



# A Pathway of Global Food Supply Adaptation in a World with Increasingly Constrained Groundwater

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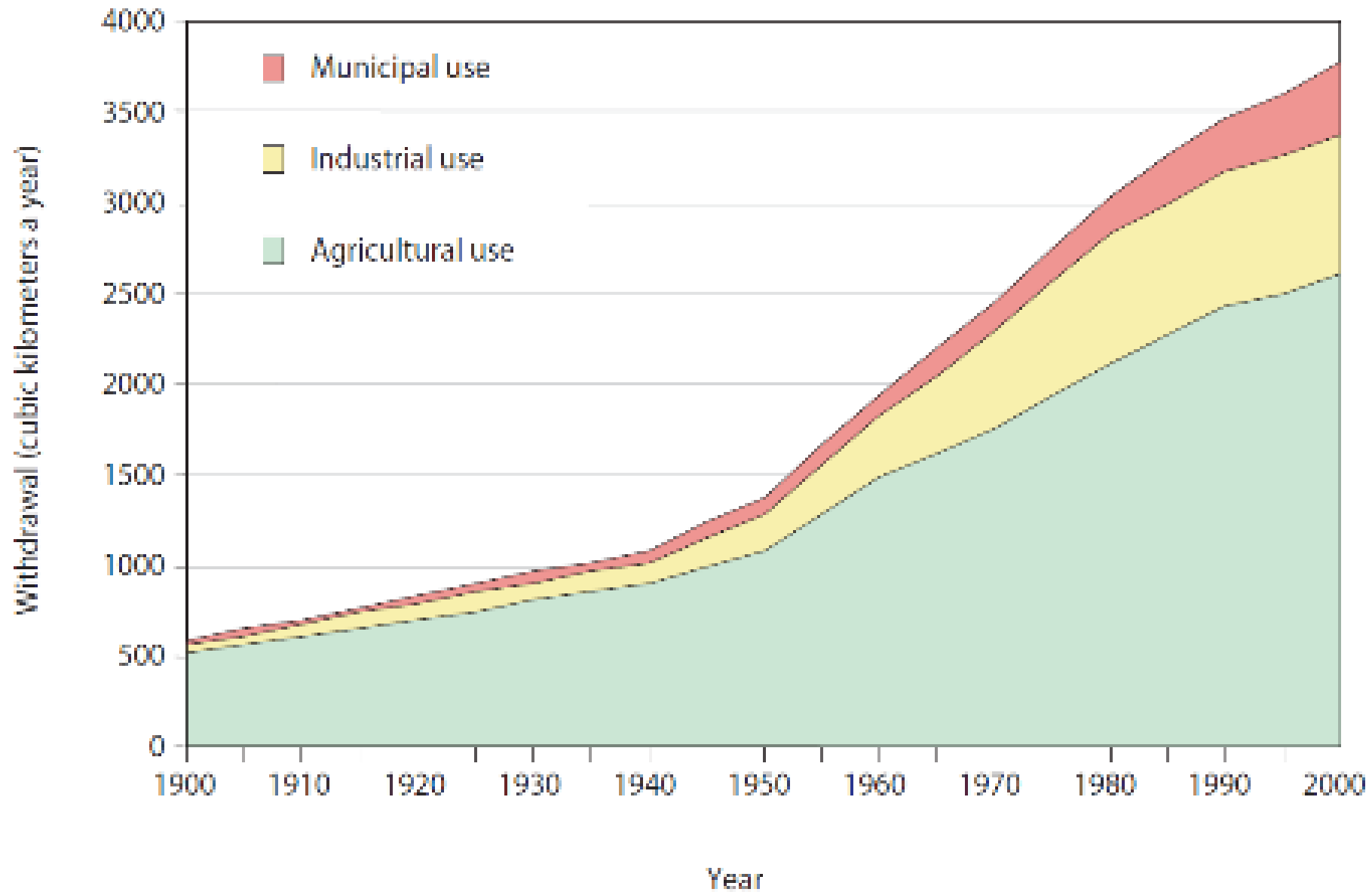
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Page Kyle, Son H. Kim**

The Joint Global Change Research Institute  
Pacific Northwest national laboratory



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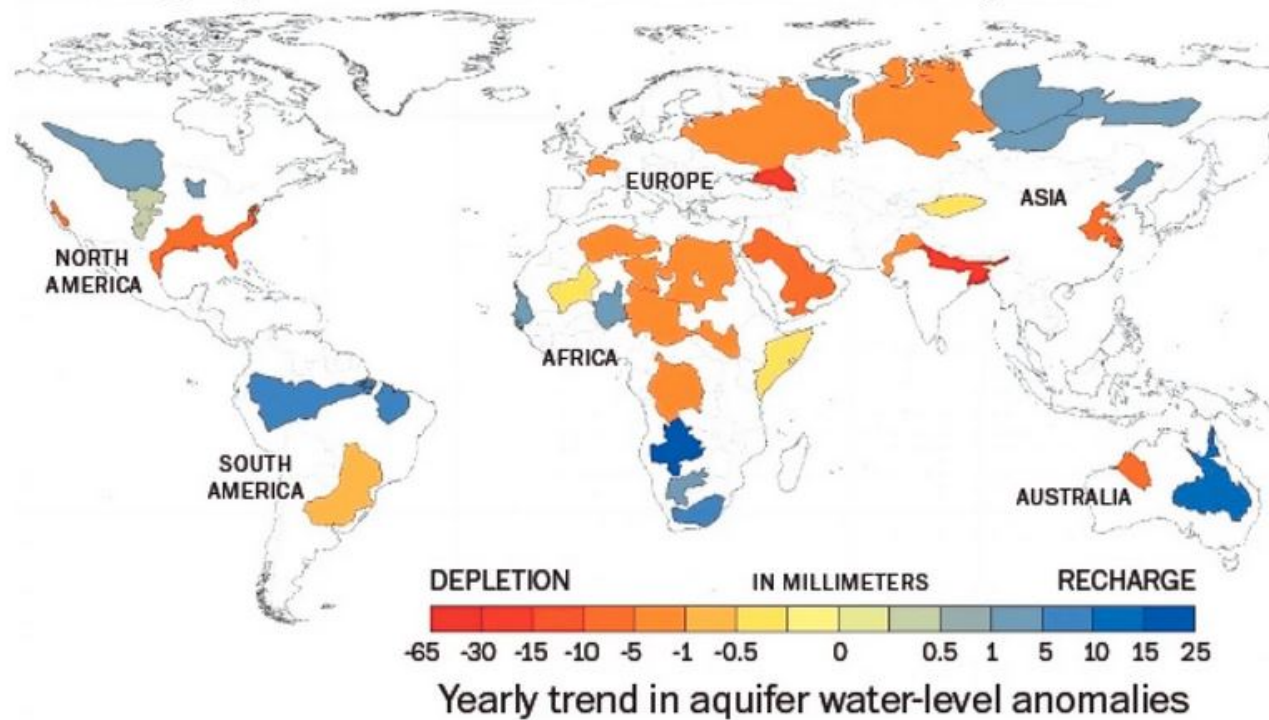
# Growing demands for freshwater resources – ~8 folds increase over the 20<sup>th</sup> century



