Water and People

Tufts University

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Tufts University
Medford, MA

Environmental Studies
Lunch & Learn
Oct 20, 2011

[Image of children carrying water vessels on their heads]
Outline

Emerging Issues:
Water and People: Some Big Problems
Water Supply – Boston Metro Region
Water and Urbanization
Water and Climate
Water and Food
Water and Human Water Use
Outline

Emerging Issues:

→ Water and People: An Intro to some big problems

Water and Health
Water Supply – NYC and Boston
Water and Urbanization
Water and Climate
Water and Food
Water and Human Water Use
Water and People: Why do people know so little about water?

Hydrologic science is an interdisciplinary science which involves the interfaces among earth, ocean and atmospheric sciences.

Hydrology is a geoscience

Why isn’t it taught like geology, biology, meteorology, or chemistry?
Water Problems are Human Problems

Global Population Growth

Population in Billions

YEAR (AD)
Water Problems Result From Human Influences and they are Ramping Up
Water and People

Water Pollution and Water Scarcity

Are the two biggest water challenges of the 21st Century
Water and People

Today, 1 out of 6 people, more than a billion

Suffer from inadequate access to safe freshwater
Who are the people lacking improved water? Where do they live? Rural areas...
Imagine yourself with nowhere to go to the toilet!!!!

- The conditions here are terrible. There is sewage everywhere. It pollutes our water. Most people use buckets and plastic bags for toilets. Our children suffer all the time from diarrhea and other diseases because it is so filthy. Mary Akinyi, Kibera, Nairobi, Kenya [UNDP 2006]
Irrigation can lift rural poor out of poverty

Average income levels & irrigation intensity in India

From U. Lall, Columbia Univ
Outline

Emerging Issues:
Water and People

→ Water Supply – Boston
Water and Urbanization
Water and Climate
Water and Food
Water and Human Water Use
Wet History of Boston

1630 – Boston Settled, water supply from spring near Boston Common
US Cities Devoted Huge Resources to Clean Water

When water from Lake Cochituate flowed into the Frog Pond on Boston Common in 1848, the dedication ceremony drew 100,000 people and was declared a public holiday.
Panoramic View of Ruins of Bostons Great Fire of 1872

Brought fire steamers to Boston from Portsmouth, N.H.
And
Led to Wachusett/Quabbin Reservoir System
The Mystic Lakes System

- In 1870 the Mystic Lakes System in Winchester, Medford and Arlington was added to the Boston System.
In 1870, the Mystic Lakes system was connected to the distribution system at Tufts University.

Old reservoir on Tufts hill, lined with brick.

Old bricks used to construct Bray Hall on Boston Ave using student labor.
Mystic Reservoir at Tufts College

Reservoir and Gatehouse
At Tufts, 1898. Reservoir was called the REZ
Mystic Reservoir at Tufts College

West Hall Dorm Built in 1871

Ballou Hall Built 1850
Mystic Reservoir at Tufts College

Parking Lot Which Replaced the REZ
Pumphouse at Chestnut Hill

Water Sources in 1895, Lake Cochituate, Sudbury Reservoirs, Mystic Lakes
Growth in Metro Boston Water Supply System

System Yield in Millions of Gallons per Day

Lake Cochituate  Mystic Lakes  Sudbury System  Wachusett Reservoir  Quabbin Reservoir
General Plan of the MWRA/MDC Water Supply System
NYC Water Supply System

Today
Quabbin Reservoir
You Couldn’t Do It Today

- 4 towns removed and legally dissolved
- 39 square miles flooded
- 2,000 residents relocated
- 1,000 buildings destroyed
- 34 cemeteries relocated
- 81,000 acres purchased for $9.6 million
- $53 million total project costs
- 26 lives lost during construction
Original Towns Eliminated by Quabbin
Moving Homes to Build Quabbin
Town Hall from Enfield still stands, but town is now gone
Old Cemeteries had to be moved
QUABBIN PARK CEMETERY
ESTABLISHED A.D. 1932
FOR MONUMENTS, HEADSTONES AND BODIES REMOVED FROM CEMETERIES ABOLISHED ON ACCOUNT OF THE CONSTRUCTION OF QUABBIN RESERVOIR

