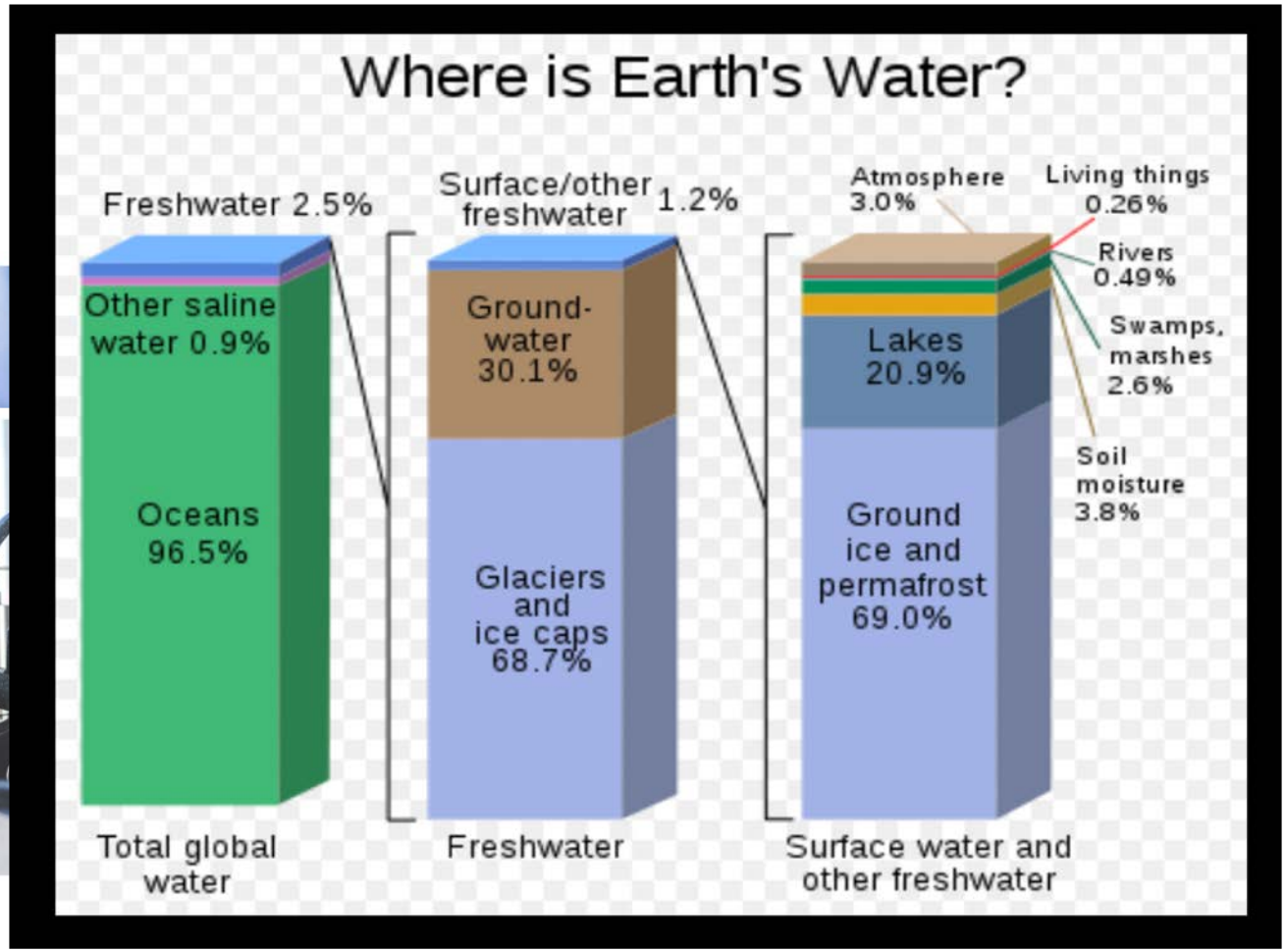
PSE Paradigms for Challenges in the Water-Food-Energy Nexus

Sirish L. Shah
University of Alberta
Edmonton, Canada
<sirish.shah@ualbeta.ca>

Water trivia



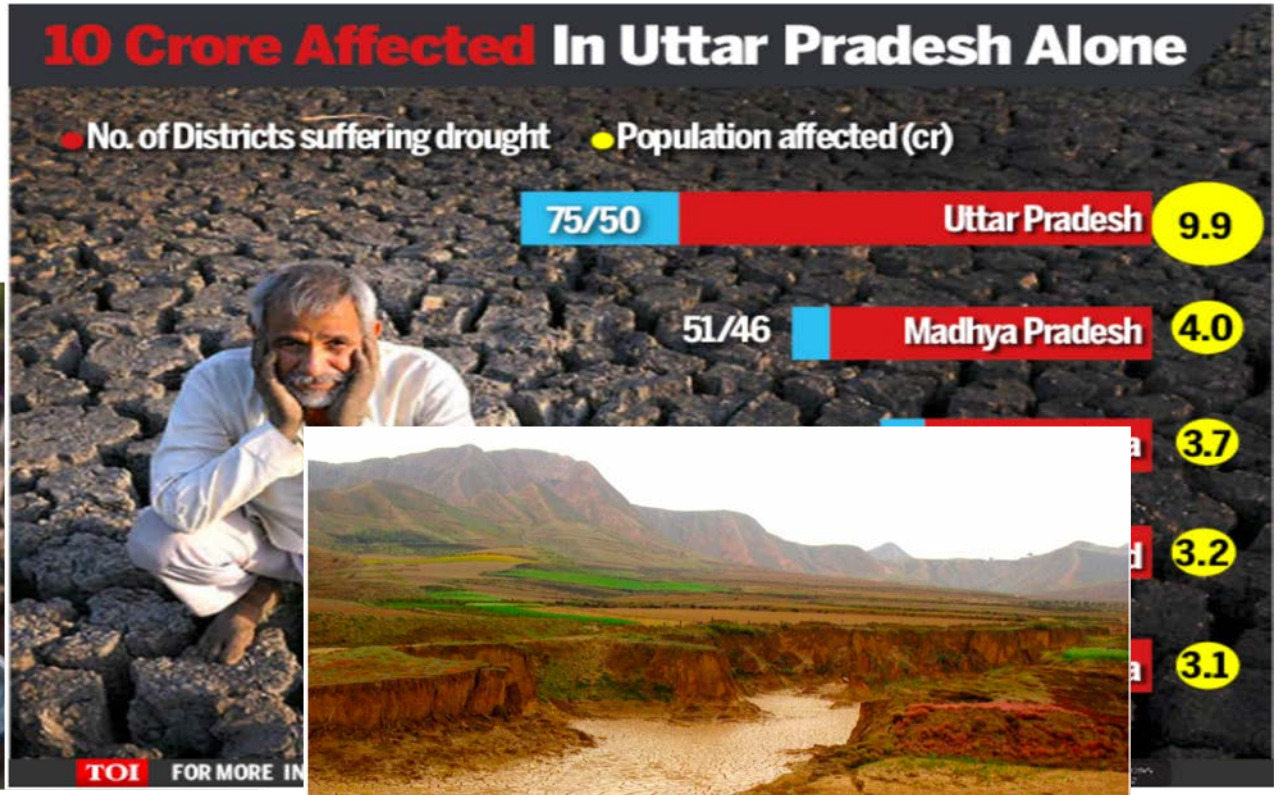
Why should the PSE community care about water?

- The water-food-energy nexus is central to sustainable development as demands for all three are increasing driven by population increases, urbanization, changing diets and economic growth.
- Food and agriculture are the largest consumers of water.
- About 70 % (or more) of the water we take from rivers and groundwater goes into irrigation.
- More than one one-quarter of the energy used globally is expended on food production and supply.

Outline

- Water 101
  - Types of irrigation
  - Water tables and aquifers
  - Receding water tables and depleting acquifers
- Open and unresolved problems in irrigation
  - Agro-hydrological systems and models
  - Measurements: what to measure; where and when to measure?
  - Feedback control? How?
  - Design of experiments to determine important features for yield improvement
  - Treatment of waste water
  - …..

