Global water security and sustainability challenges for arid lands

Aaron Packman
Professor, Dept. of Civil and Environmental Engineering
Director, Northwestern Center for Water Research

water.northwestern.edu
Outline

• Global water resources, sustainability, and risks
• Water in humid lands – Great Lakes regional concerns
  -- break --
• Water in arid lands
  – Global drivers of water availability: Why are deserts dry?
  – Water resources, risks, and solutions(?) in the Middle East
  – Water resources, infrastructure, and risks in Southeast Asia
THE WORLD'S FRESH WATER

9.26 million trillion gallons

We live on a planet covered by water, but more than 97 percent is salty, and nearly 2 percent is locked up in snow and ice. That leaves less than one percent to grow our crops, cool our power plants, and supply drinking and bathing water for households.

Click each category of fresh water below to display on map

- Permafrost
- Glaciated area or ice sheet
- Rivers and lakes
- Wetlands
- View groundwater map
- View river details

WILLIAM E. MOUNTY, NG STAFF
SOURCES: WORLD WILDLIFE FUND, ICIAR A. MARKANOV, STATE HYDROLOGICAL INSTITUTE, RUSSIA, USGS, UNIVERSITY OF KASSEL CENTER FOR ENVIRONMENTAL SYSTEMS RESEARCH, GERMANY, NATIONAL SNOW AND ICE DATA CENTER, UNIVERSITY OF COLORADO
ON NEARLY EVERY CONTINENT, GROUNDWATER IN AQUIFERS IS BEING DRAINED FASTER THAN THE NATURAL RATE OF RECHARGE.

30.1% of 2.78 million trillion gallons are beneath the ground in soil and aquifers fed by surface seepage.

Groundwater
Average rate of recharge

HIGH  MEDIUM  LOW
Global freshwater reservoirs

Aeschbach-Hertig and Gleeson, 2012
Population density

www.worldometers.info/population
Human Appropriation of Net Primary Productivity (HANPP) as a Percentage of Local Net Primary Productivity

Human Appropriation of Net Primary Productivity as a Percentage of Net Primary Productivity (NPP) identifies spatial variations in the amount of NPP consumption relative to local productivity in a way that highlights humanity's growing impact on the biosphere.

The Human Footprint Index

The Human Footprint Index (HF) expresses as a percentage the relative human influence in each terrestrial biome. HF values range from 0 to 100. A value of zero represents the least influenced - the “most wild” part of the biome with value of 100 representing the most influenced (least wild) part of the biome.
RELATIVE WATER STRESS INDEX

This map shows populations living in water-stressed (red) and relatively unstressed (blue) conditions highlighting substantial within-country differences that national estimates often obscure. Higher stress occurs when water availability is less than water demand; lower stress occurs when water availability is higher than demand.
Groundwater depletion

Aeschbach-Hertig and Gleeson, 2012
Global land temperature

Data taken from: CRU 0.5 Degree Dataset (New, et al.)
Global Annual Precipitation

Atlas of the Biosphere
Center for Sustainability and the Global Environment
University of Wisconsin - Madison

Data taken from: CRU 0.5 Degree Dataset (New et al.)
Global evaporation ("ET")

http://www.ntsg.umt.edu/project/mod16
Global temperatures 2100

CHANGE IN PRECIPITATION BY END OF 21st CENTURY
inches of liquid water per year

as projected by NOAA/GFDL CM2.1

https://www.gfdl.noaa.gov/will-the-wet-get-wetter-and-the-dry-drier/
Projected changes in global water availability

The global risks landscape

Global water insecurity – Threats and Hazards

During the next 10 years, many countries important to the United States will experience water problems – shortages, poor water quality, or floods – that will risk instability and state failure, increase regional tensions, and distract them from working with the United States on important US policy objectives.

