Hydrology

Groundwater and Groundwater Depletion

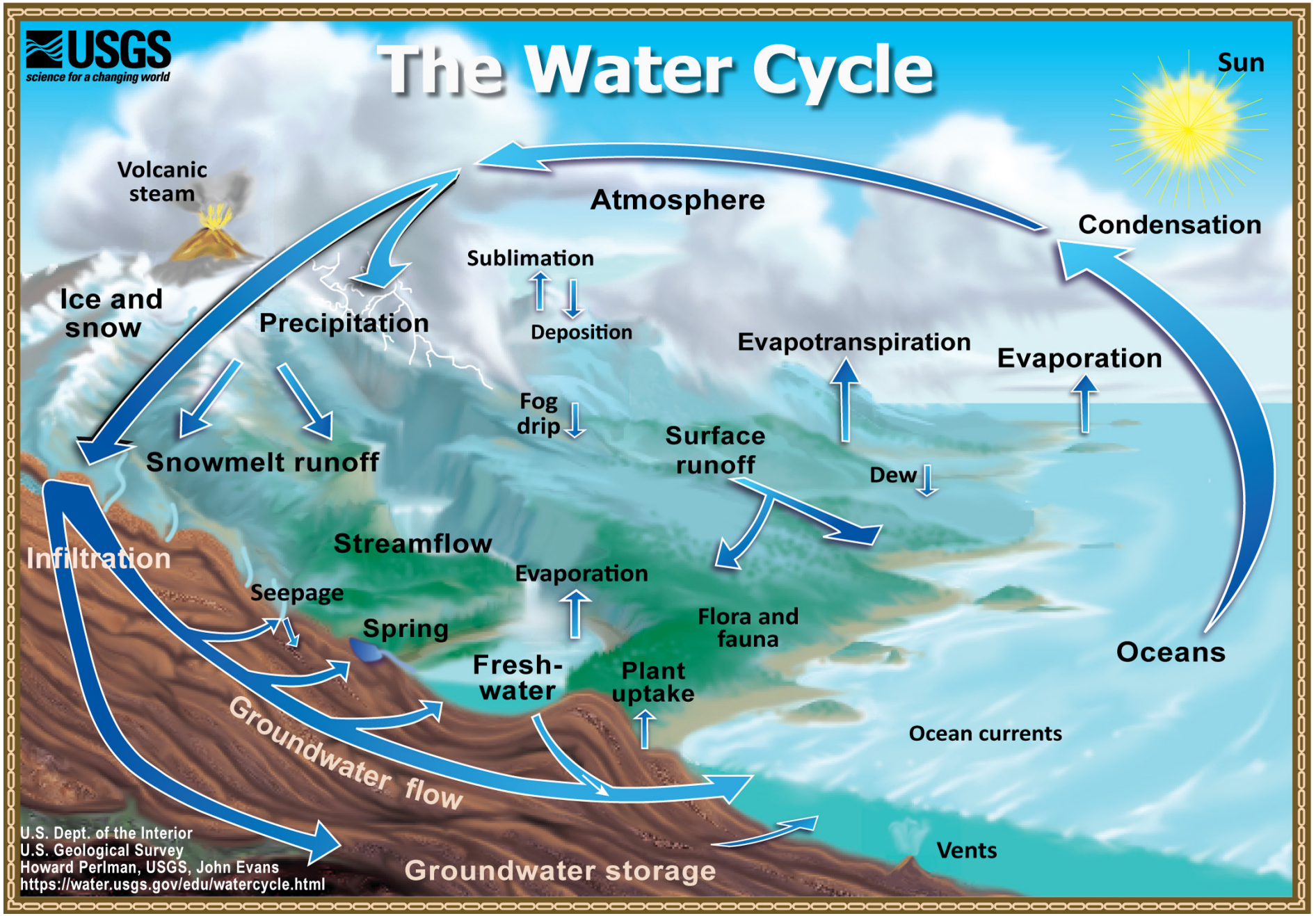
Presentation Led by Joo Eun Kim

AOSC680

Image by the Water Education Foundation

Outline:

- Overview of aquifers
  - Confined and unconfined aquifers
  - Groundwater pumping at wells
  - Basic fluid mechanics
- Sustainability
  - Definition
  - Overview
- Trends in groundwater flow
  - Groundwater depletion
  - Observations in aquifer systems globally
  - Wells
- Sustainability and Groundwater
  - Current issues
  - What’s next going forward


USGS
science for a changing world
The Water Cycle
Sun
Volcanic steam
Atmosphere
Condensation
Sublimation
Deposition
Ice and snow
Precipitation
Evapotranspiration
Evaporation
Fog drip
Surface runoff
Dew
Snowmelt runoff
Infiltration
Streamflow
Evaporation
Seepage
Spring
Flora and fauna
Fresh-water
Plant uptake
Oceans
Groundwater flow
Ocean currents
Vents
Groundwater storage
U.S. Dept. of the Interior
U.S. Geological Survey
Howard Perlman, USGS, John Evans
https://water.usgs.gov/edu/watercycle.html

