The quantity of fresh water: sources, consumption and prospects for sustainable use

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Columbia University
How much water is there

- Where
  - Key reservoirs
  - Geographic distribution
  - Stores and Fluxes
  - Renewable or Fossil
- How does its availability vary in time
  - Seasonality
  - Climate Change and Variability
What are the stores of water and how big are they?

A World of Salt
Total Global Saltwater and Freshwater Estimates

Saltwater
97.5%
1 365 000 000 km³

Freshwater
2.5%
35 000 000 km³

0.3% Lakes and river storage
30.8% Groundwater, including soil moisture, swamp water and permafrost
68.9% Glaciers and permanent snow cover

What are the annual fluxes?

How much renewable water do we have?

Principal sources of renewable fresh water

Rain ➔ highly variable in space & time
Storage, but can’t change supply
Climate change = involuntary supply change?
Groundwater residence time is very long, storage is typically high and flux is low. Renewable, but at very long time scales. Seasonal variability of deep groundwater is low. Reliable source if available → mined; also contamination is slow to flush.
Availability of groundwater is highly spatially variable. We have a general classification, but not precise estimates of the quality and quantity of groundwater available.
Renewable per capita per year

Availability of Freshwater in 2000
Average River Flows and Groundwater Recharge

Countries with the least freshwater resources
- Egypt: 26
- United Arab Emirates: 61

Countries with the most freshwater resources
- Suriname: 479 000
- Iceland: 605 000

Significant variability over the year in water availability – how to manage?
El Niño – source of seasonal to interannual variability that may be predictable.
Monsoon Rainfall Index

Red = warm NINO3 SSTA - El Niño
Blue = cold NINO3 SSTA - La Niña
How much do we use/stress

- Needs – Quantity and Quality
  - Domestic
  - Municipal and Industrial/Energy production
  - Agriculture
  - Pollution Dilution

- Usage and Supply-Demand Imbalance
  - Current
  - Projected
    - Population Increase
    - Climate Change
Basic daily water requirement (BWR)

- 50 L.cap\(^{-1}\).d\(^{-1}\) (drinking, sanitation, cooking)
- BWR does not take into account other uses of water (e.g. agriculture, ecosystem protection, industry) and represents only ~ 20 m\(^3\).cap\(^{-1}\).y\(^{-1}\)
- In 2000, 61 countries, with combined populations of 2.1 billion people, were using less than the BWR.
- By 2050, 4.2 billion people (over 45 per cent of the global total) will be living in countries below the BWR standard.

Access correlates with use →
- Household Connection: 150 to 700 L.cap\(^{-1}\).d\(^{-1}\)
- Standpipe (<1 km from home): 20 L.cap\(^{-1}\).d\(^{-1}\)
- Standpipe (>1 km from home): 10 L.cap\(^{-1}\).d\(^{-1}\)
- New York Area: 400 L.cap\(^{-1}\).d\(^{-1}\)
Water consumed for some things

- Toilet 6-30 liters
- Dishwasher per load 40 to 120
- Shower head per minute 6-30
- Agricultural items
  - One egg 150
  - Glass of milk 380
  - 1lb rice 2120
  - 1lb beef 3030
  - 1lb cotton 7730
Global Water Withdrawal and Consumption

Withdrawal = Consumption + Return

Quality of return?
Note: Domestic water consumption in developed countries (500-800 litres per person per day) is about six times greater than in developing countries (60-150 litres per person per day).
Water Availability

- 1.7 x decrease
- 4.5 x decrease
- 7.5 x decrease
Contemporary Population Relative to Demand per Discharge Stress Threshold (DIA/Q = 0.4)

Fig. 1. The global distribution of population in 1985 with respect to the relative water stress threshold of DIA/Q = 0.4 indicating severe water scarcity (10). A 30° spatial resolution is used. This mapping reflects a mean global runoff of ~40,000 km² year⁻¹ and aggregate water withdrawals of 3100 km³ year⁻¹. These estimates are highly dependent on contemporary water use statistics, which reflect a degree of uncertainty. Recent reviews (5, 36) show year 2000 global water withdrawals from assessments made even as late as 1987 to vary by >1300 km² year⁻¹. National-level water use statistics (18) for some countries are decades old. Runoff estimates for some regions may also be biased (9,13). Results should be viewed with appropriate caution.
Climate change the bogeyman or is it just people?

We are increasingly mining and evaporating water and changing land cover \(\rightarrow\) potentially major feedbacks to climate through changes in water vapor – a greenhouse gas. What this component of human forcing will do is still unclear.

