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Water Footprinting for Sustainable Development and Wise Management of Global Water

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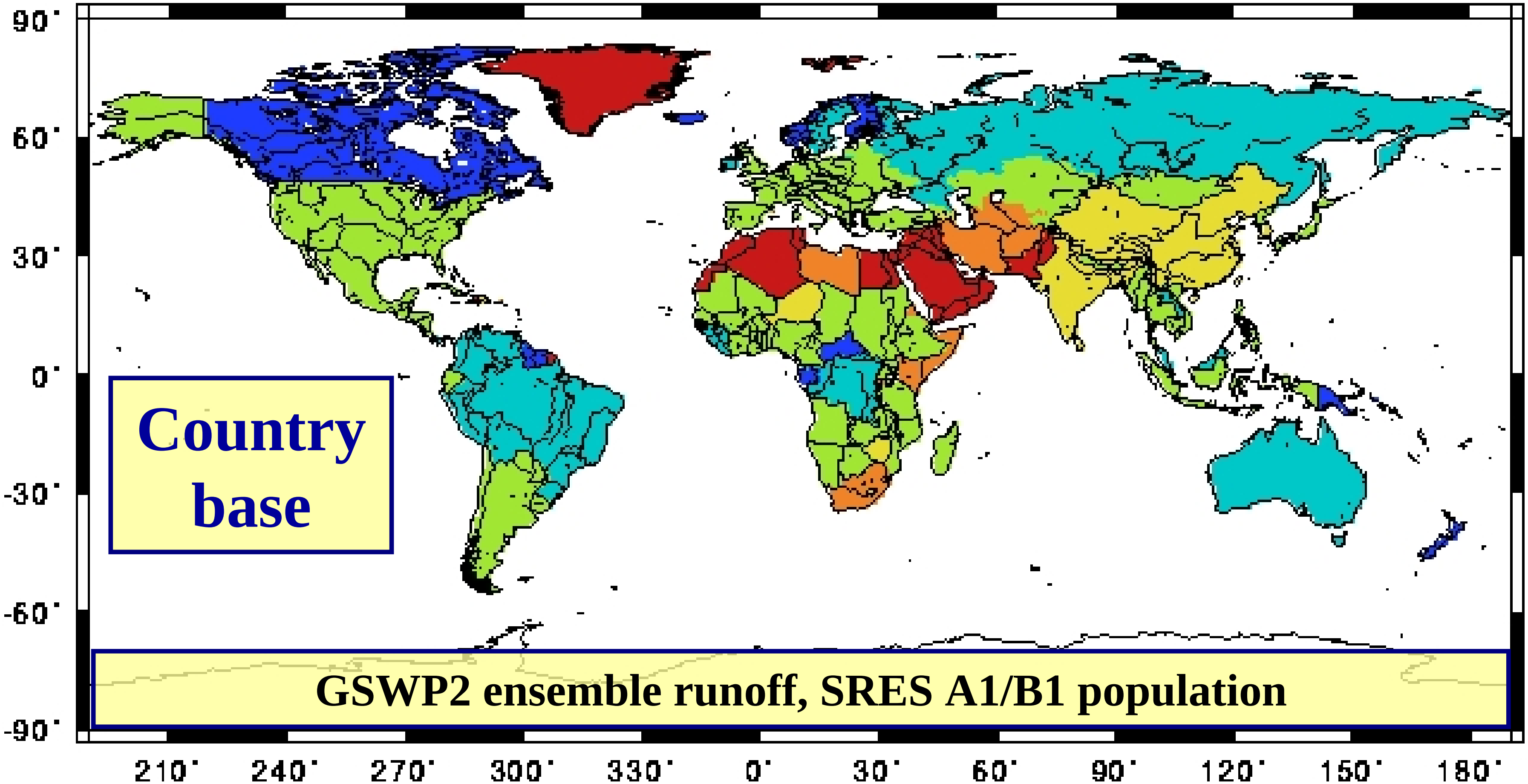
special thanks to
Drs. Naota Hanasaki (NIES) and Yadu Pokhrel

Conventional Water Resources Assessment

Potentially Available Water Resources per Capita in 2000



Seriously Stressed (~1)

Stressed (1~2)

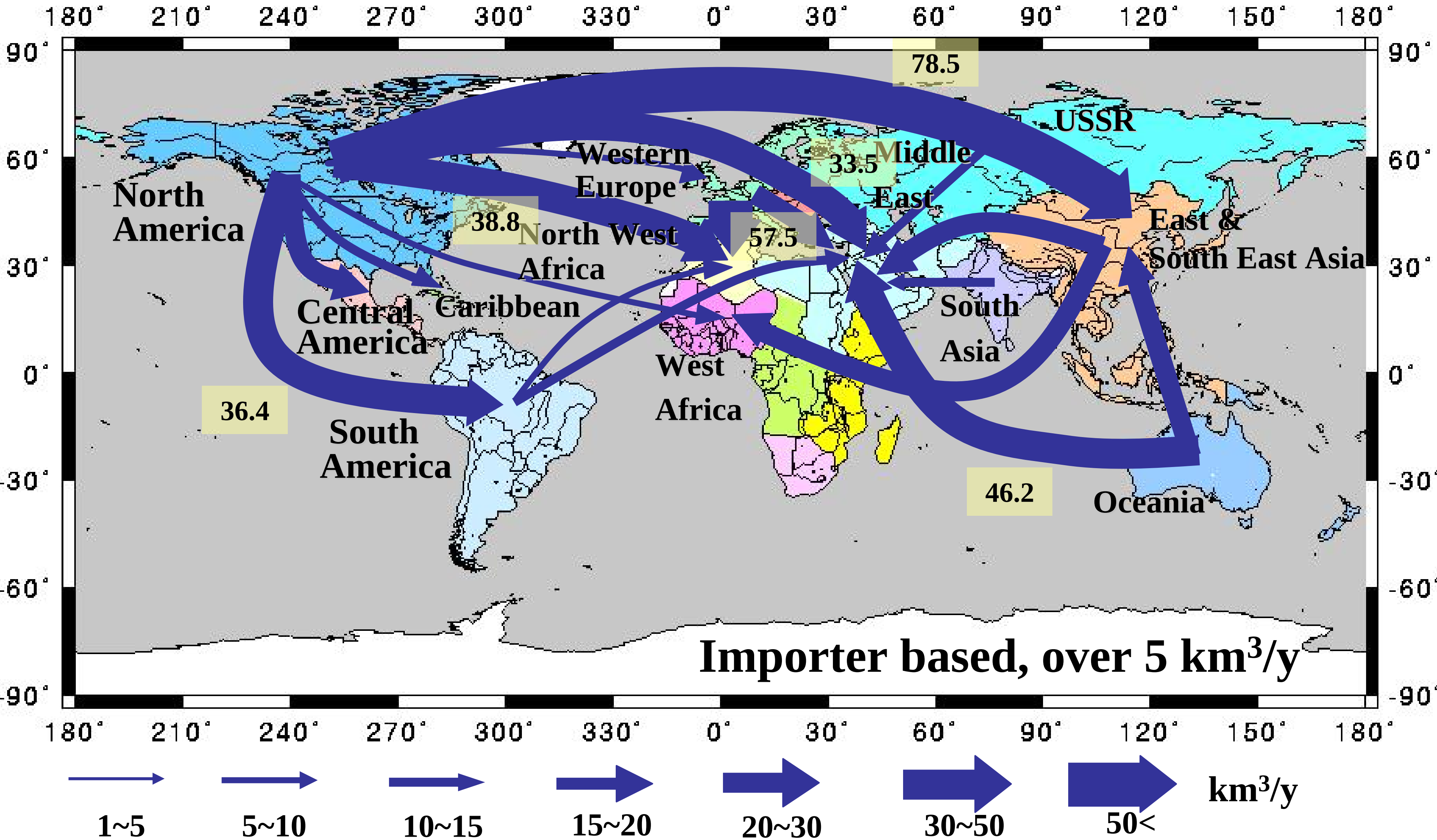
Slightly Stressed (2~5)

Moderate (5~10)

Rich (10~)