BY THE
METROPOLITAN DISTRICT WATER SUPPLY COMMISSION
COMMISSIONERS
DAVIS B. KENISTON, EUGENE C. HULTMAN
ASSOCIATE COMMISSIONERS
CHARLES M. DAVENPORT, JOSEPH H. SOLIDAY
THOMAS B. LAVELLE, EDWARD J. KELLEY
R. NELSON MOLT, SECRETARY
FRANK E. WINSOR, CHIEF ENGINEER

View of Bronze Tablet at entrance of Quabbin Park Cemetery
3/9/48 Photo Albertine 2887
Quabbin Park Cemetery
First water released from Winsor Dam
Early Projections of Water Demand Were Upward Biased
1895 Projections Led to Evaluation of Alternatives

Table 4. 1895 Evaluation of Water Supply Alternatives

<table>
<thead>
<tr>
<th>1895 ALTERNATIVES</th>
<th>Yield (mgd)</th>
<th>Watershed Area (sq.mi)</th>
<th>Distance to Boston (mi.)</th>
<th>Cost ($ millions)</th>
<th>Water Quality Color</th>
<th>Water Quality Population per sq. mi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nashua R.</td>
<td>105</td>
<td>4097</td>
<td>34</td>
<td>19.1</td>
<td>0.40</td>
<td>69</td>
</tr>
<tr>
<td>Merrimack R.</td>
<td>65+</td>
<td>360</td>
<td>77</td>
<td>17.5</td>
<td>0.34</td>
<td>31</td>
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<tr>
<td>L. Winnipesaukee</td>
<td></td>
<td></td>
<td></td>
<td>34.5</td>
<td>0.01</td>
<td>35</td>
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<tr>
<td>Assabet R.</td>
<td>28</td>
<td>34</td>
<td>30</td>
<td>0.6</td>
<td>0.36</td>
<td>60</td>
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<tr>
<td>Assawompsett</td>
<td>36</td>
<td>62</td>
<td>36</td>
<td>----</td>
<td>0.28</td>
<td>36</td>
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<tr>
<td>Charles R.</td>
<td>73</td>
<td>156</td>
<td>15</td>
<td>----</td>
<td>0.86</td>
<td>179</td>
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<tr>
<td>Deerfield R.</td>
<td>---</td>
<td>454</td>
<td>89</td>
<td>----</td>
<td>0.40</td>
<td>21</td>
</tr>
<tr>
<td>Ipswich R.</td>
<td>29</td>
<td>53</td>
<td>16</td>
<td>----</td>
<td>1.36</td>
<td>72</td>
</tr>
<tr>
<td>Saugus R.</td>
<td>---</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>1.16</td>
<td>709</td>
</tr>
<tr>
<td>Sebago R.</td>
<td>---</td>
<td>500</td>
<td>104</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Shawsheen R.</td>
<td>20</td>
<td>34</td>
<td>18</td>
<td>----</td>
<td>0.89</td>
<td>123</td>
</tr>
<tr>
<td>Squannacook R.</td>
<td>---</td>
<td>76</td>
<td>41</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Swift R.</td>
<td>200</td>
<td>185</td>
<td>64</td>
<td>----</td>
<td>0.38</td>
<td>30</td>
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<tr>
<td>Westfield R.</td>
<td>---</td>
<td>179</td>
<td>93</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Ware R.</td>
<td>71</td>
<td>99</td>
<td>51</td>
<td>6.1</td>
<td>0.75</td>
<td>32</td>
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</table>
Demand Exceeds “Safe” Yield in 1969
Again 1985 Projections Leads to Future Studies

