FOOD, WATER, and ENERGY

December 8, 2014

Robert Giegengack
EES, University of Pennsylvania
gieg@sas.upenn.edu
Water is moved close to the Earth’s surface by solar energy, gravity, and the energy of the Earth’s rotation.

The amount of fresh water available for human use is a tiny percentage of the water on Earth.

Water is a **FULLY RENEWABLE** resource!
Philadelphia has 3 plants that take water from the Delaware or Schuylkill River and treat it.
Depending on where you live, you receive drinking water from one of the city’s three water treatment plants – Baxter, Belmont, or Queen Lane.

Philadelphia operates 3 wastewater treatment plants (red)
Each red dot is the location of an EPA-permitted wastewater-treatment discharge facility upstream from Philadelphia’s water-intake sites.

But: Look upstream!
The Fairmount Water Works Interpretive Center
Hidden River
by Stacy Levy

On permanent exhibit at the
Fairmount Water Works Interpretive Center.
Hidden River
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On permanent exhibit at the Fairmount Water Works Interpretive Center.

All water is recycled!!
Singapore’s “newater”

Recycled sewage represents 25% of Singapore’s drinking water, and 35% of the drinking water of Windhoek.
**GLOBAL WATER “USE”**

Precipitation onto land surface = ~110,000 km³/yr (green circle)
~55,000 km³/yr are re-evaporated, or transpired by plants
~55,000 km³/yr flow, eventually, to the ocean, via surface runoff or groundwater (blue and brown circles)

Humankind intercepts, for “use”, 4,300 km³, or ~4% of that flow
75% of that use is for irrigated agriculture

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<table>
<thead>
<tr>
<th>Water use sector</th>
<th>Withdrawals</th>
<th>Groundwater</th>
<th>Consumptive use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation *</td>
<td>3,200 km³/a</td>
<td>42%</td>
<td>1,200 km³/a</td>
</tr>
<tr>
<td>Thermal power plants</td>
<td>530 km³/a</td>
<td>0%</td>
<td>10 km³/a</td>
</tr>
<tr>
<td>Households</td>
<td>330 km³/a</td>
<td>36%</td>
<td>50 km³/a</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>260 km³/a</td>
<td>27%</td>
<td>110 km³/a</td>
</tr>
<tr>
<td>Livestock</td>
<td>27 km³/a</td>
<td>0%</td>
<td>27 km³/a</td>
</tr>
</tbody>
</table>

Green water use 5,300 km³/a (evapotranspiration of precipitation on cropland)

*we waste 30%  
* 7 m³/person/yr
Precipitation onto land surface = $\sim 110,000$ km$^3$/yr (green circle)

$\sim 55,000$ km$^3$/yr are re-evaporated, or transpired by plants

$\sim 55,000$ km$^3$/yr flow, eventually, to the ocean, via surface runoff or groundwater (blue and brown circles)

Humankind intercepts, for “use”, 4,300 km$^3$, or $\sim 4\%$ of that flow

75% of that use is for irrigated agriculture
“Virtual”, or embodied water

Steel: 6 liters/kilogram
Microchips: 16,000 liters/kilogram
Virtual water in food: liters of water/kg of food

Tony Allan, 2006, 2011
Virtual water in food: liters of water/kg of food
>3,300 brands of bottled water are now available worldwide

Despite their brave assertions of pristine purity, all represent recycled water.
In 2009:

Americans spent $21 billion on bottled water
All water utilities in the USA spent $29 billion on renovation and maintenance of their facilities

One 500 ml bottle of water cost $1.25
Thus, one m³ of bottled water cost $2,500
One m³ of treated water delivered to an American household by a public water utility cost $0.75

That is a markup of 3,333X!

Public water utilities are beginning to wonder why they bother to deliver safe water to American households. This is an insidious risk.

If you insist on using bottled water in the USA, please buy it from those companies who bottle and sell tap water already purified by municipal utilities. EPA trumps FDA.

(After 2010, bottled-water use in the USA has begun to decline)
Distribution of fresh water by continent
China and India together represent 37% of the world’s population, but control only ~11% of the fresh-water resources.
Watersheds shared by two or more sovereign states
MAJOR RIVERS SOURCED IN TIBET

www.MeltdowninTibet.com © Michael Buckley
North: 64% of cultivated land
19% of fresh water resources

South: 36% of cultivated land
81% of fresh water resources
There are conflicting messages here....
Sixteen Essential Elements

Fig. 4-1. Periodic table of elements highlighting the 16 essential plant nutrients.
Elements (nutrients) essential to plant life:

0. major non-mineral: O, H, C

1. primary: K, N, P

2. secondary: Ca, Mg, S

3. micro: Fe, Mn, Cl, Zn, Cu, B, Mo

?. (maybe micro: Na, Si)

From atmosphere, hydrosphere; from rocks; from symbionts, lightning.

