High Plains Aquifer Groundwater Availability Study

Natalie Houston, P.G.
Hydrologist
Texas Water Science Center
Presentation outline

- Overview of the USGS Groundwater Resources Program
- Overview of the High Plains Groundwater Availability Study
- Water budget estimates and methods used
- Remotely sensed evapotranspiration data
- Preliminary results
- Northern High Plains groundwater flow model
Mission: To provide objective scientific information and develop interdisciplinary understanding necessary to assess and quantify the availability and sustainability of the Nation’s groundwater resources.
Framework for Groundwater Availability at a Regional Scale: Principal Aquifers

Total Withdrawals by Aquifer in US--2000

Source: Maupin and Barber, 2005
Regional-Scale Approach to a National Assessment

http://water.usgs.gov/ogw/gwrp/activities
Assessing Groundwater Availability in the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming

Assessing Groundwater Availability on a National Scale

The U.S. Geological Survey’s Groundwater Resources Program is conducting an assessment of groundwater availability to gain a clearer understanding of the status of the Nation’s groundwater resources and the natural and human factors that can affect those resources. The goals of this national effort are to define the current status and improve understanding of the Nation’s groundwater resources, to better estimate availability and suitability of those resources for use in the future, and to provide tools to estimate the future availability of groundwater for its various uses. Assessments will be completed for regional aquifer systems across the Nation to help characterize how much water we have, where groundwater resources are most stressed, how groundwater availability is changing, and where groundwater resources are most available for future use (Reilly and others, 2008).

The concept of “groundwater availability” means more than just how much water is usable from the aquifer and how much more is left in the aquifer. Groundwater availability depends on factors such as geology of the aquifers, environmental factors, quality of the water, regulations and water law, economics of pumping the water to the surface, and possibility that groundwater withdrawals can adversely affect surface water. The objectives of the High Plains groundwater-availability study are to (1) more fully understand regional and temporal trends in the overall water budget, including natural inflows, outflows, storage, and human uses (such as irrigation), and (2) identify the natural and human processes that control this budget. Development of tools such as groundwater models can help gain an understanding of the hydrologic system, allowing forecasts to be made about the response of the system to natural and human stresses.

Figure 1. Location of the High Plains aquifer within the central United States.

http://pubs.usgs.gov/fs/2010/3008/
### High Plains Aquifer: Stratigraphy Northern High Plains

![Stratigraphic diagram](image)

<table>
<thead>
<tr>
<th>Era</th>
<th>System</th>
<th>Series</th>
<th>Stratigraphic unit</th>
<th>Hydrogeologic unit</th>
<th>Physical characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic</td>
<td>Tertiary</td>
<td>Lower</td>
<td>Oligocene</td>
<td></td>
<td>Siltstone with sandstone as beds and channel deposits</td>
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<td></td>
<td></td>
<td></td>
<td>Brule Formation</td>
<td></td>
<td>Clay and silt</td>
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<td></td>
<td></td>
<td></td>
<td>Chadron Formation</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Miocene</td>
<td></td>
<td>Sandstone, fine to very fine. Local beds of volcanic ash, siltstone, claystone, and marl</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Ogallala Formation</td>
<td></td>
<td>Unconsolidated, poorly sorted gravel, sand, silt, and clay</td>
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<tr>
<td></td>
<td>Quaternary</td>
<td></td>
<td>Alluvial deposits, valley-fill deposits and dune sand</td>
<td></td>
<td>Gravel, sand, silt, and clay</td>
</tr>
</tbody>
</table>

*Figure 67.* Geologic units ranging in age from Oligocene to Quaternary compose the High Plains aquifer. The permeable units consist of sand, sandstone, and gravel.

Source: Robson and Banta, 1995
## High Plains Aquifer: Stratigraphy Southern High Plains