Chronological History of Boston's Water Supply System
### Incremental “Safe Yield” of Alternative Sources of Supply

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Incremental “Safe Yield” (mgd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing System (without Sudbury)</td>
<td>300</td>
</tr>
<tr>
<td>Connecticut River Diversion</td>
<td>63</td>
</tr>
<tr>
<td>Millers River Diversion</td>
<td>33</td>
</tr>
<tr>
<td>Millers &amp; Tully River Diversion</td>
<td>38</td>
</tr>
<tr>
<td>Merrimack River Diversion</td>
<td>120</td>
</tr>
<tr>
<td>Watershed Management</td>
<td>5</td>
</tr>
<tr>
<td>Sudbury (including 3 Framingham reservoirs)</td>
<td>20</td>
</tr>
</tbody>
</table>
Demand Management, Conservation and Leak Repair Worked!

Demand was reduced from:
- 336 in 1987 to
- 256 mgd in 1997

MWRA Annual Average System Demand

- MGD

- 350
- 300
- 250
- 200
- 150
- 100

Outline

Emerging Issues:
- Water and People
- Water Supply – NYC and Boston

→ Water and Urbanization
- Water and Climate
- Water and Food
- Water and Human Water Use
Water and Urbanization

Increased U.S. Flood damages 1932-1997 adjusted to 1995 dollars

Are increased damages due to:

- Climate Change?
- Urbanization?
- Agriculture?
- All three?
We live in a watershed and we are part of the problem.

Land Management is Water Management.
Urbanization Increases Flows in Rivers and Streams

Changes to single-event hydrograph
Aberjona River, Massachusetts
24 sq. mi. urban watershed near Tufts
Like Clockwork, and Like Urbanization, Annual Maximum Flood Discharges are steadily increasing.
It is not only floods on Aberjona River which are influenced by urbanization.
One Partial Remedy: Low Impact Development

No curbs
Bioretention
No pipes
No manholes

Mimics Nature
How can we make residential developments function hydrologically like natural systems?
High Impact Development

- Removal of trees
- Soil erosion
- Impervious areas

Result: Stormwater pipes and detention pond
FEATURES OF A NATURAL CHANNEL

STREAM-SIDE VEGETATION

STREAM CHANNEL - FLOODPLAIN

BANKFULL CHANNEL

LOW FLOW CHANNEL

RIPARIAN WETLAND

INSTREAM CHANNEL DIVERSITY

BEDROCK

THALWEG
STEELHEAD TROUT – EGGS AND ALEVINS

CONCRETE LINED TRAPEZOIDAL FLOOD CONTROL CHANNEL
TROUT BROOK - WEST HARTFORD, CT

- Low Flow Channel
- Bankfull Width
- Floodplain
- No Instream Habitat Value
- Low Flow Channel
VEGETATION LINED FLOOD CONTROL CHANNEL
TROUT BROOK - WEST HARTFORD, CT

Designed by: James MacBroom
**Ecology** - The study of plants, animals, and their environment, with emphasis on aquatic systems, wetlands, and riparian forests.

**Water Quality** - The study of the physical, biological, and chemical characteristics of surface waters and groundwaters.

**Hydrology** - The study of precipitation, infiltration, surface runoff, streamflow rates, water storage in wetlands, detention basins, and reservoirs, plus water use and diversions.

**Hydraulics** - The study of the stream’s water velocity, flow depth, flood elevations, channel erosion, storm drains, culverts, bridges, and dams.

**Engineering** – The application of science and mathematics in analysis, design, and permitting.

**Socioeconomic** - The study of the sociology, social relationships, economic impacts, and their interconnections.

**Construction** – The application of the design
Outline

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Projections of Global Surface Warming
Water and Climate

Carbon Dioxide in the Atmosphere

Carbon Dioxide Levels Today are Higher than over the Past 650,000 Years


Industrial CO₂ Levels
- Pre-industrial CO₂ Levels

New Antarctic ice core data extends the record back to 650,000 years before the present and shows that CO₂ levels were below 300 ppmv.
“Today the time for doubt has passed. The IPCC has unequivocally affirmed the warming of our climate system, and linked it directly to human activity.”