Nutrients other than O, H, C, and N predominantly form positively charged ionic cations, which are absorbed and stored on unsatisfied negative ionic sites on clay-mineral skeletons and organic debris in soils.

Nitrogen predominantly forms negatively charged anions, which are flushed through soils to ground and surface water and, eventually, to the global ocean.
The Phosphorus cycle

- Animal manures and biosolids
- Plant residues
- Organic Phosphorus: Microbial, Plant residues, Humus
- Crop harvest
- Atmospheric deposition (dust)
- Mineral fertilizers
- Runoff and erosion
- Soluble P: $\text{H}_2\text{PO}_4^-$, $\text{HPO}_4^{2-}$
- Primary minerals (apatite)
- Mineral surfaces (clays, Fe and Al oxides, carbonates)
- Secondary compounds (CaP, FeP, MnP, AlP)
- Plant uptake
- Immobilization
- Mineralization
- Desorption
- Adsorption
- Dissolution
- Precipitation
- Leaching (usually minor)
To ground and surface water we waste 30% of applied N as guano.
Global oceanic dead zones

USDA, 2012
Everybody’s favorite dead zone
Cropland Per Capita

Africa

N& C America

Europe

Asia

So America

USSR (former)

Ecosystem Overfishing

- FISHING
- PHYSICAL IMPACT OF FISHING GEAR
- BYCATCH
  - Economic discards
  - Regulatory discards
  - Collateral mortality
- INCIDENTAL MORTALITY
  - Discarded Bycatch and Offal

Harvest Mortality

BIOLOGICAL INTERACTIONS
- Predator-prey interactions
- Competitive interactions
- Changes in marine food webs

Habitat Modification or Destruction

Decline in Mean Trophic Level

Altered Ecosystem Structure and Function

Source: Adapted from Pauly et al., 1998; Goñi, 2000.

Art: John Michael Yanson

MIT Mission 2015: Biodiversity
Grand Banks Cod Fishery ~1400

FISHING

PHYSICAL IMPACT OF FISHING GEAR

BYCATCH
• Economic discards
• Regulatory discards
• Collateral mortality

INCIDENTAL MORTALITY

Habitat Modification or Destruction

Discarded Bycatch and Offal

HARVEST MORTALITY

DECLINE IN MEAN SIZE

DECLINE IN MEAN TROPHIC LEVEL

BIOLOGICAL INTERACTIONS
• Predator-prey Interactions
• Competitive interactions
• Changes in marine food webs

ALTERED ECOSYSTEM STRUCTURE AND FUNCTION

Source: Adapted from Pauly et al., 1998; Goñi, 2000.

MIT Mission 2015: Biodiversity
<table>
<thead>
<tr>
<th>Species Group</th>
<th>Discard</th>
<th>Landed</th>
<th>D/L</th>
<th>D/T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrimps, prawns</td>
<td>9,511,973</td>
<td>1,827,568</td>
<td>5.20</td>
<td>0.84</td>
</tr>
<tr>
<td>Redfishes, basses, congers</td>
<td>3,631,057</td>
<td>5,739,743</td>
<td>0.63</td>
<td>0.39</td>
</tr>
<tr>
<td>Herrings, sardines, anchovies</td>
<td>2,789,201</td>
<td>23,792,608</td>
<td>0.12</td>
<td>0.10</td>
</tr>
<tr>
<td>Crabs</td>
<td>2,777,848</td>
<td>1,117,061</td>
<td>2.49</td>
<td>0.71</td>
</tr>
<tr>
<td>Jacks, mullets, sauries</td>
<td>2,607,748</td>
<td>9,349,055</td>
<td>0.28</td>
<td>0.22</td>
</tr>
<tr>
<td>Cods, hakes, haddocks</td>
<td>2,539,068</td>
<td>12,808,658</td>
<td>0.20</td>
<td>0.17</td>
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<tr>
<td>Miscellaneous marine fishes</td>
<td>992,356</td>
<td>9,923,560</td>
<td>0.10</td>
<td>0.09</td>
</tr>
<tr>
<td>Flounders, halibuts, soles</td>
<td>946,436</td>
<td>1,257,858</td>
<td>0.75</td>
<td>0.43</td>
</tr>
<tr>
<td>Tunas, bonitos, billfishes</td>
<td>739,580</td>
<td>4,177,653</td>
<td>0.18</td>
<td>0.15</td>
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<tr>
<td>Squids, cuttlefishes, octopuses</td>
<td>191,801</td>
<td>2,073,523</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Lobsters, spiny-rock lobsters</td>
<td>113,216</td>
<td>205,851</td>
<td>0.55</td>
<td>0.35</td>
</tr>
<tr>
<td>Mackerels, snooks, cutlassfishes</td>
<td>102,377</td>
<td>3,722,818</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Salmons, trouts, smelt</td>
<td>38,323</td>
<td>766,462</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Shads</td>
<td>22,755</td>
<td>227,549</td>
<td>0.10</td>
<td>0.09</td>
</tr>
<tr>
<td>Eels</td>
<td>8,359</td>
<td>9,975</td>
<td>0.84</td>
<td>0.46</td>
</tr>
<tr>
<td>Total</td>
<td>27,012,099</td>
<td>76,999,942</td>
<td>0.35</td>
<td>0.26</td>
</tr>
</tbody>
</table>
GLOBAL FISHERIES