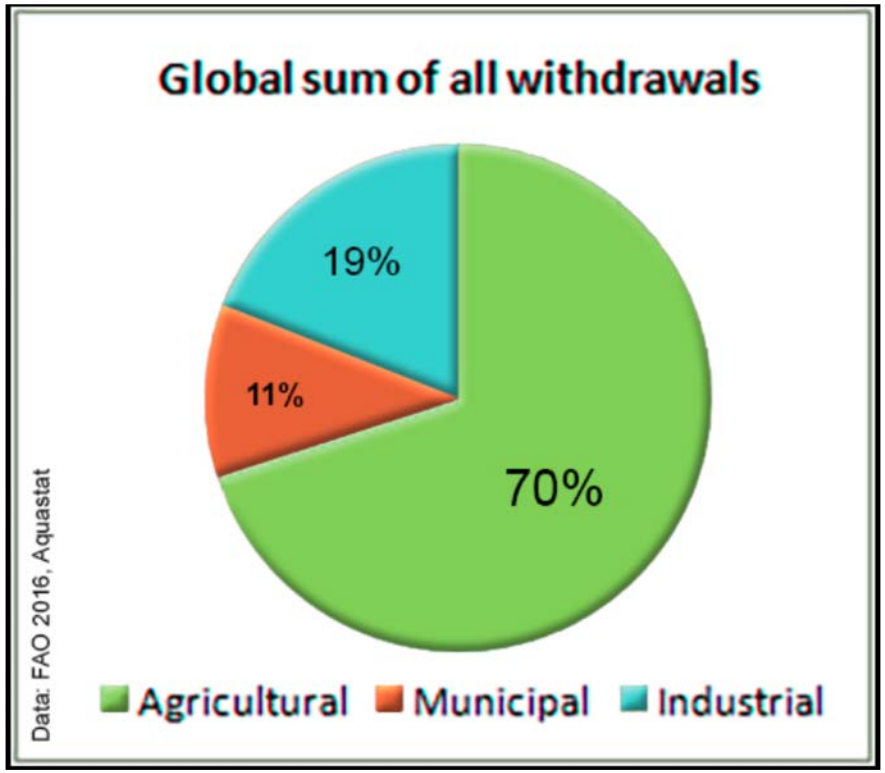
The big thirst



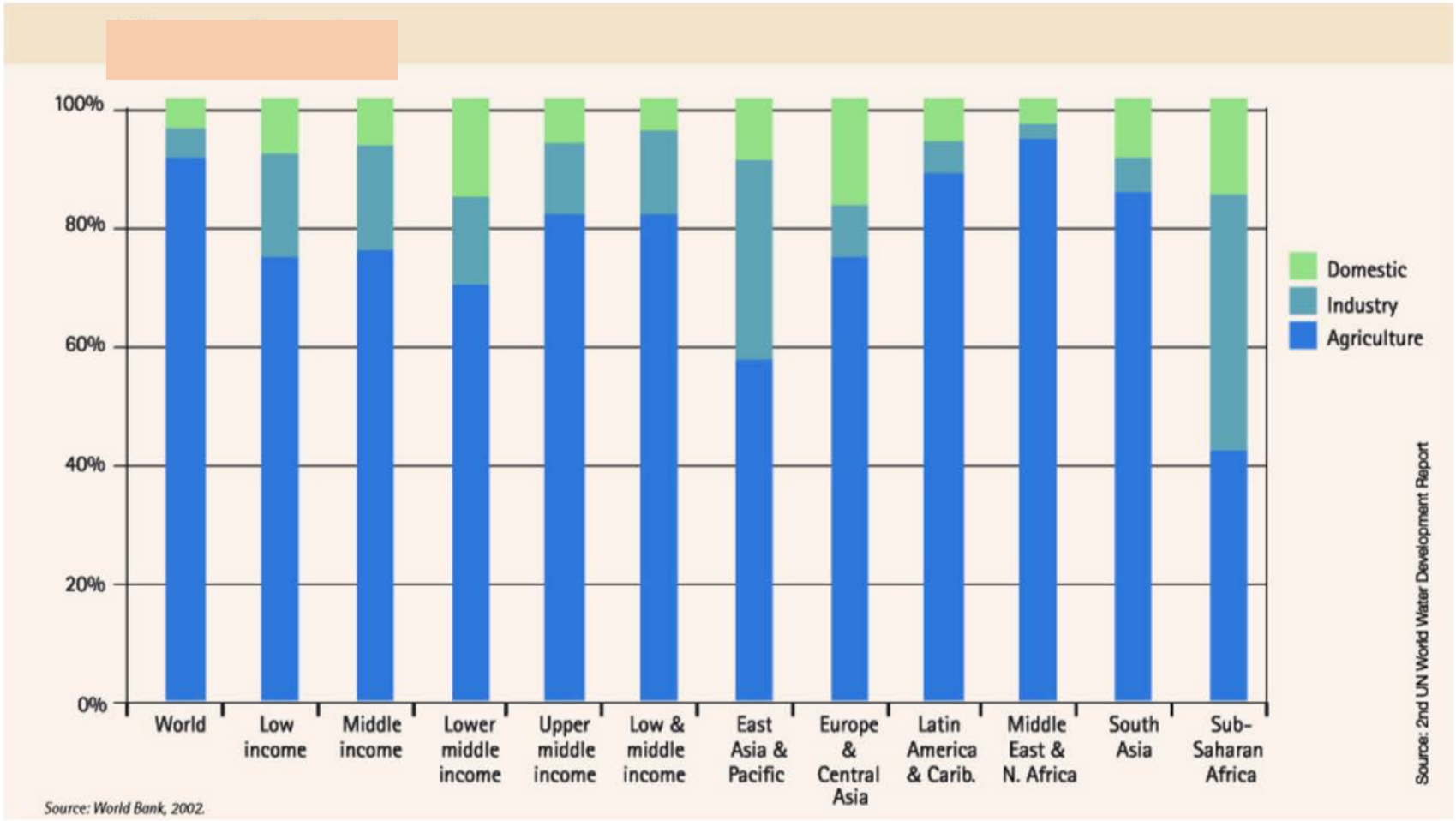
Awaiting day zero in Cape Town

Fresh water withdrawal for agriculture use

- Food and **agriculture** are the largest consumers of **water.**
- Up to 70 % of the **water** we take from rivers, lakes and groundwater goes into irrigation.



