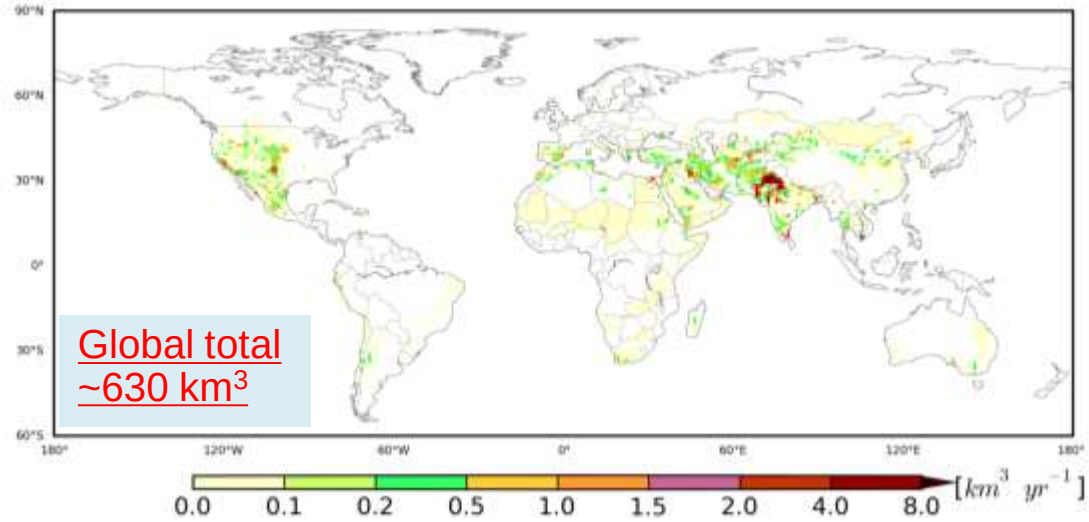
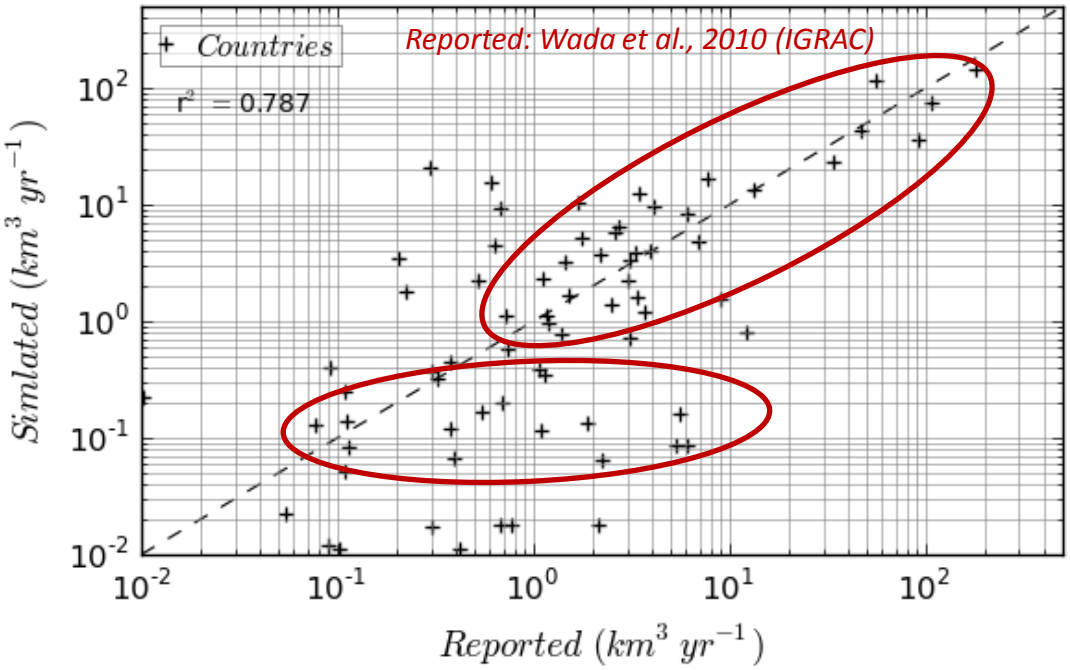
Global Groundwater Withdrawal



- ✓Large withdrawals in North India, Western US, Middle East, Spain
- ✓More than 90% is used for **irrigation**



- ✓Results agree **fairly well** for many countries
- ✓Even the reported values may have significant **uncertainties** as they are **reconstructed** based on population distribution

Groundwater withdrawal

Groundwater withdrawal in major countries

Unit: km^3/yr	This study	WRI (2007)
India	129.3	169.1
USA	78.8	68.4
Pakistan	47.3	54.0
Mexico	12.3	16.0
Bangladesh	6.6	9.4
Saudi Arabia	6.0	13.0

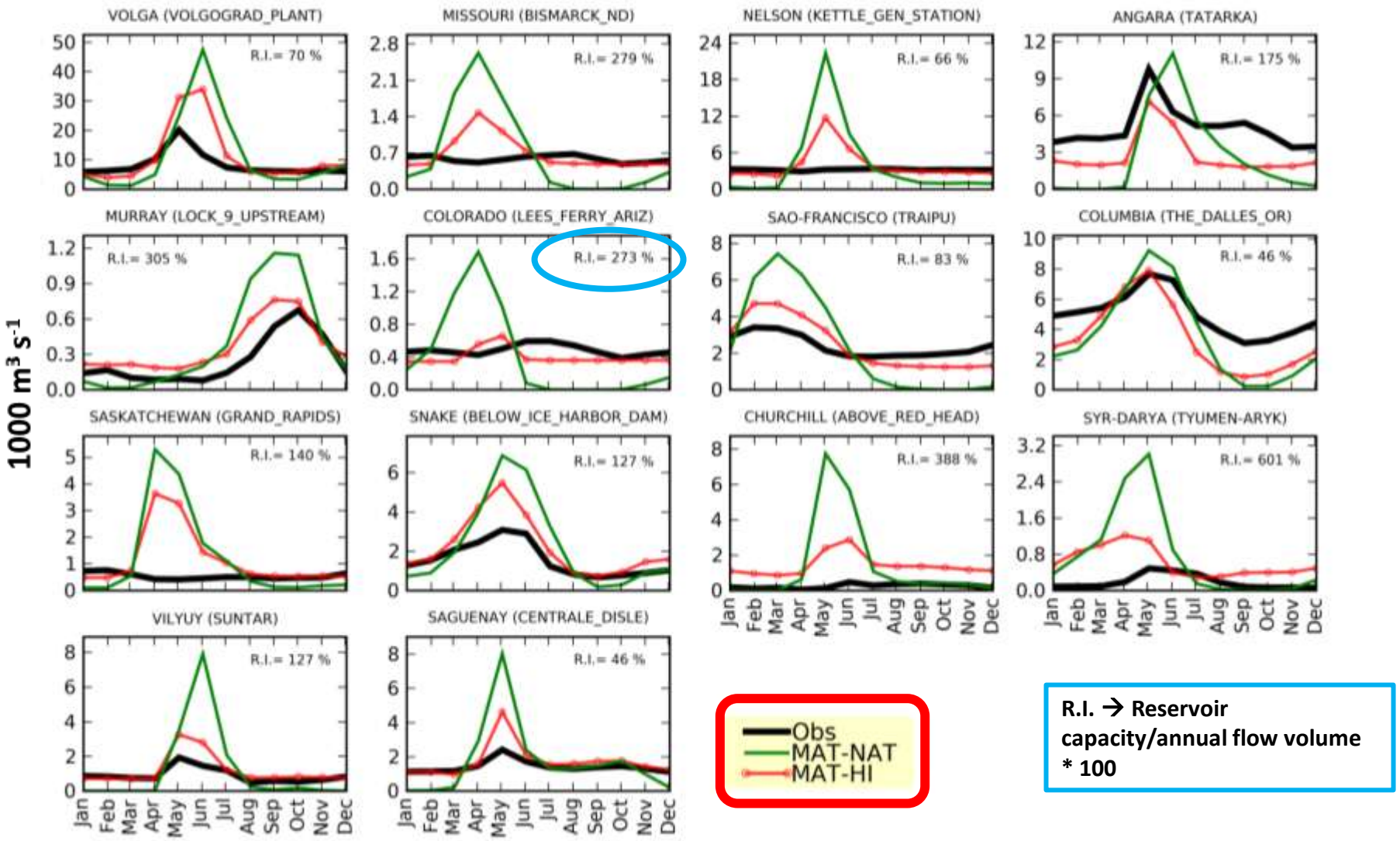
Ground water withdrawal in the Ogallala aquifer