10^3 m^3/capita/year

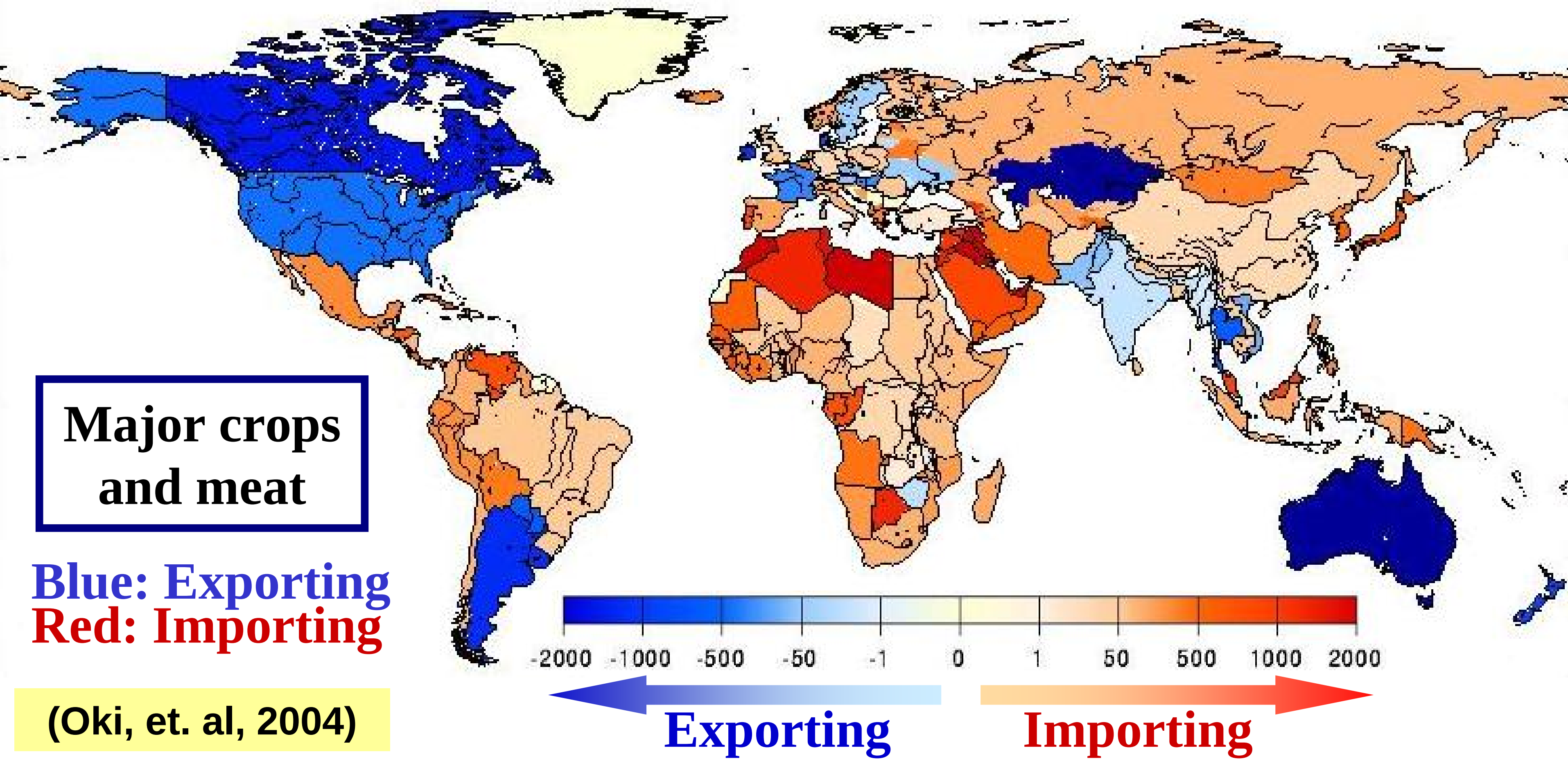
"Virtually Required Water" Trade between Regions in 2000 (cereals only)



(Oki, et. al, 2004)

(Based on Statistics from FAO etc., for 2000)

