Long-Term Groundwater Depletion in the United States: A National Perspective

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Reston, VA

Sharing Water Conference: Floridan Aquifer
Monticello, Florida
October 2, 2014
WATER SUPPLY FROM WELLS

Drilling a Water-supply Well

Los Angeles County production well

Flowing artesian well near Artesia, Eddy County, New Mexico.

Pumping irrigation well, near La Junta, Colorado.
What is the long-term change in volume of groundwater contained in the subsurface?

C.V. Theis (1940)
REMOVAL OF WATER STORED IN SYSTEM

INCREASE IN RECHARGE

PUMPAGE

DECREASE IN DISCHARGE

CAPTURE

“SOURCE OF WATER DERIVED FROM WELLS”

C.V. Theis (1940)
Timing: Sources of Water to a Well

WATER FROM STORAGE DEPLETION

WATER FROM CAPTURE
(increased recharge + decreased discharge)

% OF GW PUMPAGE

0 50 100

PUMPING TIME

Modified from Heath, 1983
POSSIBLE EFFECTS OF GROUNDWATER DEPLETION:

• LOWER WATER TABLES & POTENTIOMETRIC HEADS
• GREATER PUMPING LIFTS & ENERGY COSTS
• REDUCED WELL YIELDS
• REDUCED BASE FLOW OF STREAMS & SPRINGS
• REDUCED GW DISCHARGE TO WETLANDS, LAKES, ESTUARIES, & OCEANS
• LAND SUBSIDENCE
• DEGRADATION OF GROUNDWATER QUALITY
• UNSUSTAINABLE SUPPLIES
• FEWER WATERLOGGING PROBLEMS
• SEA-LEVEL RISE
Sustainability for the Nation
Resource Connections and Governance Linkages

National Academy of Sciences (2013)
Gulbenkian Think Tank on Water and the Future of Humanity

Water and the Future of Humanity
Revisiting Water Security

Gulbenkian Foundation (2014)
MEASURES OF GROUNDWATER DEPLETION:

WATER-LEVEL DECLINE VS VOLUMETRIC DECREASE
Water Level in Well, Las Vegas, NV

SOURCE: U.S. Geological Survey
Groundwater Level vs Population, Las Vegas

GROUNDWATER LEVEL (ft BLS)

1950 1970 1990 2010

WATER LEVEL IN WELL

POPULATION

GROUNDWATER LEVEL (ft BLS)

0 10 20 30 40 50 60 70

700,000 600,000 500,000 400,000 300,000 200,000 100,000 0

1950 1970 1990 2010

0 1 2 3 4 5 6 7

200,000 100,000 50,000 0

GROUNDWATER LEVEL (ft BLS)

150 100 50 0
GW DEPLETION NEAR DENVER, CO

Crisis looms as aquifers drawn down

Tapping the waters of the
groundwater of the Denver
area, the water supply of the
state, is a major concern. The
possibility of another
withering drought.

People from every department except Sports in the room.

About the stories we believe important to produce to
understand our situation our was

Running dry

Much of Douglas County’s well water, once thought abundant
even for a century, could drop out of reach in 10 to 20 years.

Home buyers in dark

Most new Douglas County homes have water tests, poll

Water bill: $3 billion

Warning signs ignored

Rocky Mountain News

Douglas water supply sinking

Experts: Many wells could be useless in 10-20 years

Special Report: Running Dry

Rocky Ridge

Continued on next page

Headlines courtesy of John E. Moore
A 1942 photograph of a reach of the Santa Cruz River south of Tucson, Arizona, shows stands of mesquite and cottonwood trees along the river (left photograph, Arizona Game and Fish Department). A replicate photograph of the same site in 1989 shows that riparian vegetation has largely disappeared (right photograph, Robert H. Webb). Data from two nearby wells indicate that the water table has declined more than 30 meters due to pumping; this pumping appears to be the principal reason for the loss of vegetation.

From: USGS Circular 1308 (2007)
AREAS & WELLS WITH WATER-LEVEL DECLINES > 40 FT SINCE PREDEVELOPMENT (>25 FT IN UNCONFINED AQUIFERS)

From: USGS Circ. 1323 (Reilly et al., 2008)
W.C. Mendenhall (future Director of the USGS) in 1909 stated the need for conservation of groundwater (a shared resource), warning that:

• “continued drilling and use of wells in an artesian region diminishes the area in which the wells will flow …”
• “A strong public sentiment, therefore, should be created, which will under all circumstances oppose the careless use of artesian wells.”
• “… the man who wastes or uses needlessly a product on whose abundance the prosperity of the section depends is his own and his neighbor’s worst enemy.”

*From: USGS Water-Supply Paper 225*
MEASURES OF GROUNDWATER DEPLETION:

WATER-LEVEL DECLINE VS VOLUMETRIC DECREASE
Water levels in the deep Cambrian-Ordovician confined aquifer, Chicago and Milwaukee areas, 1864-1980

DEEP WELL IN COOK CO.