# Many of the world's major freshwater aquifers are being unsustainably tapped due to the growing demands for irrigation

## Satellite system flags stressed aquifers

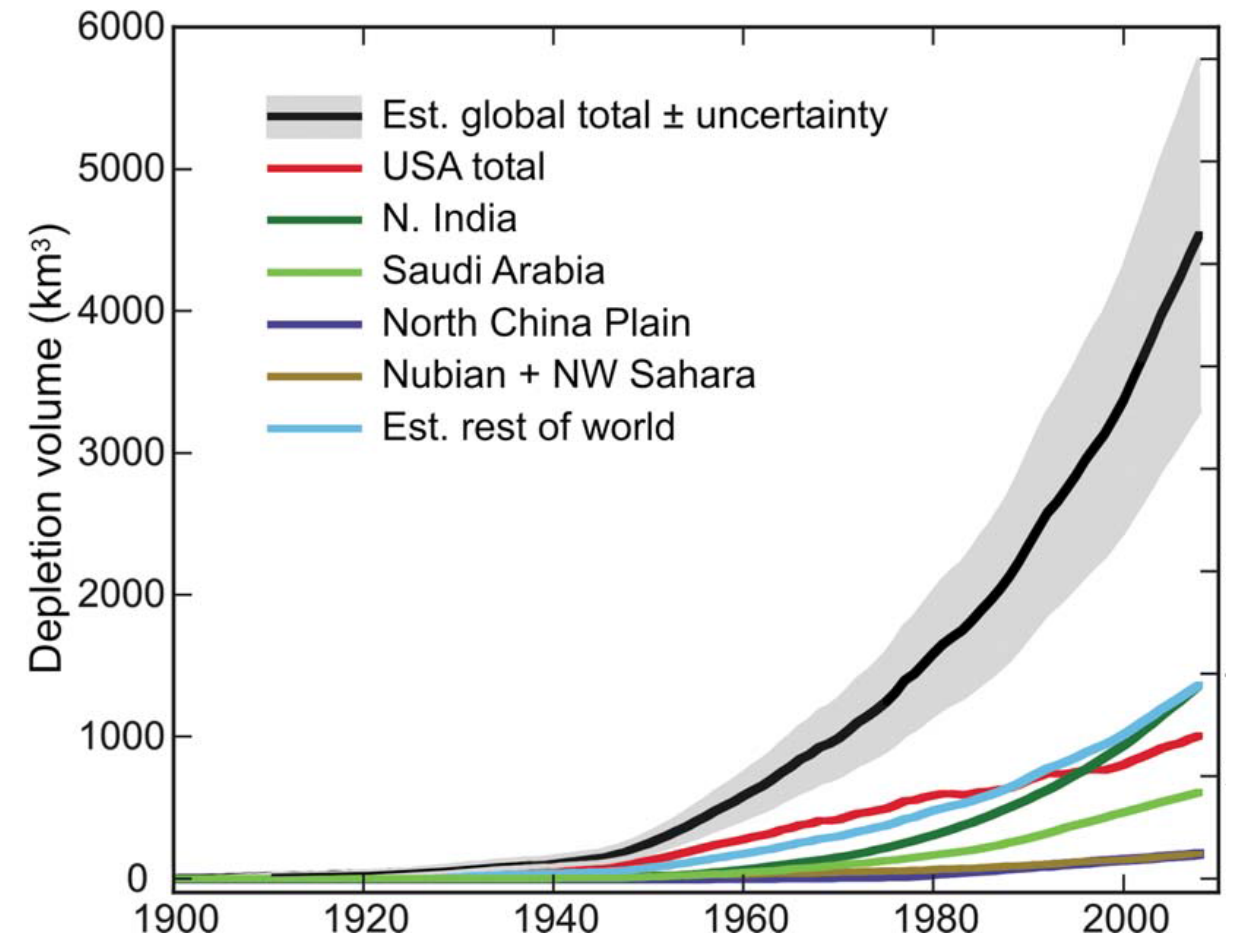
More than half of Earth's 37 largest aquifers are being depleted, according to gravitational data from the GRACE satellite system.