Aquifers

- Aquifer:
- Unconfined:
- Confined:

Aquifers and wells

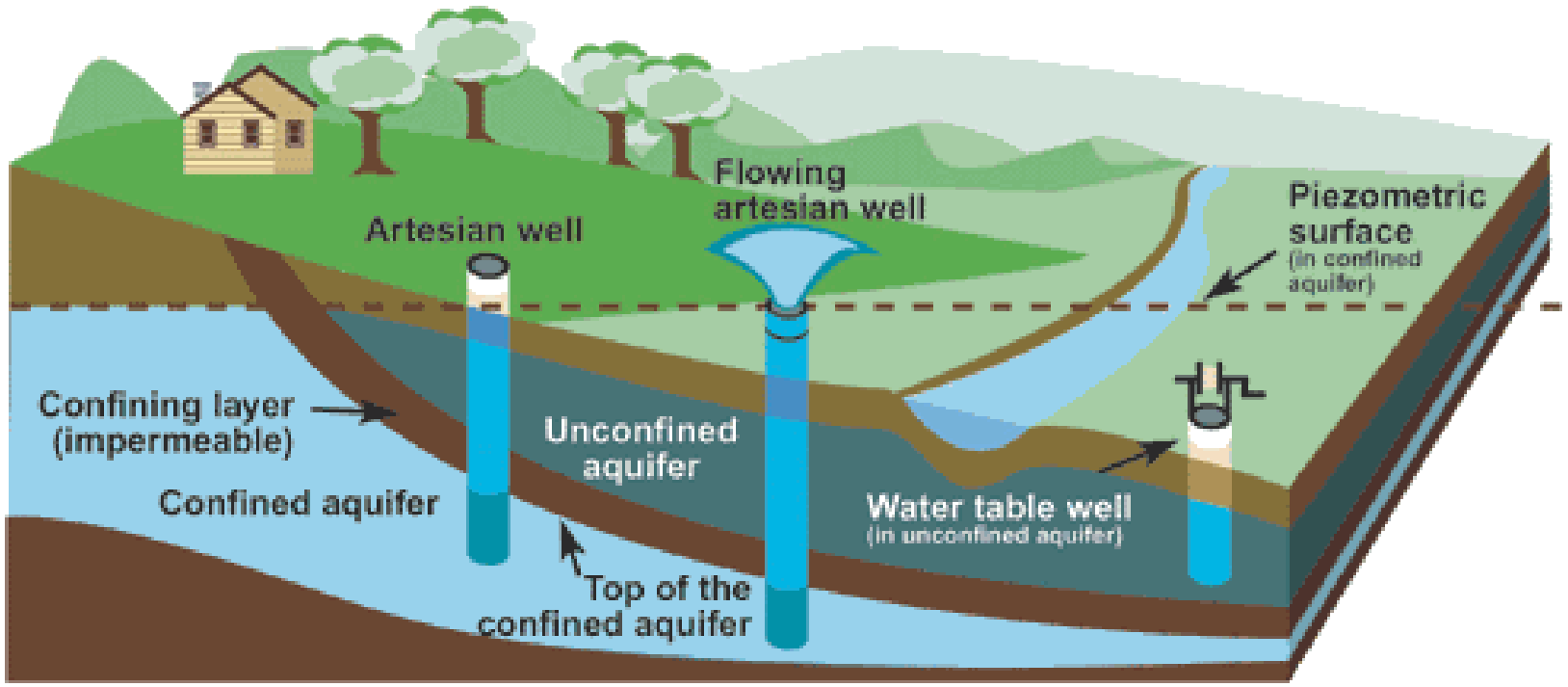
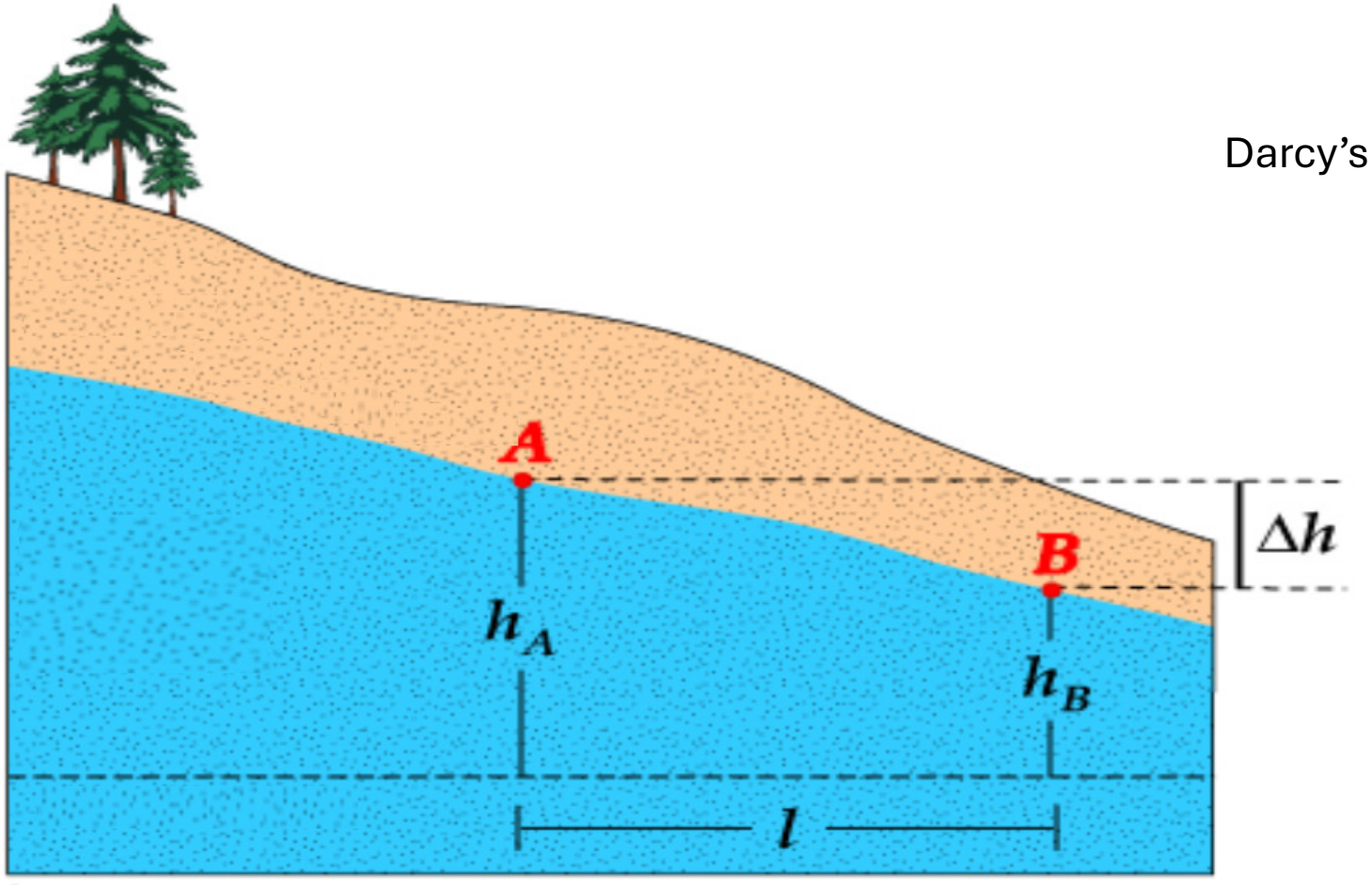