<table>
<thead>
<tr>
<th>Era</th>
<th>System</th>
<th>Series</th>
<th>Group</th>
<th>Formation</th>
<th>General Lithology and Depositional Setting</th>
<th>Hydrostratigraphic Units</th>
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<td>Holocene</td>
<td>Blackwater</td>
<td>Tule</td>
<td></td>
<td>Playa deposits</td>
<td>Local zones of perched groundwater</td>
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<td>Pleistocene</td>
<td>Blackwater</td>
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<td></td>
<td>Eolian and lacustrine clastics, freshwater limestones</td>
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<td>Tertiary</td>
<td>Miocene</td>
<td>Blanco</td>
<td></td>
<td></td>
<td>Fluvial, eolian, and lacustrine clastics</td>
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<td>Pliocene</td>
<td>Ogallala</td>
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<tr>
<td>Mesozoic</td>
<td>Cretaceous</td>
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<td>Kiowachi</td>
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<td></td>
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<td>Edwards</td>
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<td>Walnut</td>
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<td></td>
<td></td>
<td>Trinity</td>
<td>Paluxy</td>
<td></td>
<td>Transgressive sand and gravel</td>
<td>Edwards-Trinity (High Plains) aquifer</td>
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<td></td>
<td></td>
<td>Morrison</td>
<td></td>
<td></td>
<td>Marine sandstone and shale</td>
<td></td>
</tr>
</tbody>
</table>

Source: Dutton and others, 2003
Groundwater flow models in the High Plains Aquifer since RASA

Explanation
- Ogallala Aikaree Model
- Elkhorn-Loup Model
- North Platte Optimization
- Cooperative Hydrology Study
- Republican River
- Hecox Model
- Kansas Geological Survey Model
- Middle Arkansas
- Equus Beds Aquifer
- High Plains (Luckey & Becker 1999)
- Northern Ogallala GAM
- Southern Ogallala GAM
- High Plains Aquifer Boundary
High Plains Aquifer: Work Plan

1. Refine both pre-development and current water budgets for the entire High Plains aquifer.

2. Develop a methodology using remotely sensed data and land-cover modeling to estimate evapotranspiration and irrigation through space and time.

3. Construct a MODFLOW groundwater flow model for the northern High Plains aquifer using updated data and advances in technology.

4. Assess groundwater availability for the northern High Plains aquifer. Use the MODFLOW ground-water flow model for the northern High Plains aquifer to extrapolate the effects of predicted natural (climatic) and anthropogenic stresses on the revised water budgets. Evaluate long-term water supply for the northern High Plains aquifer.
High Plains Aquifer – Analysis Areas
Central and Southern High Plains
Task 1: Refine Water Budgets for Entire High Plains Aquifer

Water budget for Oklahoma Panhandle

Simplistic Water Budgets

Luckey and Becker, 1999
Water Budget Components Analyzed

- Precipitation
- Evapotranspiration
- Recharge
- Surface water
- Groundwater fluxes to and from adjacent units
- Irrigation
- Groundwater in storage
Methods used to estimate components of the water budget

- **SOWAT**—Soil Water Balance Model
  Designed primarily to estimate irrigation pumpage

- **SWB**—A Modified Tornthwaite-Mather Soil-Water-Balance Code
  Designed primarily to estimate recharge

- **BFI program version 4.15**—Base Flow Index
  A Computer program for determining an Index to Base Flow
SOil WATer Balance Model

- Monthly time-step
- Grid-based geospatial input (ESRI)
- Implemented in Python with GDAL (Geospatial Data Abstraction Library)

Output
- Grids (monthly, annual, simulation period)
- Model-wide monthly budget (csv)
- Zone budgets (utility script)
SOil WATer Balance Model

\[ \Delta SM = PR + IR - ETa - DR - GF \]

- **Actual evapotranspiration (ETa)**
- **Irrigation (IR)**
- **Precipitation (PR)**
- **Direct runoff (DR)**
- **Soil Moisture Storage (SM)**
- **Soil Moisture Capacity (SMC)**
- **Maximum Allowable Depletion (MAD)**
- **Groundwater flux (GF)**
Variables

- **Initial conditions**
  - SMI = Initial soil moisture (mm) – computed by SOWAT for previous month using available water capacity layer

- **Monthly climate input rasters**
  - EP = Effective precipitation ((rain + snowmelt) - runoff) (mm)
  - ETa = Actual evapotranspiration (mm)

- **Soil and Land cover Input Rasters**
  - LC = Land cover (categorical)
  - AWC = Available water capacity
  - GW = Fraction of irrigation supplied by groundwater
Groundwater Resources Program


Techniques and Methods 6–A31

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

http://pubs.usgs.gov/tm/tm6-a31/
R = (P + snowmelt + inflow) – sources
(intercception + outflow + ET) – ΔS soil
sinks
Variables