Unit: mm/yr	This study	USDA (2002)	Area km^2
Maize	369	331	36.02
Wheat	408	247	6.33
Cotton	434	255	5.55

(Hanasaki et. al, *J. Hydrol.* , 2010)

Simulated River Discharge (Highly Regulated Basins)

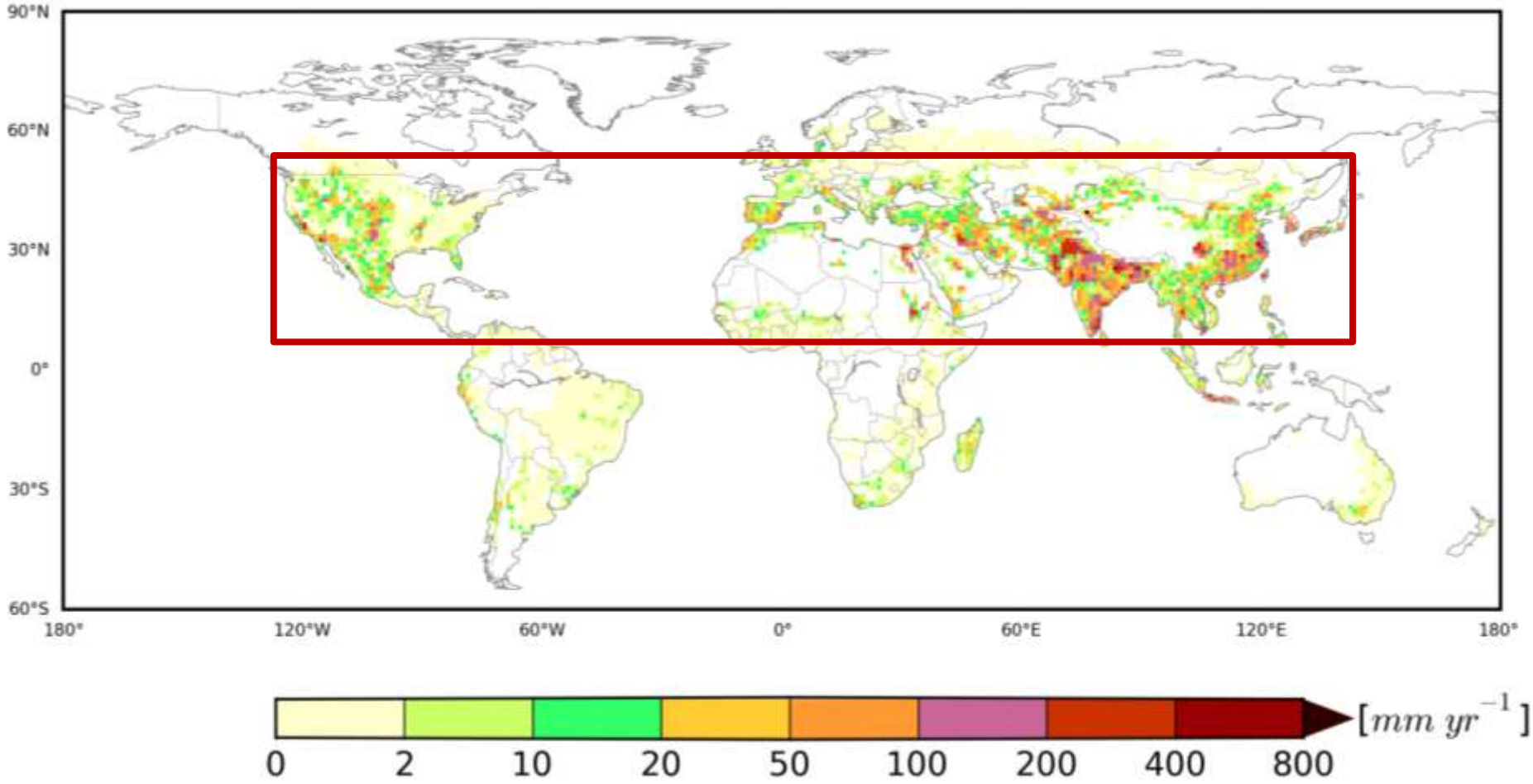
Seasonal variation improves significantly in many regulated basins.



