/publications/ofr/00-168/
http://pubs.er.usgs.gov/pubs/wri/wri984214

Models

Selected models for documenting surfacewater-groundwater interactions are identified below.

A list of popular models used to document interactions is online at http://water.usgs.gov/nrp/models.html.


Documentation of a computer program (Streamlink) to characterize direct-flow connections in a coupled ground-water and surface-water model is presented at http://pubs.er.usgs.gov/pubs/wri/wri934011.

A finite-element model for simulating hydraulic interchange of surface and ground water is online at http://pubs.er.usgs.gov/pubs/wri/wri864319.

A modification of the finite-difference model for simulation of two dimensional ground-water flow to include surface-ground water relationships is presented at http://pubs.er.usgs.gov/pubs/wri/wri834251.

Supplemental Information

Appendix 1 - Data and Findings for Streamflow Gain-Loss Studies in Texas

Introduction

As part of the Ground-Water Availability Modeling (GAM) Program currently (2001) being conducted by the Texas Water Development Board (TWDB), data are needed to quantify the interaction of surface water and ground water for the nine major aquifers (Ashworth and Hopkins, 1995) and most of the 20 minor aquifers in Texas. Where streams flow across aquifer outcrops, channel gains and losses constitute aquifer discharge and recharge, respectively. To make this aquifer discharge and recharge information available for the GAM Program, the U.S. Geological Survey (USGS), in cooperation with the TWDB, compiled data and computed streamflow gains and losses from all available records of gain-loss studies done by the USGS in Texas.

Since 1918, the USGS has conducted streamflow gain-loss studies on streams throughout much of Texas. The usual objective of the gain-loss studies was to obtain data that could be used to estimate discharge from or recharge to shallow aquifers. Most gain-loss studies were done during low-flow conditions because low flows are more likely to be steady (not changing with time) than
other flows (except in reaches downstream from major springs or reaches downstream from reservoirs where sustained releases account for most of the flow).

In 1958, the data for all known streamflow gain-loss studies were compiled and published in a report by the Texas Board of Water Engineers (currently the TWDB) and the USGS (Texas Board of Water Engineers, 1960). The data for most of the studies done since 1958 have been published in annual data reports and other reports by the USGS. This study carries the documentation of gain-loss studies a step farther: The gains and losses in stream subreaches (channel segments between flow-measuring sites in a reach) were related to major and minor aquifer outcrops in digital and geographic information system (GIS) databases.

**Purpose and Scope**

The purpose of this report is to summarize the results of 366 gain-loss studies involving 249 unique reaches of streams throughout Texas since 1918. The locations of subreaches for which gains and losses were computed are indicated by streamflow-measurement sites on maps of major and minor aquifer outcrops. The gain-loss studies are tabulated by sequential number, major river basin, stream name, and reach identification, and the total gain or loss for each reach is given. The gains and losses for each subreach are tabulated by sequential number for the gain-loss study and located by latitude and longitude of the upstream end of the subreach. Where applicable, the major or minor aquifer outcrop traversed by a subreach is identified.

**Ancillary Benefits**

The compilation of streamflow gain-loss data could be beneficial to the Water Uses and Availability Section of the Water Resources Management Division of the Texas Natural Resource Conservation Commission (TNRCC). That section is responsible for permitting surface-water withdrawals in Texas. Most of the recently issued permits represent contingency permits, which authorize surface-water withdrawals only when the streamflow exceeds a threshold rate. The threshold streamflow rate for each contingency permit generally represents the total discharge needed to sustain permitted withdrawals downstream from the withdrawal point for the contingency permit plus any streamflow required as inflow to receiving bays or estuaries. Contingency permits are used to protect the existing water rights of users downstream from newer users.

The TNRCC and others associated with surface-water usage often use USGS current streamflow data available on the World Wide Web to verify existing streamflow conditions pertinent to contingency permits. However, there are only about 350 existing streamflow-gaging stations, and the location of withdrawal points for contingency permits often are many miles from the nearest streamflow-gaging station. Stream-channel gain and loss data can be used, along with the current streamflow rates for gaging stations, to estimate the current streamflow for sites remote from the gaging stations, including sites that represent surface-water withdrawals for contingency permits.

