Land, Water and Climate Change Adaptation
Steve Carpenter (srcarpen@wisc.edu)
Topics for the Talk:

Trends and links

Water withdrawals

Biogeochemical cycles

What could we do about it?
Topics for the Talk:

Trends and links

Water withdrawals

Biogeochemical cycles

What could we do about it?
Population Projections: MA Scenarios

United Nations high scenario

United Nations low scenario

MA scenarios
- Order from Strength
- Adapting Mosaic
- TechnoGarden
- Global Orchestration

Source: Millennium Ecosystem Assessment
Agricultural Area

~13% of land surface

~24% of land surface
AGRICULTURE

GREENHOUSE GAS EMISSIONS

CH$_4$ 52%
N$_2$O 84%
CO$_2$ 37%

HABITAT, WILD ORGANISMS

GROUNDWATER

Recharge
Withdrawal

AGRICULTURE

WATER QUALITY

Biocides
N flux (>2X)
P flux (>3X)

SURFACE WATER

Withdrawal
Runoff

37% of Land Area
Topics for the Talk:

Trends and links

Water withdrawals

Biogeochemical cycles

What could we do about it?
The grey band represents the difference between the amount of water extracted and that actually consumed. Water may be extracted, used, recycled (or returned to rivers or aquifers) and reused several times over. Consumption is final use of water, after which it can no longer be reused. That extractions have increased at a much faster rate is an indication of how much more intensively we can now exploit water. Only a fraction of water extracted is lost through evaporation.

Groundwater:

~25% of global water withdrawals; ~50% of the world’s potable water

1.5 to 2.8 B people drink groundwater, including more than half the world’s megacities (>10M people)

Withdrawal / renewal ratio varies hugely among countries:

Lowest and Highest: 0.4% Brazil, 950% Saudi Arabia

High-population countries: China 6.5%, India 43%

U.S. 8.5%

Global average 5.8%

“Institutions for managing groundwater sustainably have universally failed”.

Global Trends in Water Shortage

Kummu et al., ERL 2010
Topics for the Talk:

Trends and links

Water withdrawals

Biogeochemical cycles

What could we do about it?
## Human-Driven Changes in Biogeochemical Cycles

<table>
<thead>
<tr>
<th>Element</th>
<th>Natural Flux (10^6 MT/year)</th>
<th>Human Flux (10^6 MT/year)</th>
<th>% Change from Human Activity</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>61,000</td>
<td>8,000</td>
<td>+13</td>
<td>Terrestrial total respiration; Fossil fuel and land use C</td>
</tr>
<tr>
<td>N</td>
<td>130</td>
<td>140</td>
<td>+108</td>
<td>Natural biological fixation; Fertilizers, combustion, rice</td>
</tr>
<tr>
<td>P</td>
<td>12.5</td>
<td>18.5</td>
<td>+248</td>
<td>Weathering; Mining</td>
</tr>
<tr>
<td>S</td>
<td>80</td>
<td>90</td>
<td>+113</td>
<td>Natural emissions; Fossil fuel + biomass burning</td>
</tr>
<tr>
<td>H &amp; O</td>
<td>111x10^{12}</td>
<td>18x10^{12}</td>
<td>+16</td>
<td>As Water; Precipitation over land; Human use</td>
</tr>
<tr>
<td>Sediment</td>
<td>1x10^{10}</td>
<td>2x10^{10}</td>
<td>+200</td>
<td>Preindustrial suspended load: Modern suspended load</td>
</tr>
</tbody>
</table>

Eutrophication & Harmful Algal Blooms

Red tide, Maine, USA

Cyanobacteria, Chaohu Lake, China
Opportunities for Innovative Management Of Biogeochemistry

**Phosphorus recycling**: retain P on land to maintain high water quality and avoid cost increases as global P reserves decline and P exporters (China, Morocco, U.S.) raise prices

“**Designer crops**”: adapt landraces to local conditions for efficient yield while maintaining soil and water quality

**Adapt practices to store carbon**: 14% of global GHG emissions can be offset by agriculture if carbon price reaches $100/ton
Topics for the Talk:

Trends and links

Water withdrawals

Biogeochemical cycles

What could we do about it?
What Could We Do About It?

“Complete Accounting”: Include water, nutrients, carbon, habitat and wild species in decision frameworks for agriculture.

Innovate a lot faster: Make local innovation a global trend.
Natural Capital and Ecosystem Services of an Agricultural Watershed

Local outputs, benefits, costs

Natural Capital
- Soil
- Hydrology
- Vegetation
- Habitat
- Biotic Interactions etc.

Human Use and Management
- Institutions, incentives, regulations
- Markets
- Operators
- Equipment etc.

Changes in Land Cover, Ecosystem heterogeneity, Water infiltration & runoff, Carbon storage, Nutrient flows, Soil fertility, Biota, etc.

Ecosystem Services: Food & Fiber Production, Freshwater, Flood Regulation, Nutrient Regulation, Carbon Sequestration, Recreation, Aesthetics, etc.

Carpenter, Matson & Turner, unpublished
Create a Global Pattern of Local Innovation

Increase production efficiency (production per unit fertilizer, land, water). Increase diversity of crops and adaptability to changing conditions. Increase human well-being per unit crop production.
CONCLUSIONS

The future depends on inventing a new global agriculture:
  High yield
  Carbon-neutral or better
  Does not overdraw water
  Does not emit P and reactive N
  Friendly to land and wild organisms
  Resilient to changing conditions
The future depends on inventing a new global agriculture:

- High yield
- Carbon-neutral or better
- Does not overdraw water
- Does not emit P and reactive N
- Friendly to land and wild organisms
- Resilient to changing conditions

This requires new interdisciplinary work:

- Agricultural sciences
- Terrestrial & atmospheric environmental sciences
- Economics
- Institutional design
- Etc.

CONCLUSIONS
Some Specific Issues for Latin America

**Virtual water trade**: how will exports of water-demanding commodities affect water budgets?

**Virtual nutrient trade**: how will exports of nutrient-rich meat and soy affect nutrient budgets and water quality?

**Climate change**: How will a changing climate affect water availability?

**Institutions**: How can Latin America adapt to changing market forces and changing climate that impact agriculture, water, and human well-being?
Perspective:

• Integrated economies and societies

• The living resource base as the foundation for the integration

• Strengthening the ability of people to enhance Earth’s life support capacity for societal development and human wellbeing

Make sustainable development possible

Slide courtesy of Carl Folke, Stockholm Resilience Center
How will we innovate, adapt, and transform to maintain human life support in a changing world?

A problem of managing social-ecological complexity.