R.I. → Reservoir capacity/annual flow volume * 100

Global Irrigation Water Requirements

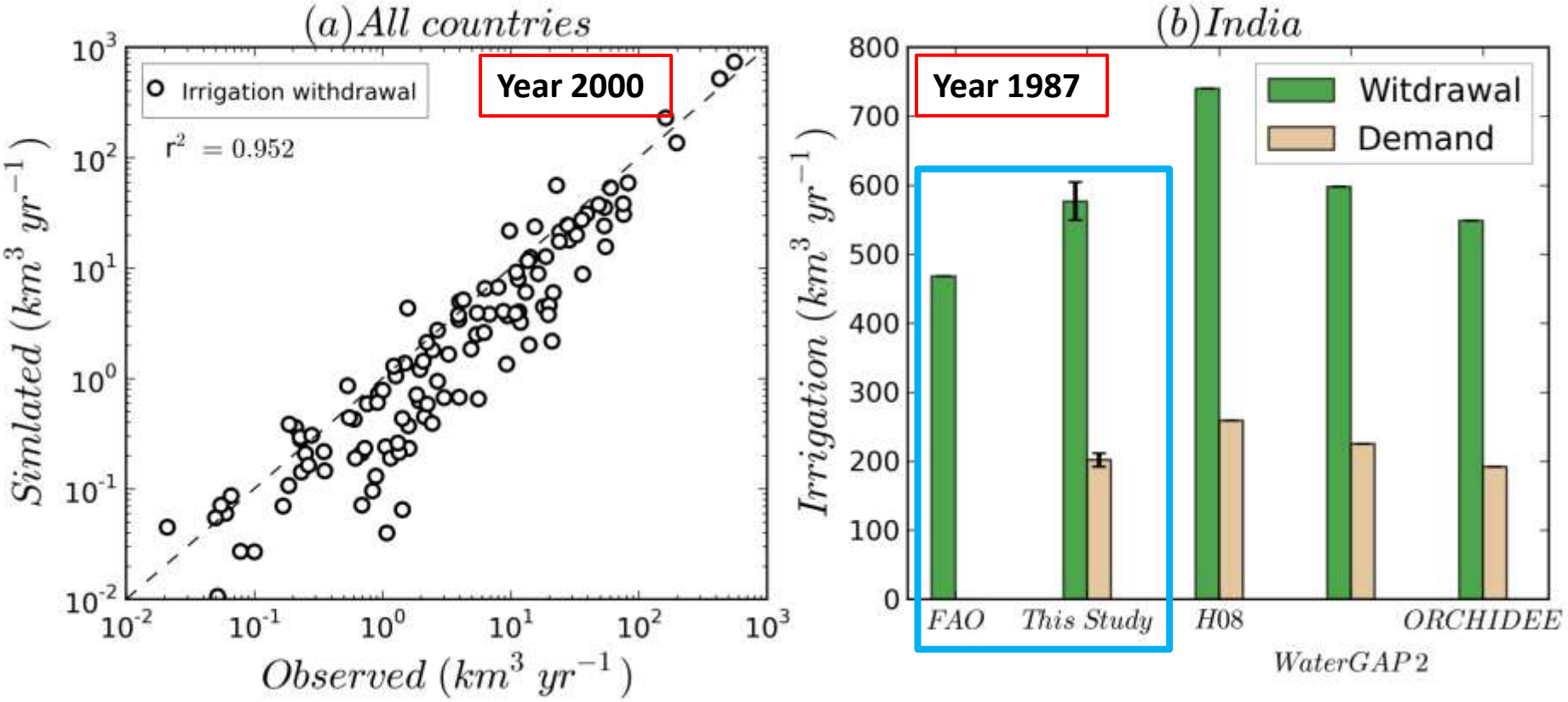
Simulated net irrigation water requirement: grid averaged values.



Validation of Irrigation Water Use

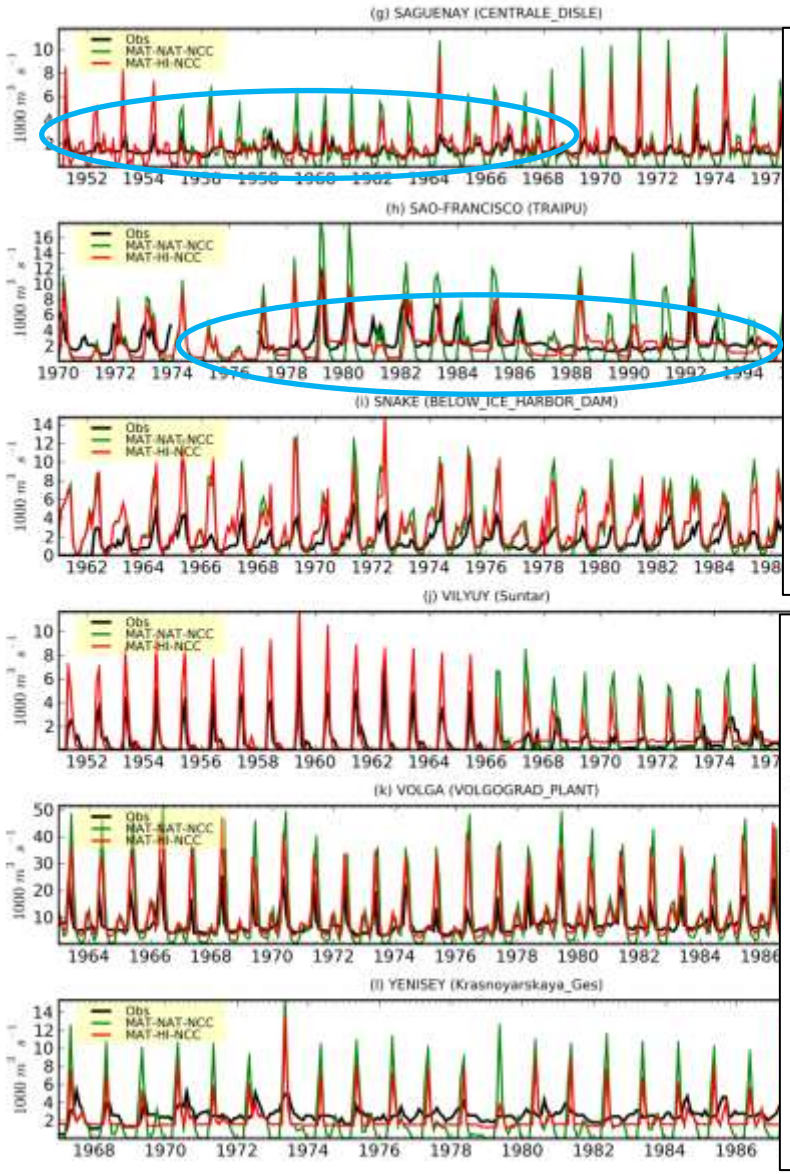
Observed data: FAO AQUASTAT (country statistics), 1998~2002

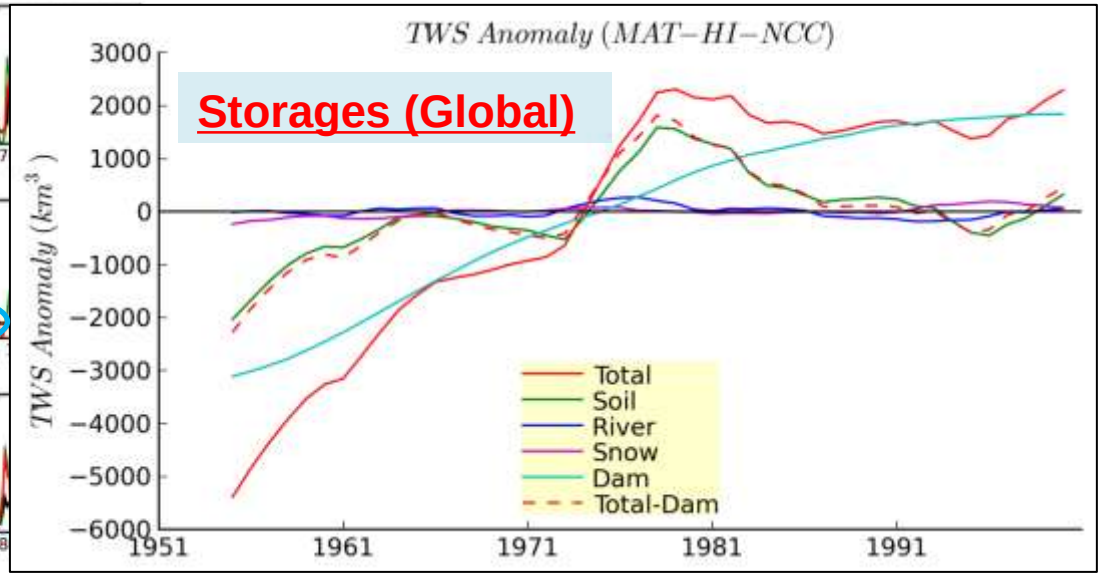
Water use efficiency: Doll & Siebert (2002)

