Water Resources and Climate: An Overview

Lecture 1

JAN 13th 2021
Water is a fundamental resource

- ..... for all life on earth
- It is the key feature of extreme events such as drought and floods
- Its abundance and timely delivery are critical for meeting societal and ecological demands
- Water resources are critical to sustainable development and poverty reduction
Widespread flooding from severe December 2015 rainfall affected large sections of the central and southern United States. Stress on the Nation's major rivers continued into 2016, as portions of the Ohio River, Missouri River, and Mississippi River threatened to match or exceed 2011 levels.
Too much – or too little of water – makes headlines

- 2019 Midwestern U.S. floods
- March 2018 and March 2019 side-by-side comparison of the Omaha–Council Bluffs metropolitan area showing effects of flooding of the Platte and Missouri Rivers.

Too much – or too little of water – makes headlines

- 2011–2017 California drought
Too much – or too little of water – makes headlines

- **2011–2017 California drought.**
  - A historic event in its severity and longevity.
  - California had only received 33 inches of precipitation, rather than the typical 53 inches over the same 30-month timeframe.
  - Caused over $5 billion in damage to agriculture alone
  - Substantial impacts to fisheries, soil health and infrastructure, depleting water reservoir storage, and drying out vegetation which increased wildfire danger.
• **2017 Pacific Winter Floods.**
  
  • Caused by widespread rains across California and western Nevada..
  
  • Northern California flooded from Gilroy to Sacramento.
  
  • "If we had a catastrophic disaster that takes down the California economy, that is a problem of national significance," former USGS Director Macia McNutt told the New York Times, emphasizing the financial cost to the entire country.

  • In 2011, the USGS released their report on the ARKstorm Scenario. The “AR” in “ARK” stand for “atmospheric river,” a weather phenomena in which a band of moisture floats through the air. In all, 25 percent of the state could end up submerged. [“Think of an atmospheric river as a fire hose that funnels moisture from the tropical Pacific towards California,” ]
Too much – or too little of water – makes headlines

- **2019 drought in eastern Australia** so depleted the wheat crop that it had to be imported for the first time in 12 years.

Murray-Darling water reserves
Water Resources Related Issues Are.....

- Natural
- Manmade
Water management is not on a sustainable track...

- About 2.2 billion people around the world do not have safely-managed drinking water (WHO/UNICEF 2017). In the future, by the year 2050, their number could reach 3 billion.
- 4.5 billion people lack safely managed sanitation services (WHO/UNICEF 2017).
- 3 billion lack basic handwashing facilities (UNICEF/WHO).
- 340,000 children under 5 die every year from diarrheal diseases (WHO/UNICEF 2015).
- Water scarcity already affects 4 out of every 10 people (WHO).
Water management is not on a sustainable track...

- 90% of all natural disasters are water-related (UNISDR)
- 80% of wastewater flows back into the ecosystem without being treated or reused (UNESCO, 2017)
- Around two-thirds of the world’s transboundary rivers do not have a cooperative management framework
- Agriculture accounts for 70% of global water withdrawal (FAO)
- Roughly 75% of all industrial water withdrawals are used for energy production (UNESCO, 2014)
“Water Resources Security”

“The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.”

--- UN-Water’2013
Key Questions

• Where is the water available around the globe?

• When is water available around the globe?

• How much of, and how are those patterns changing?

• How best to get water into the hands of the people who need it?
Forces Driving Water Resources

Security of water resources, storage, and access are guided by an improved understanding of the forces that are affecting and changing water security at local to large scales.
• Water/Hydrological cycle describes the pilgrimage of water as water molecules make their way from the Earth’s surface and subsurface to the atmosphere and oceans, and back again.

• The water cycle is a gigantic system that is powered by energy from the Sun (heating)
Water on Earth is present in **three phases**

- **In liquid form**, precipitation meets basic water demands by humans, animals, and plants
- **It runoffs** into streams & sustains ecosystems
- **Along with percolation** into aquifers, ensures long term storage and supply for human uses
- **The oceans are** the world's primary source of atmospheric **water vapor (gas)** that feeds precipitation
- **In water's frozen (solid) form**: sea ice, snow cover, and glaciers, especially those at mid-latitudes, provide water storage and summer supply for both agriculture and urban areas around the world
Components of the water cycle

Storage units + Transport

**Storage (reservoirs/pools)**

- Oceans
- Cryosphere – polar icecaps, glaciers, permanent snow
- Groundwater (soil moisture, aquifers)
- Surface liquid water (lakes, rivers, streams)
- Atmospheric water (air moisture/water vapor)

**Transport processes**

- evaporation
- transpiration
- sublimation
- condensation
- melting
- streamflow, surface runoff
- infiltration, percolation
- groundwater flow, runoff
- advection
- precipitation
How much water is held by every storage system?