SOURCE: Water Resources Research

PATTERSON CLARK / THE WASHINGTON POST

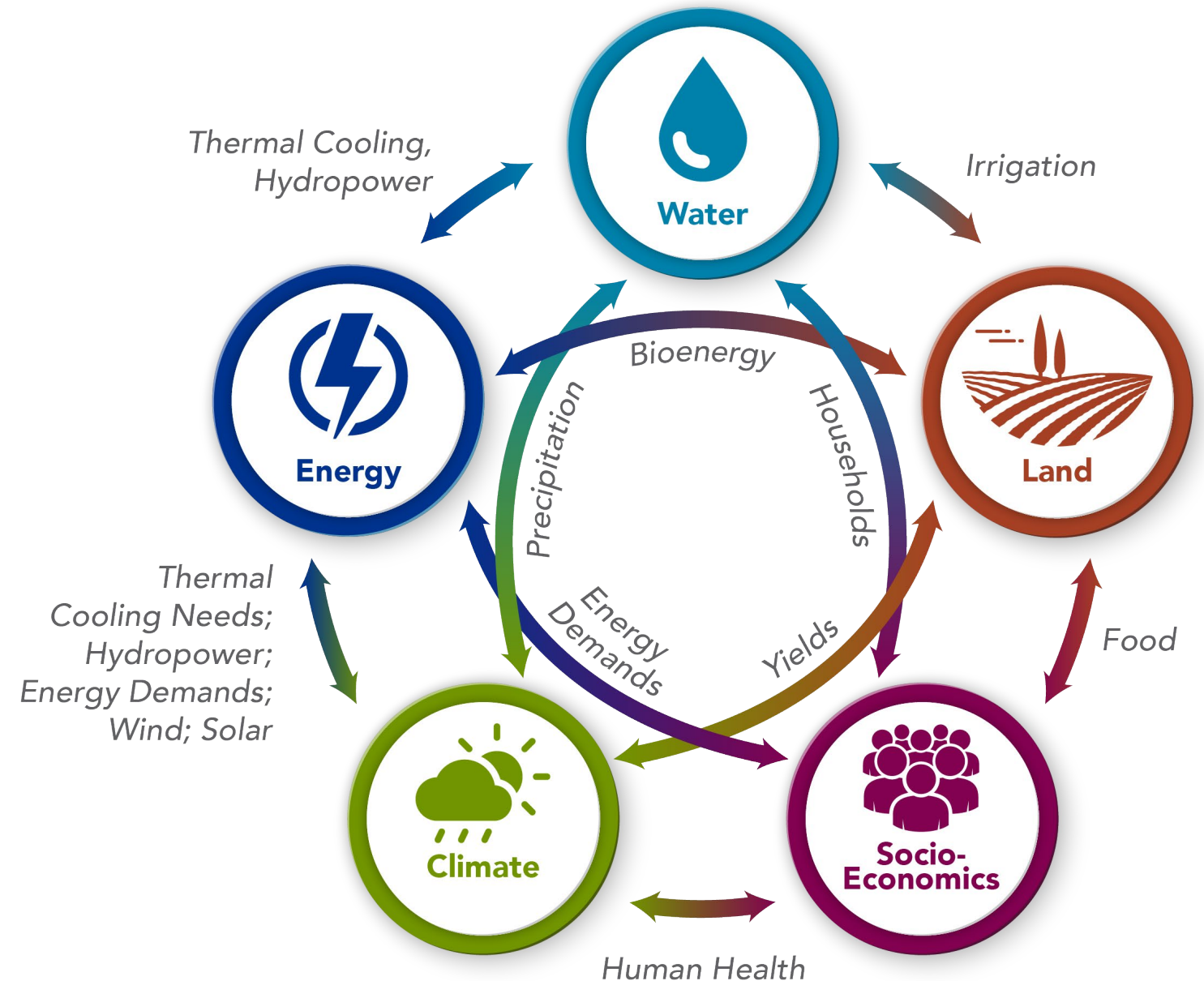
Cumulative groundwater depletion from 1900 to 2008, in billion cubic meters



Konikow et al. (2011)

# Research Objectives

- ▶ Assess the capacity of the global agriculture sector to adapt in a world with decreasing groundwater reserves
- ▶ Embed global groundwater resource cost curves into the Global Change Assessment Model (GCAM)
- ▶ Simulate the behaviors of water users facing increasing costs and restricted availability of groundwater—and then compare simulations against a scenario without these constraints



# The work is documented in two recent publications -- Will focus on the second paper

## Earth's Future

Turner SWD, M Hejazi, C Yonkofski, SH Kim, and P Kyle. 2019. "Influence of Groundwater Extraction Costs and Resource Depletion Limits on Simulated Global Nonrenewable Water Withdrawals Over the Twenty-First Century." *Earth's Future* 7(2):123–135, <https://doi.org/10.1029/2018EF001105>

### RESEARCH ARTICLE

10.1029/2018EF001105

#### Key Points:

- Nonrenewable groundwater cost curves with global coverage are embedded into an integrated assessment model and exposed to dynamically generated water demands
- The simulation is the first to consider the effects of groundwater cost and availability on global and

## Influence of Groundwater Extraction Costs and Resource Depletion Limits on Simulated Global Nonrenewable Water Withdrawals Over the Twenty-First Century

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## A pathway of global food supply adaptation in a world with increasingly constrained groundwater

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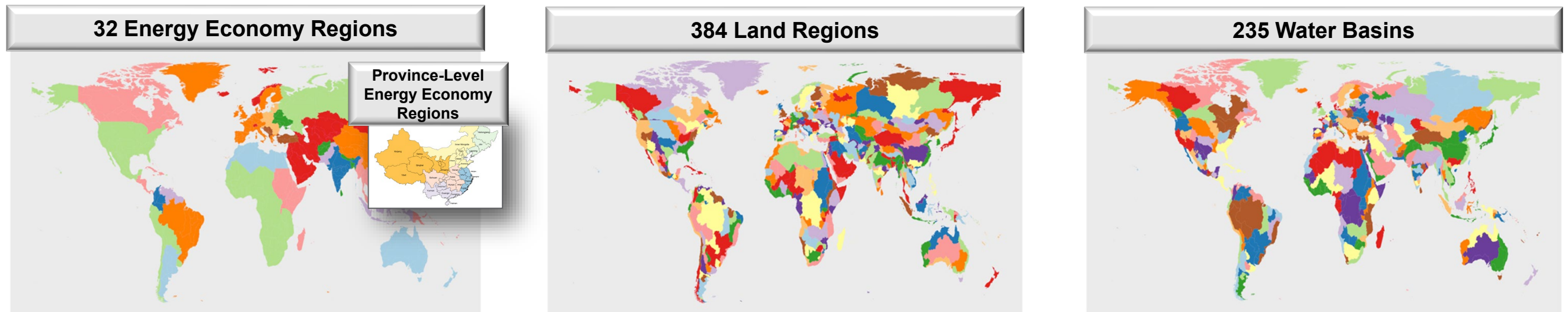
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# The Global Change Assessment Model (GCAM)