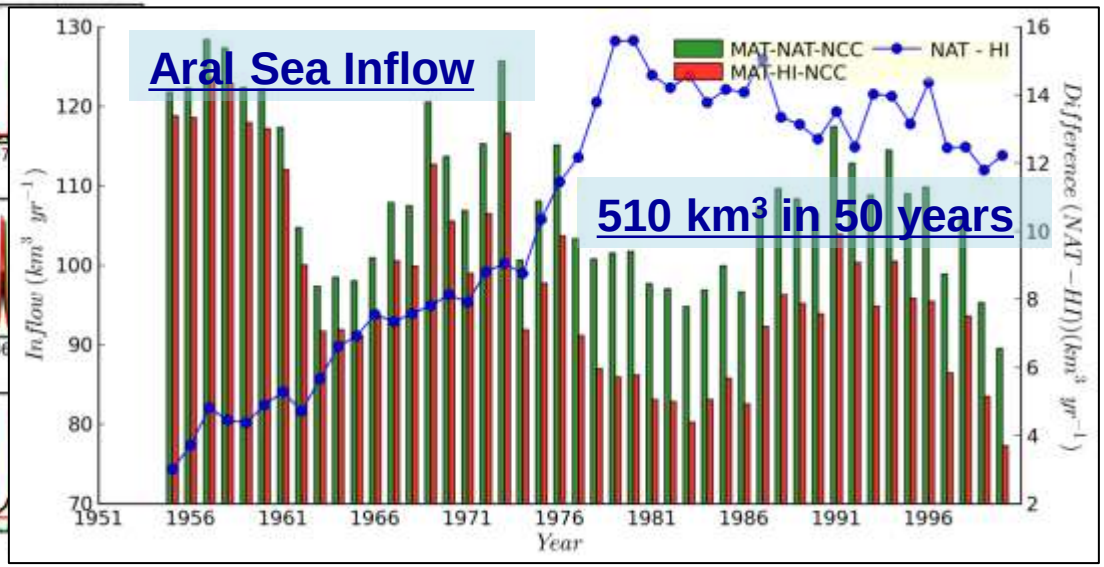


The model estimates of irrigation water withdrawals agree well with the observations. Error bars: **uncertainty due to precipitation** data.