Image from USGS, *Aquifers and Groundwater*

Henry Darcy

- Born in Dijon, France, on ____
- French Engineer
- Legacy:
  - Darcy's Law
  - Darcy-Weisbach

Groundwater Flow

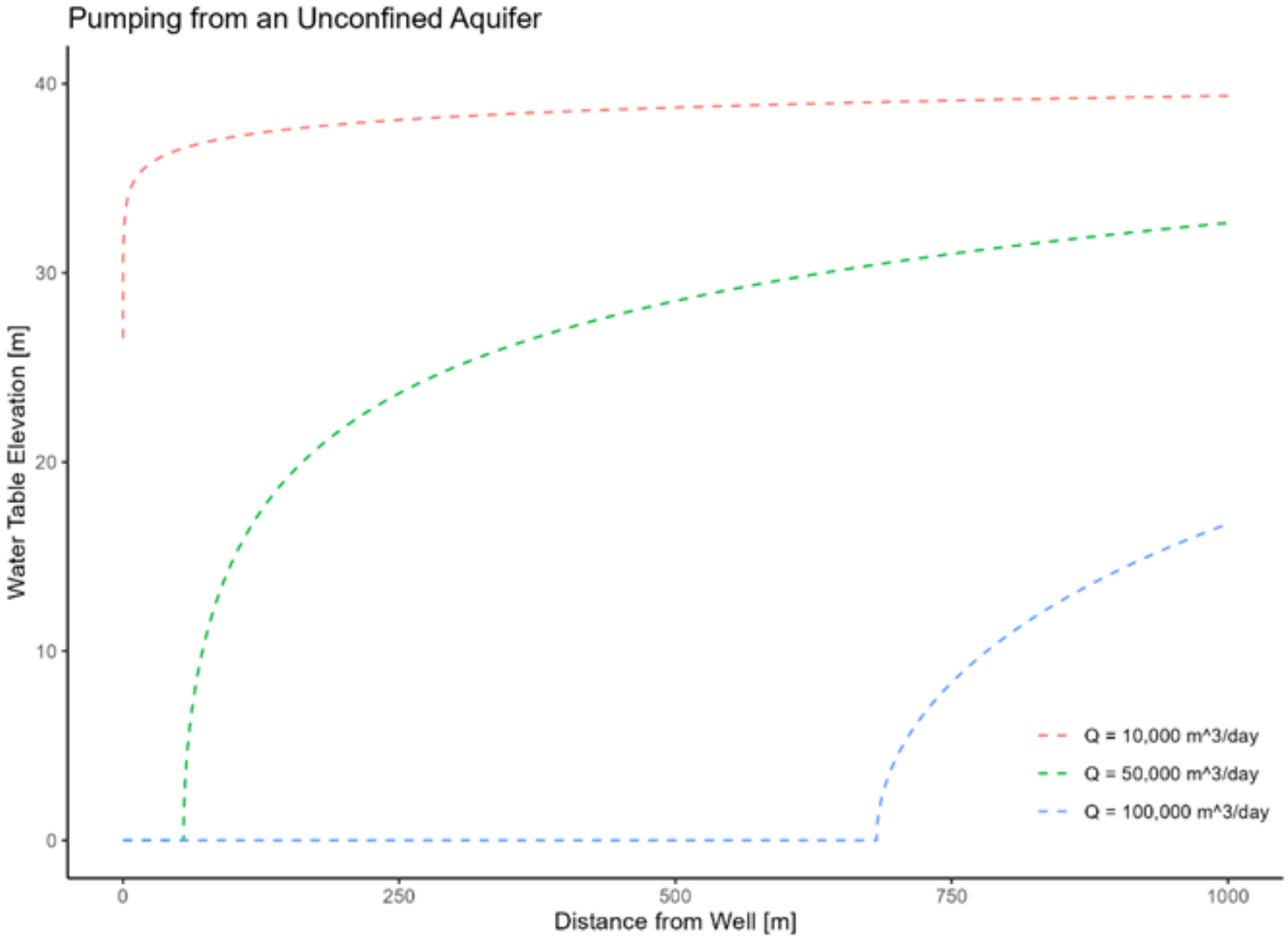


Darcy's Law: $v = -K\frac{dh}{dl}$

Darcy flux

Hydraulic conductivity

Hydraulic gradient



Thiem-Dupuit:

$$h = \sqrt{h_e^2 + \frac{W}{2K}(r_e^2 - r) - \frac{Q}{\pi K}\ln\left(\frac{r_e}{r}\right)}$$

- Unconfined aquifers
- Simple modeling

Importance of Groundwater

- Much of the world's unfrozen freshwater is beneath the surface in _____?
- Approximately what percent of unfrozen groundwater is in aquifers?

- Critical to global water supply and food security
  - Main source of water for _____ of people
  - Main source of water for nearly ____ of irrigated agriculture
- Importance often understated… *out of sight, out of mind*
- Consequently, there is a *hidden crisis beneath our feet*
  - Unsustainable pumping of groundwater
  - Groundwater depletion

Ogallala Aquifer

Original image by USGS

Significance:

- How many depend on this aquifer for drinking water?
- What sector is concentrated in this general area?
- What fraction of the country's agricultural groundwater comes from this aquifer?

Sustainability

- What is *sustainability*?
  - Dictionary definitions:
    - The ability to be maintained at a certain rate or level.
    - Avoidance of the depletion of natural resources in order to maintain an ecological balance.
  - 1987 Brundtland Report – *Our Common Future*

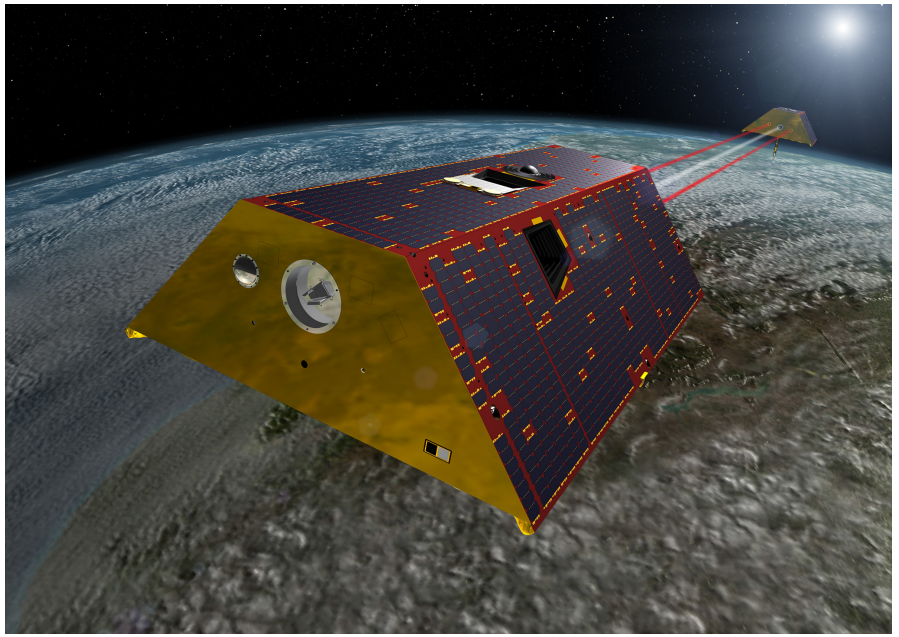
- Sustainable development by finding a balance between:
  - Social
  - Economic
  - Environment

