Water Cycle, Freshwater Availability and Distribution: the Major Challenges for Water in the Next 100 Years

Alberto Montanari
University of Bologna - Italy
Premise: water is with us, but it is not easy to understand

Flood occurred at Barcellona di Pozzo di Gotto (Sicily) on Nov 26, 2011
The Lake Aral Disaster
The Lake Aral Disaster

July - September, 1989  August 12, 2003
The Lake Aral Disaster


This presentation is available at the web address http://www.albertomontanari.it – E-mail: alberto.montanari@unibo.it
Humans only recently started to study water

Until the Middle Age (around 1600 AD) flow in rivers was assumed to mainly come from groundwater and only marginally from rainfall. This was an ancient theory that is attributed to Aristotelis.

Only some 400 years ago an Italian abbé, Benedetto Castelli, postulated that water balance on the Earth is mainly driven by rainfall input. He proved his theory by measuring rainfall with a glass and using the collected data to reconstruct the inflow to the Lake Trasimeno, located in Central Italy.

Curiously, no one had the idea of observing rainfall and river flows before. Humans started observing stars more than 5000 years ago, but waited until 400 years ago to observe water (with the exception of ancient civilizations, like Egyptians, that collected a few observations of water levels).
We wish we started before....

The results is that humans do not have long records of water observations (meteorology, water resources....).

The longest rainfall series today available is the one collected in Padua (Italy), which was observed every day from 1725 (with only a few missing values up to today).

If we had longer observation records, we would not spend much time discussing about climate change, water resources variability and so forth.
What is hydrology? It is the science of the water cycle

From Wikipedia:
Hydrology is the study of the movement, distribution, and quality of water on Earth and other planets, including the hydrologic cycle, water resources and environmental watershed sustainability (http://en.wikipedia.org/wiki/Hydrology)

Image from: http://ga.water.usgs.gov/edu/watercycle.html
Hydrological cycle

Image from: http://ga.water.usgs.gov/edu/watercycle.html
Hydrological cycle

There are many details of the water cycle that are not fully known. For instance:

• How rainfall partitions into infiltration and overland flow?

• How does groundwater flow take place?

• What is the amount of direct fluxes of spring water into the oceans?

The watershed is still a partial mystery!
(Picture produced by NASA)
How rainfall partitions into infiltration and overland flow?

“Hortonian” mechanism of surface runoff formation
Infiltration excess
How rainfall partitions into infiltration and overland flow?

“Dunnian” mechanism of surface runoff formation
Saturation excess
How groundwater flows?

Groundwater flow can take millennia to develop!

Humans have an impact!
Some groundwater flows directly into the ocean...

- There is a considerable direct flux of groundwater into the oceans.
- Although hydrologists are trying to set up global models, at the current state of the art we can get a very rough estimate only of such fluxes.
- Yet, mathematical models of ocean circulation show that these fluxes are impacting the major stream like the Gulf Stream.
- Therefore these fluxes are impacting future climate.

Topical research fields: looking for drop paths….

- Tracer studies

Source: http://serc.carleton.edu/microbelife/research_methods/environ_sampling/hydrotrace.html
Topical research fields: looking for vegetation functioning
Topical research fields: analysis of human impact

• Sociohydrology

Source: courtesy by A. Sikorska - Warsaw University of Life Sciences
Socio-hydrology

Aquifers and wells

Groundwater exploitation
Irrigation: blue to green water diversion

Civil water use

Global warming
Climate change

Water quality control

Quality control of natural (water) environment

Prevention of sea water intrusion

Storage of reclaimed water

Advanced wastewater treatment

Separate usage of advanced waste water treatment

In situ reuse of reclaimed water

Groundwater recharge

Prevention of sea water intrusion

Chemical risk assessment

Heat island phenomena

Population congestion

Natural depuration

In situ reuse of reclaimed water

Recreational water

MBR plant

Industrial water

MBR plant

Community MBR

Industrial plant

Water recycle

Water treatment plan

Daily life water

Water quality control

Groundwater depletion

Groundwater usage

This presentation is available at the web address http://www.albertomontanari.it – E-mail: alberto.montanari@unibo.it
### How much water do we have?