- Fully exploited: 52%
- Overexploited: 17%
- Depleted: 7%
- Recovering: 3%
- Moderately exploited: 20%
- Underexploited: 1%

FAO, 2008
Causes of fisheries depletion:

Where is climate change?

- Pollution
- Invasive species
- Habitat loss/degradation
- Exploitation

*Industrial, agricultural, pharmaceutical, domestic*

MIT, Biodiversity 2015
Farmed vs wild-caught food:

Per capita consumption of red meat and poultry:  
USA: 96 kg/yr  
world: 42 kg/yr

Per capita consumption of marine fish and shellfish:  
USA: 6.5 kg/yr  
world: 14 kg/yr

USA per capita consumption of wild-caught game (deer, ducks, geese):  
<1 kg/yr; ~1%

USA per capita consumption of wild-gathered grains and vegetables (mushrooms, blueberries, “wild” rice):  
<<0.1 kg/yr; <<0.1%

In the USA, aboriginal ecosystems are preserved in parks, wildlife refuges, etc.; aboriginal ecosystems elsewhere in the USA have been replaced by farmland, grazing land, food animals

In the USA, we hunt/gather ~1% of our land-based food
Worldwide, 65% of fish/shellfish is still wild caught, using hunter/gatherer technology; 35% is produced via aquaculture.

Productivity and diversity of marine ecosystems have been sharply reduced, but marine biota have not been replaced by domestic biota.

Aquaculture represents the lowest-hanging fruit...

This is more like it....
Energy use in the global and US food system

Steinhart & Steinhart, 1974
Energy use in the global and US food system

No net increase since 1970

Steinhart & Steinhart, 1974
Where does bottled water plot?
WE WASTE:

Water: via careless application, contamination, over-extraction
Soils: via urban/suburban development, erosion
Nutrients: via overfertilization; loss of storage capacity
Fisheries: via overexploitation, pollution, bycatch, loss of gear, habitat destruction

ENERGY: via excessive use at every stage
Opportunities: renewable energy sources, IT-managed applications, hydroponics, aquaculture
Finished product (food): the theme of this conference

THIS WASTE CANNOT BE ATTRIBUTED TO CLIMATE CHANGE
History of our food system

World Population Growth Through History

From "World Population: Toward the Next Century," copyright 1994 by the Population Reference Bureau
The Big Surprise: Africa
A large, unanticipated rise in Africa’s future population accounts for almost the entire increase in the 2100 global projection. Data from 2010 censuses and subsequent surveys show that African fertility rates remain higher than predicted, and death rates from AIDS have eased, thanks to better treatment. The population of Asia (green) will be slightly higher; that of Latin America (orange) will be lower.

Fischetti, Mark
11/18/2014
Scientific American
Stone tools
World Population Growth Through History

From "World Population: Toward the Next Century," copyright 1994 by the Population Reference Bureau
Domestication of food animals

From "World Population: Toward the Next Century," copyright 1994 by the Population Reference Bureau
World Population Growth Through History

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World Population Growth Through History

Billions of People

Universities

From "World Population: Toward the Next Century," copyright 1994 by the Population Reference Bureau
Coal, gas, oil
Sanitary engineering
Modern medicine
Bone meal; rock phosphate
Haber-Bosch

Fritz Haber  Carl Bosch  1911-1913

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World Population Growth Through History

Billions of People

Old Stone Age
New Stone Age Commences
Iron Age
Middle Ages
Modern Age
Black Death - The Plague
2025

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World Population Growth Through History

Billions of People

Old Stone Age | New Stone Age Commences | New Stone Age | Bronze Age | Iron Age | Middle Ages

2-5 million years | 7000 B.C. | 6000 B.C. | 5000 B.C. | 4000 B.C. | 3000 B.C. | 2000 B.C. | 1000 B.C. | A.D. 1000 | A.D. 2025

From "World Population: Toward the Next Century," copyright 1994 by the Population Reference Bureau
World Population Growth Through History

Billions of People

From "World Population: Toward the Next Century," copyright 1994 by the Population Reference Bureau
We can’t go back:

To return to traditional agriculture will require that \( \geq 3 \) billion people starve

And 60% of those who survive must return to manual tillage of the soil

In contemporary subsistence-agriculture societies, neonatal mortality is ~50% and life expectancy is ~40 years

No Smartphones, no internet, no NFL, no oranges in NYC in January, no Upenn, no Novocaine….