Water use by sector



Irrigation methods…1

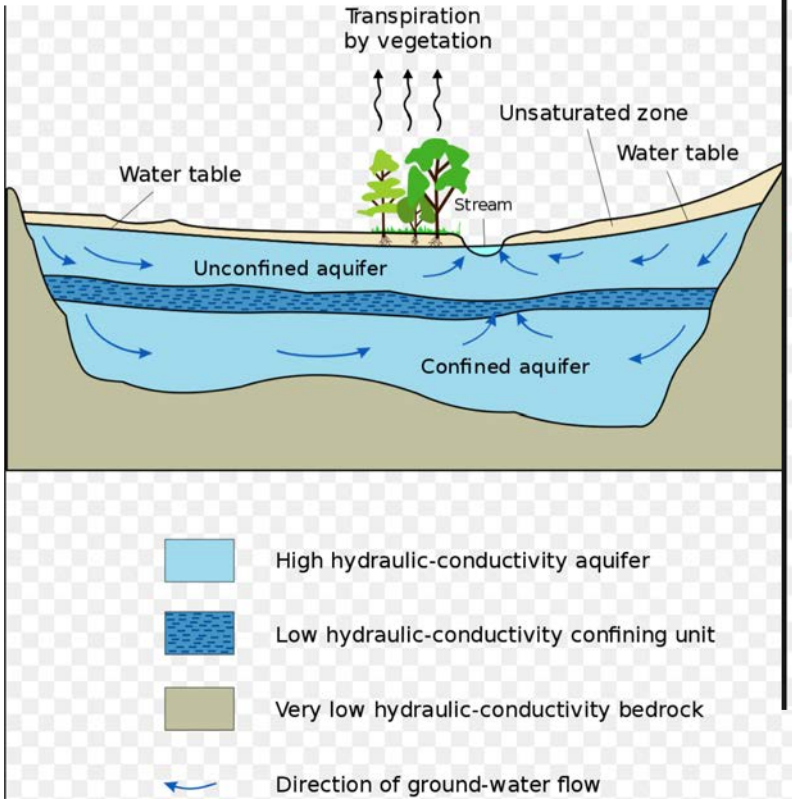
Centre pivot irrigation

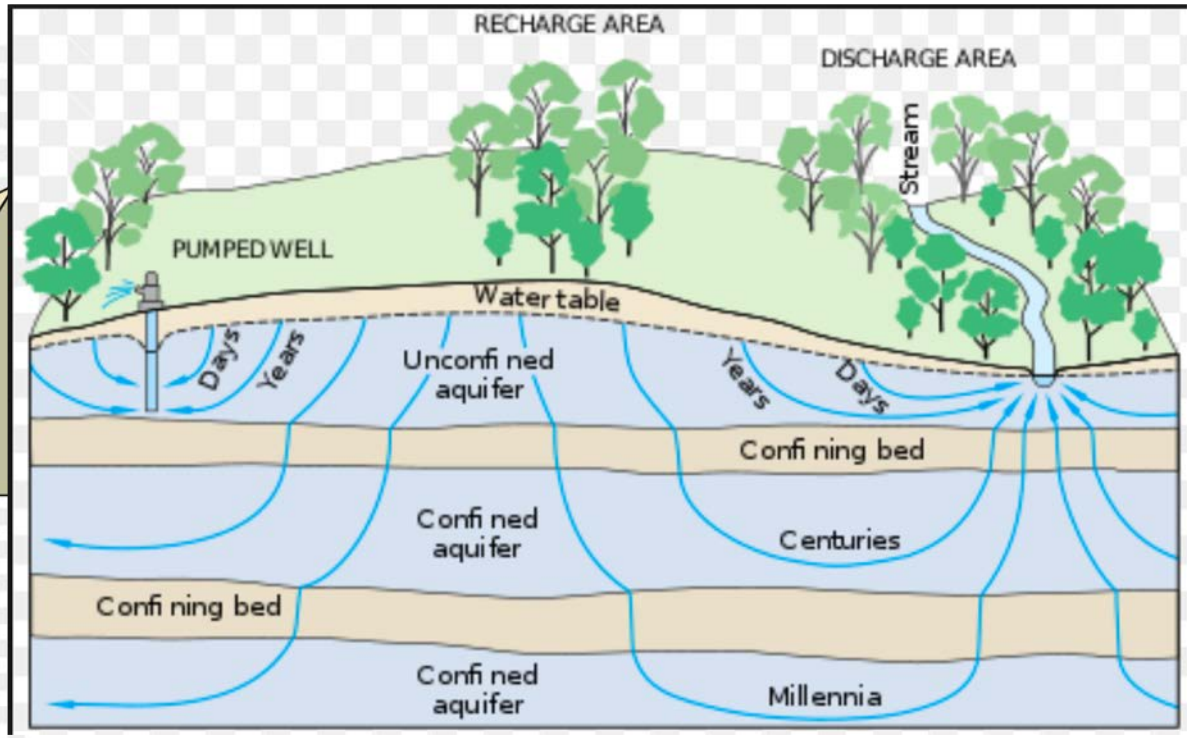
Irrigation methods…2

Aquifer depletion at record rates

- Intensive agriculture
- Nutrient loading

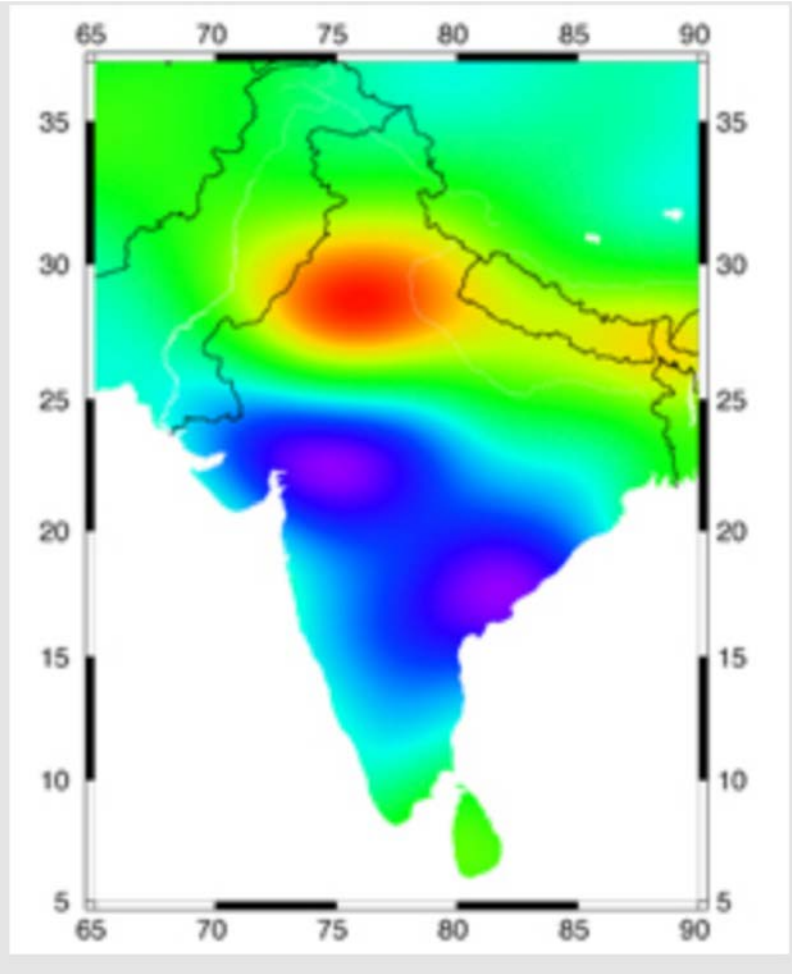
Water tables and aquifers



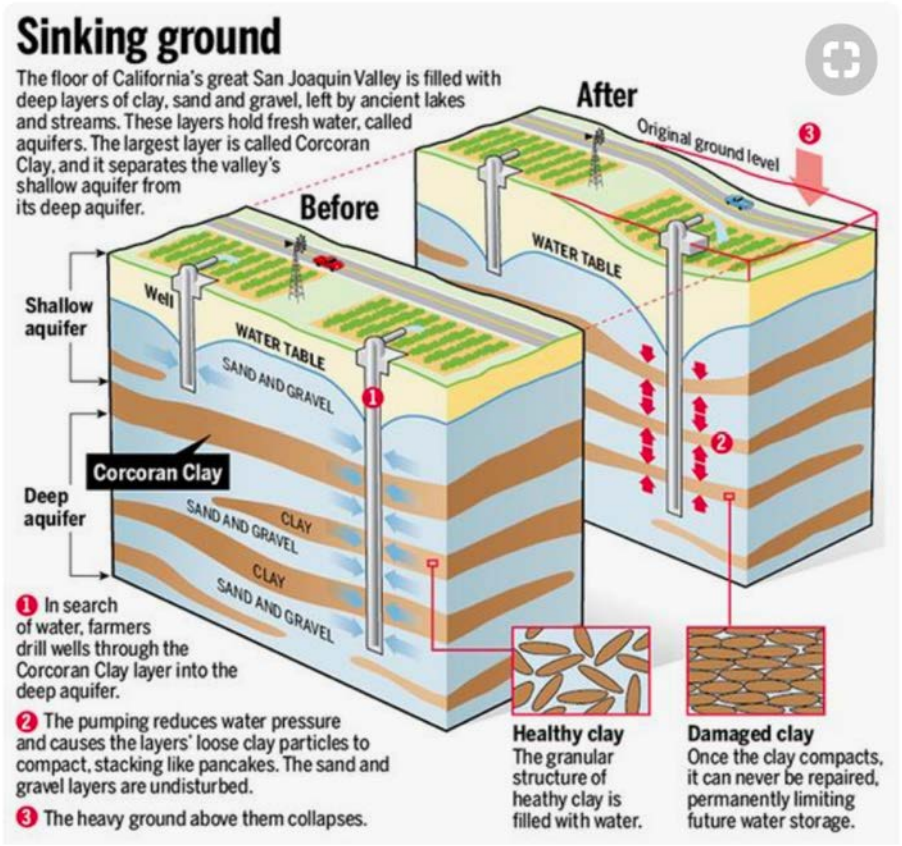


NASA Satellites Unlock Secret to Northern India's Vanishing Water

- Where is northern India’s underground water supply going? According to Rodell *et al*., it is being pumped and consumed by human activities -- principally to irrigate cropland -- faster than the aquifers can be replenished by natural processes. They based their conclusions -- published in the August 20 issue of Nature -- on observations from NASA’s Gravity Recovery and Climate Experiment (GRACE).
- Data provided by India's Ministry of Water Resources suggested groundwater use was exceeding natural replenishment, but the regional rate of depletion was unknown. Rodell and colleagues did their case study. The team analyzed six years of monthly GRACE gravity data for northern India to produce a time series of water storage changes beneath the region’s land surface.
- They found that groundwater levels have been declining by an average of one meter every three years (one foot per year).