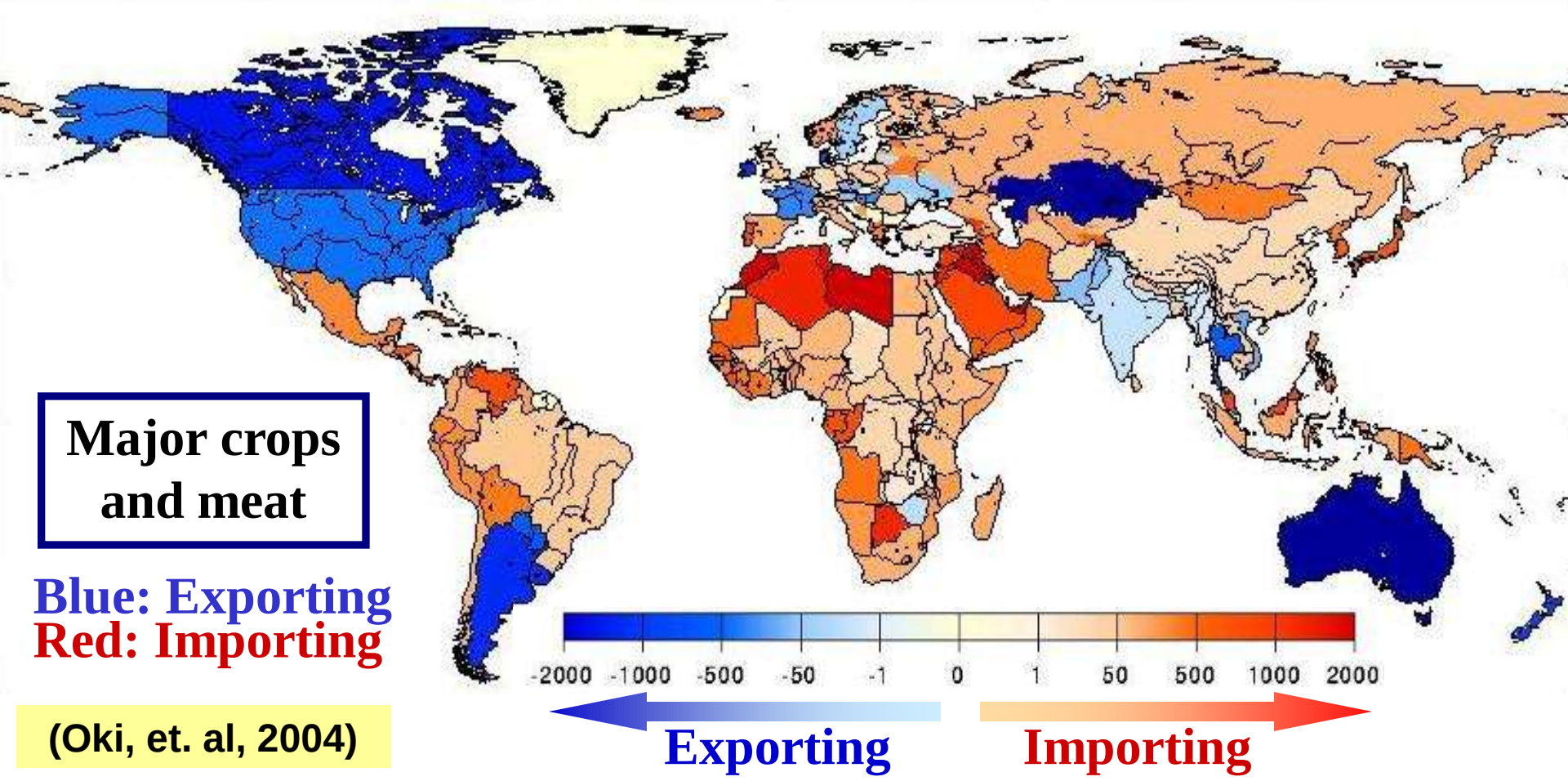
Human Impacts: River Discharge and TWS







Virtual Water Balance in Countries (m^3/c/y) in 2000



Major crops and meat

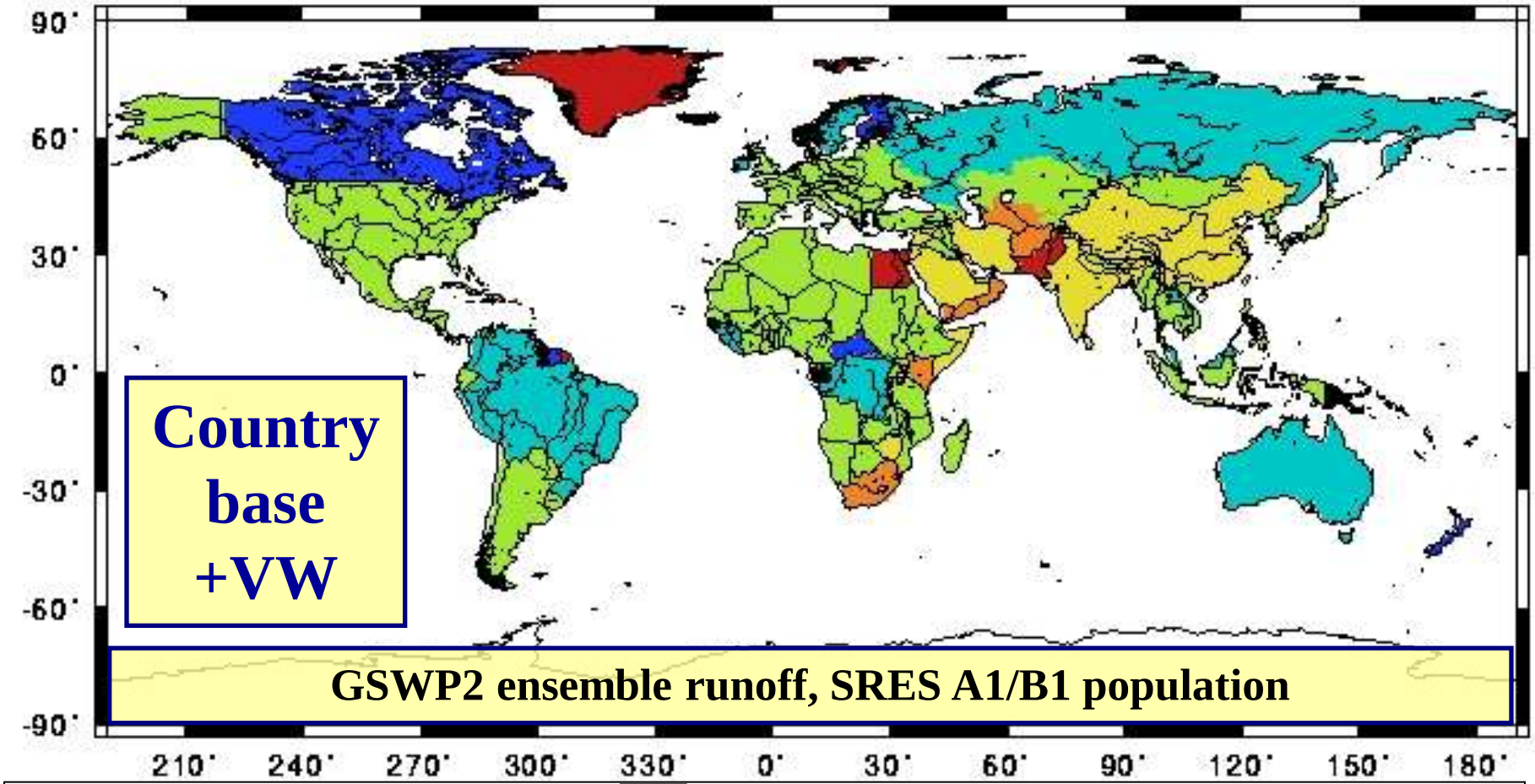
Blue: Exporting
Red: Importing

(Oki, et. al, 2004)

- **7 out of top 10 importing countries are seriously poor in water resources.**
- **7 out of top 10 exporting countries are rich in water resources.**
- **Denmark (10) and India (18) are water stressed but exporting *RW* in net.**

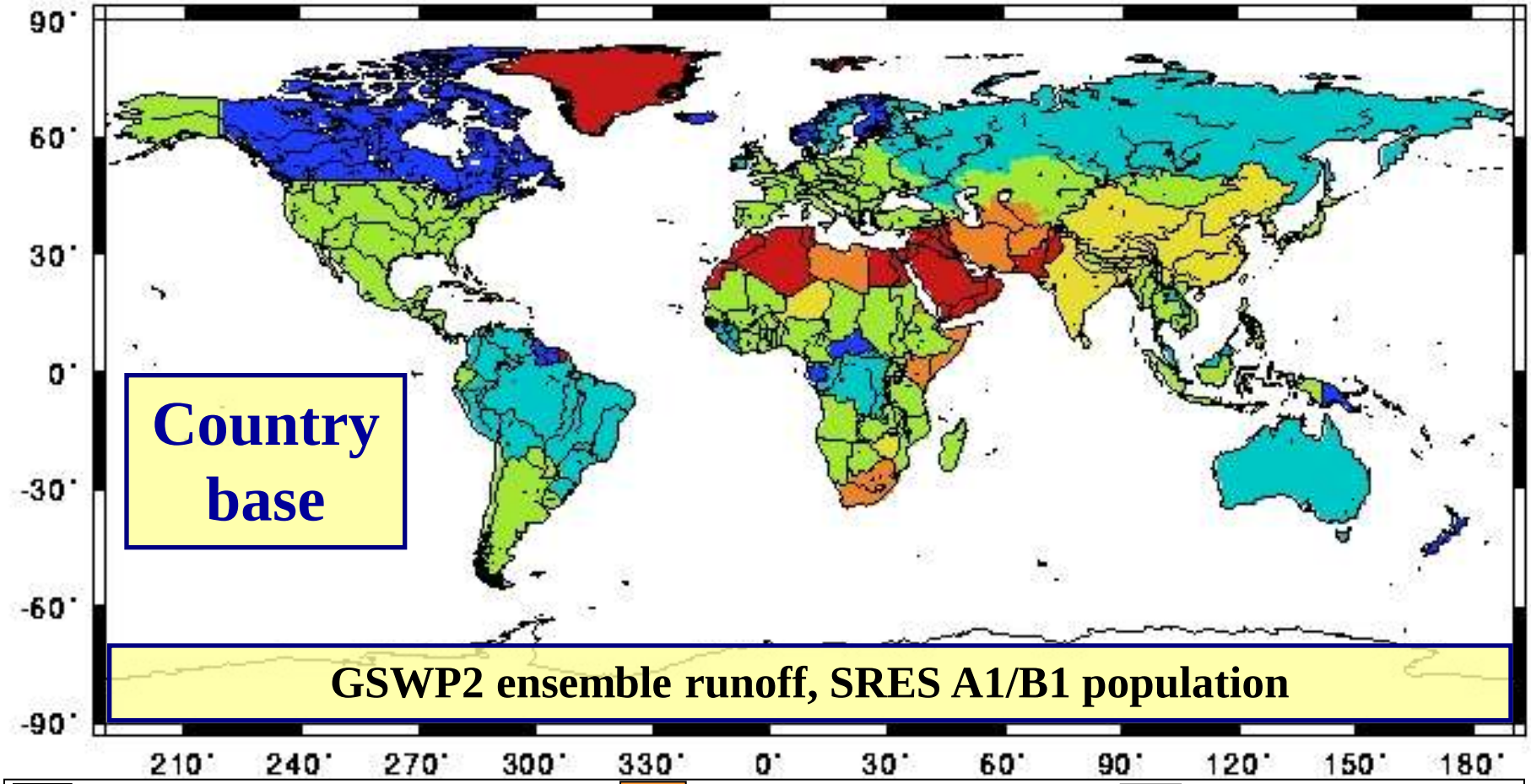
World Water Resources Considering Virtual Water Trade