Quantifying Groundwater Storage

- GRACE
  - Gravity Recovery and Climate Experiment
  - Joint mission between NASA and DLR
    - Deutsches Zentrum für Luft-und Raumfahrt
  - Twin satellites
  - GRACE-1 and GRACE-2 (2002–2017)
  - GRACE-1FO and GRACE-2FO (2018–Present)

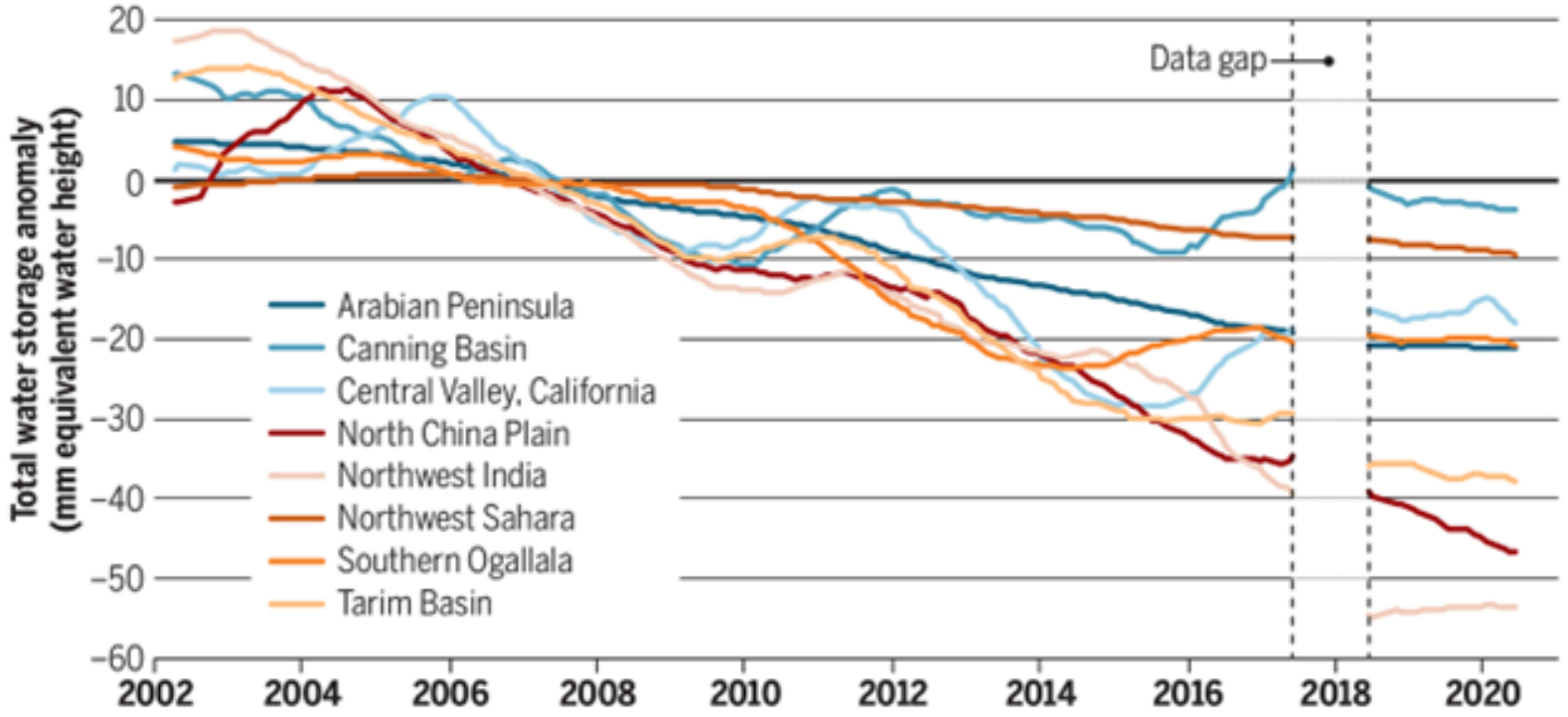
- Purpose of the GRACE Satellites:
  - Tracking Earth's water movement
  - Monitor changes in…
    - Underground water storage
    - Amount of water in lakes and rivers
    - Soil moisture
    - Ice sheets
    - Glaciers
    - Sea level