Land subsidence due to over-exploitation of aquifers



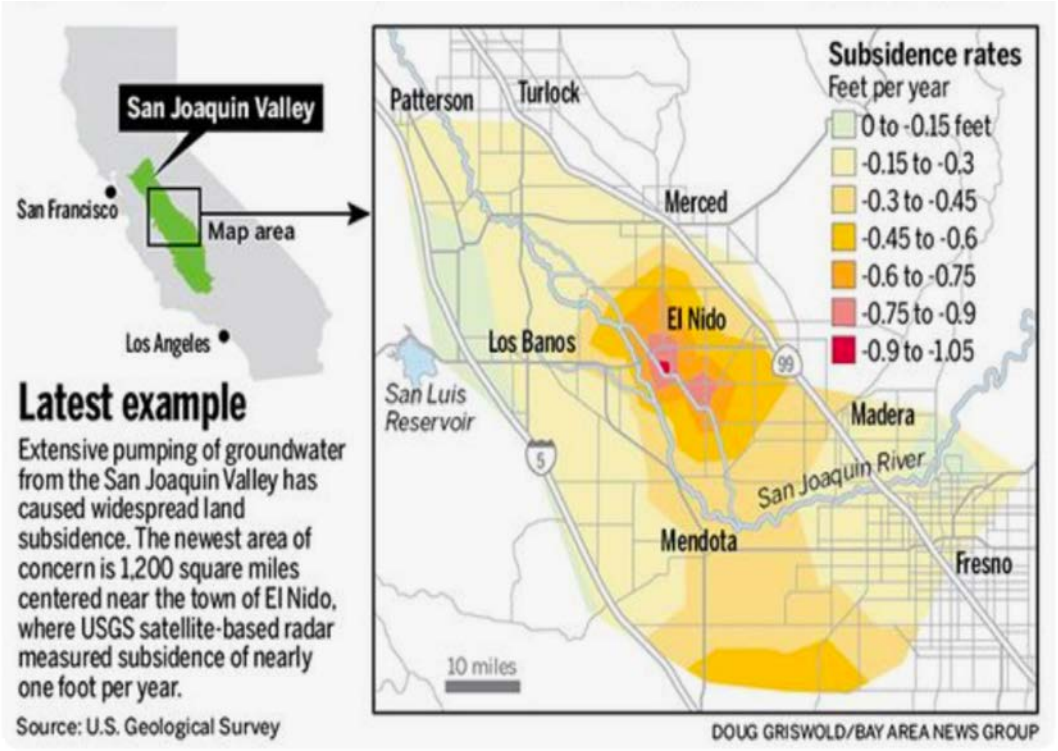
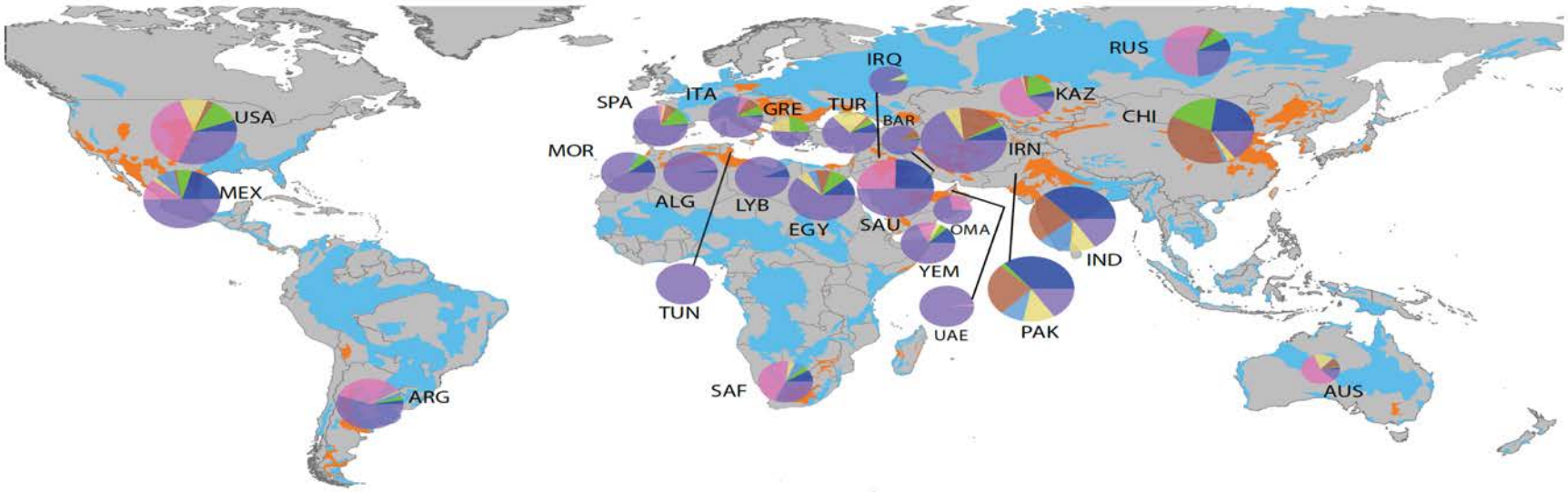


Figure 2 Crop-specific contribution to groundwater depletion worldwide in 2010



Groundwater stress index*

- >1
- <1

Groundwater depletion for irrigation

- >30 km³ yr⁻¹
- 10-30 km³ yr⁻¹
- 2-10 km³ yr⁻¹
- 1-2 km³ yr⁻¹
- <1 km³ yr⁻¹

- Wheat
- Maize
- Rice
- Sugarcane
- Cotton
- Fodder grasses
- Other

Outline

- Water 101
  - Types of irrigation
  - Water tables and aquifers
  - Depletion of water tables
- Open and unresolved problems in irrigation
  - Agro-hydrological systems and models
  - Measurements: what to measure; where and when to measure?
  - Feedback control? How?
  - Design of experiments to determine important features for yield improvement
  - Treatment of waste water

Some open and unsolved problems

The main causes of wasteful and unsustainable water use for agriculture are:

- Leaky and open-loop irrigation systems
- Wasteful field application methods
- Cultivation of thirsty crops not suited to the environment
- Optimization: What features are important for improving yields?

  Water footprint for tomato production: Gallons per pound (2010)

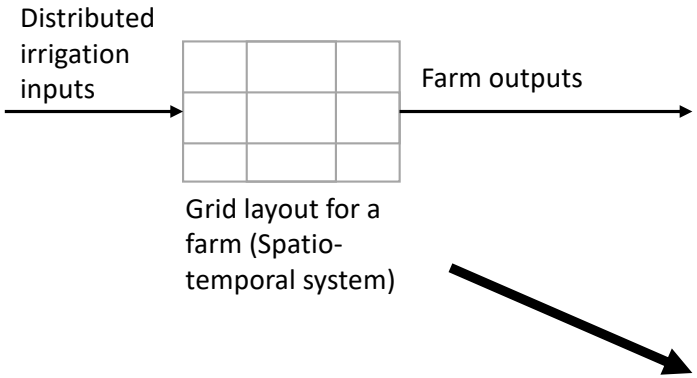
  1.1 (NL) ; 15.2 (USA); 25.6 (Global average); 34.0 (china)

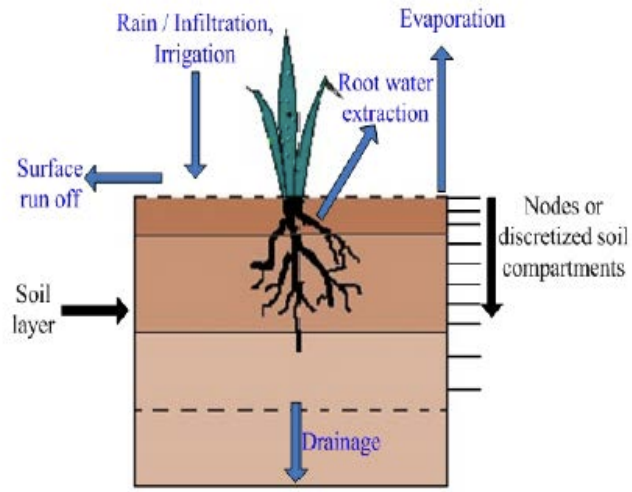
Some open and unsolved problems

The main causes of wasteful and unsustainable water use for agriculture are:

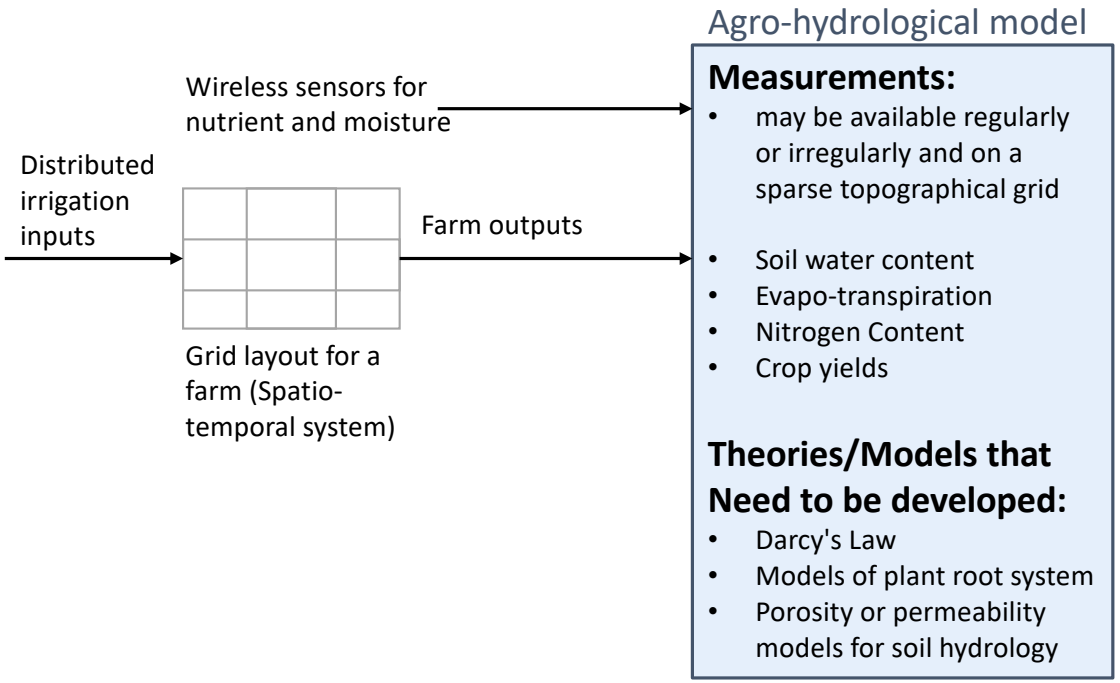
- Leaky and open-loop irrigation systems
- Wasteful field application methods
- Cultivation of thirsty crops not suited to the environment
- Optimization: What features are important for improving yields?
- Design of experiments
- Farm to table supply chain optimization
- Water pollution due to nutrient loading
- Many others….