(UN Secretary General, November 2007)
Do you think human activity is a significant contributing factor in changing mean global temperatures?

The answer is generally yes.

A Gallop Poll
Shrinking of Arctic Sea Ice
(from Epstein, 2008)

Extent of Ice Cover (millions of sq. mi)

Arctic sea ice

1978      Year      2008
Glacial Melt – Reduction in Long Term water storage and fluxes

Figure 6. Field photograph of terminus region of Chhota Shigri glacier, Lahaul and Spiti district, of HP taken in 1988 and 2003. In 1988, glacial ice is exposed on the surface and small portion of the terminus is covered by debris. By year 2003, the entire terminus zone is covered by debris.

Glacial retreat in Himalaya using Indian Remote Sensing satellite data

Anil V. Kulkarni¹, I. M. Bahuguna¹, B. P. Rathore¹, S. K. Singh¹, S. S. Randhawa², R. K. Sood² and Sunil Dhar³
Examples of human-induced climate change are now apparent on every continent.
Increased Coastal Flooding under Climate Change

Wetland Inundation and Loss
Increased Coastal Flooding under Climate Change

- More coastal erosion

Brandt Beach Long Beach Island, NJ

Dr. Norbert Psuty
Increased Coastal Flooding under Climate Change

Higher sea levels and more frequent flooding

Winthrop, MA
Coastal Flooding in Boston under Present and High Emission Sea Levels

Source: NECIA/UCS 2007
Boston: The Future 100-Year Flood under the Higher-Emissions Scenario

Source: NECIA/UCS, 2007 (see: www.climatechoices.org/ne/)

Landmarks
A. Commonwealth Avenue
B. Newbury Street
C. Old South Church
D. Copley T Station
E. The Esplanade
F. Copley Square
G. Trinity Church
H. John Hancock Tower
I. Hatch Shell
J. Arlington T Station
K. Public Garden and Swan Boats

Source: NECIA/UCS, 2007 (see: www.climatechoices.org/ne/)
New York City: Today’s 100-Year Flood Could Occur Every 10 Years under the High-Emissions Scenarios

Landmarks
A. West Side Highway
B. Battery Park
C. Brooklyn-Battery Tunnel
D. South Ferry Subway Station
E. Ferry Terminals
F. Franklin D. Roosevelt Drive
G. Wall Street
H. South Street Seaport

Emerging Issues:

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Water and Human Water Use
“If present trends continue, the livelihoods of one third of the world’s population will be affected by water scarcity by 2025.

We could be facing annual losses equivalent to the entire grain crops of India and the US combined.”

Frank Rijsberman, Director General
International Water Management Institute 2003
Kenya 1998-2000 drought: $2.4 billion in losses

Every 5 seconds a child younger than ten dies of hunger
Why are Food and Water Related?
Water Scarcity and Food Scarcity are Related

The driving forces are similar:

• Growing population
• Dietary changes
• Urbanization
• Conflicting needs for water
• Climate change impacts
• Biofuel production
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→ Water and Human Water Use
Blue versus Green Water

Balancing Water for Humans and Nature, 2004
by M. Falkenmark and J. Rockström

Blue Water – Water in rivers and lakes

Green Water – Vertical fluxes such as evapotranspiration

(evapotranspiration = evaporation and transpiration)
65% of the continental precipitation is green water, supporting terrestrial ecosystems, 35% is blue water, supporting societal uses and aquatic ecosystems.
Traditionally water engineers have only managed blue water.