DEPLETION VOLUME $\approx 2 \text{ km}^3$

From: Alley et al. (1999) USGS Circ. 1186
CHANGES IN GROUNDWATER LEVELS IN HIGH PLAINS AQUIFER (PREDEVELOPMENT-2009)

VOLUME REMOVED FROM STORAGE
≈ 243 km$^3$ (by 2000)
& 338 km$^3$ (by 2008)

from: V.L. McGuire (2011); SIR 2011-5089
CUMULATIVE VOLUMETRIC GROUNDWATER DEPLETION (1900-2008) in km$^3$

NONDIMENSIONAL RELATIONS

PUMPAGE = DEPLETION + CAPTURE

DEPLETION FRACTION = DEPLETION VOLUME / CUMULATIVE PUMPAGE

CAPTURE FRACTION = 1 - (DEPLETION FRACTION)
TOTAL U.S. GW DEPLETION
(1950-2005)

= 15% of Q

(85% of Q from CAPTURE)
DEPLETION FRACTION IN SELECTED U.S. AQUIFERS

DEPLETION FRACTION

- 0.0 to 0.2
- 0.2 to 0.4
- 0.4 to 0.6
- 0.6 to 0.8
- 0.8 to 1.0

n = 31

U.S. TOTAL (1950-2005): 0.15
<table>
<thead>
<tr>
<th>AREA</th>
<th>DEPLETION FRACTION</th>
<th>CAPTURE FRACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH PLAINS (OGALLALA) AQUIFER</td>
<td>0.27</td>
<td>0.73</td>
</tr>
<tr>
<td>NEBRASKA H.P.</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>TEXAS H.P.</td>
<td>0.42</td>
<td>0.58</td>
</tr>
</tbody>
</table>

(1950-2000)
AVERAGE GW DEPLETION RATE (20TH CENTURY)

DEPLETION RATE (km³/yr)

- Blue: -0.5 to 0.0
- Orange: 2 to 4
- Green: 0.0 to 0.5
- Yellow: 1.0 to 2.0
- Dark green: 0.5 to 1.0
- Olive green: 4 to 7
- Red: 7 to 11

n = 40
AVERAGE GW DEPLETION RATE (2001-2008)
CHANGE IN AVERAGE GW DEPLETION RATE
(FROM 1961-80 TO 2001-2008)
DEPLETION INTENSITY
(in m/yr)

\[
= \frac{\text{Depletion Volume (km}^3\text{)}}{\text{Area (km}^2\text{)} \times \text{Time (yrs)}} \times \frac{1000 \text{ m}}{\text{km}}
\]
DEPLETION INTENSITY (2000-2008)

DEPLETION INTENSITY (m/yr)
-0.015 to 0
0.030 to 0.045
0 to 0.015
0.045 to 0.060
0.015 to 0.030
0.060 to 0.080

n = 40
LONG-TERM GROUNDWATER DEPLETION IN THE U.S.

- **TOTAL U.S.**
- **HIGH PLAINS AQUIFER**
- **MISSISSIPPI EMBayment**
- **CENTRAL VALLEY, CALIFORNIA**
- **ARIZONA ALLUVIAL BASINS**
- **OTHER WESTERN BASINS**
- **GULF COASTAL PLAIN LOWLANDS**
- **AGRICULTURAL DRAINAGE**
- **DEEP CONFINED AQUIFERS**
- **ATLANTIC COASTAL PLAIN**
- **VOLCANIC SYSTEMS**

**DEPLETION VOLUME, in km³**

- **1,000 km³ in 2008**
- **800 km³ in 2000**

**EQUIVALENT SEA-LEVEL RISE (mm)**

**Time Period:**
- **1900**
- **1920**
- **1940**
- **1960**
- **1980**
- **2000**
DECADAL SCALE RATE OF GROUNDWATER DEPLETION IN THE UNITED STATES, 1900 TO 2008
CUMULATIVE GLOBAL GW DEPLETION, 1900-2008

- 4,530 km$^3$ in 2008
- 3,370 km$^3$ in 2000
CUMULATIVE GLOBAL GW DEPLETION, 1900-2008

20TH CENTURY: 9.3 mm ≈ 5.5 %
RECENT SLR = 3.1 mm/yr;
GWD: 0.40 mm/yr ≈ 13%

CUMULATIVE GLOBAL GW DEPLETION, 1900-2008

DEPLETION VOLUME (km³)

1900 1920 1940 1960 1980 2000

EST. GLOBAL TOTAL
TOTAL U.S.
N. INDIA
SAUDI ARABIA
NW SAHARA + NUBIAN
N. CHINA
EST. REST OF WORLD

EQUIVALENT SEA-LEVEL RISE (mm)
The future?

- GROWING POPULATION $\rightarrow$ INCREASED DEMANDS FOR FOOD & WATER SUPPLY (DRIVING FORCE)

- CAN WE (& SHOULD WE) DO ANYTHING TO CONTROL/LIMIT GROUNDWATER DEPLETION? (MANAGEMENT/LEGAL/POLITICAL/SOCIO-ECONOMIC ASPECTS)
CONCLUSIONS

- IN U.S., GW DEPLETION IS GROWING
- DEPLETION RATE IS ACCELERATING
CONCLUSIONS

ON AVERAGE:

• MOST GW WITHDRAWALS BALANCED BY CAPTURE

• LESS BALANCED BY GW STORAGE DEPLETION
CONCLUSIONS

• GROUNDWATER DEPLETION CAN AFFECT SUSTAINABILITY & VIABILITY OF WATER SUPPLY

• DEPLETION CAN CAUSE DETRIMENTAL ENVIRONMENTAL EFFECTS

• INNOVATIVE WATER MANAGEMENT ACTIONS CAN HELP MITIGATE PROBLEMS
MANAGEMENT/POLICY OPTIONS

(LINKED WITH TECHNOLOGY ADVANCES & ENGINEERING SOLUTIONS)

• DECREASE DEMAND (esp. in IRRIGATED AGRICULTURE)

• INCREASE SUPPLY, for example:
  ➢ MANAGED AQUIFER RECHARGE
  ➢ DESALINATION
  ➢ ALTERNATE SOURCES OF SUPPLY