Visions of a smart irrigation system





Visions of a smart irrigation system



Challenges in modeling of the Agro-hydrological process

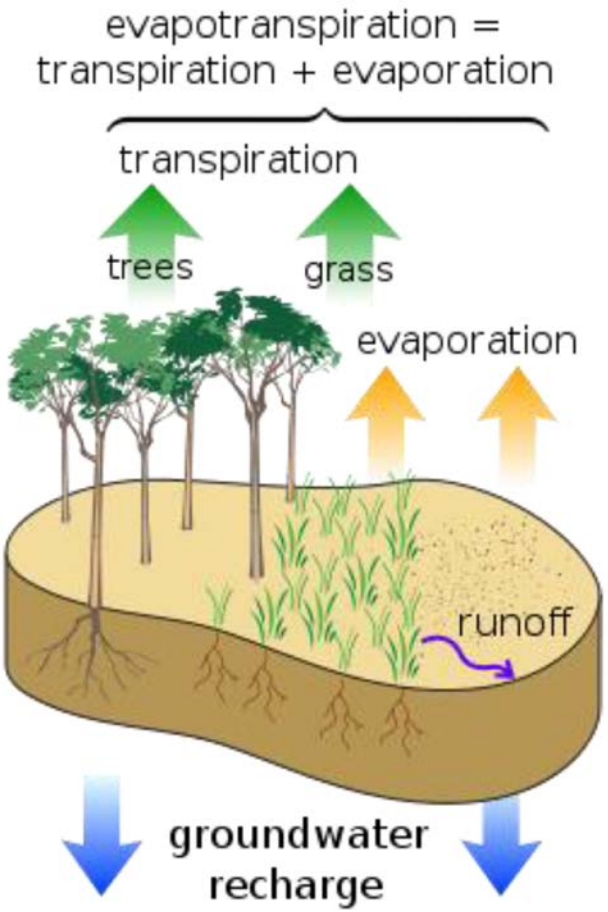
Measurements:

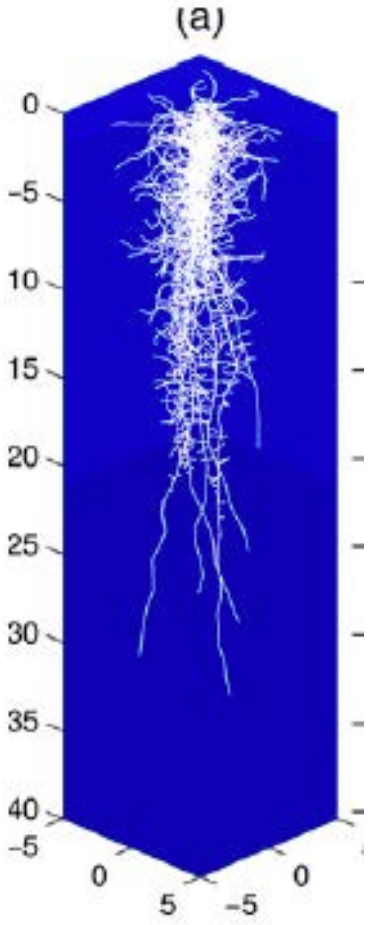
- may be available regularly or irregularly and on a sparse topographical grid
- Soil water content: where to locate sensors?
- Evapo-transpiration
- Nitrogen Content
- Crop yields

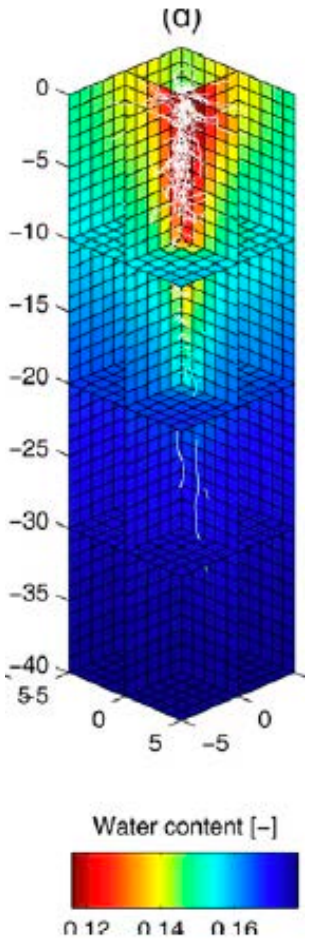
Theories/Models that Need to be developed:

- Darcy's Law
- Models of plant root system
- Porosity or permeability models for soil hydrology

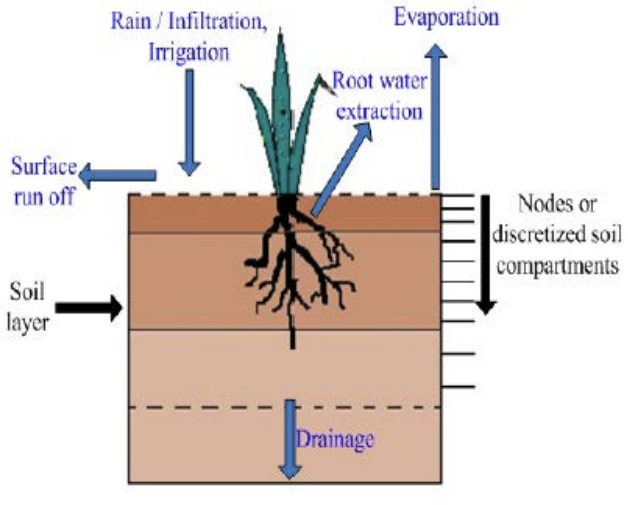
3D models for predicting root water uptake