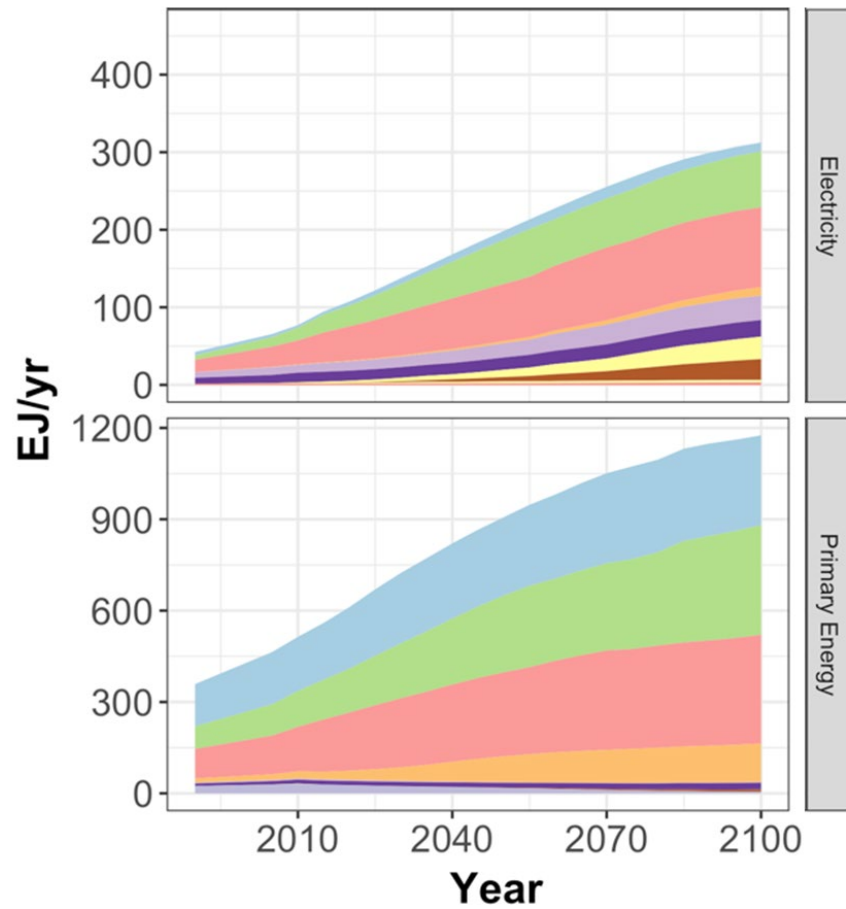
- ▶ GCAM is a global integrated human-Earth systems model
- ▶ GCAM links **Economic**, **Energy**, **Land-use**, **Water**, and **Climate** systems



- ▶ GCAM is a community model -- Documentation available at: [wiki.umd.edu/gcam](http://wiki.umd.edu/gcam)
- ▶ Typically runs in **5-year time-steps**
- ▶ Meant to analyze consequences of policy actions and interdependencies
- ▶ Used to evaluate impacts of *socioeconomic development, climate treaty compliance, technology and resource developments, energy policies, etc.*

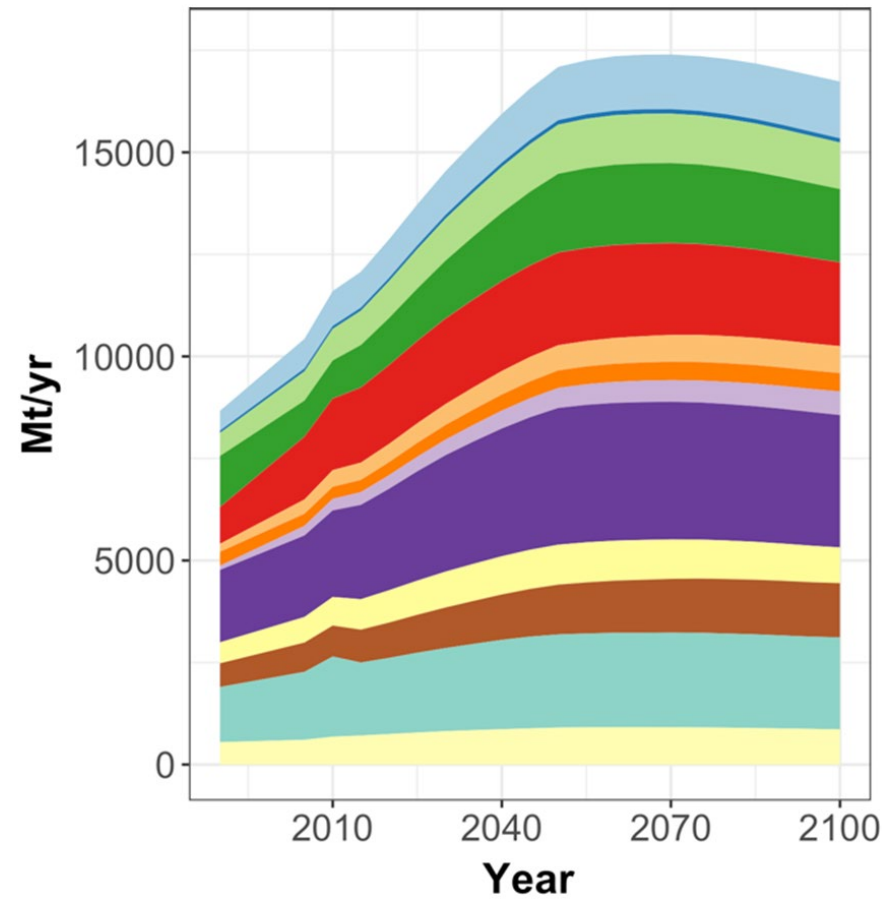
# Water-Energy-Land Systems over the 21st Century