GRACE-1FO and GRACE-2FO



Artist rendition by NASA

Watching groundwater depletion from the sky



From *The Hidden Crisis Beneath our Feet*
Original graphic by David Ferris, University of Saskatchewan

- Includes several regions within mid-latitude aquifer systems
- Data collection:
  - GRACE: March 2002 to October 2017
  - GRACE-FO: May 2018 to June 2020

What is the graph showing us?

Is there a general trend?

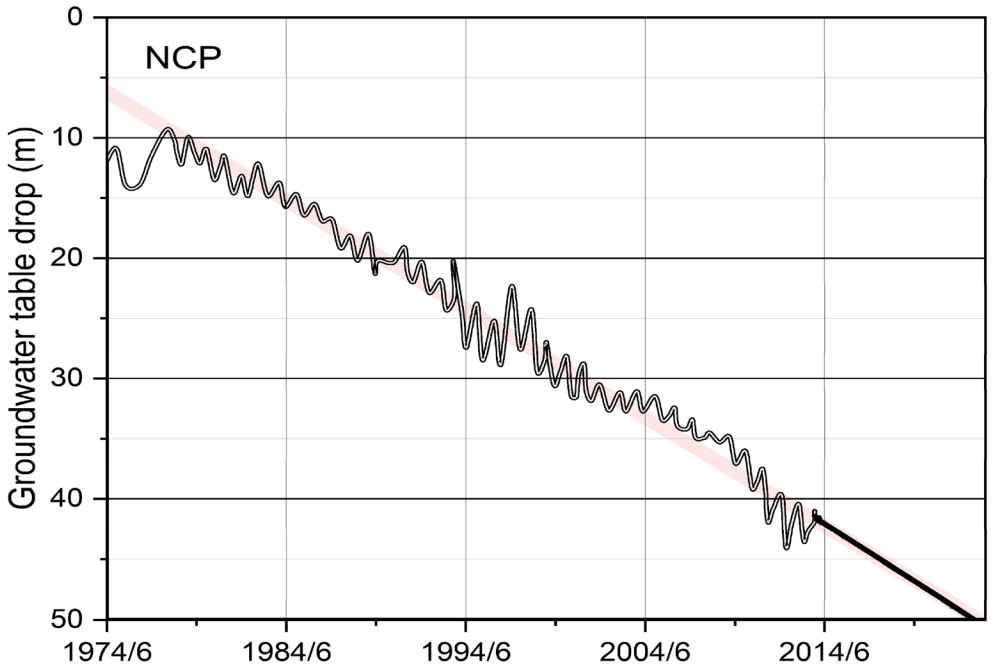
Any particular regions having it worse than others?

Groundwater Depletion in the North China Plain

- Depletion and degradation as a result of…
  - _____
  - _____

- Review by Du et al. (2024)
  - Aquifer system consist of 4 layers
  - Fulfills 60% of drinking water requirements
  - Used for 70% of irrigation
  - Groundwater pumping exceeds recharge
    - Low recharge = low P, high ET
    - First aquifer is already depleted
    - Second aquifer nearing depletion
  - ”World’s fastest depleting groundwater region”

Historical Groundwater Water Table Drop in the NCP



Graphic by Du et al. (2024), adapted from
doi: https://doi.org/10.1371/journal.pone.0115269.g004

Limitations with GRACE

- What GRACE can do: Identify large-scale trends in groundwater storage changes

- What GRACE can't do: Measure water table height and fluctuations

- Out of sight, making it difficult to observe groundwater…
  - Difficulties in characterizing the hydraulic properties of the subsurface
  - Need breakthroughs in characterization and monitoring of groundwater systems

- The key challenge in groundwater hydrology
  - Understanding when and where wells might go dry
  - Predicting changes in water levels

Consequences of Groundwater Depletion

- What does groundwater depletion mean?
  - _____
  - _____
  - _____

- Consequences:
  - Major threats to food production and security
  - Adversely affects the health and livelihoods of people who depend on groundwater
    - Famiglietti and Ferguson bring up the potential for civil unrest
  - Groundwater depletion itself

Paper by Jasechko and Perrone (2021)

- Groundwater level decline observed globally
  - Agriculture?
  - People?