Global Water Security, Intelligence Community Assessment, ICA 2012-08, February 2012
Global water insecurity – Threats and Hazards

“One-fifth of the world’s population lacks access to clean water, and by 2025, 1.8 billion people will be living in areas where water is scarce.”
Forbes, April 15, 2013

“Water problems will hinder the ability of key countries to produce food and generate energy, posing a risk to global food markets and hobbling economic growth.”
US Intelligence Community Assessment, February 2, 2012

“Cost to update all U.S. water infrastructure” ranges from $600 billion to $2.5 trillion over the next 20 years.
Forbes, September 26, 2012

“From now through 2040 water shortages and pollution probably will harm the economic performance of important trading partners.”
US Intelligence Community Assessment, February 2, 2012
Central water challenges

• Lack of water availability (arid lands)
• Lack of water quality (available but unusable/unsafe)
• Lack of infrastructure (inability to deliver safe water)
• Lack water monitoring / oversight
• Lack of shared governance & transboundary cooperation
Water in humid lands – Chicago and the Great Lakes

http://earthobservatory.nasa.gov/Features/IntotheBlack/page3.php
The Great Lakes basin
Great Lakes water diversions

http://www.ijc.org
Waterborne disease and toxic algae

Racine, WI December 5, 2014 -

**MAYORS CALL FOR ACCELERATED ACTION TO PROTECT DRINKING WATER FROM TOXIC ALGAE**

How tap water became toxic in Flint, Michigan

By Sara Ganim and Linh Tran, CNN

(CNN) — Flint, Michigan, lies about 70 miles from the shores of the largest group of fresh water bodies in the world: the Great Lakes. Yet its residents can't get clean water from their taps.

Nearly two years ago, the state decided to save money by switching Flint's water supply from Lake Huron (which they were paying the city of Detroit for), to the Flint River, a notorious tributary that runs through town known to locals for its filth.
Flint: Water, Lead, and Infrastructure

Flint water crisis timeline: Key Actions and Observations

- **April 2014**: Flint switches to local Flint River water supply as a temporary cost-saving measure (est. savings $5M over two years).
- **April-August 2014**: Color, taste and odor complaints; high coliform and trihalomethane (THM) levels.
- **August-September 2015**: Independent study (VA Tech) finds high corrosion potential and high lead levels. State DEQ disputes findings.
- **September 24, 2015**: Hurley Medical Center study finds high lead levels in children (<5 years old) doubled after change to Flint River water.
- **October 2015**: Flint switches back to Detroit water.

http://flintwaterstudy.org/
http://www.nbcnews.com/storyline/flint-water-crisis
LeeAnne Walters displays tap water samples at a public meeting in January 2015. Ryan Garza/Detroit Free Press/ZUMA

http://www.motherjones.com/politics/2016/01/mother-exposed-flint-lead-contamination-water-crisis
Pediatric lead exposure in Flint, MI: Concerns from the Medical community

Zip Codes With High Water Lead

- Focus on zip codes (48503 and 48504) with high water lead levels
- Total n=742, pre n=394, post n=348

Results:
- PRE-SWITCH % EBL: 2.5%
- POST-SWITCH % EBL: 6.3%
- p < 0.05; STATISTICALLY SIGNIFICANT CHANGE

EBL = elevated lead blood level
Quotes from state officials

Time of water switchover

April 2014

Mayor Dayne Walling: “It's regular, good, pure drinking water, and it's right in our backyard.” “This is the first step in the right direction for Flint, and we take this monumental step forward in controlling the future of our community's most precious resource.”

Michael Prysby, Michigan DEQ Office of Drinking Water: “the quality of the water being put out meets all of our drinking water standards and Flint water is safe to drink.”

http://michiganradio.org/post/team-testing-flint-water-lead-sample-sample-sample#stream/0
Flint pH and lead timeline

http://cen.acs.org/articles/94/i7/Lead-Ended-Flints-Tap-Water.html
GETTING THE LEAD IN
Tests show toxic lead is leaching into Flint's tap water. Here's how.

Lead solder:
Copper pipe connections, especially in pre-1986 homes, can contain lead.

Corrosive water:
Researchers have found Flint water to be more corrosive to pipes than water from the Detroit system, Flint's previous water source.

Water treatment plant:
The city draws and disinfects water from the Flint River.

Service lines: Pipes connecting water mains and individual homes or businesses can be made of lead. Lead can leach directly from the pipe wall into the water.
Phosphate corrosion inhibitor helps maintain a mineral passivation layer on the inside of Flint’s pipes, protecting them from corrosion. With little corrosion, chlorine disinfectant levels remain stable.

Lack of a corrosion inhibitor, high chloride levels, and other factors cause the passivation layer to dissolve and fall off, leading to increased corrosion in Flint’s pipes. As the pipes corrode, chlorine disinfectant breaks down.