## ENERGY



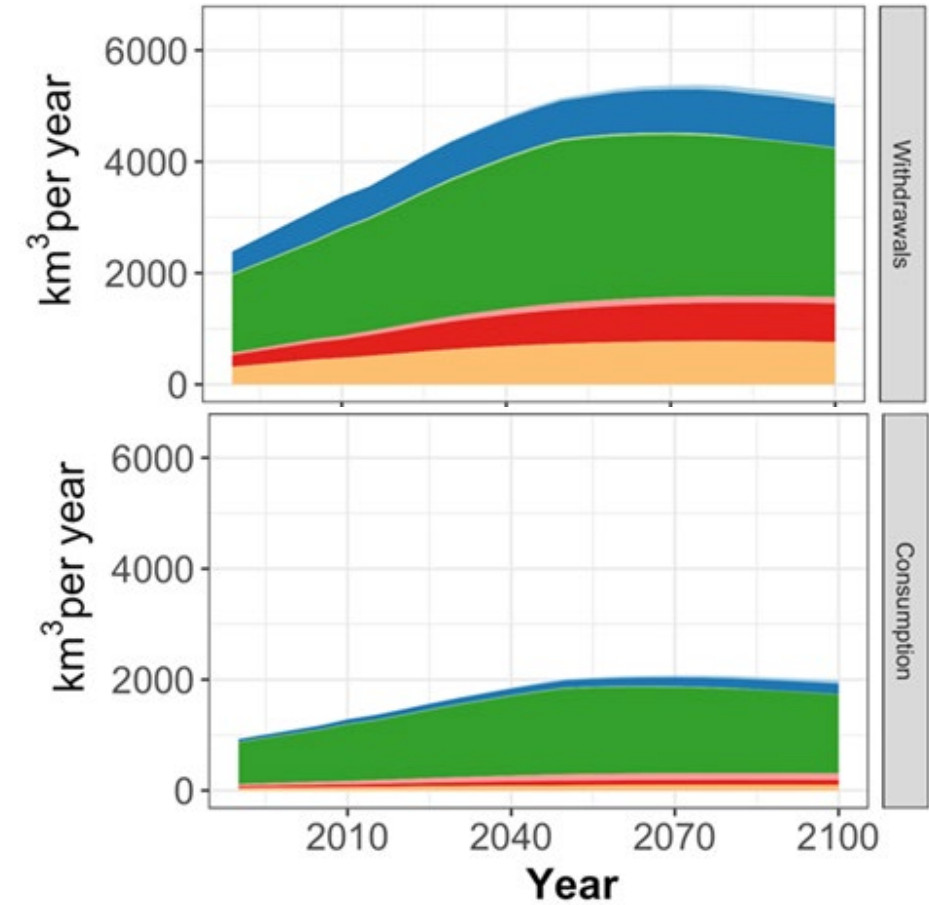
- a oil
- a oil CCS
- b natural gas
- b natural gas CCS
- c coal
- c coal CCS
- d biomass
- d biomass CCS
- e nuclear
- f hydro
- g wind
- h solar
- i geothermal
- l geothermal
- j traditional biomass
- k chp

## AGRICULTURE



- Corn
- FiberCrop
- FodderGrass
- FodderHerb
- Forest
- MiscCrop
- OilCrop
- OtherGrain
- PalmFruit
- Pasture
- Rice
- Root\_Tuber
- SugarCrop
- Wheat

## WATER



- bioenergy
- electricity
- energy
- irrigation
- livestock
- manufacturing
- municipal

# Adaptations in GCAM

## Energy Systems

Energy trade

Energy fuel mix

Energy storage

## Land Systems

Agricultural trade

Land use change

Irrigated/rainfed

Land intensification

Dietary mix

## Water Systems

Virtual water trade

Cooling technology mix

Groundwater extraction

Desalination



## Question: What is the capacity of the global agriculture sector to adapt in a world with decreasing groundwater reserves?

Unconstrained  
Scenario

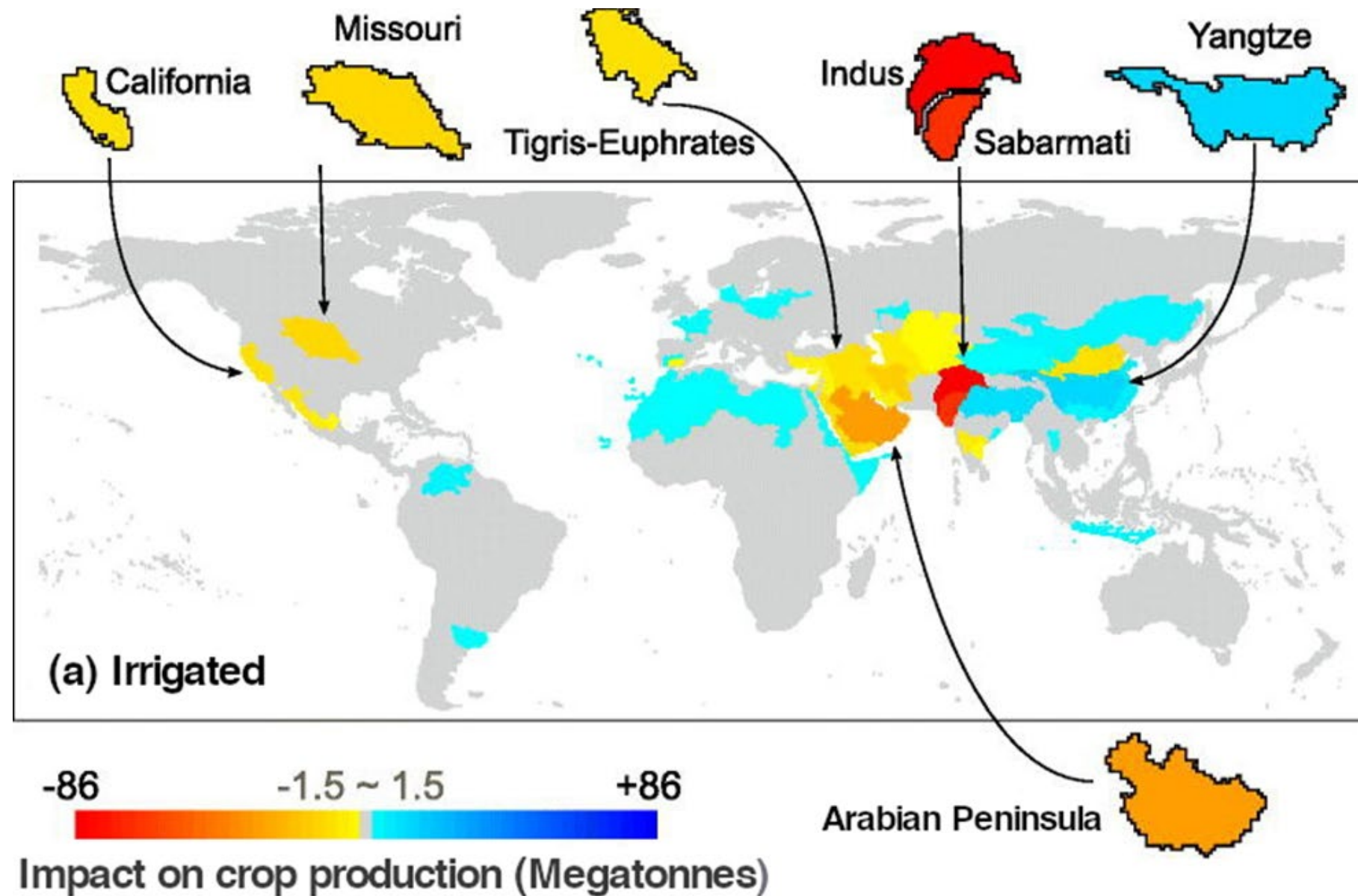
Simulated crop production facing unlimited groundwater resources