Fig 3. Maps of the change in water reuse index \(\Delta DIA/Q\) predicted by the CGCM1/WBM model configuration under Sc1 (climate change alone), Sc2 (population and economic development only), and Sc3 (both effects). Changes in the ratio of scenario-specific \(\Delta DIA/Q\) to contemporary \(\Delta DIA/Q_{base}\) are shown. A threshold of \(\pm 20\%\) is used to highlight areas of substantial change.
What are the choices?

- Temporal Imbalance
  - Storage (Seasonal to Multi-Year) – ecological/social impacts

- Spatial Imbalance
  - Conveyance – ecological/social impacts

- Chronic Deficit
  - Conservation/Demand Management - limits
  - Migration – social impacts
  - Purification/Desalination/Reuse – Energy constrained
  - Groundwater Mining – energy/ecological impacts
Climate Variability & Growth

Kenya: variability & shock

<table>
<thead>
<tr>
<th>Event</th>
<th>Injury/Effect</th>
<th>Cost (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/97 - 2/98</td>
<td>Flood</td>
<td></td>
</tr>
<tr>
<td>10/98 - 5/00</td>
<td>Drought</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Infrastructure Damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Crop loss</td>
<td>$0.24 b</td>
</tr>
<tr>
<td></td>
<td>Livestock loss</td>
<td>$0.14 b</td>
</tr>
<tr>
<td></td>
<td>Reduction in hydropower</td>
<td>$0.64 b</td>
</tr>
<tr>
<td></td>
<td>Reduced industrial prod.</td>
<td>$1.39 b</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>$2.41 b</td>
</tr>
<tr>
<td>10/97 - 05/00</td>
<td>Cost of Climate Variability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Approx (annual) GDP</td>
<td>($9 b/yr)</td>
</tr>
<tr>
<td></td>
<td>Impact as % GDP/annum</td>
<td>22%</td>
</tr>
</tbody>
</table>

Kenya: variability & shock

Natural legacy:
extreme climate variability

Slide by Grey & Sadoff
75,000 dams in the continental United States
Av. Storage ~ mean annual flow
West dams > 3 year’s runoff
N. East and N. West ~ 25% of ann. flow.

Area per dam varies from 44 km²
(17 miles²) per dam in New England to 811 km² (313 miles²) per dam in the Lower Colorado basin.
Storage volumes, range from 26,200 m³/km² in the Great Basin to 345,000 m³/km² in the South Atlantic

The nation’s dams store 5000 m³ (4 acre-feet) of water per person.
Dams provide multiple benefits – water supply, recreation, energy, flood control, etc.

Dams change the timing and availability of downstream flows leading to higher vulnerability/sensitivity and impact downstream.

Cumulative effects of dams on flows, ecology and biogeochemistry.
### Water storage and the poverty trap

<table>
<thead>
<tr>
<th>Country</th>
<th>Water Storage (m³/cap)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethiopia</td>
<td>43</td>
</tr>
<tr>
<td>South Africa</td>
<td>746</td>
</tr>
<tr>
<td>Thailand</td>
<td>1,287</td>
</tr>
<tr>
<td>Laos</td>
<td>1,406</td>
</tr>
<tr>
<td>China</td>
<td>2,486</td>
</tr>
<tr>
<td>Brazil</td>
<td>3,255</td>
</tr>
<tr>
<td>Australia</td>
<td>4,729</td>
</tr>
<tr>
<td>North America</td>
<td>6,150</td>
</tr>
</tbody>
</table>

- Stable pop. & GDP, raising Ethiopia’s storage to South Africa (12% of USA) ~ 6 × GDP
- Or 5% of GDP for over 100 yrs
Irrigation can lift rural poor out of poverty

Average income levels & irrigation intensity in India
<table>
<thead>
<tr>
<th>Country</th>
<th>Renewable freshwater</th>
<th>Total withdrawals</th>
<th>Sectoral withdrawals (% of total withdrawals)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m³/capita</td>
<td>km³</td>
<td></td>
</tr>
<tr>
<td>Bangladesh</td>
<td>813</td>
<td>105.0</td>
<td>14.64</td>
</tr>
<tr>
<td>Bhutan</td>
<td>44,728</td>
<td>95.0</td>
<td>0.002</td>
</tr>
<tr>
<td>India</td>
<td>1,244</td>
<td>1260.6</td>
<td>500.00</td>
</tr>
<tr>
<td>Nepal</td>
<td>8,282</td>
<td>198.2</td>
<td>29.00</td>
</tr>
<tr>
<td>Pakistan</td>
<td>541</td>
<td>84.7</td>
<td>155.60</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>2,656</td>
<td>50.0</td>
<td>9.77</td>
</tr>
</tbody>
</table>
Waterlogging, salinization and deep groundwater decline
Human modification of global water vapor flows from the land surface

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Fig. 4. Spatial distribution of net changes in vapor flows between potential vegetation and actual deforested and irrigated vegetation in mm/yr. The aggregated global change as compared with the potential vegetation is small (400 km³/yr), but the map illustrates the large spatial redistribution of water vapor flows from the land surface at the global scale.
Figure 93. Land subsidence has affected large areas of the Central Valley. Most of the subsidence is the result of compaction of fine-grained sediments, which has been caused by large withdrawals of ground water.