Potentially Available Water Resources per Capita in 2000



Conventional Water Resources Assessment

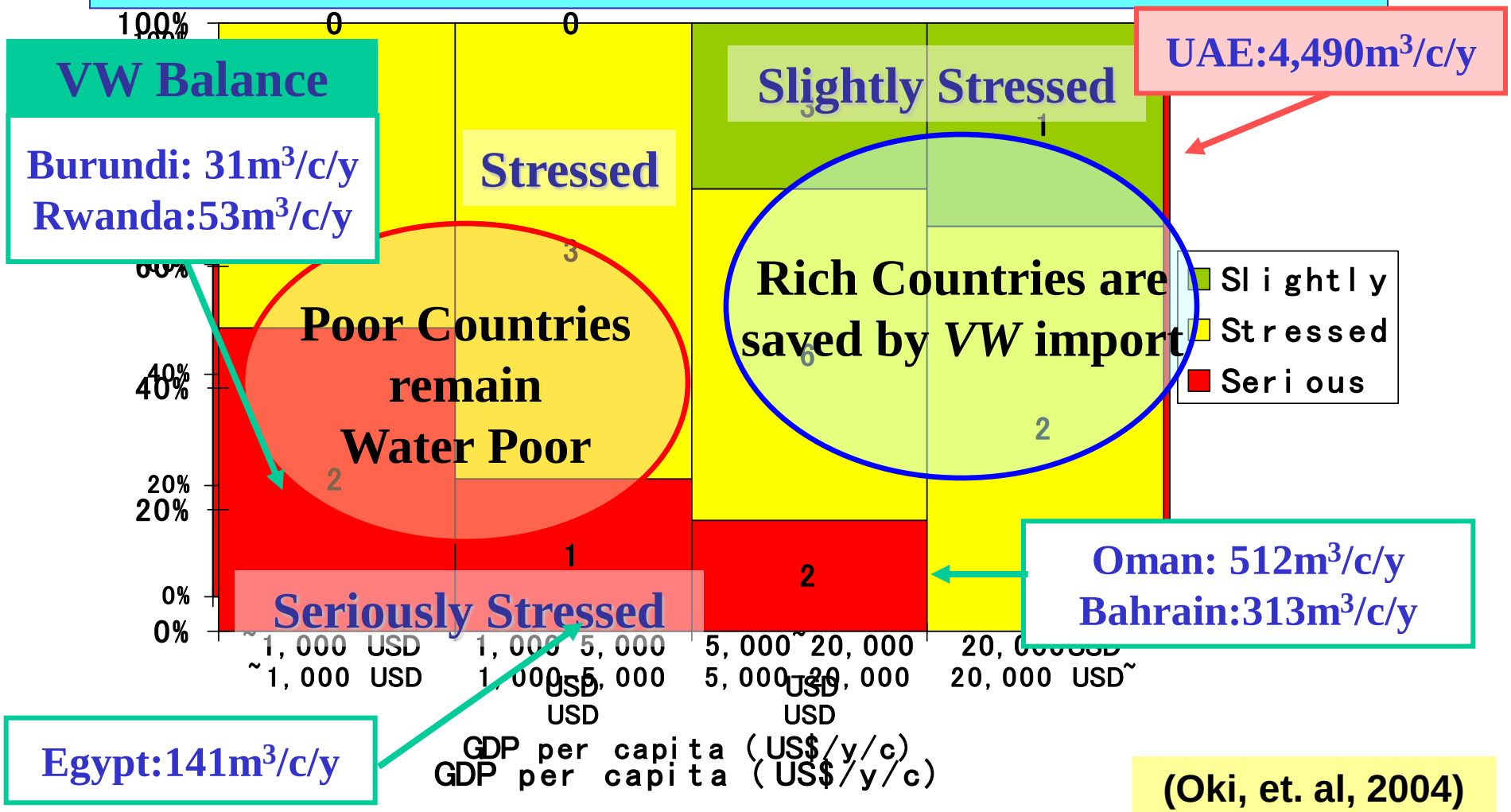
Potentially Available Water Resources per Capita in 2000