Oxidants such as dissolved O₂ corrode pipes and leach soluble metal.

Exposed iron reduces free chlorine used as disinfectant

Flint pipe corrosion

“For Flint, it is quite possible that the damages from corrosive water could ultimately be in the range of a hundred million dollars or even more. On top of that, this analysis does not consider damages to consumers plumbing, which tend to be even more expensive.”

One in six Flint homes has lead levels above the EPA’s action level...

...and the rate of young children with high blood lead levels has soared.

Source: Flint Water Study, Hurley Medical Center

http://www.motherjones.com/politics/2016/01/mother-exposed-flint-lead-contamination-water-crisis
Water risk assessment

FLINT, Mich. — An official with Flint's water plant said Tuesday he had planned to treat the drinking water with anti-corrosive chemicals after the city began drawing from the Flint River but was overruled by a state environmental regulator.

Mike Glasgow, then a supervisor at the plant and now the municipal utilities administrator, said he received the instruction from district engineer Mike Prysby of the Michigan Department of Environmental Quality during a meeting to discuss the final steps before Flint switched from the Detroit water system as a cost-saving measure in April 2014.

Glasgow said Prysby told him a year of water testing was required before a decision could be made on whether corrosion controls were needed, which the state DEQ has since acknowledged was a misreading of federal regulations on preventing lead and copper pollution. The omission enabled lead to leach from aging pipes and fixtures and contaminate tap water that reached some homes, businesses and schools.

“That one meeting was the difference between this city being poisoned and not being poisoned”

Lee-Anne Walters
Quotes from state officials and independent researchers

MDEQ spokesman Brad Wurfel

July 13, 2015: "Let me start here — anyone who is concerned about lead in the drinking water in Flint can relax."

Preliminary tests show the Walters test was an "outlier." "It does not look like there is any broad problem with the water supply freeing up lead as it goes to homes."

September 2015: "I don't know how they're getting the results they're getting...I know that it doesn't match with any of the other surveillance in the area."

Independent study conducted by Virginia Tech
Marc Edwards, Lead Project Investigator

August 24, 2015

Conclusion: The high rates of iron corrosion from using Flint River water as a drinking water source are damaging the Flint distribution system. The corrosion is also causing chlorine to disappear quickly, which may make it more likely for harmful bacteria to grow in the water.

September 8, 2015

FLINT HAS A VERY SERIOUS LEAD IN WATER PROBLEM.

Preliminary tests show 'serious' levels of lead in city water.

NPR, August 20, 2015: Lead-Level Samples Excluded From Report
The MDEQ dropped two samples from its initial report on lead levels from the city, which put the result within federally mandated levels.
Michigan's attorney general has filed charges against three officials over contaminated water supplies in Flint. Two state employees in the environmental department have been charged with misleading the US government about the problem. And a Flint employee is being charged with altering water test results.

"They had a duty to protect the health of families and citizens of Flint and they failed," said Michigan Attorney General Bill Schuette.

Stephen Busch (MDEQ water supervisor), and Mike Prysby (MDEQ water engineer) each face six charges, including misleading federal regulatory officials, manipulating water sampling and tampering with reports.

Mike Glasgow, former City laboratory and water quality supervisor who now serves as the city's utilities administrator, is accused of tampering with evidence and willful neglect of duty.
Central water challenges – humid lands

- Lack of water availability (arid lands)
- Lack of water quality (available but unusable/unsafe)
- Lack of infrastructure (inability to deliver safe water)
- Lack water monitoring / oversight
- Lack of shared governance & transboundary cooperation
Break
Water in Arid Lands – why are deserts dry?

Deserts are a consequence of one of the following mechanisms*

• Air mass subsidence (basically, air moving downward from the high atmosphere).
• Rain shadows (air stripped of moisture by mountains).
• Distant moisture sources (air stripped of moisture by travel over continents).
• Cold sea-surface temperatures (little atmospheric moisture).