Constrained  
Scenario

Simulated crop production facing realistic costs and limits on groundwater extraction

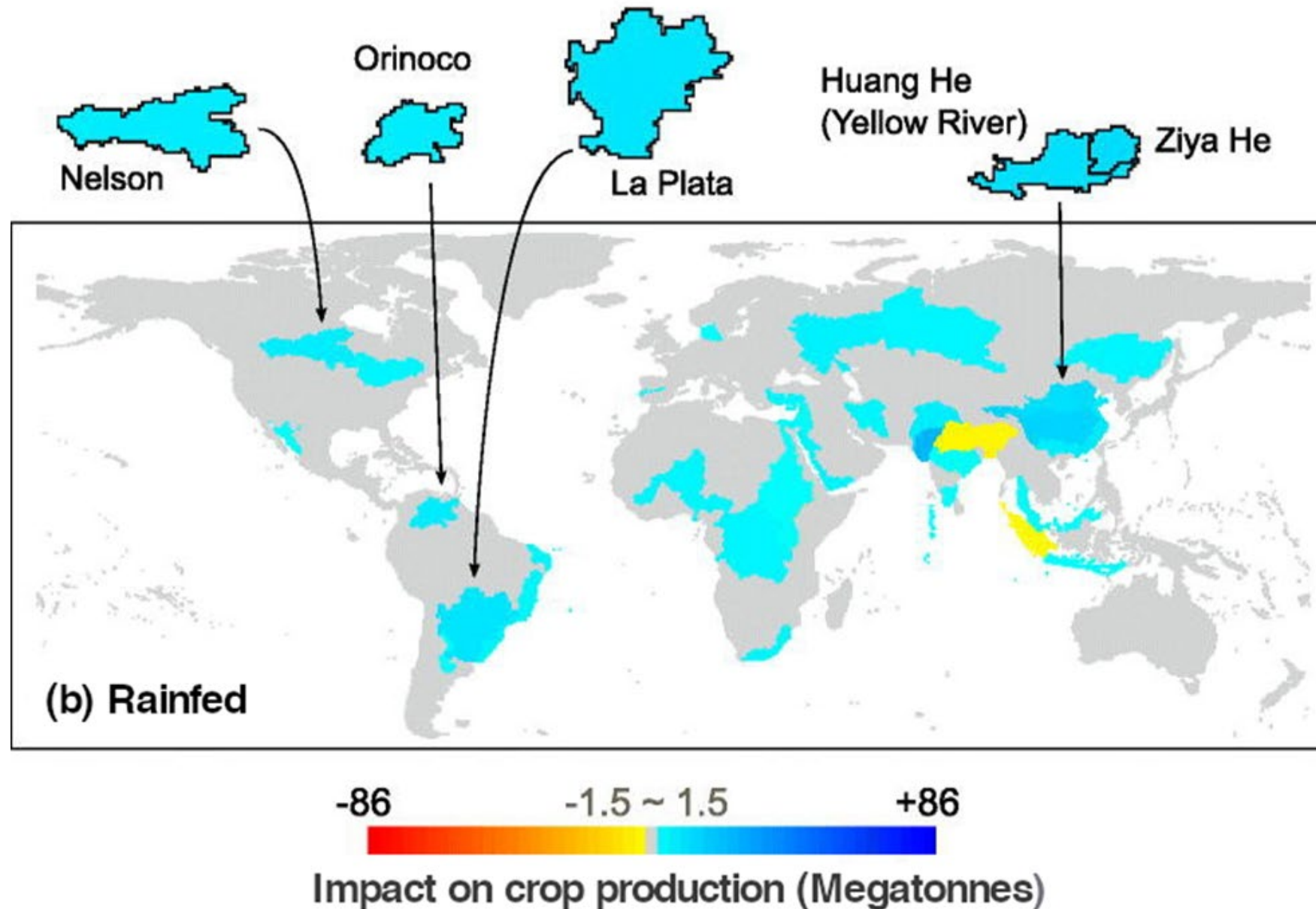
# Production of irrigated crops moves elsewhere...

A net loss of 284 Mt/year global irrigated production by the year 2100 relative to the unconstrained scenario (approximately 8% difference)



# ... and rain fed crops comprise a larger share of production

A net increase of 190 Mt/year global rainfed production by the year 2100 relative to the unconstrained scenario (approximately 1.8% difference)



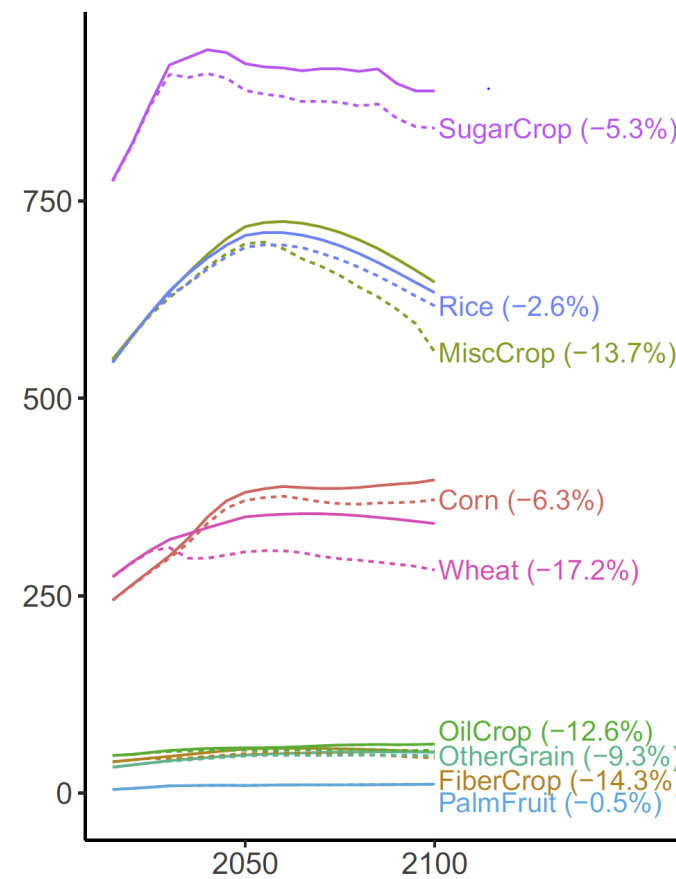
# So the story isn't necessary one of doom and gloom