Reservoir owners also could benefit from the compilation of streamflow gain-loss data. Many reservoir owners are required to release sufficient water to sustain the permitted withdrawal rate for downstream water rights. The permitted users are guaranteed a specific withdrawal rate. The gains and losses of channel flow can be used by reservoir owners to help determine reservoir release rates needed to sustain permitted downstream withdrawal rates.
Method of Gain-Loss Studies

The usual method of gain-loss studies is to identify a stream reach and obtain streamflow measurements along the main channel of the reach. The location of each main-channel measurement site is referenced and documented as a distance on the stream channel, usually upstream from its mouth. The channel gain or channel loss can be computed for the subreach between each main-channel measurement site by equating inflows to outflows plus flow gain or loss in the subreach:

\[
Qu + Qt + Qr = Qd + Qw + Qe + Qg,
\]

Where

- \(Qu\) = streamflow in at upstream end of subreach;
- \(Qt\) = streamflow from tributaries into subreach;
- \(Qr\) = return flows to subreach;
- \(Qd\) = streamflow out at downstream end of subreach;
- \(Qw\) = withdrawals from subreach;
- \(Qe\) = evapotranspiration from subreach; and
- \(Qg\) = gain (positive) or loss (negative) in subreach.

Thus,

\[
Qg = Qu + Qt + Qr - Qd - Qw - Qe.
\]

For most streams, underflow (flow parallel to stream through shallow channel-bed deposits) and bank storage are considered negligible or minimal.

Many of the studies were done during winter to minimize evapotranspiration. Also, the short length of most subreaches and minimal width of the streams during low-flow conditions would allow only minimal evapotranspiration losses. Therefore, \(Qe\) is assumed to be zero in the computations for this report. In each gain-loss study, attempts were made to identify and measure the discharge for all flowing tributaries, return flows, and withdrawals. If these discharges could not be measured, attempts were made to obtain the discharges from other sources such as the TNRCC. However, the USGS cannot verify that all inflow or outflow sources for the reaches were accounted for.

Results

Studies in All Reaches

Three-hundred sixty-six streamflow gain-loss studies in 249 unique reaches were identified and included in this investigation. More than one study has been done at many of the reaches. The locations of streamflow-measurement sites for the studies are shown on plate 1. The studies included about 4,941 measurements of which 3,238 were made at sites on the main channels of the study reaches; the remaining measurements were made on tributaries to the main channels or represent withdrawals. A tabular summary of the flow-loss studies (table 1) includes for each study the major river basin, stream name, study reach identification, date of study, reach length (in river miles), total number of measurement sites, number of sites on the main channel, major aquifer outcrop(s) intersected by the reach, total streamflow gain or loss in the reach, streamflow gain or loss per mile of reach length, and reference for the data. The reaches for many studies are identified in table 1 by eight-digit numbers for streamflow-gaging stations. Station numbers and associated station names for Texas streamflow-gaging stations with daily streamflow data are listed in table 2.

Table 3 presents selected streamflow characteristics for all streamflow-gaging stations with computer-stored discharge measurements and daily mean streamflows in Texas (346 sites). These data include the station number and name, latitude and longitude, contributing drainage area, and the following data pertinent to median flow conditions: the streamflow, gage height, stream width, stream cross-sectional area, mean velocity, and mean stream depth. Also presented is the elevation of the datum of the gage, which can be added to the gage height to obtain the water-surface elevation above sea level for the median streamflow. The streamflow at the gaging station during a gain-loss study can be compared to the median streamflow to assess the flow conditions during the study.
Equation 2 was used to compute the streamflow gain or loss for each subreach. The data and information for the gains or losses in each of 2,872 subreaches (table 4) include the latitude and longitude at the upstream end of the subreach, the underlying major or minor aquifer outcrop, the streamflow gain or loss, the stream subreach length, the location (river mile) of the upstream end of the subreach, and a descriptive location for selected upstream ends.

**Appendix 2 - Selected References for Streamflow Gain-Loss Studies in Texas**


**Appendix 3 - Reports Presenting the Reconnaissance of the Chemical Quality of River Basins**

(basins in alphabetical order)


TWDB Report 087, Reconnaissance of the Chemical Quality of Surface Waters of the Sulphur River and Cypress Creek Basins, Texas, by D. K. Leifeste, December 1968.