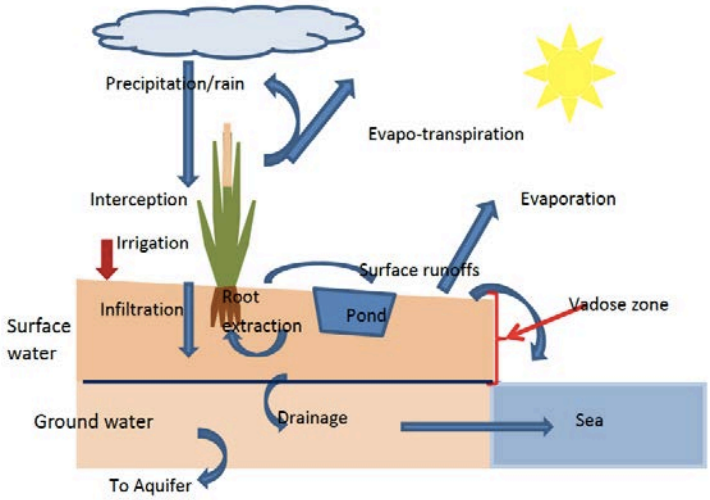




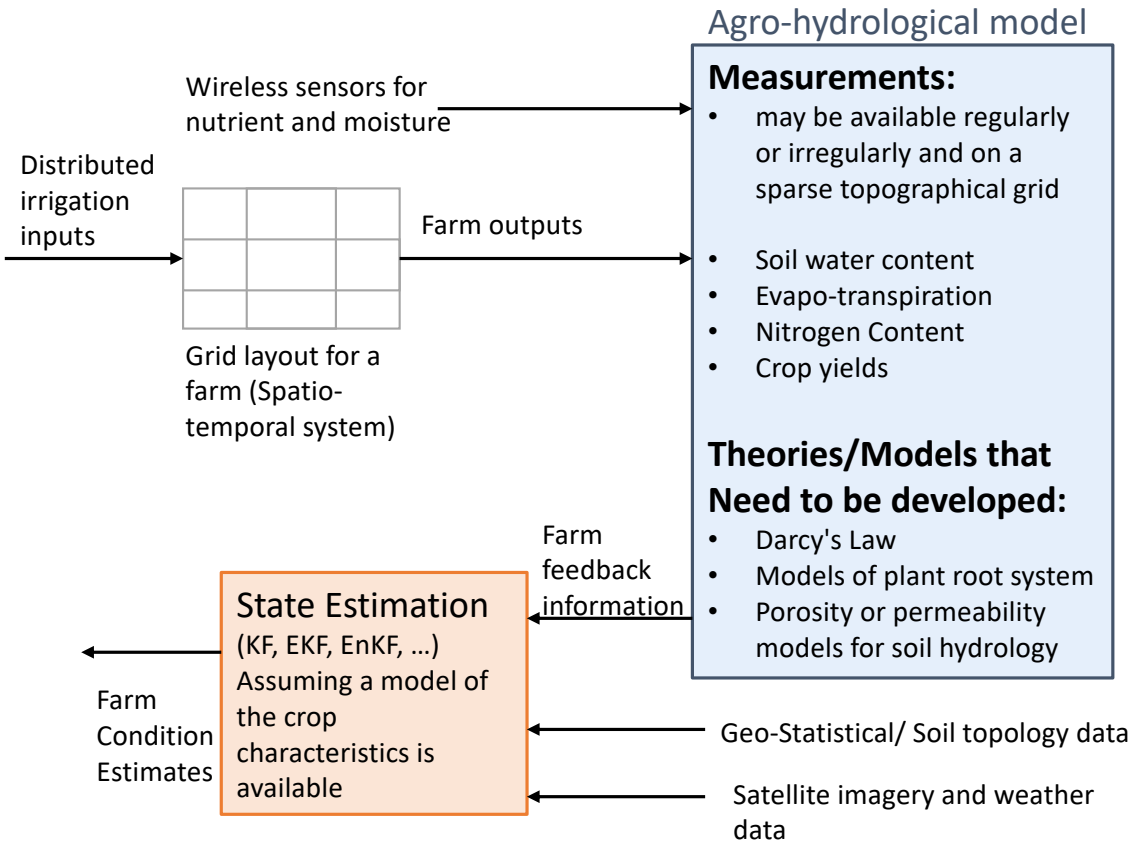


Agro-hyrdrological system

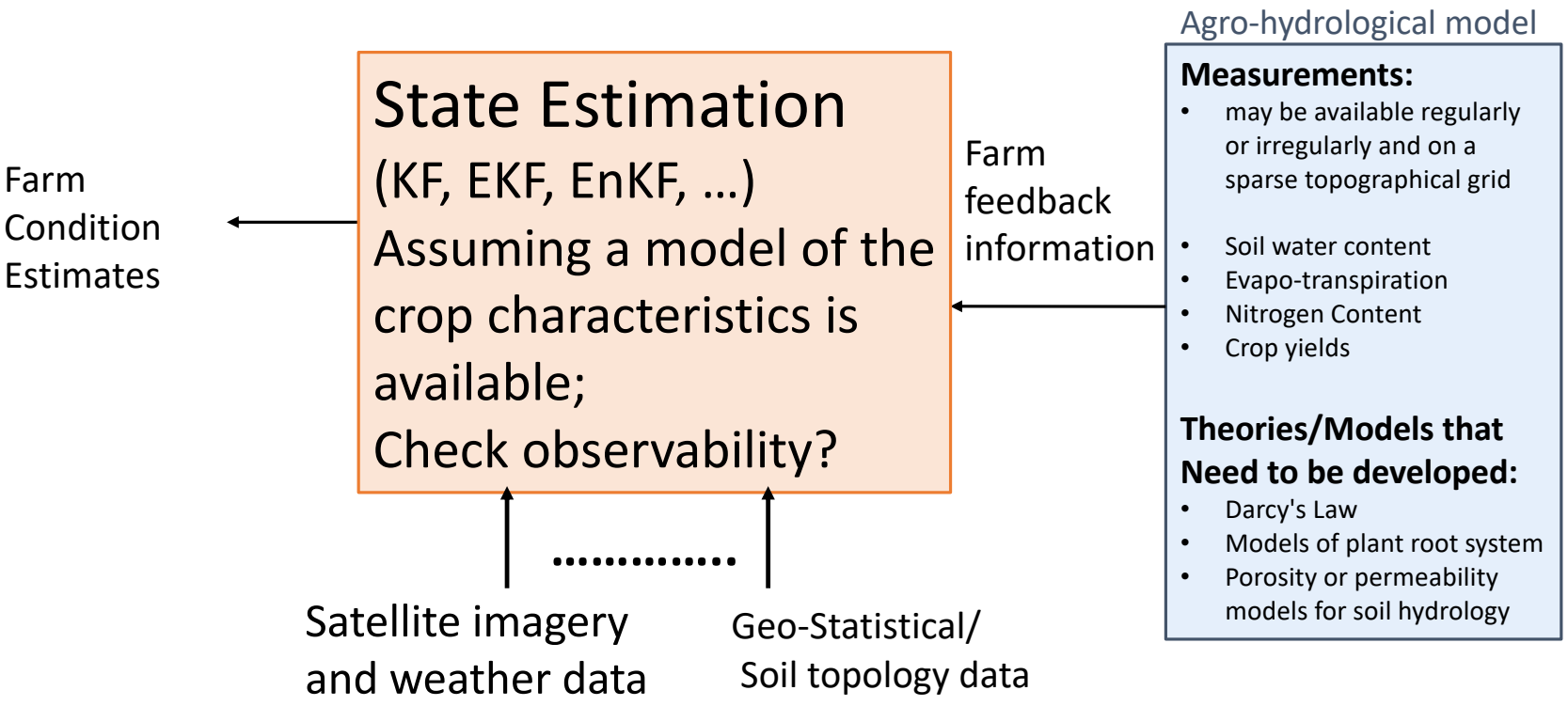




Visions of a smart irrigation system

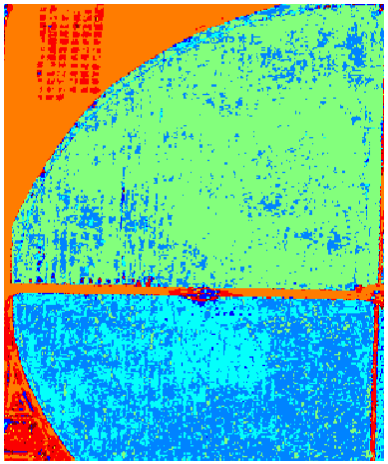


Challenges in estimation

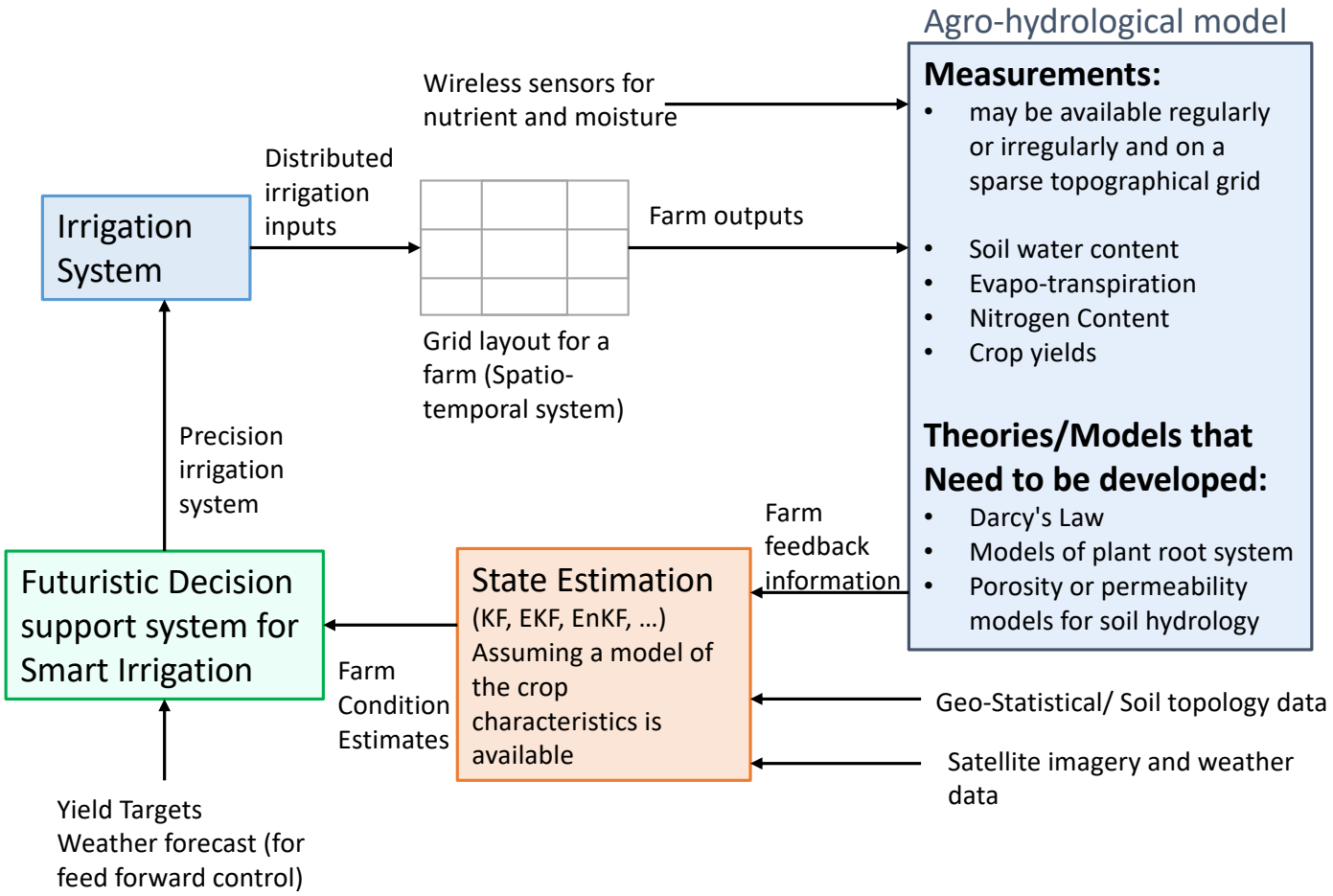


Sensor/Information fusion for efficient irrigation

Active | Instruments emit their own signal and the sensor measures what is reflected back. Sonar and radar are examples of active sensors.

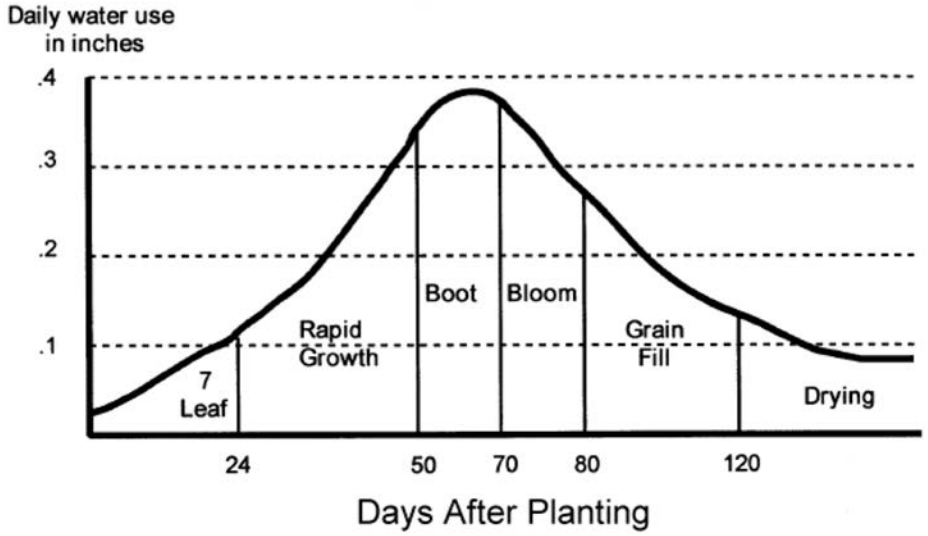


Visions of a smart irrigation system



Challenges: Many features: Would DoE help??

- Which variables are important?
- Water amounts; nutrients; soil type; complimentary crop types; plant characteristics and many others….
- Can farming be considered a ‘batch’ operation ?



Many features to investigate using DoE