<table>
<thead>
<tr>
<th>Water source</th>
<th>Water volume, in cubic kilometers</th>
<th>Percent of freshwater</th>
<th>Percent of total water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans, Seas, &amp; Bays</td>
<td>1,338,000,000</td>
<td>--</td>
<td>96.54</td>
</tr>
<tr>
<td>Ice caps, Glaciers, &amp; Permanent Snow</td>
<td>24,064,000</td>
<td>68.6</td>
<td>1.74</td>
</tr>
<tr>
<td>Ground water</td>
<td>23,400,000</td>
<td>--</td>
<td>1.69</td>
</tr>
<tr>
<td>Fresh</td>
<td>10,530,000</td>
<td>30.1</td>
<td>0.76</td>
</tr>
<tr>
<td>Saline</td>
<td>12,870,000</td>
<td>--</td>
<td>0.93</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>16,500</td>
<td>0.05</td>
<td>0.001</td>
</tr>
<tr>
<td>Ground Ice &amp; Permafrost</td>
<td>300,000</td>
<td>0.86</td>
<td>0.022</td>
</tr>
<tr>
<td>Lakes</td>
<td>176,400</td>
<td>--</td>
<td>0.013</td>
</tr>
<tr>
<td>Fresh</td>
<td>91,000</td>
<td>0.26</td>
<td>0.007</td>
</tr>
<tr>
<td>Saline</td>
<td>85,400</td>
<td>--</td>
<td>0.007</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>12,900</td>
<td>0.04</td>
<td>0.001</td>
</tr>
<tr>
<td>Swamp Water</td>
<td>11,470</td>
<td>0.03</td>
<td>0.0008</td>
</tr>
<tr>
<td>Rivers</td>
<td>2,120</td>
<td>0.006</td>
<td>0.0002</td>
</tr>
<tr>
<td>Biological Water</td>
<td>1,120</td>
<td>0.003</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

How much water do we have?

From http://ga.water.usgs.gov/edu/earthwherewater.html

Global water uses

Global water uses

Are these uses sustainable? The case of Po River (Italy)

- Precipitation: $78 \times 10^9$ m$^3$
- Civil and industrial use: $5 \times 10^9$ m$^3$
- Evapotranspiration: $22 \times 10^9$ m$^3$
- Discharge: $47 \times 10^9$ m$^3$
- Groundwater recharge: $9 \times 10^9$ m$^3$
- Irrigation: $17 \times 10^9$ m$^3$
- Groundwater withdrawal: $6.5 \times 10^9$ m$^3$

The current situation is sustainable but there are concerns for the future.
Are these uses sustainable?

The size of the symbols is proportional to total population of the country.

Question: is freshwater availability enough to satisfy these countries?

The answer depends on A and B:

A: Percentage of freshwater availability that can be effectively withdrawn

B: Water needs for human use.
The Italian picture:

Italy is efficient in exploiting water and has moderate water needs.

The situation of Italy is matched and reflects reduced margins to ensure sustainability in the future.
Are these uses sustainable?

What happens if the water use is less efficient?

Countries located below the blue line need to be very efficient in water use.
Are these uses sustainable in the face of climate change and increasing population?

Climate change is potentially much influential.
Conclusions

• Hydrology is a young science; many of the processes taking place in the water cycle are still not known.

• Hydrology is a very fertile science, and hydrologists feel a profound sense of community.

• Focused research is needed to address the world water problem. Water is a priority!

• Climate change is related to water, and conditions water availability in the future. Water will be a priority, no matter of climate change.

• Everyone of us needs to better learn about water. Only with an increasing and public awareness of water dynamics we can improve our efficiency in planning water uses. Please help us to spread water knowledge among the public.
Thank you!