Appendix 4 – Investigations of Springflow Resources in Texas

In 1981, Mr. Brune also published a book entitled "Springs of Texas, Volume I" (Brune, Gunnar. 1981. Springs of Texas, Volume I. Branch-Smith, Inc., Fort Worth, Texas). This unique book not only describes springs' geology and hydrology in 183 of Texas' 254 counties, it also describes the flora and fauna found around the springs. Where possible, Mr. Brune included historical water flow and water quality measurements. Mr. Brune's interest in history and archaeology are represented in this document as well. He describes the use of individual springs in reference to their role in Texas pre-historical (pre-European) and historical settlement.

Unfortunately, Mr. Brune's self-published book languished after his death in 1995. Texas A&M Press, along with editor Helen Besse (Ecological Recovery Foundation) reprinted this Texana classic in 2002. For that publication, Ms. Besse provided a new introduction that updates the introductory sections of the older printing. The quality of spring waters, the prehistoric setting of springs, and the decline of springs, are examples of new material in the updated version. Particular attention was paid to Texas water law and the vanishing species that inhabit spring waters as these areas have changed considerably since Mr. Brune originally compiled his book in the 1970s. The new edition of "Springs of Texas, Volume I" is available from Texas A&M Press (www.tamu.edu/press) or from Ecological Recovery Foundation.

Because 71 counties are lacking in the original "Springs of Texas, Volume I" book, TAMU Press has asked Helen Besse (along with Ecological Recovery Foundation) to complete this important research. They will publish "Gunnar Brune's Springs of Texas, Volume II" when the research can be completed and compiled. At this writing, Ms. Besse has found over 1,500 springs in the 71-county area (mostly within the central portions of the state). She has completed field studies in several western counties. Because of the role of springs in keeping Texas' rivers flowing and the importance of springs (and their ensuing creeks) in maintaining quality habitat for wildlife and plant species, several state agencies are now committed to springs research. The Texas Water Development Board (through funding from the U.S. Corps of Engineers) has allocated funding for springs research. The Texas Parks and Wildlife Department is currently studying springs in some portions of the Texas Hill Country, and Regional Water Planning Groups must identify significant springs within their planning regions, as required by the state.

Independent from Ms Besse’s work, an ongoing USGS project began several years ago with funded support from the TWDB, has identified springs throughout Texas. Upcoming work identified with the project include aggregating existing springflow measurements and water-quality data for all known springs, documenting major springs in Texas, and collecting springflow and water-quality data for major springs. In the current phase of this project, the USGS is seeking information from agencies, groups, and individuals about springs in their geographic locales. In their goal of identifying several hundred "significant" springs for future monitoring, the USGS is looking at various parameters to determine a significant spring: importance as habitat, cultural or historical significance aquifer source and geographic location among others.


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Definitions for codes in the “Texas Springs” HTML file can be found in the Appendix of the file “TWDB Ground-Water Data Dictionary” online at http://www.twdb.state.tx.us/publications/manuals/UM50%20Data%20Dictionary/um50.pdf
The code definitions are presented in the Appendices of the dictionary as follows:

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<th>Code in “Texas Springs” file</th>
<th>Appendix name in “TWDB Ground-Water Data Dictionary”</th>
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</thead>
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<td>B</td>
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<tr>
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<td>aquifer_cd</td>
<td>D</td>
</tr>
<tr>
<td>basin_cd</td>
<td>E</td>
</tr>
</tbody>
</table>

**Appendix 5 - TxDOT Driller’s Logs at Bridges and Culverts Over Water**

Driller’s logs exist for almost all federal and state system bridges in Texas. The logs generally present lithologic descriptions of streambed material. Some logs of older bridges may be incomplete. Very little data may exist for bridges owned by cities and counties. Throughout most of the State, the logs extend to bedrock--in parts of east Texas the logs may extend down to a material suitable to support the bridge, but even in these cases the logs are deep.

Driller’s logs at bridges and culverts can be requested from the appropriate TxDOT District Office. A map of TxDOT districts is available at http://www.dot.state.tx.us/localinfo/localinfo.htm. The counties in each district are identified. The site will also allow a district associated with a county of interest to be identified.

Clicking on a district depicted on the map also will provide contact information for that district. Each district generally has its own operating procedures. However, the likely person to contact would be the District Bridge Engineer--there is no public listing for this position thus they would have to be identified on a district-by-district basis.