- Outline of study:
  - ~39 million wells
  - Each contains a record:
    - Location
    - Depth
    - Purpose
    - Construction date
  - Understand spatiotemporal patterns

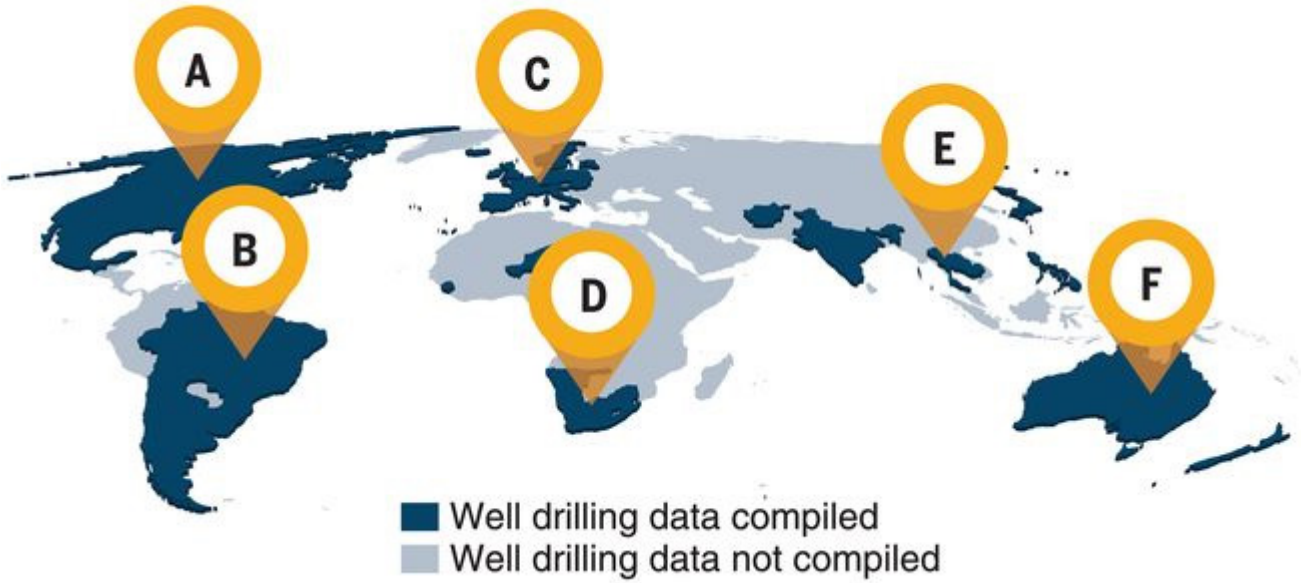


Image by Jasechko and Perrone (2021)

- Things of note:
  - Groundwater data is difficult to obtain
  - Wells represent 40% of global ice-free land
  - Half of global groundwater pumping within areas of study

Paper by Jasechko and Perrone (2021)

Results and/or findings:

- ___% to ___% of wells affected if water table declines by a few meters
- Some shallow wells may run dry because of _____ and _____
- Generally, newer wells are constructed _____ than older wells.

Paper by Jasechko and Perrone (2021)

- Jasechko and Perrone list some solutions to a well running dry:
  - _____
  - _____
  - _____
  - _____
  - _____
- What about _____?