Water Resources Assesment Considering VW trade

22 Countries were classified into "seriously stressed" in 2000 by conventional water resources assessment.

➔ +Virtual Water Import

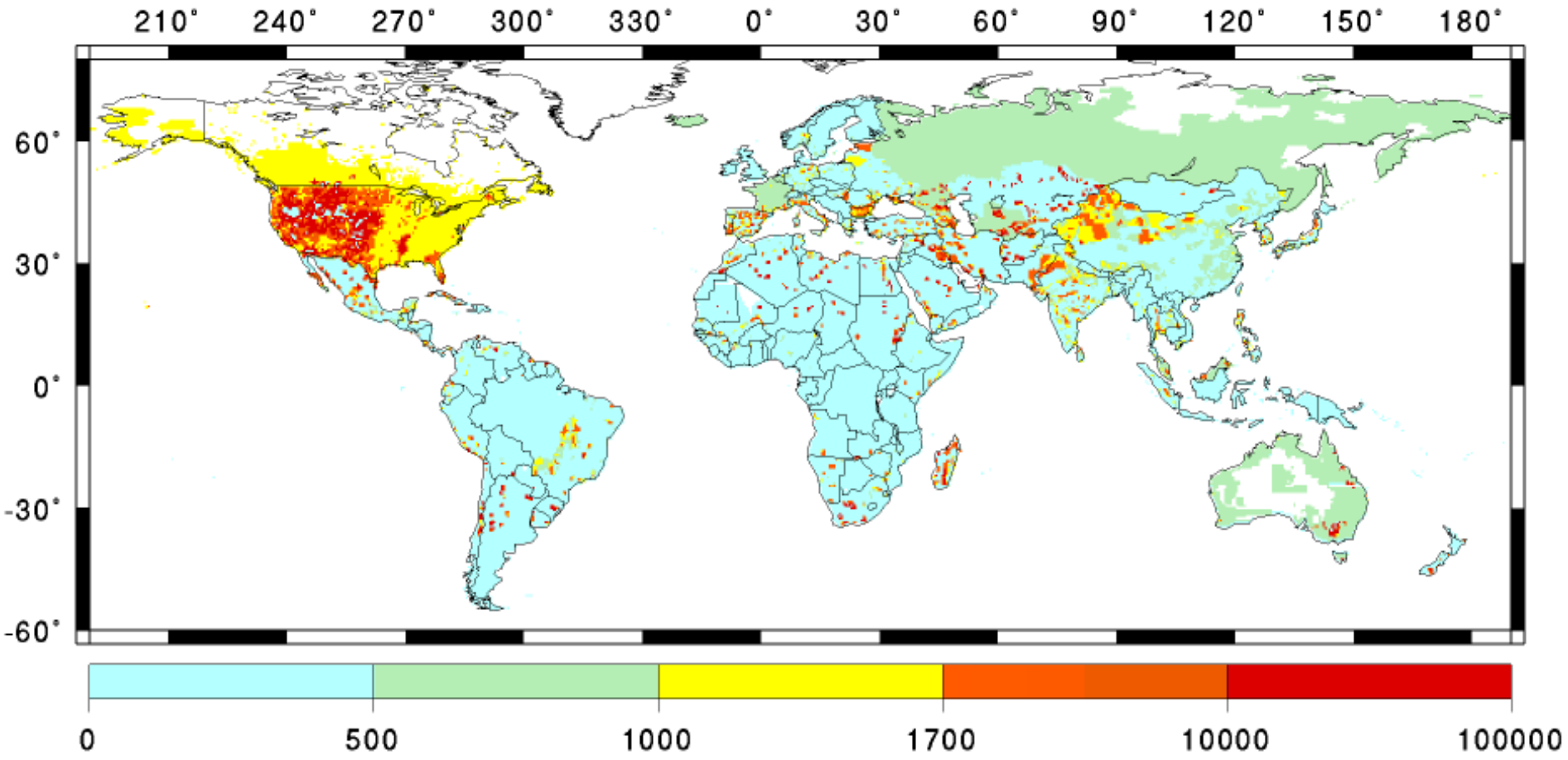


(Oki, et. al, 2004)

Annual Water Demand per capita

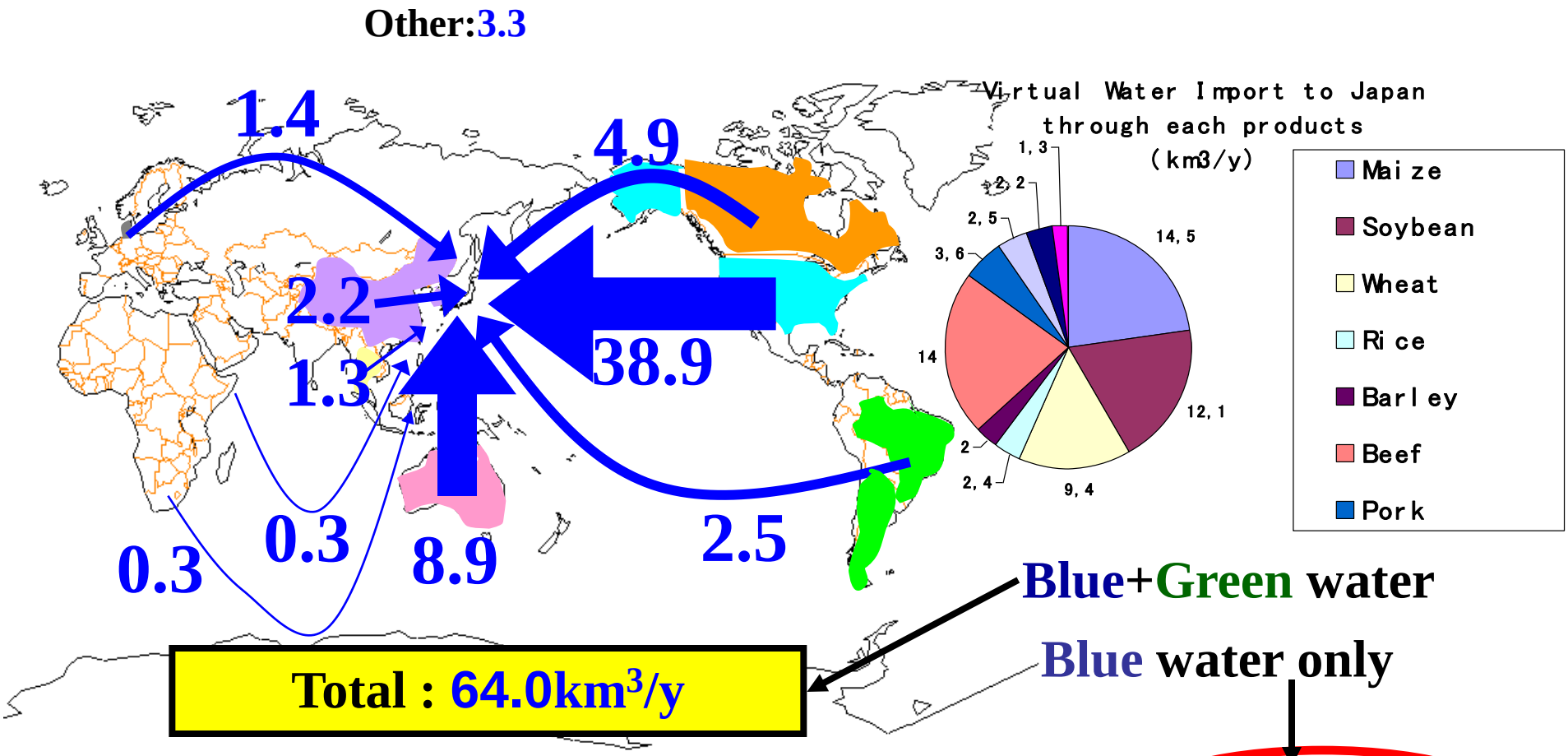
(W - S) / population [m^3 / year / person]

1995



R_{ws}= *(W-S)/Q* and A_{wc}= *Q/C*(m^3/y/c) have similar global distribution → Is *(W-S)/C* globally uniform?

Virtual Water Import to Japan

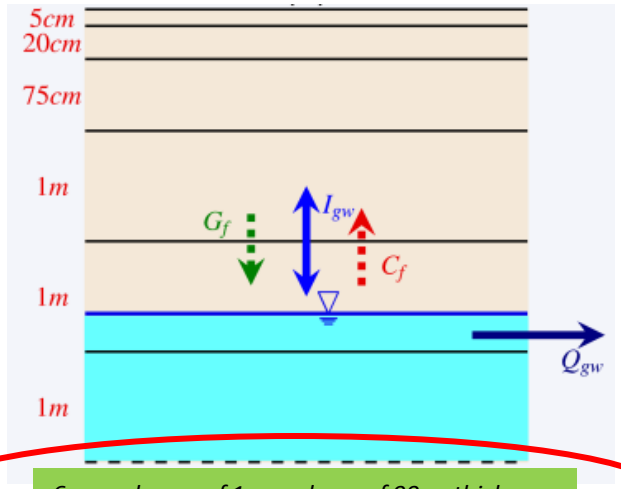


(for JFY in 2000)

Domestic Withdrawals in Japan: 89 km³/y
Domestic Blue Water in Japan: 400 km³/y
Domestic Green Water in Japan: 30 km³/y

(Oki, et. al, 2002, IHE-UNESCO)

Groundwater Representation



Koirala (2010)