A major future challenge involves managing green water using:

- rainwater collection
- managing crop evapotranspiration
- land use management
- etc
Blue Water – Green Water and Food

• 80% of global cropland is rainfed

• 60-70% of world's food is produced on rainfed land

• In sub-Saharan Africa food production depends on >95% green water
A Blue-Green Water Availability Index

Based on work in progress at USGS and Tufts University 2011
Blue – Green Water Availability in Africa

From Freeman and others, Tufts Unive, under review, 2011
“Fierce competition for fresh water may well become a source of conflict & wars in the future.”

Kofi Annan, March 2001
Water Conflicts Involve Multiple Objectives
And Now The Fish and Other Biota have Place at the Negotiating Table
# Human Water Use Conflicts

## The Colorado River Compact, 1922

<table>
<thead>
<tr>
<th>Political Entity</th>
<th>Annual allocation (in acre-feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Basin States</td>
<td>7,500,000*</td>
</tr>
<tr>
<td>Colorado</td>
<td>3,900,000*</td>
</tr>
<tr>
<td>New Mexico</td>
<td>800,000*</td>
</tr>
<tr>
<td>Utah</td>
<td>1,700,000*</td>
</tr>
<tr>
<td>Wyoming</td>
<td>1,000,000*</td>
</tr>
<tr>
<td>Lower Basin States</td>
<td>7,500,000</td>
</tr>
<tr>
<td>California</td>
<td>4,400,000</td>
</tr>
<tr>
<td>Arizona</td>
<td>2,800,000</td>
</tr>
<tr>
<td>Nevada</td>
<td>300,000</td>
</tr>
<tr>
<td>Mexico</td>
<td>1,500,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16,500,000</strong></td>
</tr>
</tbody>
</table>
Low flow in the Colorado River Basin spurs water shortage discussion among seven states

The “Observed” Lees Ferry Flows

Data source: Bureau of Reclamation, May 2006
The Net Impact of Dams and Human Water Use

Colorado River Delta Runs Dry


Fig. 1. Colorado river flows below all major dams and diversions, 1905 to 2001. Data are flows of the Colorado River as measured at U.S. Geological Survey Gage 09-5222, 35 km downstream from Morelos Dam. As shown, flows reaching the Colorado River delta have dropped to near zero in most years.
South Africa Water Law

New principles

The National Water Policy

• guarantees access to sufficient water for basic domestic needs
• makes sure that the requirements of the environment are met
• takes into account the interconnected nature of the water cycle, on which the sustainability and renewability of the resource depends
History of US Dam and Reservoir Construction
Worldwide Construction of Large Reservoirs in 20th Century

Fig. 4. Construction of large reservoirs worldwide in the 20th century. Average numbers of reservoirs with volume greater than 0.1 km³ built by decade, through the late 1990s, are normalized to dams per year for different periods. Note that there was a peak in construction activities in the middle of the 20th century, tapering off toward the end of the century. The period 1991 to 1998 is not a complete decade; note also that the period 1901 to 1950 is half a century. “Other regions” include Latin America, Africa, and Oceania (46).

Dams „flatten“ the downstream streamflow regime

Shading denotes degree of homogenization in flow regimes due to dams

(from Poff et al. 2007, PNAS)
Its Not So Simple!

The Quabbin Reservoir Tailwater Region, Just Below the Spillway Attracts Fly Fisherman from all over the Region!
Total Number of Dams in US ~82,642

Greater than 25 feet high

Total Number of Dams Removed: ~748

Dams Removed in 2008 64
Dams Provide Many Benefits Including:

- Water Supply
- Hydropower
- Irrigation
- Recreation
- Cooling Water
- And …
Dams Also Provide Flood Protection
Visible overuse of water

- Rio Grande (USA/Mexico), in 2001 for the first time failed to reach the Gulf of Mexico (Economist, 2001)
- Yellow River (China) running dry on the last 100 km
  - 1972 during 15 days
  - 1996 during 133 days
  - 1997 during 226 days