- A net reduction of 94 Mt by 2100 relative to the unconstrained scenario, a -0.7% by 2100

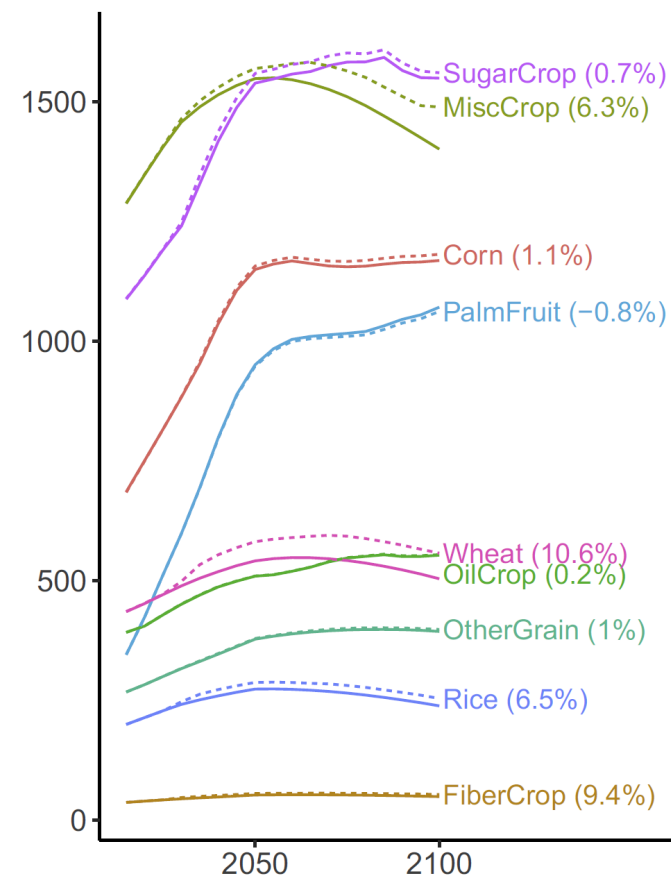
- Shifts from irrigated to rainfed production are evident in miscellaneous crops, wheat, rice, corn, and sugar crop

- The reduced demand for crops reflects changes in consumer behavior (e.g., livestock producers substitute a small proportion of animal feed for pasture, while the power sector reduces its reliance on biomass crops)

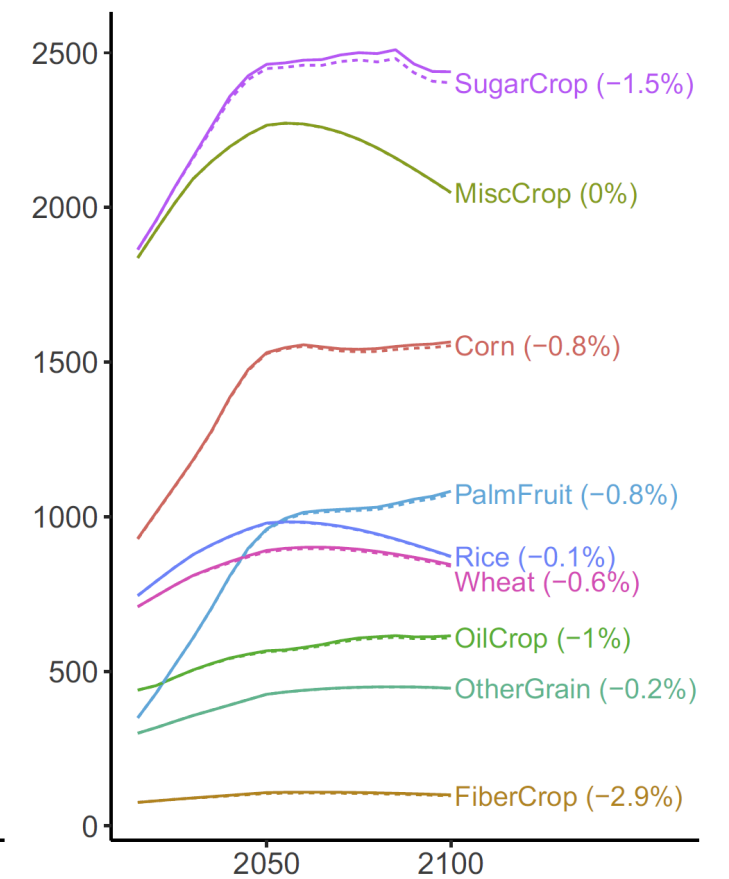
(a) Irrigated production (Mt/year)



(b) Rain-fed production (Mt/year)