- Based on ***Yeh and Eltahir (2005a,b)***
- Soil Column has **explicit saturated and unsaturated** soil zones.
  - Interacting through **exchange of moisture flux** (GW recharge)
- GW Recharge is estimated based on Richards' equation:

$$I_{gw} = k\left(\frac{d\psi}{dz} - 1\right)$$

- Lateral flow between grid cells is not considered

- Water Balance of GW reservoir:

$$S_y \frac{\Delta d_{gw}}{\Delta t} = I_{gw} - Q_{gw}$$

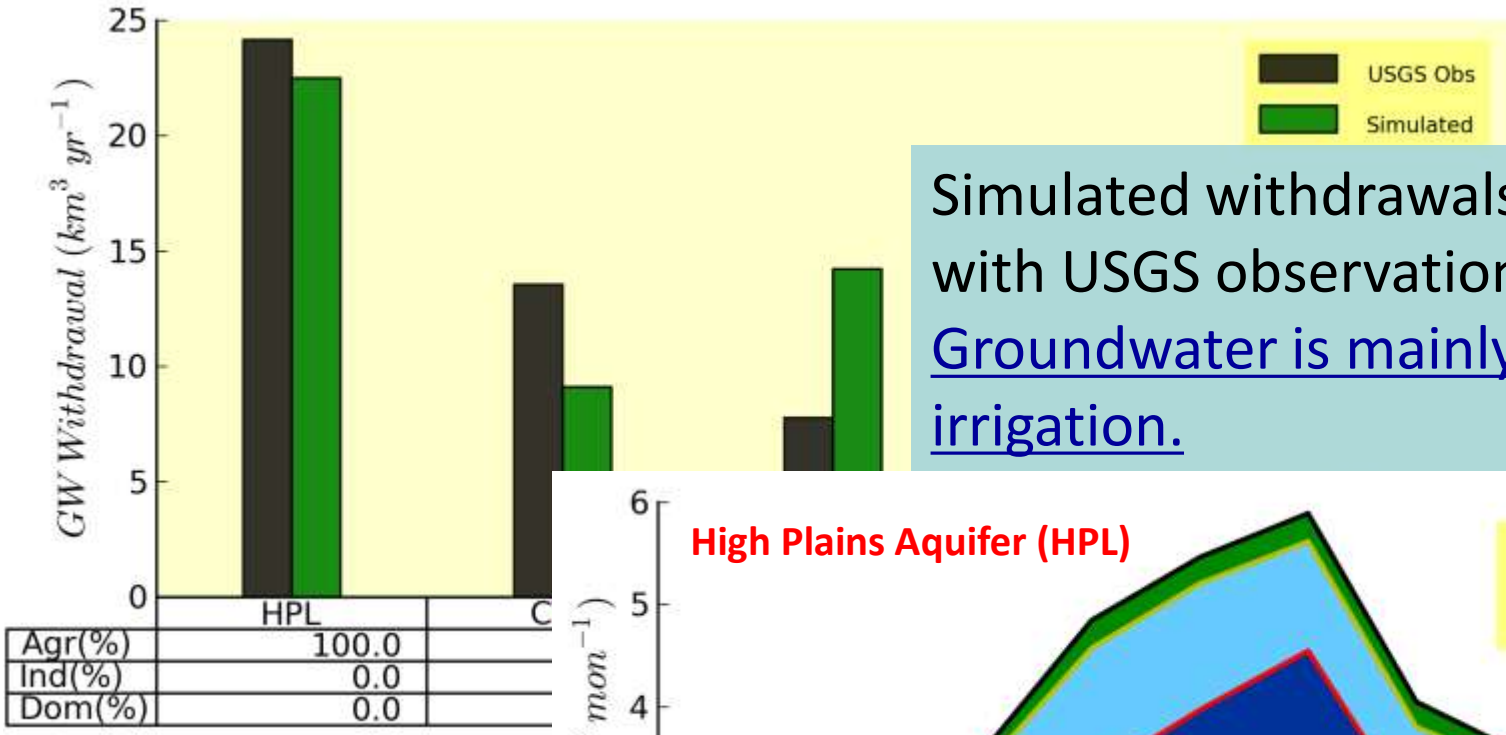
- Baseflow initiates when WTD is shallower than threshold value:

$$Q_{gw} = K\left(d_0 - d_{gw}\right) \quad if \;\; 0 \le d_{gw} \le d_0$$

$$Q_{gw} = 0 \quad if \;\; d_{gw} \ge d_0$$

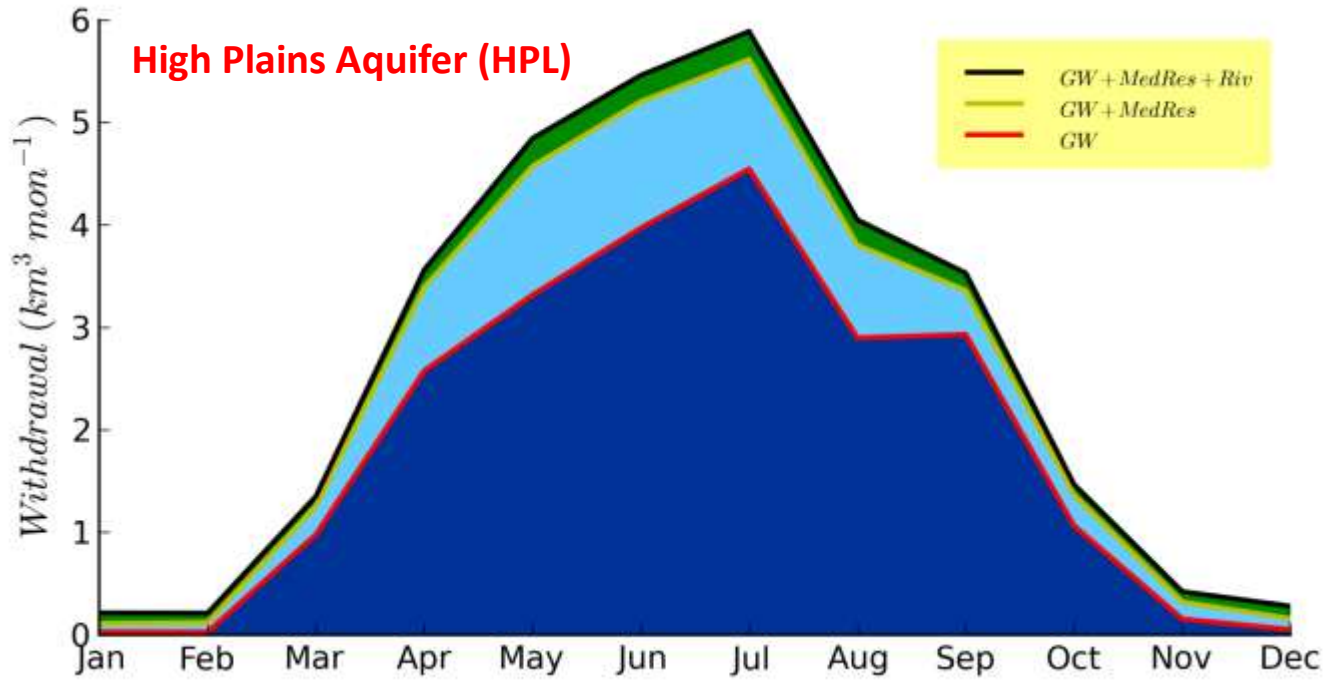
S_y: Specific yield, I_{gw}- recharge, Q_{gw} is baseflow, d_{gw}- water table depth (WTD), d_0- threshold WTD, K-outflow constant.

Groundwater Withdrawal (US Aquifers)



Simulated withdrawals compare well with USGS observations.

Groundwater is mainly used for irrigation.



Groundwater contributes ~75% of all water uses in areas overlying the HPL.