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



Major crops and meat

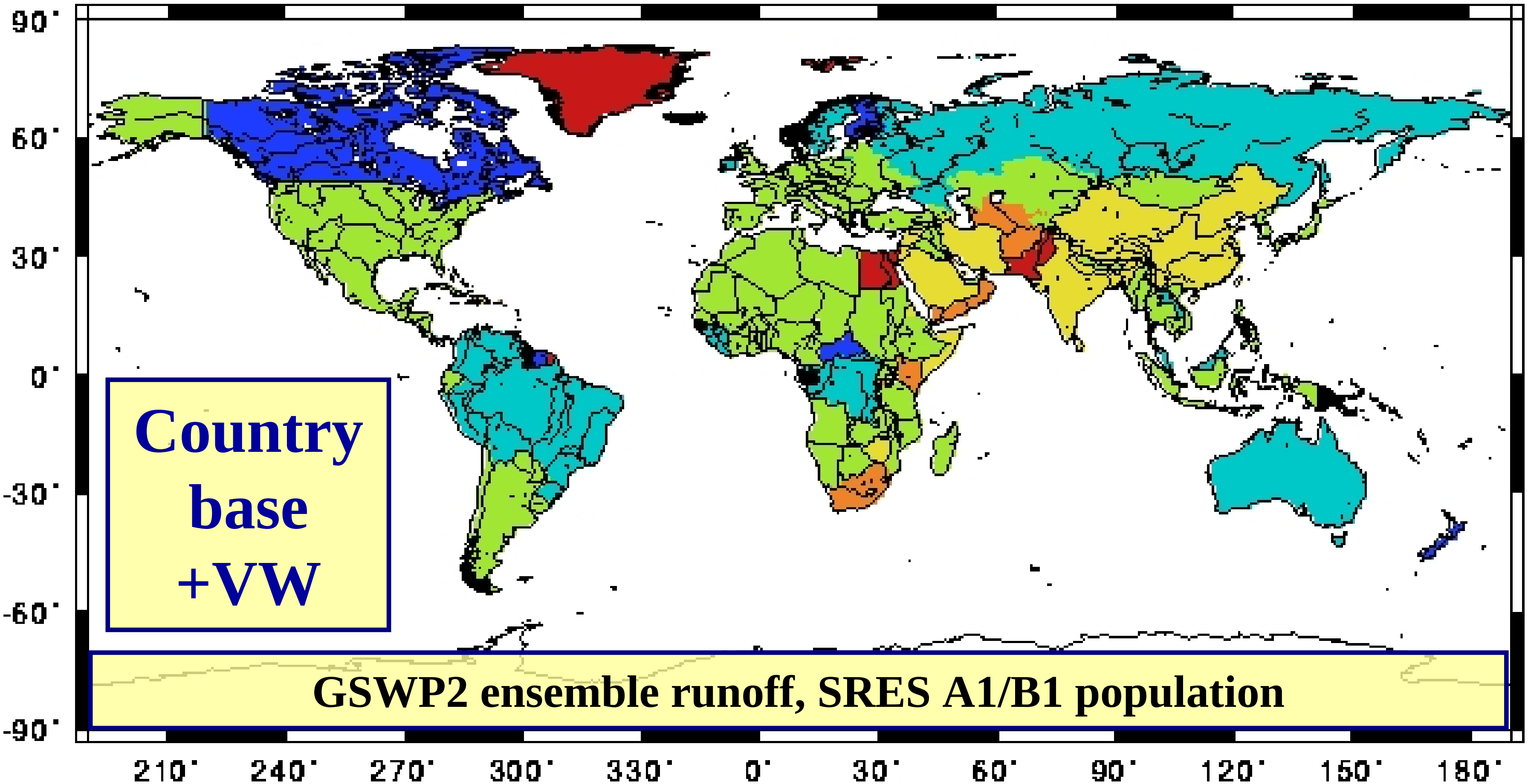
Blue: Exporting
Red: Importing

(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

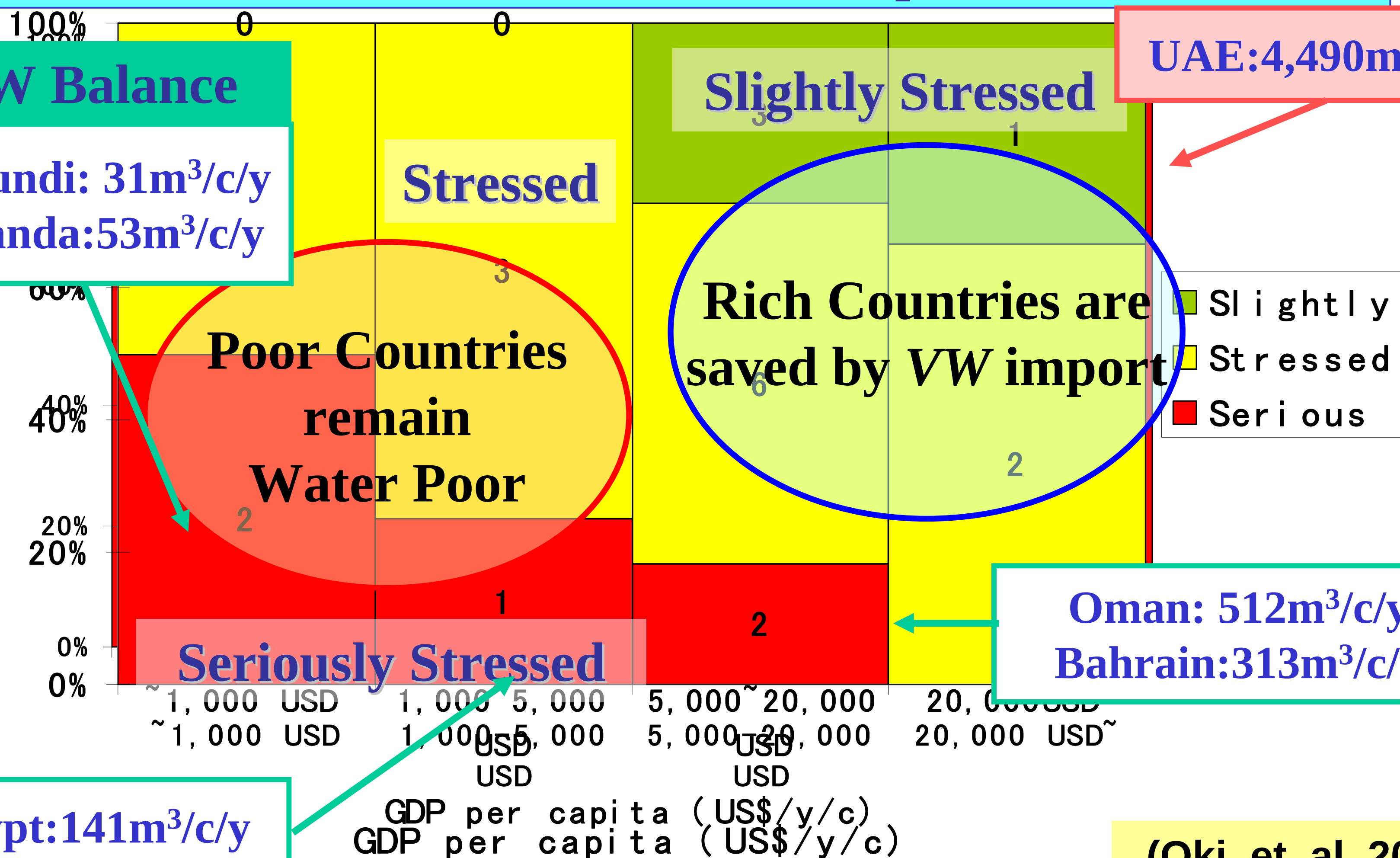


Seriously Stressed (~1)
Stressed (1~2)
Slightly Stressed (2~5)
Moderate (5~10)
Rich (10~)
10^3 m^3/capita/year

Water Resources Assesment Considering VW trade

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

➔ +Virtual Water Import



VW Balance

Burundi: $31m^3/c/y$
Rwanda: $53m^3/c/y$

Egypt: $141m^3/c/y$

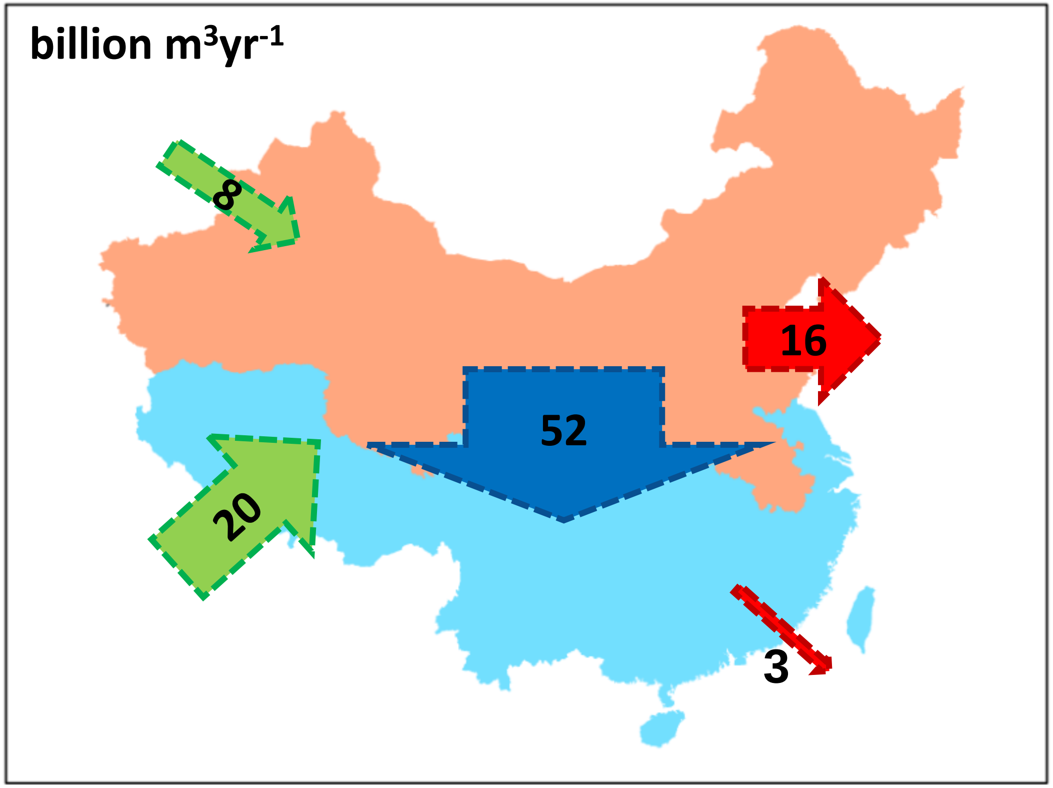
UAE: $4,490m^3/c/y$

Oman: $512m^3/c/y$
Bahrain: $313m^3/c/y$

Poor Countries remain Water Poor

Rich Countries are saved by *VW* import

(Oki, et. al, 2004)



Virtual Water Transfer

North to South : 52 billion m^3 yr^{-1}

Huang-huai-hai	→	Southeast	13
Huang-huai-hai	→	South-central	13
Northeast	→	Southeast	13
Northeast	→	South-central	13

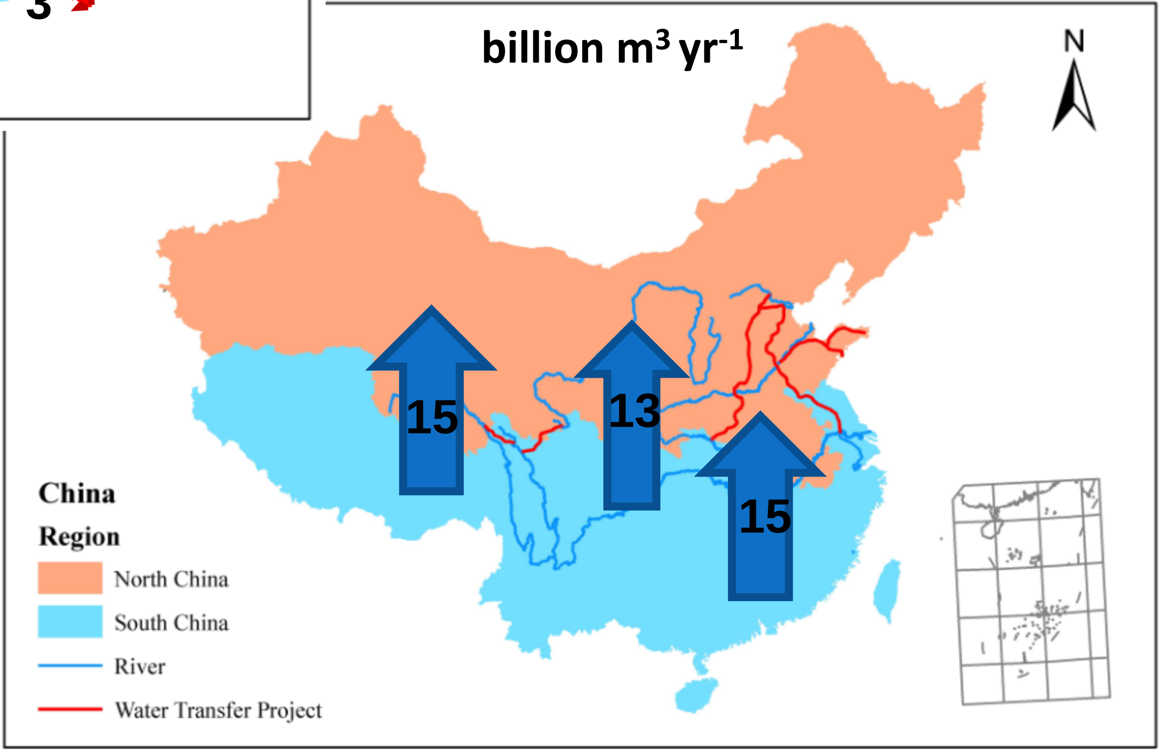
Real Water Transfer

South to North: 43 billion m^3 yr^{-1}

South to North Water Transfer Project, SNWTP

East Route of SNWTP	15
Middle Route of SNWTP	13
West Route of SNWTP	15

(Source: Liu et al., 2008, *Nature*. Courtesy from Prof. Dr. Junguo Liu, Beijing Forestry University, China)



Can we quantify water withdrawals by sources?