– (Oceans – Cryosphere – Groundwater systems – Surface Liquid Water Systems – Atmosphere)
Earth’s water distribution

Overall distribution

- Oceans ~ 97%
- Fresh water ~ 2.5%
  - ~69% in glaciers and icecaps
  - ~30% underground
  - ~1.2% is surface water, serving most of life’s needs
    - Mostly in ground ice
    - ~21% in lakes
    - ~0.5% in rivers

Humans get a large portion of their water from rivers!
All water

All liquid freshwater (including surface and groundwater)

Freshwater in lakes and rivers

~75% of the earth’s surface is covered by water (mainly the oceans)

http://ga.water.usgs.gov/edu/earthhowmuch.html
And **freshwater** is not homogeneously distributed..

(Source: http://www.unep.org/dewa/vitalwater/index.html)
How is the Earth’s freshwater distributed?

**Surface Water Availability in Major Rivers**

**Basin:** Land area where surface water from *precipitation and runoff* converges at a single point at a lower elevation. Sub-basins can be defined for specific rivers.

**Watershed**
relevant unit for ecology and resource management

![Major River Basins of the World](image)
<table>
<thead>
<tr>
<th>River</th>
<th>Location</th>
<th>Area of discharge basin (km²)</th>
<th>Drainage rate (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Amazon</td>
<td>South America</td>
<td>6,150,000</td>
<td>175,000</td>
</tr>
<tr>
<td>2. Congo</td>
<td>Africa</td>
<td>3,822,000</td>
<td>39,000</td>
</tr>
<tr>
<td>3. Mississippi</td>
<td>North America</td>
<td>3,222,000</td>
<td>17,270</td>
</tr>
<tr>
<td>4. La Plata</td>
<td>South America</td>
<td>3,100,000</td>
<td>22,900</td>
</tr>
<tr>
<td>5. Nile</td>
<td>Africa</td>
<td>2,802,000</td>
<td>3,000</td>
</tr>
<tr>
<td>6. Yenisey/Yenisei</td>
<td>Russia</td>
<td>2,619,000</td>
<td>18,000</td>
</tr>
<tr>
<td>7. Lena</td>
<td>Russia</td>
<td>2,478,000</td>
<td>16,000</td>
</tr>
<tr>
<td>8. Ob-Irtysh</td>
<td>Russia</td>
<td>2,470,000</td>
<td>10,000</td>
</tr>
<tr>
<td>9. Niger</td>
<td>Africa</td>
<td>2,092,000</td>
<td>5,700</td>
</tr>
<tr>
<td>10. Amur</td>
<td>North Asia</td>
<td>2,050,000</td>
<td>9,800</td>
</tr>
</tbody>
</table>

Source: UNEP – please notice that these numbers vary according to the source
Aquifers: Pools of storage for groundwater. They are composed of permeable rock or unconsolidated geologic material (gravel, sand, silt). Aquifers are recharged by surface water.

Regional aquifer systems

Aquifers are major sources of freshwater resource!
Water transport processes

Water Budget

--- An accounting of the inflow, outflow, and storage of water in a designated hydrologic system

--- balancing the gains and losses of water in the region with the quantities of water stored in the region

\[ \Delta S = \text{inflow} - \text{outflow} \]

\( \Delta S \): changes in water storage

\( \Delta S = 0 \) (steady state)
\[ \Delta S = \text{inflow} - \text{outflow} \]

\[ \Delta S = (P + iA + iR) - (oA + oR + T + E + D) \]

- \( \Delta S \): changes in water storage
- \( P \): precipitation (rain and snow)
- \( E \): evaporation
- \( T \): transpiration
- \( A \): moisture advection
- \( R \): runoff
- \( D \): drainage
- \( i \): incoming
- \( o \): outgoing

For the Earth’s budget:

\[ \Delta S = 0 \]

\text{inflow} = \text{outflow}
What is wrong with this diagram?
$\Delta S = \text{inflow} - \text{outflow}$

$\Delta S = (P + iA + iR) - (oA + oR + T + E + D)$

$\Delta S$: changes in water storage
P: precipitation (rain and snow)
E: evaporation
T: transpiration
A: moisture advection
R: runoff
D: drainage
i: incoming
o: outgoing

For the Earth’s budget:

$\Delta S = 0$

inflow = outflow
and...there are more transport processes involved in the water cycle ...

Where is the Human?
Water residence time (RT): How long would a water molecule “reside” within a hydrological storage unit?

The residence time represents the average amount of time that a water particle spends in a given reservoir (e.g., atmosphere, oceans, etc.)

**Storage vs. Flux**

Why is RT important?

Even a small unbalanced flow (inflow different from outflow) can have an impact on the reservoir’s resources.
Example: RT of water in the atmosphere

residence time = \( \frac{\text{size of pool}}{\text{flux}} \)  

e.g., global precipitation

global mean residence time of atmospheric water  
\( \sim 8.9 \pm 0.4 \text{ days} \) (uncertainty given as 1 standard deviation).
Example: RT of water in the oceans

\[
\text{residence time} = \frac{\text{size of pool}}{\text{flux}} + \text{precipitation over oceans + river discharges}
\]

\[
\text{residence time} \sim 3069 \text{ years}
\]
Different components of the hydrologic cycle will be more affected by different timescales...
READING FOR DISCUSSION

Oki & Kanae, 2006, Science
“Global Hydrological Cycles and World Water Resources”

Jan 20th