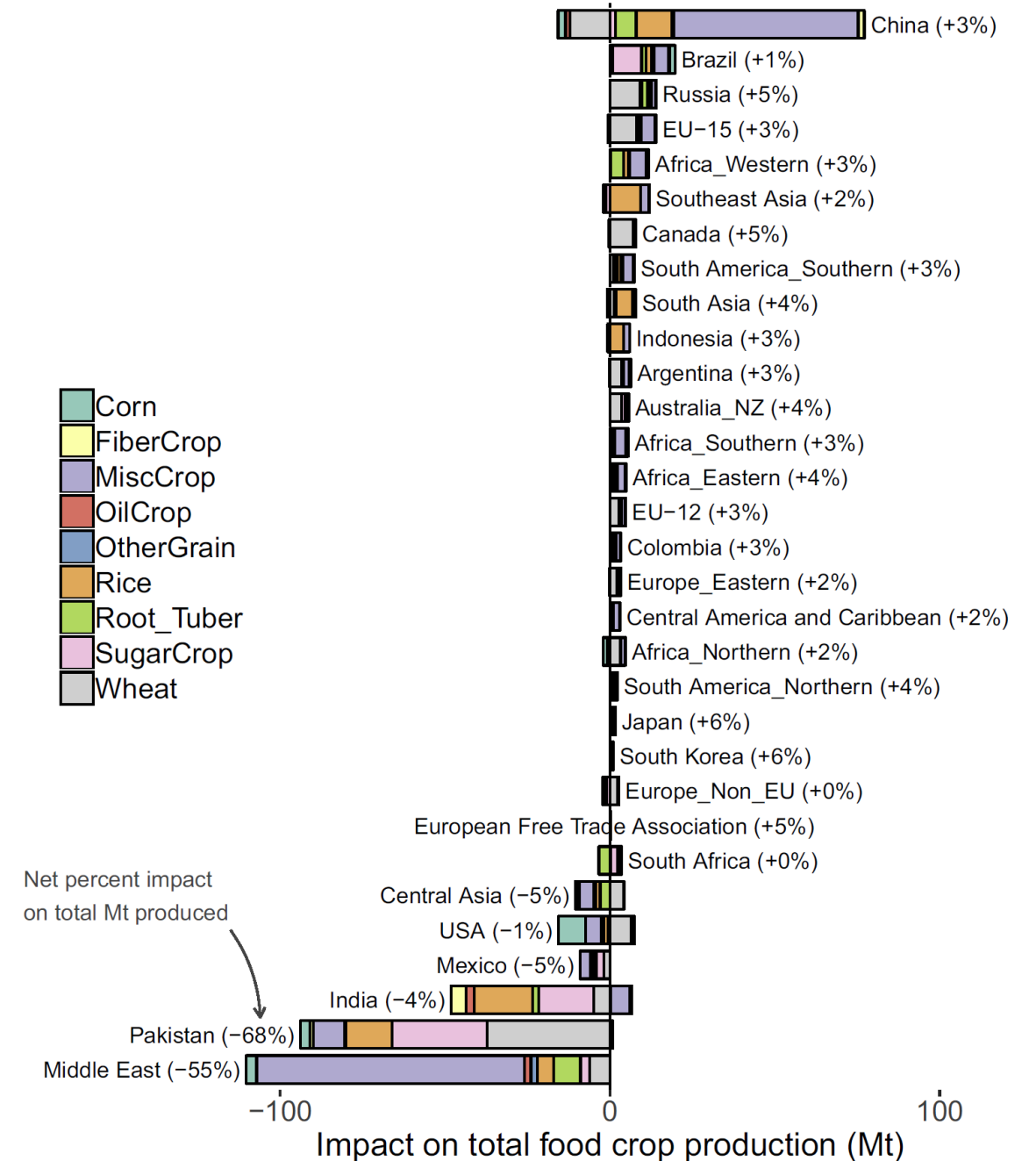
(c) Total production (Mt/year)



Water scenario — Unconstrained - - - Constrained

# While the global impact is small, the region-level results reveal a far more drastic effect of water constraints on future crop production

- The Middle East (-\$75 billion) and Pakistan (-\$17 billion) are the most heavily affected, followed by India, Central Asia, the US, and Mexico
- Crop growing regions with plentiful land resources benefit most, with China (+\$54 billion) and Brazil accounting for much of the expansion
- High value miscellaneous crops shift out of the Middle East and into China
- Rice shifts out of Pakistan and India and into China and Southeast Asia
- Wheat shifts out of Pakistan and China, and into nearly every other region



# Sensitivity to water exploitability assumptions

- Adjustments in both the assumed reservoir expansion and the exploitability of groundwater affect the magnitude of the results without altering the general conclusions emerging from this study
- That is, a loss of irrigated production (loss of 4.3–8.8%), an increase in rainfed production (additional 0.9–2.1%), and a marginal reduction in overall crop production across all scenarios

Constraining scenario	Impact on irrigated production			
	2050		2100	
	Abs. (Mt)	Rel. (%)	Abs. (Mt)	Rel. (%)
Low NRW, restricted RW	–198	–5.0	–334	–8.8
<i>Mod. NRW, restricted RM**</i>	–146	–3.7	–284	–7.5
High NRW, restricted RW	–139	–3.5	–261	–6.9
Low NRW, expanded RW	–140	–3.5	–182	–4.8
Mod. NRW, expanded RM	–118	–3.0	–168	–4.5
High NRW, expanded RW	–116	–2.9	–162	–4.3

Constraining scenario	Increase in rain-fed production			
	2050		2100	
	Abs. (Mt)	Rel. (%)	Abs. (Mt)	Rel. (%)
Low NRW, restricted RW	126	1.2	226	2.1
<i>Mod. NRW, restricted RM**</i>	83	0.8	190	1.8
High NRW, restricted RW	77	0.7	171	1.6
Low NRW, expanded RW	78	0.7	108	1.0
Mod. NRW, expanded RM	60	0.6	97	0.9
High NRW, expanded RW	58	0.5	93	0.9

## Takeaway message 1: Agriculture sector may be able to adapt through marginal increases in irrigated and rainfed production across regions where water remains plentiful

- Expansion of international trade in agricultural commodities is key
- The net loss in production is balanced by a downshift demand for certain crops used for livestock feed (which can be replaced by pasture) and biomass (which can be reduced by relying on other electricity generating technologies)
- The demand shifts observed here can be considered conservative estimates because this version of GCAM does not fully capture changing dietary preferences in response to global food crop prices

## Takeaway message 2: Regions with unsustainable groundwater use could experience major agricultural and economic declines

- The economic impacts will likely be particularly acute in regions that have limited scope for expanding rain-fed cropland (such as throughout the Middle East)
- Severe food shortages could occur in regions that lack the logistical or financial means to import food – need to ease cross-border trade, substantial investment in transport infrastructure (shipping/ports)
- With up to a quarter of total physically-exploitable groundwater resources allowed to be depleted before considering the aquifer to be unviable, severe and irreversible environmental damage could occur due to this level of depletion



# Thank you

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