- Water amounts; nutrients; soil type; complimentary crop types; plant characteristics and many others….
- Can farming be considered a ‘batch’ operation ?
- Which features are important?
- What to adjust and when as crops mature…
- Do a design of experiments…Recall Fisher’s work with tomatoes !!!

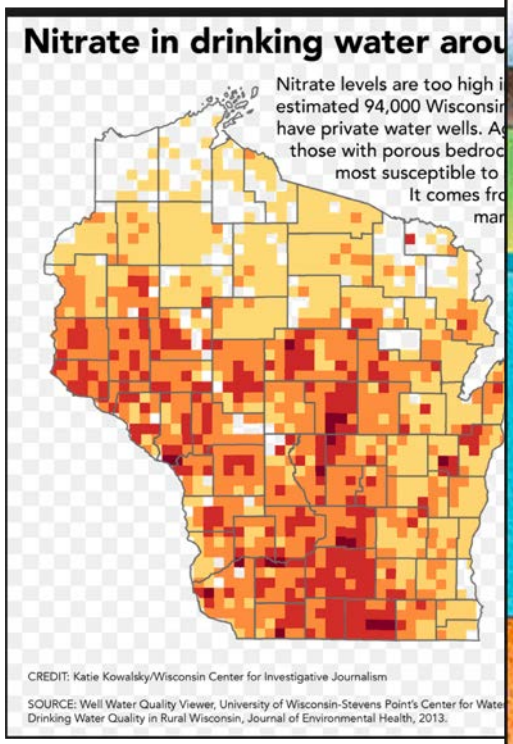
Challenges in ‘Farm to table’ supply chain optimization

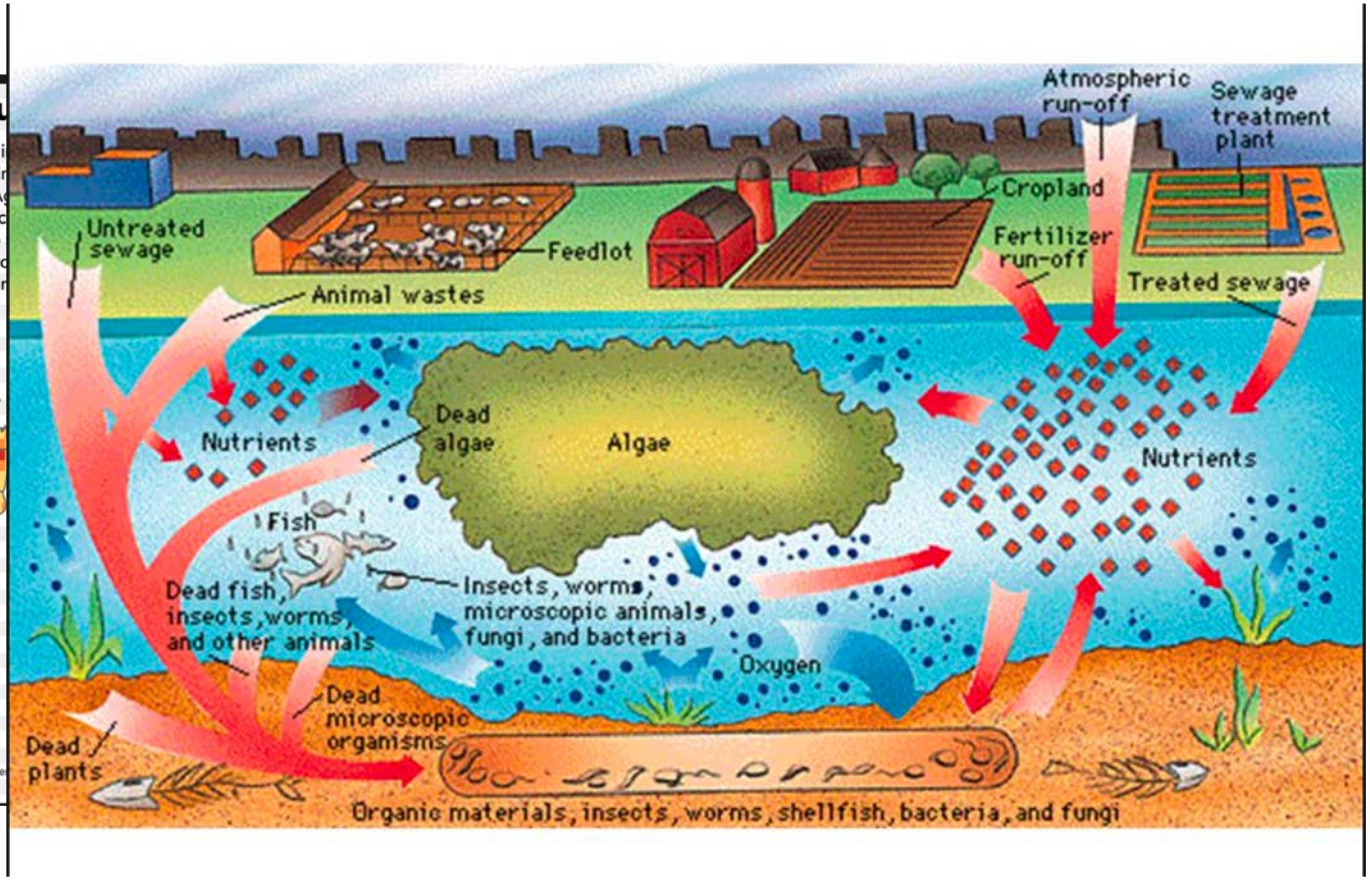
- Logistics of food transport*:*
- Dealing with perishables and time-critical harvesting
- Delivery constraints….decision support models and tools would have to be built in order to improve the supply chain performance.
- Deal with a combination of transport solutions, packaging issues, storage conditions, information flow, waste management, quality checks, and stock ordering and
- Preservation techniques have to be considered.
- Products have limited life time