Mean annual precipitation (log scale) 1988-1994

Global Precipitation Climatology Project (GPCP) data

http://www.science.co.il/Weather/Middle-East-Climate/
Global atmospheric circulation (Hadley cells)

https://www.seas.harvard.edu/climate/eli/research/equable/hadley.html
Effect of Hadley circulation on climate of Africa and the Middle East

[Diagram of Earth showing Hadley circulation]

Apollo 17 photo
Effect of Hadley circulation on climate of Africa and the Middle East
Middle East – The Fertile Crescent
Flood agriculture in the Fertile Crescent

Flood agriculture in the Fertile Crescent

Ma’dan (“Marsh Arabs”) floating village. Created by the annual flooding of the Euphrates and Tigris rivers
Flood agriculture in the Fertile Crescent

NASA Visible Earth
http://water.usgs.gov/edu/gallery/freshwater-nile.html
Flood agriculture in the Fertile Crescent

http://www.shaduf-eu.org/
http://www.fao.org/docrep/010/ah810e/ah810e06.htm
Wadi – Ephemeral river valley

http://blogs.agu.org/georneys/2011/05/05/geology-word-of-the-week-w-is-for-wadi

wadi of Ein Avdat, Sede Boker
Mountain front recharge - Alluvial fans

http://pages.uoregon.edu/miller/fan.html
Mountain front recharge - Alluvial fans

http://awwatersheds.org/alluvial-fan/
http://earthobservatory.nasa.gov/IOTD/view.php?id=36041
Qanat – Ancient water supply infrastructure

http://www.waterhistory.org/histories/qanats/
Qanat construction


Where water is more precious than gold: Iran’s southern valleys – in pictures, Bijan Roghanchi, The Guardian, 20 October 2015
http://www.theguardian.com/world/iran-blog/gallery/2015/oct/20/iran-qanat-ancient-water-system-pakam-pictures
Qanat Niavaran in Tehran

https://en.wikipedia.org/wiki/Qanat
Population density of N. Africa and the Middle East
Middle East and N. Africa Climate

![Climate Map of Middle East and N. Africa](image)

**CLIMATE TYPES**
- Humid subtropical
- Mediterranean
- Semiarid / steppe
- Desert
- Tropical savanna
- Undifferentiated highland
Rain in the Middle East occurs primarily during winter months; summers are so hot and dry, except in some northern and highland areas, that irrigation is necessary for most summer crops even where rainfall totals 20 to 40 inches.

Mean Annual Rainfall

- **Under 10 inches**: Nomadic herding; no cultivation possible without heavy irrigation
- **10 to 20 inches**: Wheat, barley, sorghums, dry beans, olives, almonds
- **20 to 40 inches**: Winter vegetables, maximum grain yields
- **Over 40 inches**: Corn, tobacco

The mean annual rainfall for Washington, D.C. is 40 inches.
Regional Precipitation & Evaporation

Recent changes in water storage

Nile and Negev

NASA Visible Earth

http://water.usgs.gov/edu/gallery/freshwater-nile.html
Population density of N. Africa and the Middle East
N. Africa & Middle East: Current & projected Precipitation

N. Africa & Middle East: Current and Projected Evaporation

Synopsis – Water in the Middle East

• Regional water limitations from global climate
• Exacerbated by population growth and climate change
• Ancient water management practices for drinking (water) and irrigation (food)
• Considerable water over-use today
• Major concerns for regional water insecurity and unsustainability
Water in Israel and the Middle East
Israel – Geology, Topography, and Climate
Israel - Climate

• Between Sahara and the Eastern Mediterranean
• Mediterranean to Desert
  • Hot and dry summer season
  • Short, cold winter season
• Most precipitation in the north
• Extremely arid in the south (Negev desert)
Israel – Water Resources

Lake Kinneret recharge area

Negev Desert
http://mfa.gov.il/MFA/ForeignPolicy/Peace/Guide/Pages/Water_Israel_Palestinians-Feb_2012.aspx#
Major Groundwater Aquifers - Israel

Jordan River Basin + National Water Carrier
Israel – Modern water achievements & potential for transboundary water cooperation

- National water carrier to deliver water south (70-year investment)
- National water law (all water belongs to the state)
- National water pricing (expensive)
- Highest rate of wastewater reuse in the world
- Major investment in desalination
- Now poised to export water to neighboring countries.
Water Consumption in Israel (2014)

- Agriculture: 1204.6 MCM (58%)
- Domestic: 733.2 MCM (35.3%)
- Industry: 138.3 MCM (6.7%)
- Potable: 460.6 MCM (38%)
- Recycled wastewater effluent: 400 MCM (33%)
- Brackish+ marginal: 344 MCM (29%)

courtesy Noam Weisbrod, BGU/ZIWR
Increasing Water Use Efficiency:
Reduce soil water evaporation via enclosed agriculture, subsurface drip irrigation, monitored pulse-response irrigation