Figure 94. Some of the most severe recorded land subsidence in history occurred in the western San Joaquin Valley near Mendota, where the land surface has subsided nearly 30 feet.

A $160 billion project to link all major Indian Rivers

India, China, Brazil still considering Mega storage projects
Agriculture

- “Agricultural Water Productivity has increased at least 100% in the last 40 years” -- Renault, 2003
- Food storage generates real water savings.
  - For example, in the Syrian Arab Republic, 1988 was a surplus year for the cereal production with 1.9 million tonnes of cereals stored
  - 1989 was very dry, and 1.2 million tonnes of cereals were then withdrawn from storage. Based on the water productivities recorded for these years (Oweis, 1997), this is equivalent to 4000 million m$^3$ of virtual water.
- Global virtual water trade:
  450 km$^3$ in 1961 to 1 340 km$^3$ in 2000 equal to 26 percent of the total water required for food
Swaminathan Foundation –
Genomics to the rescue: Mangrove and Salt Tolerant Wild Rice Genes splices on to rice and other crops

The ever-Green Revolution

Approaches to breeding for salinity tolerance - a case study on Porteresia coarctata

By R LATHA, C SRINIVAS RAO, H M SR SUBRAMANIAM, P EGANATHAN and M S SWAMINATHAN

Fig. 1. Porteresia habitat
Aerobic Rice Cultivation – no transplanting → direct seeding + watering every 15-20 days ==30 to 60% water saving same yield
Design and Sustainability Assessment of Scenarios of Urban Water Infrastructure Systems

Harald Hiessl, Rainer Walz, Dominik Toussaint
Figure 2: AKWA-2100 scenario “Municipal Water Reuse”
Desalination

Table 1. Desalination processes.

<table>
<thead>
<tr>
<th>Phase-change processes</th>
<th>Membrane processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Multi-stage flash (MSF)</td>
<td>1. Reverse osmosis (RO)</td>
</tr>
<tr>
<td>2. Multiple effect boiling (MEB)</td>
<td>— RO without energy recovery</td>
</tr>
<tr>
<td>3. Vapour compression (VC)</td>
<td>— RO with energy recovery (ER–RO)</td>
</tr>
<tr>
<td>4. Freezing</td>
<td>2. Electrodialysis (ED)</td>
</tr>
<tr>
<td>5. Solar stills</td>
<td></td>
</tr>
<tr>
<td>— conventional stills</td>
<td></td>
</tr>
<tr>
<td>— special stills</td>
<td></td>
</tr>
<tr>
<td>— wick-type stills</td>
<td></td>
</tr>
<tr>
<td>— multiple-wick-type stills</td>
<td></td>
</tr>
</tbody>
</table>

Can clean up bio and chemical pollutants
Significant Energy Cost ~ 40%, 1m$^3$/day = 1 ton oil/year
Evaporative (heating) or membrane (pressure)
Solar (heating) wind (mechanical)
Electricity generation efficiency from Solar (PV or Concentrator) is only ~10 to 15%
Thermal from Solar could be 80 to 90% efficient
Solves Wind/Solar Energy storage problem also
Desalination/ Pasteurization for Drinking water from contaminated Water
Summary

- Water Stress is a current global problem. As population increases, it will be critical for large areas in the next 10-20 years. Climate change may compound this problem. Water Quality degradation will add to it.

- More challenging than the CO$_2$ problem in that stimulus and impacts are perceived as local. No one technological or policy fix. Virtual water issues map to global impacts from national agricultural policies.

- Solutions at different scales are emerging, both technical and policy. By 2030-2050, we need these to be in place. Bold measures need to be developed and tested now:
  - Agricultural productivity increase + use regulation
    - Storage, Irrigation, Crop Choice / Seed Improvement, Tillage
    - Use of Brackish waters
  - Better Management through Economics – transfers, pricing, insurance, financing
  - Solar-thermal and wind based energy technologies applied to water reuse/desalination
  - General conservation and climate informed optimization of use of surface and ground waters
  - Asian/African developing countries and the Middle/Near-East need an accelerated implementation program