- The source of evapotranspiration
  - Precipitation
  - Irrigation water
    - Stream flow
    - Reservoirs and ponds
    - Renewable groundwater
    - Fossil groundwater

Low environmental impact
Sustainable
Low opportunity cost

High environmental impact
Less-sustainable
High opportunity cost

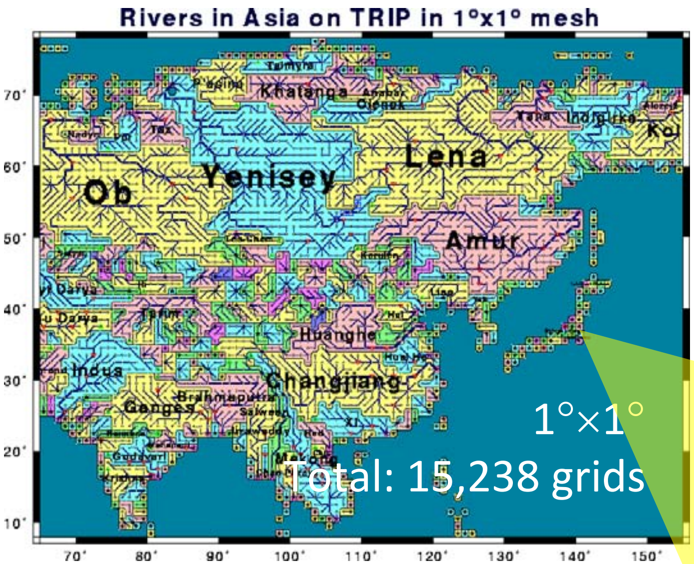
model

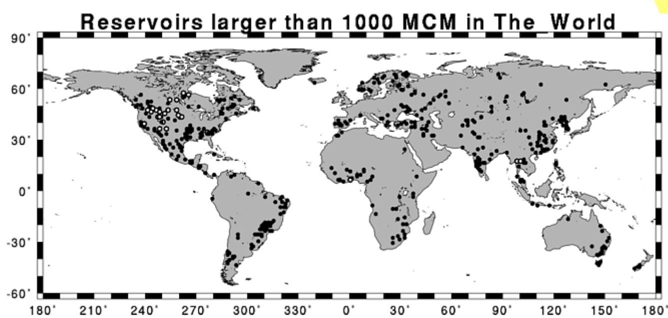
Step 1

Hanasaki et al., 2006, *J. of Hydrol.*
Hanasaki et al. ,2008a,b, *Hydrol. Earth Sys. Sci.*

東京大学
THE UNIVERSITY OF TOKYO

Global water resources model H08





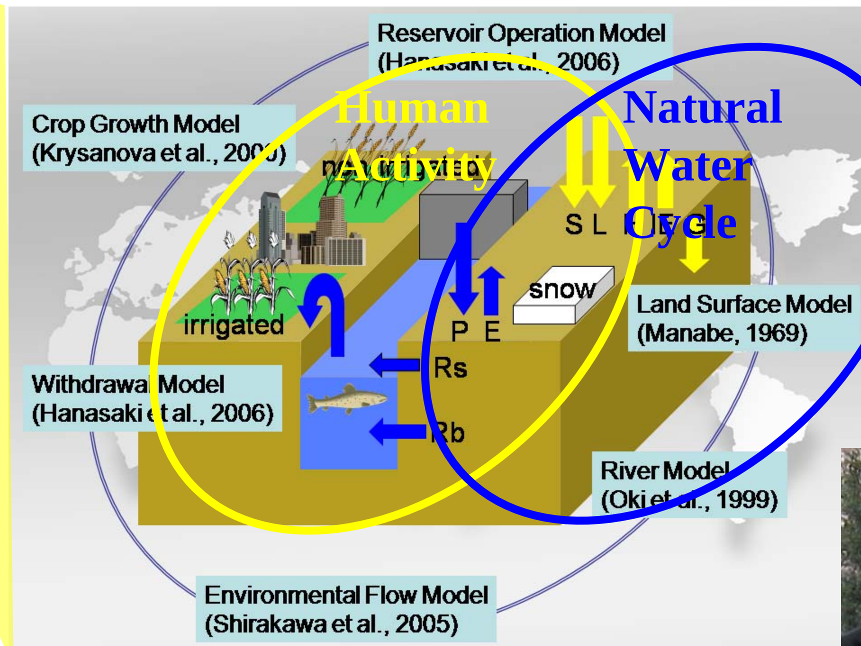
452 reservoirs, 4140 km³

Requirements

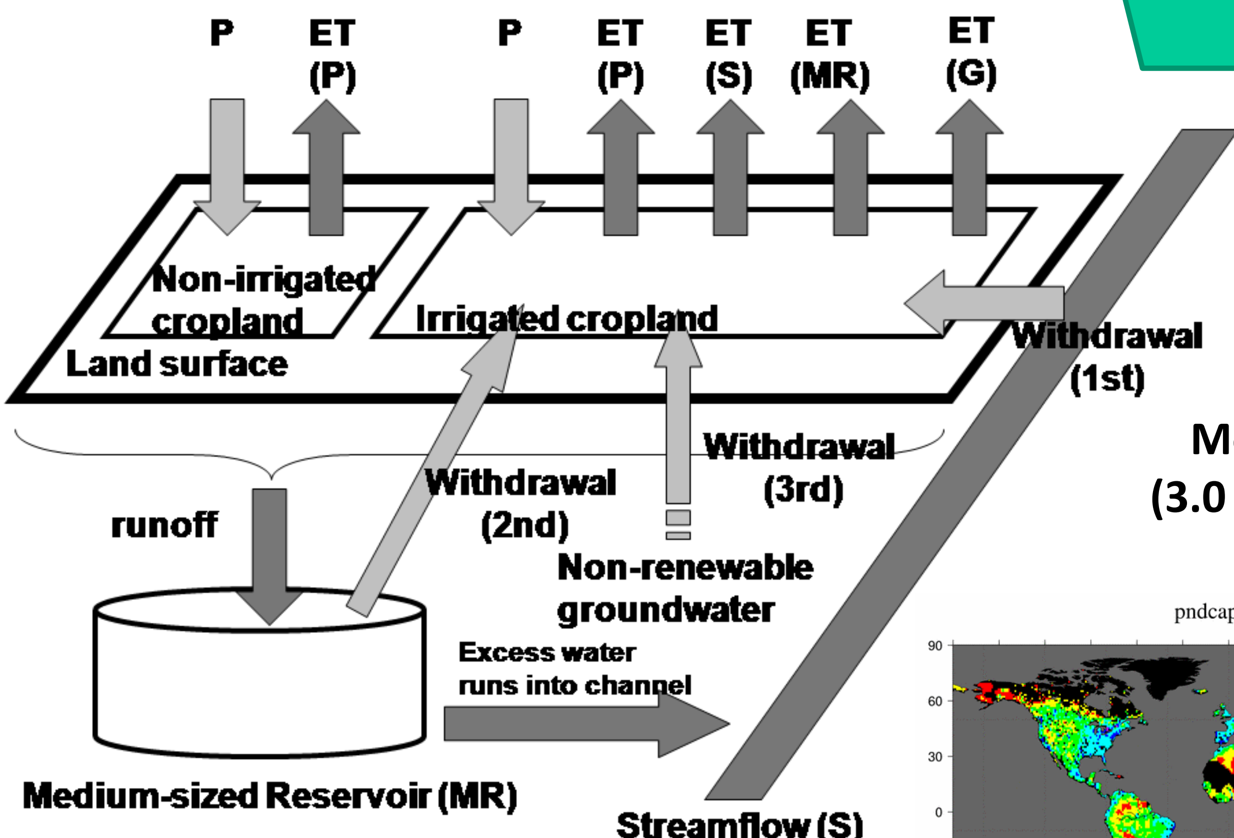
1.Simulate both water availability (streamflow) and water use at daily-basis

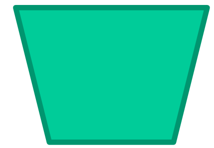
2.Deal with interaction between natural hydrological cycle and anthropogenic activities