- _____ → We will explore these two further

The Global Groundwater Crisis

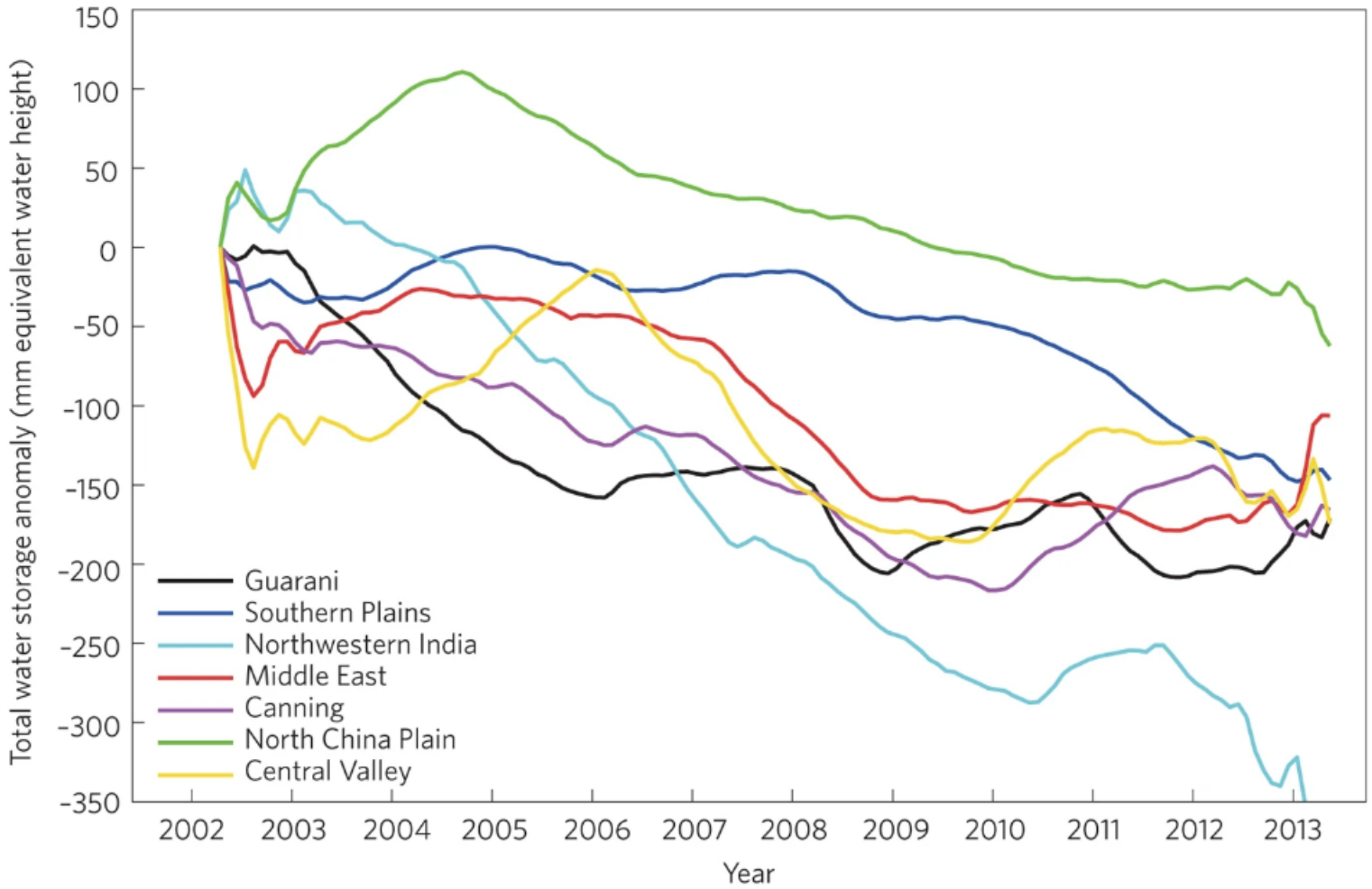
- Importance of groundwater
  - Accounts for ___% of total water withdrawals worldwide
  - Again, contributes half of irrigation water globally
  - *The savings account*

- However, despite its importance, groundwater is poorly managed and monitored
  - Insufficient attention compared to surface water
  - *Out of sight, out of mind*

“Groundwater depletion the world over poses a far greater threat to global water security than is currently acknowledged”

Figure 2: Water storage declines (mm equivalent water height) in several of the world's major aquifers in Earth's arid and semi-arid mid-latitudes, derived from the NASA GRACE satellite mission.

From: The global groundwater crisis



The Global Groundwater Crisis

- Issues stemming from poor and/or insufficient management of groundwater:
  - “Free for all” – Those who can, will
  - Productivity fueled by unsustainable consumption

- Drivers of groundwater depletion
  - Rate of groundwater pumping exceeds rate of recharge. Why?
    - _____
    - _____
    - _____
  - Climate change
    - Changing patterns of precipitation
    - Increasing frequency and severity of extreme events
    - “Wet gets wetter, and dry gets drier”

The Global Groundwater Crisis

Consequences of groundwater depletion:

- Decreasing freshwater availability
  - Drinking water
- Need to dig deeper wells
  - Can get expensive and physically infeasible
  - Accessible only to the relatively wealthy
- Impacts on agriculture
  - Irrigation
- Other unintended consequences:
  - Land surface subsidence
  - Saltwater intrusion
  - Sea-level rise
  - Streamflow depletion
  - Loss of springs
  - Loss of wetlands
  - Ecological damages
  - Climate feedbacks from irrigation

The Path to Groundwater Sustainability

- Challenges to be addressed:
  - Effective management
  - Definition of groundwater sustainability
  - Governance
- Governance is especially important
  - Major aquifer systems are regional and transboundary
  - New institutions and networks on a global scale
  - A global coordinating body to…
    - Share knowledge, tools, and best practices
    - Raise the importance of groundwater with respect to SDGs

Image by the United Nations
Department of Economic and Social Affairs

Bringing Everything Together

- What needs to be done to ensure groundwater sustainability?
  - AT 18: Question 3b
  - Famiglietti states five essential steps that warrant “immediate, international” attention if we want to manage our way through the global groundwater crisis

- 1.)

- Implicit in the 1st step is the need for _____

- 2.)
- 3.)

- 4.)

- 5.)

The global economy, geopolitics, and the water-energy-food nexus are intertwined

To tackle the issue of groundwater sustainability, we need to address…