Ain’t gonna happen…..
Just in the last 100 years, humankind has committed to an industrialized, energy-intensive, technology-facilitated food system. That has been made possible by low-cost fossil-fuel energy.

In that century, the human population has grown from 1.6 to 7.2 billion, and is now predicted to reach 11 billion before declining birth rates lead to a stable, or even shrinking, human population.

We require unsustainable practices to feed the people now on Earth.

We can realize very substantial reduction in resource use (and mis-use) by improving efficiencies of current systems.

*We can feed 11 billion people*

We will still be far from “sustainability”. 
Global strategies to feed 11 billion people:

1. Achieve universal gender-neutral education
2. PRICE ENERGY REALISTICALLY *(gradually...)*
3. Eat lower in the food chain *(for some cultures, eat less)*
4. Use only agricultural waste for biofuel
5. Mandate energy efficiency in construction and renovation; achieve transition to renewable energy sources; cover all buildings built after 2015 with PV cells
6. Grow food where the water is – *reform irrigation technology*
7. Apply fertilizer only as utilized by crops; recycle nutrients; apply pesticides, herbicides only as needed
8. Protect soils from erosion
9. Recycle sewage as drinking water
10. Close most of global ocean to fishing; replace by aquaculture *recycle nutrients between hydroponics and aquaculture*
11. Use gene manipulation to further increase agricultural yields, reduce loss to pests, *enhance photosynthetic efficiency*
12. Eat insects
13. Reduce waste late in the food-production process
Bon appétit
Bon appétit
WATER ON EARTH: \( 4 \pi r^2 \times 0.7 \times 4 \text{ km} \)

\[ 4\pi \times (6,000)^2 \times 0.7 \times 4 \times 10^9 \times 10^3 \times 55 \times (6 \times 10^{23}) = 5 \times 10^{49} \text{ molecules of water on Earth} \]

(except for deep ground water and Glacier ice, the world’s water mixes in 2,000 years)

Water that has passed through any one human being = 4 liters/day \( \times \) 365 days \( \times \) 50 years \( \times \) 55 moles \( \times \) (6 \( \times \) 10\(^{23}\))

= \( 2.4 \times 10^{29} \) molecules

Proportion of water on Earth that has passed through Moses: \( 2.4 \times 10^{29}/5 \times 10^{49} = 5 \times 10^{-19} \)
A 250-ml glass of water contains 13 moles, or $10^{25}$ molecules.

Number of molecules in a 250 ml glass of water that have passed through Moses:

$$10^{25} \times 5 \times 10^{-19} = 2 \times 10^5$$

200,000 molecules of water in the glass of water have passed through Moses.

**CONCLUSIONS:**

1. Avogadro’s number is a *BIG* number
2. The wisdom of the ages resides in each glass of water
3. *All water is recycled*
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CONCLUSIONS:

1. Avogadro’s number is a BIG number
2. The wisdom of the ages resides in each glass of water
3. All water is recycled.
Not a drop of water makes it to the Sea of Cortez

McDonald, NAE, 2007
Flow of the Colorado River at Lees Ferry in the Grand Canyon

Data from the Lees Ferry Gauging Station: 1904-2012, and reconstructed from tree rings 1500-1904 AD

NAE, 2007
Water allocation 1922: 
- Upper Basin 7.5 maf/yr
- Lower Basin 7.5 maf/yr
- Mexico 1.4 maf/yr *(caveat)*
Global fish harvest, salt- and fresh-water, 1950-2000

Univ. of Michigan, Global Change
Very little of this combined impact on our food system can be attributed to anthropogenic climate change. The primary effect of excess CO$_2$ on food production is fertilization.

Sea level is rising, and reducing total arable land. This effect is slow, and trivial compared to the record of human manipulation of natural resources. Deliberate destruction of agricultural land reduces global cropland more than sea-level rise.

Humans have always struggled to produce enough food – in warming times, in cooling times...........humans have fared better in warming times than in cooling.

Today, all bets are off – there are many people, we are depleting resources at an unprecedented rate, and we are contaminating remaining resources. Lessons of the past may be less valuable........

Among our affronts to the systems that sustain us, the impact of the food industry on ocean biota, direct and indirect, represents simple abuse – it does not rise to the level of mismanagement.
World Population Growth Through History

Billions of People

- Old Stone Age
- New Stone Age Commences
- New Stone Age
- Bronze Age
- Iron Age
- Modern Age
- Middle Ages

2-5 million years B.C.
7000, 6000, 5000, 4000, 3000, 2000, 1000 B.C.
A.D.
2025

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Nuclear power?