3.Applicable for future climate change simulation



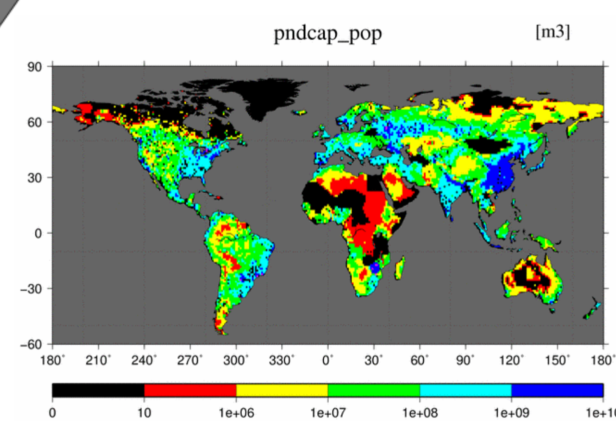
Enhancement of the H08 model





Large reservoirs
(1.0 x 10^9m^3 ≤S)
4140km^3

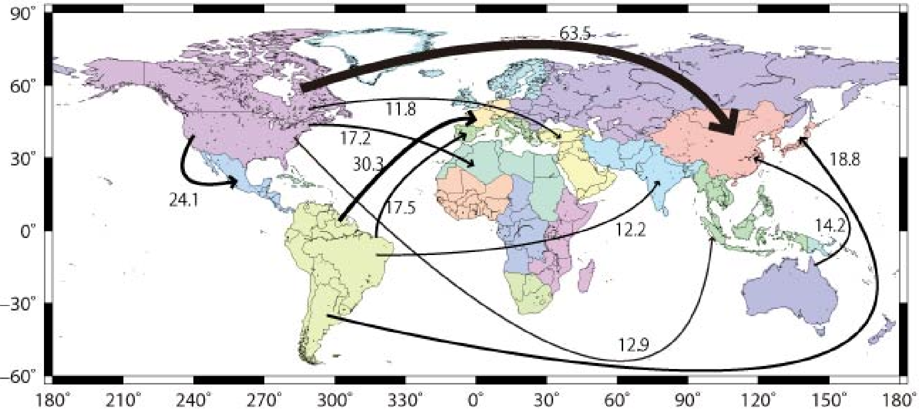
Medium-sized reservoirs
(3.0 x 10^6m^3≤S< 1.0 x 10^9m^3)
3280km^3



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

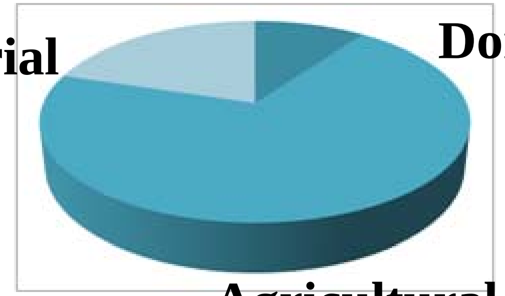
Global flows of virtual water export

Virtual water export (total)



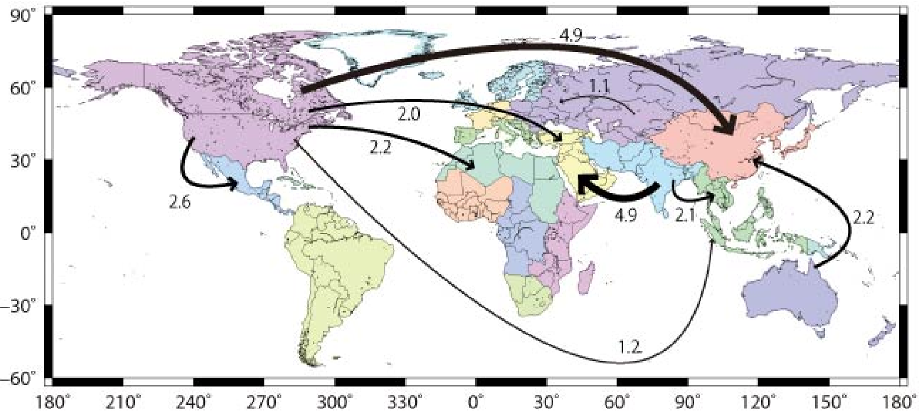
Total 545km^3 yr^{-1}

Total water withdrawal：3,800km^{3}yr^{-1}



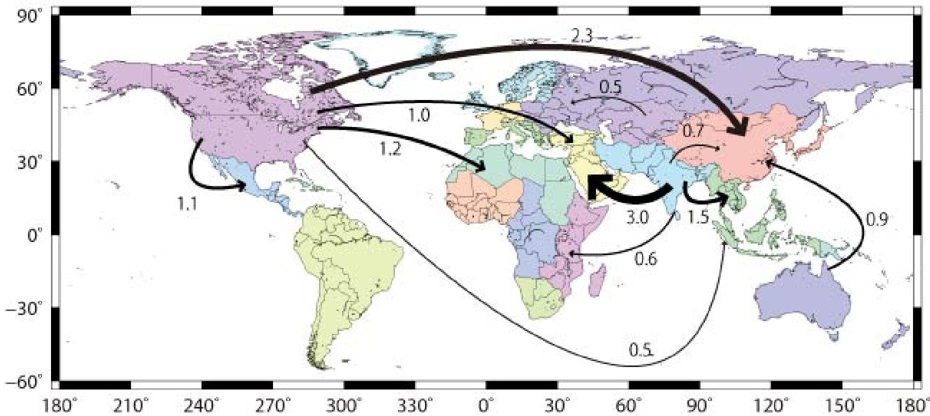
Shiklomanov, 2000

Virtual water export (irrigation)



Total 61km^3 yr^{-1}

Virtual water export (Nonlocal/Nonrenewable Blue Water)



Total 26km^3 yr^{-1}

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

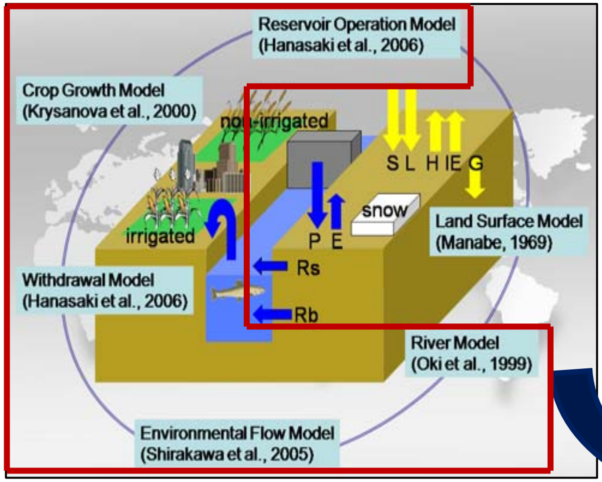
model

Step 2

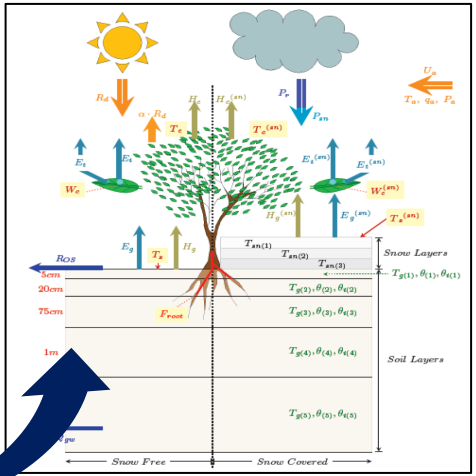
MODELS: MATSIRO & H08

- ☑ Land Surface Models (LSMs) are designed to be coupled with GCMs
  - **No Human Impacts (HI) representation**
- ☑ Numerous Global Hydrological Models (GHMs) with HI representation exist, but
  - Mostly designed for **offline simulations**
  - Simple ET parameterizations (**energy balance not considered**)
  - Vegetation dynamics/Carbon cycle not accounted