Summary of open problems

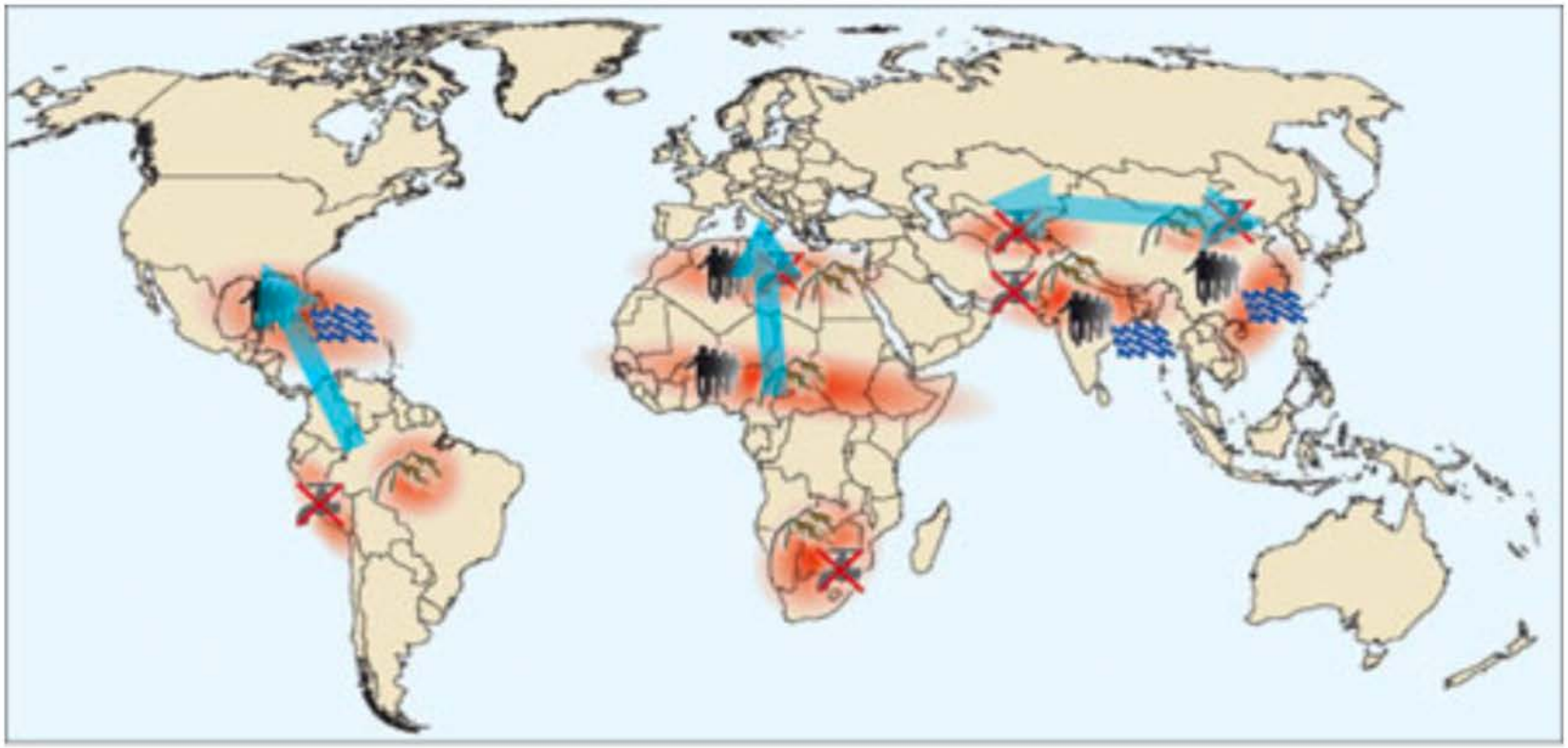
- Models for agro-hydrological systems
- Irrigation with feedback control
- Sensor development and location: what to measure and where to measure
- Supply chain optimization and logistics of food delivery and security
- Design of experiments: Features to consider…crop type; crop density; watering schedule,…nutrient composition; moisture content at different depths,….Fisher's tomato experiment…
- Treatment of waste water for agriculture run offs

Waste water treatment





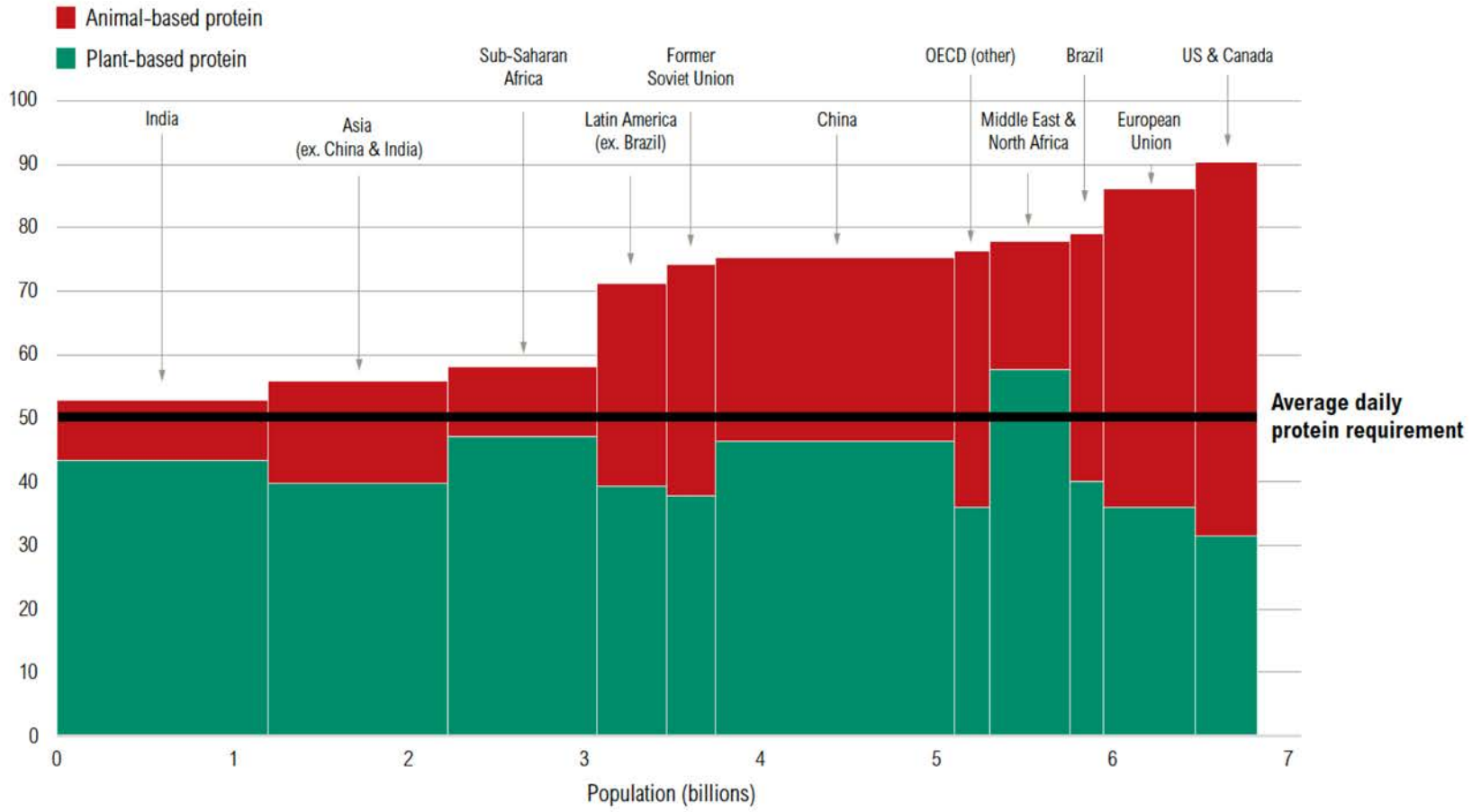
Migration pattern due to ecological degradation and climate change



Conflict constellations in selected hotspots

Figure 7 | **Protein Consumption Exceeds Average Estimated Daily Requirements in All the World's Regions, and is Highest in Developed Countries**

g/capita/day, 2009



PER TON PROTEIN CONSUMED