Protected cultivation
Net houses & Green Houses

courtesy Noam Weisbrod, BGU/ZIWR
Improved control of water for irrigation

More crop per area
More crop per drop

courtesy Noam Weisbrod, BGU/ZIWR
Seawater Desalination in Israel

In accordance with the Government decisions, large scale seawater desalination facilities are being built:

- **Hadera**: Production since 12/09, 350 MLD (127 MCM/Y)
- **Ashdod**: Production since 8/13, 400 MLD (150 MCM/Y)
- **Palmachim**: Production since 6/07, 245 MLD (100 MCM/Y)
- **Ashkelon**: Production since 12/05, 330 MLD (120 MCM/Y)

Total annual production (MCM/year) since 2/16:
- 270 MLD

Production since 2/16, 270 MLD (120 MCM/Y)

Production since 6/07, 245 MLD (100 MCM/Y)

Production since 8/13, 400 MLD (150 MCM/Y)

Production since 12/09, 350 MLD (127 MCM/Y)

Production since 12/05, 330 MLD (120 MCM/Y)

Total annual production (MCM/year):
- 0
- 36
- 100
- 130
- 145
- 160
- 280
- 305
- 405
- 505
- 600
- 750

courtesy Sara Elhanany, Israel Water Authority
The water revolution in Israel

~50% of total consumption today is “manufactured” water

- Treated wastewater: 400 MCM/year (2015)
- Seawater Desalination: 600 MCM/year (2015)
- Brackish water desalination
- Water conservation: 18% (2015)

Natural Resources ~50%


Natural Resources ~90%

courtesy Sara Elhanany, Israel Water Authority
Tibetan plateau

Precipitation in Asia

http://www.diercke.com/kartenansicht.xtp?artId=978-3-14-100790-9&seite=95&id=17557&kartennr=4
Population Density in Asia
Rivers draining the Tibetan plateau
China South-to-North Water Transfer project

https://www.thethirdpole.net/2015/10/20/can-chinas-south-north-water-transfer-project-and-industry-co-exist/
Three Gorges Dam

- Length: 1.4 mi. (2.3 km)
- Height: 600 ft. (185 m)
- Reservoir: Holds back 20 billion tons of water
- Energy: 85 billion kilowatt hours a year by 2009

Human toll
- About 1.3 million people relocated
- About 100 towns were submerged

Environmental impact
- Threatened species: Yangtze dolphin, Chinese sturgeon, finless porpoise
- Landmarks: Scenic deep gorges, about 1,000 archaeological sites submerged
- Farmland: About 60,500 acres (24,500 ha) of farmland, orchards flooded


http://hubei.chinadaily.com.cn/gov/2012-01/19/content_14583328.htm
http://www1.american.edu/ted/ICE/china-dam-impact.html
China South-to-North Water Transfer project

Opening the Spigot

China built an elaborate water-transfer system to help the typically dry north, but many cities lack the local infrastructure necessary to fully tap the resource.

South-to-north water project routes

Total surface and ground water available per person (in cubic meters)

100 500 1,000 2,000 5,000 14,250

Sources: China Statistical Yearbook; Office of the South-to-North Water Diversion Project Commission of the State Council

https://www.thethirdpole.net/2015/10/20/can-chinas-south-north-water-transfer-project-and-industry-co-exist/
Rivers draining the Tibetan plateau
Mekong River

https://www.britannica.com/place/Mekong-River
Mekong River

https://www.britannica.com/place/Mekong-River
Mekong region wildlife (WWF)

http://wwf.panda.org/what_we_do/where_we_work/greatermekong/
The Global Risks Interconnections Map 2016

Natural resources and hazards

Society, Infrastructure, and Governance

Recap: Central water challenges

- Lack of water availability (arid lands)
- Lack of water quality (available but unusable/unsafe)
- Lack of infrastructure (inability to deliver safe water)
- Lack water monitoring / oversight
- Lack of shared governance & transboundary cooperation

Mixture of global limitations (climate, people), regional management (infrastructure, efficiency), and multiscale feedbacks (climate, runoff, evaporation).

Major questions of *overall* efficiency, equitability, security, reliability, and sustainability in arid *and* humid lands.