H08: *Hanasaki et al. (2008a, 2008b)*



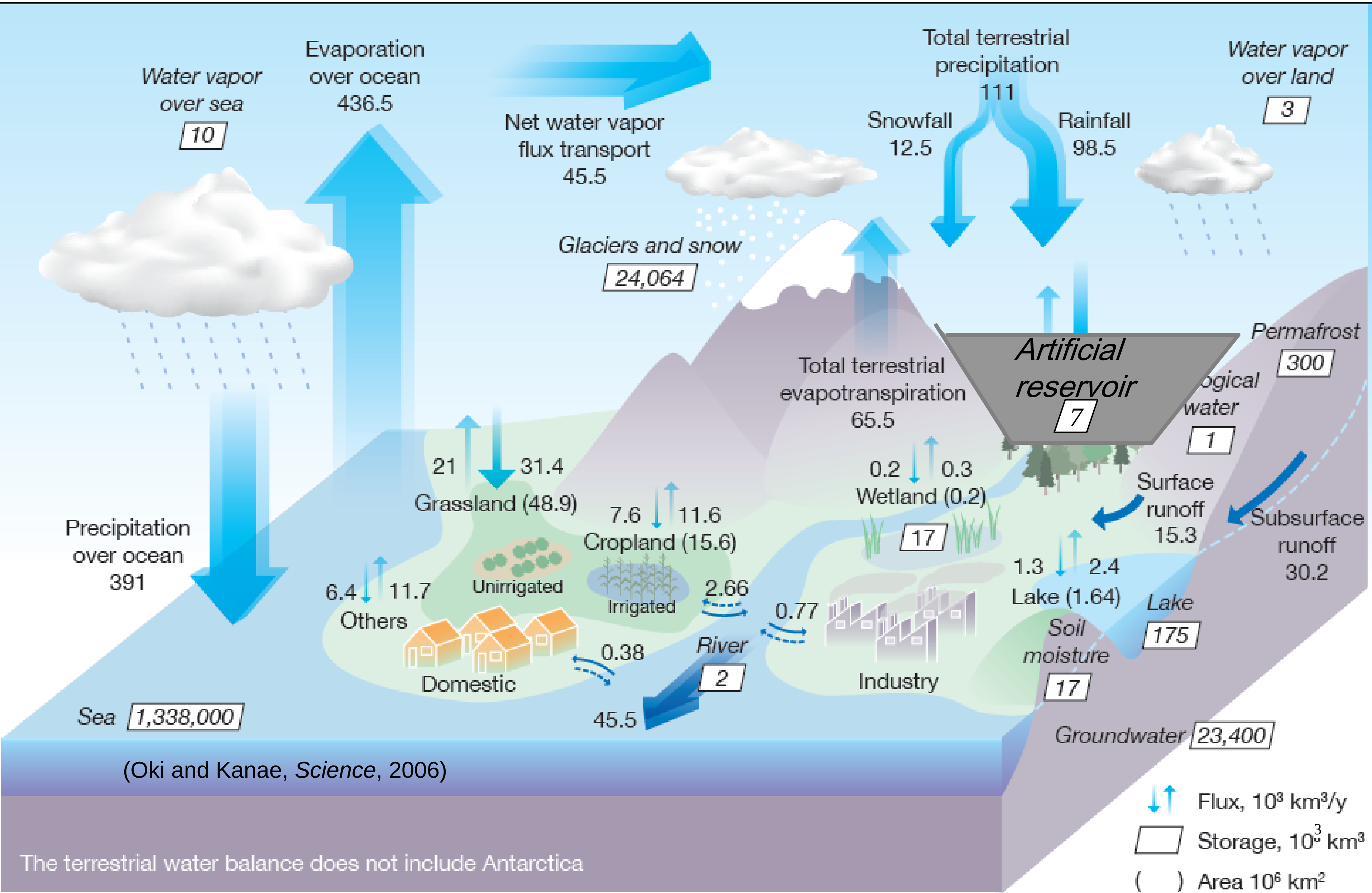
MATSIRO: *Takata et al. (20003)*



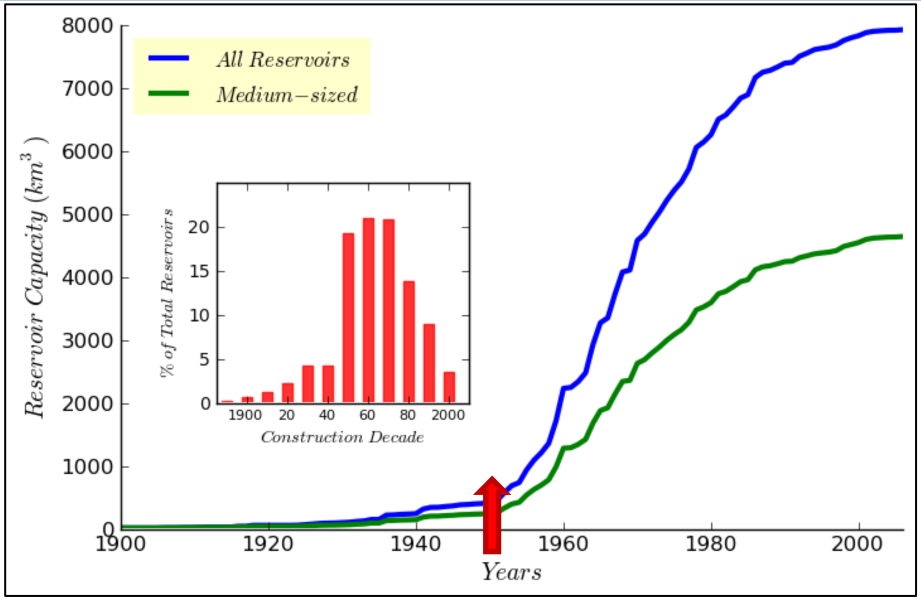
- ✓ Land surface hydrology scheme is a simple **Bucket Model**
- ✓ **Vegetation** : accounted implicitly

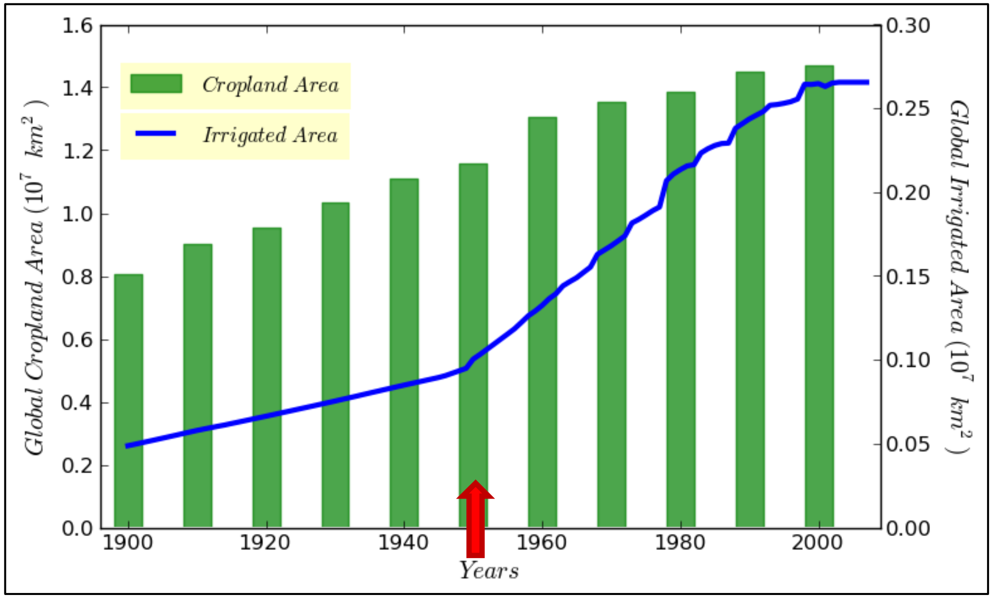
- ✓ **Further, new irrigation scheme for MATSIRO LSM is developed**
- ✓ **Water table dynamics and a newly developed pumping scheme**