Source: Ren and Walker, Environmental consequences of human activity on the Yellow River; *Physical Geography* 19.1998.5, pp 421-432
Groundwater Depletion Reduces Streamflow

River and Well Hydrographs from North China Plain
(from Konikow and Kendy, "Groundwater depletion: A global problem, 2007")
Acceleration in annual global water withdrawals: 1900–2000

From Postel, 1992
The big squeeze on global water is expected to increase as

- Populations increase
- Incomes increase
By 2025 two thirds of the people in the world are expected to live in areas of water shortage or stress.
Virtual Water

- Water embedded in products
- Water used in production of product or service
Now a global issue: virtual water flows between world regions (average 1997–2001)

From Yang et al. unpublished; quoted in Zehnder
Ship Virtual Water?

Exporting wheat to an arid country avoids need for water in that country

1 kg of wheat takes 1,000 liters of water to produce
Bottled Water is Not a Solution

• Americans spent $11 billion on bottled water in 2006
• Manufacturing 1 bottle of water takes
  • 2 bottles of water to make plastic bottle
  • 3-9 bottles of water for filtration process
Systems Modeling Methods are Needed

Integrated Watershed Management Modeling: Generic Optimization Model Applied to the Ipswich River Basin

Viktoria I. Zoltay, A.M.ASCE\(^1\); Richard M. Vogel, M.ASCE\(^2\); Paul H. Kirshen, M.ASCE\(^3\); and Kirk S. Westphal, M.ASCE\(^4\)
SW = surface water; GW = groundwater; WTP = water treatment plant; P use = potable water use; NP use = nonpotable water use; ASR = aquifer storage and recharge; and WWTP = wastewater treatment plant
Beirut, Lebanon

- Integrated water supply optimization model
- Includes wastewater disposal, and reuse options
- Considers entire anthropogenic water cycle
- Considers both potable and nonpotable sources
WATER SOURCES, s

Conventional:
- Rivers
- Groundwater

Non-conventional:
- Desalination
- Secondary Treatment, Disinfection
- Advanced Treatment

USES, u

Conventional:
- Municipal Water Use (MUP)
- Non-municipal Water Use (MN)

Non-conventional:
- Industrial Use (IP)
- Agricultural Use (AGp)
- Agricultural Use (AGn)

WASTE SITES, w

Consumptive use
- Centralized Wastewater Treatment Plant (CWWTP) (via sewer system)

Groundwater (via infiltration)

To Sea

LEGEND
- ○ Water use sector
- ● Onsite treatment
- → Potable quality flow path
- --- Nonpotable quality (or better) flow path
- Reuse path
- ➔ Wastewater flow path

MU=municipal, AG=agricultural, I=industry, Subscript P=potable, Subscript N=nonpotable
A Systems Approach to Solving Flood Problems on Aberjona River

Optimal Location of Infiltration-Based Best Management Practices for Storm Water Management

Cristina Perez-Pedini, M.ASCE1; James F. Limbrunner, M.ASCE2; and Richard M. Vogel, M.ASCE3
Aberjona river discharges are on the rise
Where Should We Site Best Management Practices on Aberjona River to Control Downstream Flooding?

Aberjona flood, Winchester Center 2001
Results
Factors Influencing BMP Placement

- High CN values
- Large and impervious contributing areas
- Flow arrival time resonance with other hydrologic response units
Summary

We can no longer ignore anthropogenic influences on the hydrologic cycle.

Water policy, science and engineering approaches must deal with a changing hydrosphere.

All water textbooks need to be rewritten to include humans and to deal with nonstationarity due to climate change, urbanization and other human impacts.
Hydrologic Extremes Without People

(from Weiskel, Vogel and others., 2011, in prep.)
Source-Sink Index

Sinks are rivers which **lose** water naturally moving downstream.

Weiskel, Vogel and Wolock, 2011
Extreme Hydrology With Humans

(from Weiskel, Vogel and others 2007)