- **Sources**
  - R = Recharge
  - P = Precipitation
  - Snowmelt
  - Inflow = Flow from adjacent cells from flow direction grid

- **Sinks**
  - Interception = Amount of rainfall that is presumed trapped and either evaporated or transpired
  - Outflow = Surface runoff
  - ET = Evapotranspiration
  - $\Delta S = $ Change in soil moisture
Task 2: Remote Sensing of Actual Evapotranspiration

- MODIS instrument aboard 2 satellites, Terra and Aqua
- Terra passes from north to south across the equator in the morning
- Aqua passes south to north over the equator in the afternoon
- Acquires data in 36 spectral bands
- View the entire Earth's surface every 1 to 2 days
Simplified Surface Energy Balance (SSEB) Approach

- Adapted the “hot” and “cold” pixel concept from SEBAL (Bastiaanssen et al., 1998).

- Assumes a linear relationship between latent heat flux (ET) and land surface temperature.

- Actual evapotranspiration (Eta) is a product of ET fraction and reference ET.

Preliminary Results
Task 3: Develop a groundwater flow model of the northern High Plains aquifer

High Plains RASA 1980’s Aquifer Base
Aquifer Base Surfaces Developed After RASA
Expand and refine using newer test holes
Summary

- Refine water budgets for the entire High Plains aquifer
- Remote sensing techniques for evapotranspiration and irrigation
- Construct a MODFLOW groundwater flow model for the northern High Plains aquifer, using updated data and advanced approaches, such as Farm Process
- Assess groundwater availability for the northern High Plains aquifer
High Plains Groundwater Availability Study

Description of Study

The objective of the U.S. Geological Survey Groundwater Availability Study is three fold: 1) quantify the current groundwater resources of the priority aquifer; 2) evaluate how these resources have changed over time, and 3) provide tools to forecast aquifer responses to stresses from future human and environmental uses. The High Plains (fig. 1) Groundwater Availability Study began in 2009.

Water availability is a function of many factors, including the quantity and quality of water and the laws, regulations, economics, and environmental factors that control its use. The focus of the High Plains Groundwater Availability Study is on improving fundamental knowledge of the water balance of the basin, including the flows, storage, and water use by humans and the environment. An improved quantitative understanding of the basin’s water balance not only provides key information about water quantity but also is a fundamental basis for many analyses of water quality and ecosystem health.

A new groundwater-flow model for the northern High Plains aquifer (fig. 2) will be developed and used as a tool to understand how the aquifer responds to the continuing and in some cases growing demands on the groundwater resources in the northern High Plains aquifer. Additionally, through the collection of existing information a water budget will be developed for the entire aquifer.

Figure 1. Location of the High Plains Aquifer

Figure 2. Northern High Plains Aquifer.
Project Team

Steven M. Peterson, P.G.
High Plains Groundwater Availability Study Project
Manager U.S. Geological Survey Nebraska Water Science
Office telephone: 402.328.41511
E-mail: speterson@usgs.gov

Scott Christenson
Hydrologist –Emeritus
U.S. Geological Survey New Mexico Water Science Center
Office telephone: 505.830.796
E-mail: schris@usgs.gov

Sarah Falk
Hydrologist
U.S. Geological Survey New Mexico Water Science Center
Office telephone: 505.830.7952
E-mail: sefalk@usgs.gov

Amanda Saunders Flynn
Physical Scientist
U.S. Geological Survey Nebraska Water Science Center
Office telephone: 402.328.4144
E-mail: aflynn@usgs.gov

Sophia Gonzales
Geographer
U.S. Geological Survey Texas Water Science Center
Office telephone: 512.927.3507
E-mail: slhurtad@usgs.gov

Sharon L. Qi
Hydrologist
U.S. Geological Survey Colorado Water Science Center
Office telephone: 360.993.8977
E-mail: slqi@usgs.gov

Derek Ryter, Ph.D. P.G.
Physical Scientist
U.S. Geological Survey Nebraska Water Science Center
Office telephone: 402.328.4123
E-mail: dryter@usgs.gov

Jennifer S. Stanton
Hydrologist
U.S. Geological Survey Nebraska Water Science Center
Office telephone: 402.261.0458
E-mail: jstanton@usgs.gov
Questions?

Natalie Houston, P.G.
Hydrologist
Texas Water Science Center
Office Telephone: 512.927.3565
Email: nhouston@usgs.gov