Synthesized Global Water Cycle



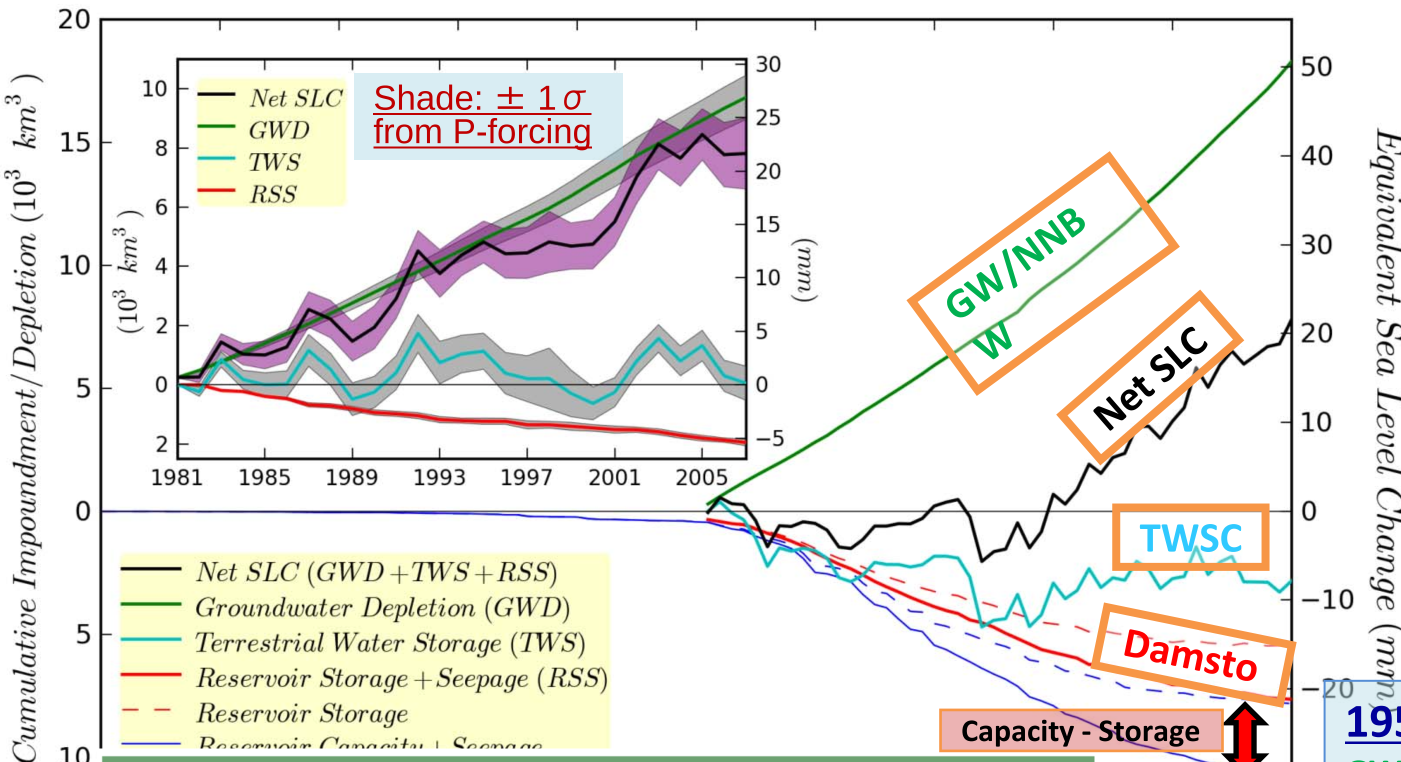
Historical Reservoir Storage & Irrigated Areas





- ☑ Reservoir storage and irrigated areas largely increased from 1950s
- ☑ 1950—2000 simulation is conducted:
  - Simulations: **MAT-NAT-NCC** (no HI), **MAT-HI-NCC** (with HI)
  - Forcing data: **NCC** (Ngo-Duc et al., 2005)
  - Historical Reservoirs/Land Use Change/Irrigated Areas Data:
    - ✓ Compiled from various sources: time-varying gridded datasets

Sea Level Change: Anthropogenic TWS Contributions



Source	Sea Level Rise (mm yr⁻¹) 1961–2003	1993–2003

Seepage from reservoirs is accounted by using a simple **dynamic fluid diffusion** model: **seepage decrease with time as 1/√t**

1951-2007 SLC:
GW: +0.99 ± 0.07 mm/yr
Dam: -0.39 ± 0.02 mm/yr
TWS: -0.10 ± 0.05 mm/yr
IRR: +0.03 mm/yr
Net: +0.53 ± 0.08 mm/yr

1961-2003 SLC:
Net: +0.74 (IPCC:+0.7) mm/yr

1993-2003 SLC:
Net: +1.50 (IPCC:+0.3) mm/yr

Other factors that potentially affect sea level change:

- ✓ Land use change/deforestation: partly accounted by land use change data
- ✓ Wetland drainage, atmospheric water content change: relatively small
- ✓ Various factors are not fully independent: coupled land-atmosphere simulations

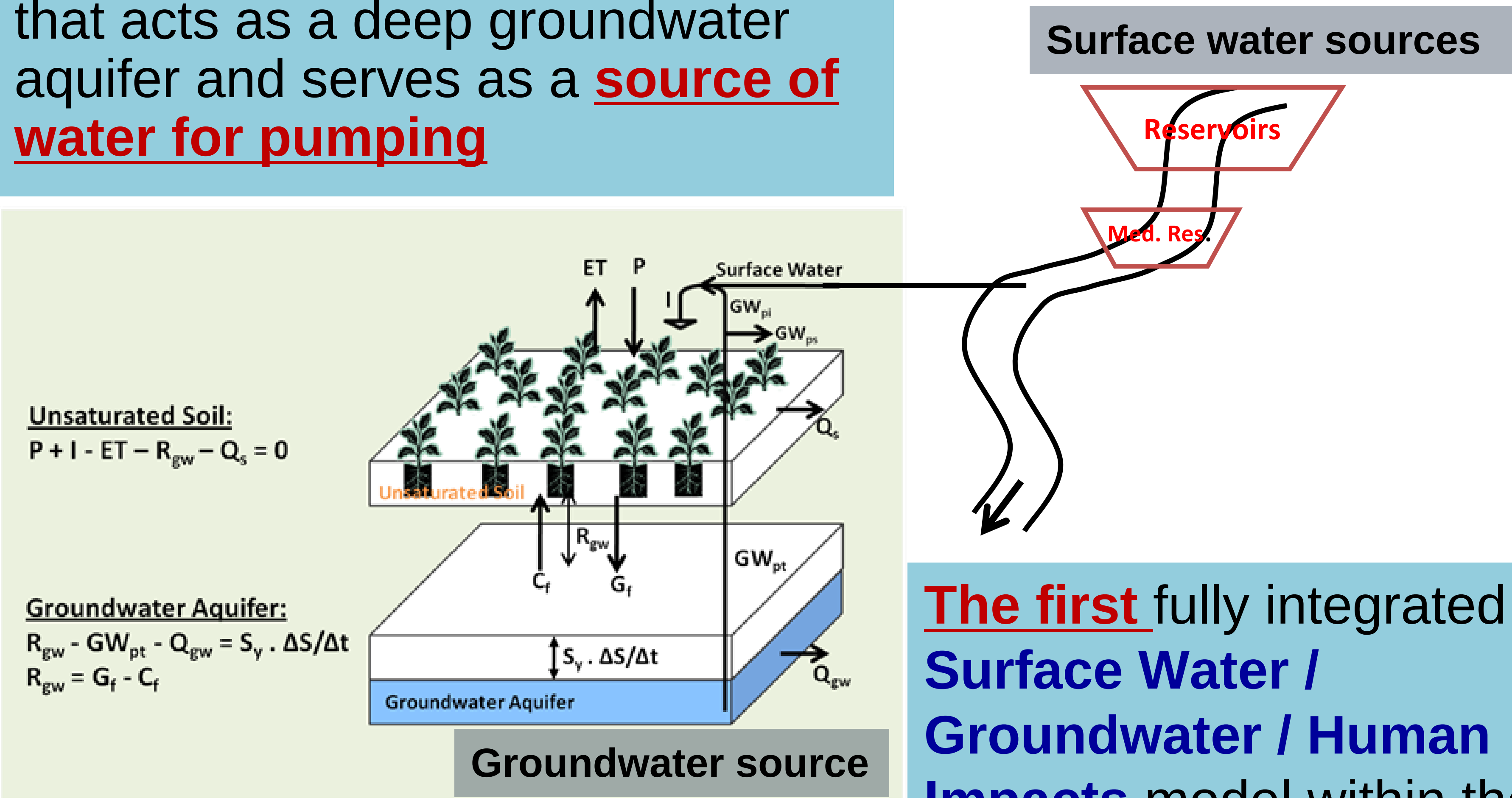
Pokhrel, Y., et al.: Anthropogenic terrestrial water storage contributions to global sea level change, *in Preparation*.

model

Step 3

Groundwater Pumping Scheme

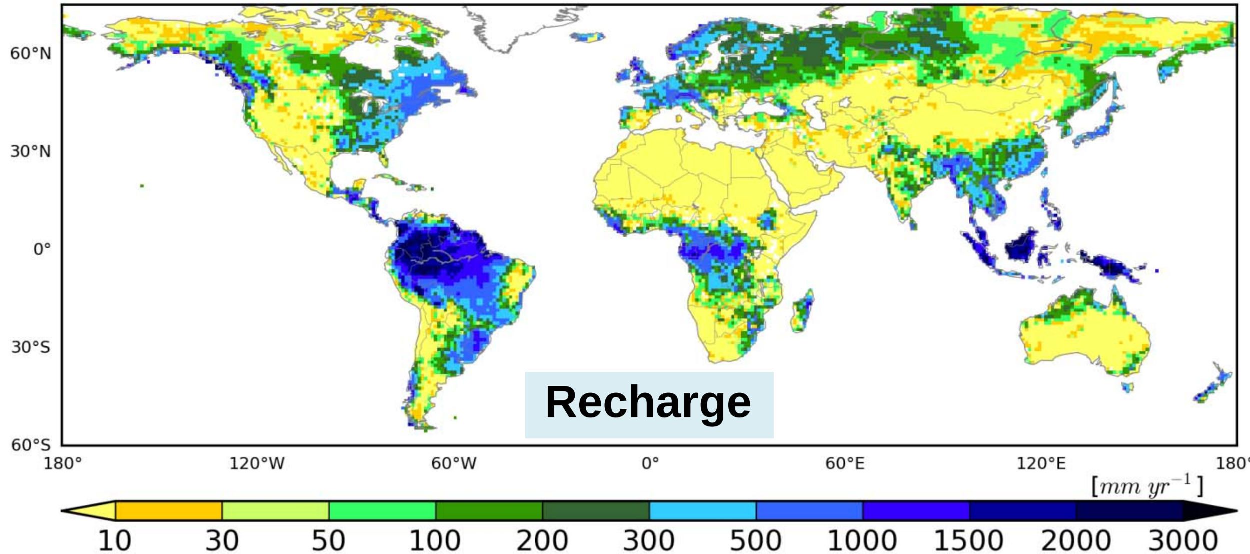
A thick bottom layer (90m) is added that acts as a deep groundwater aquifer and serves as a **source of water for pumping**

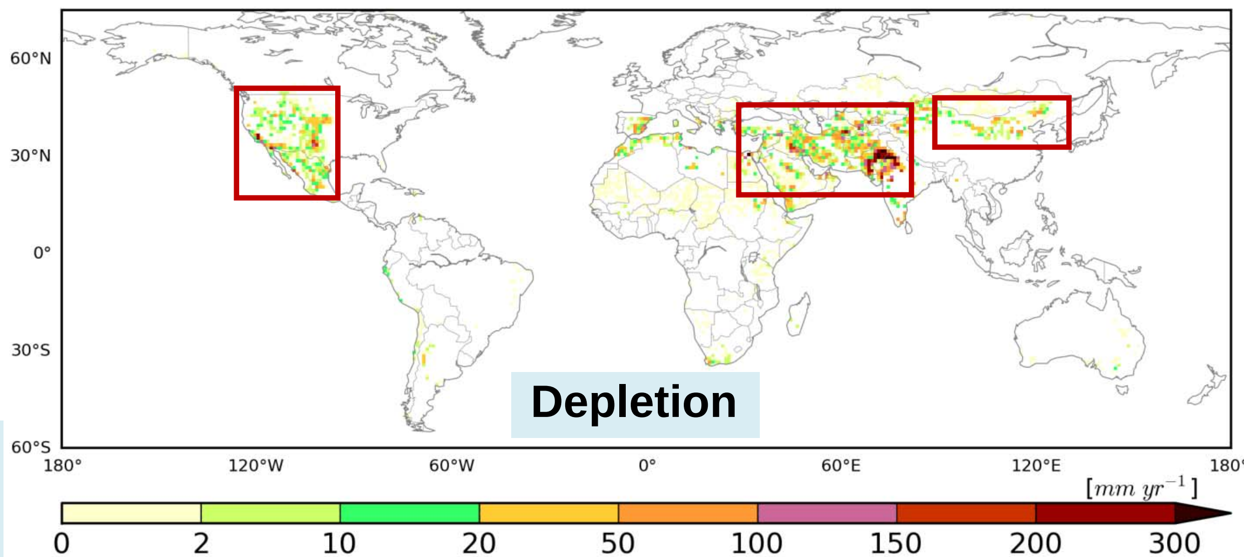


The first fully integrated **Surface Water / Groundwater / Human Impacts** model within the framework of **global LSM**

Global Groundwater Depletion

- ✓ Both **withdrawal** and **recharge** are simulated
- ✓ Groundwater **depletion** is estimated as the difference of **withdrawal and recharge**



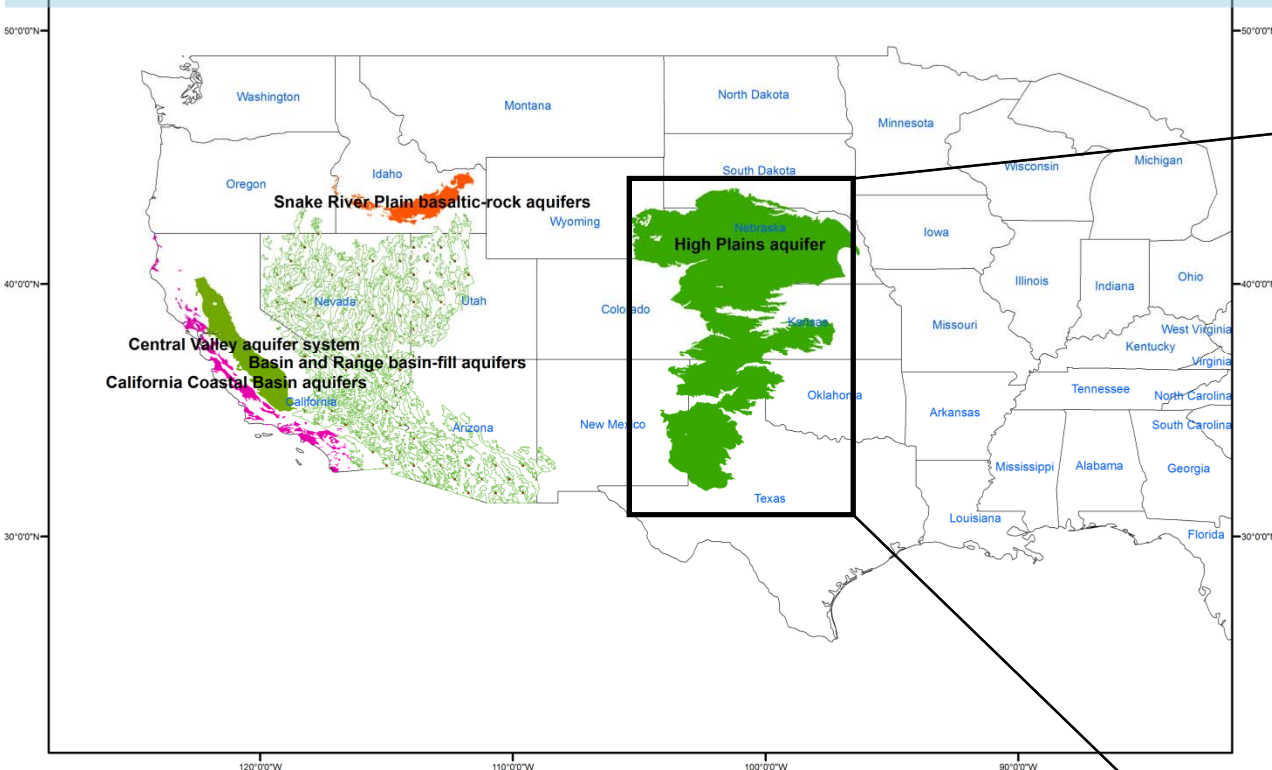


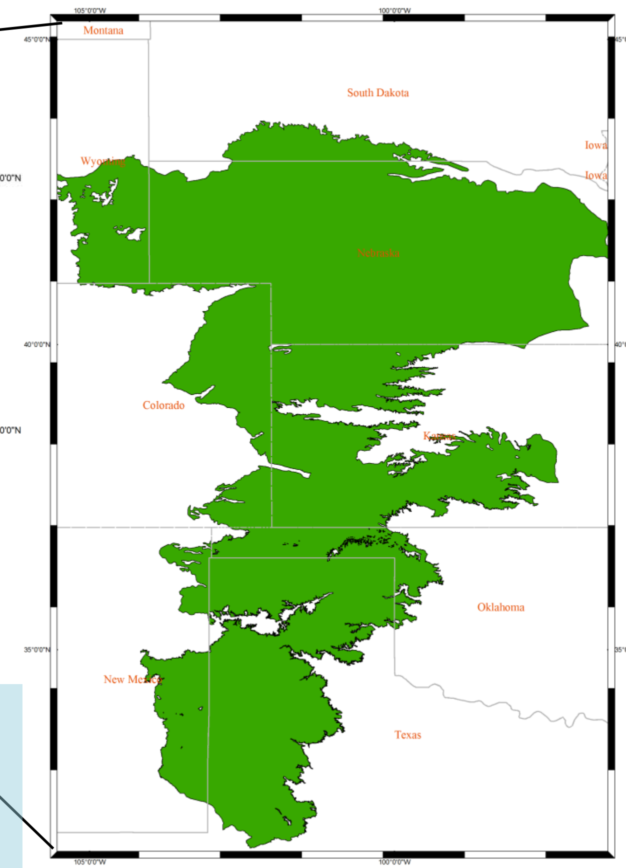
Global total ~370 km³/y

Wada et al, 2010: ~290 km³/y

Groundwater Use: Validation in US Aquifers

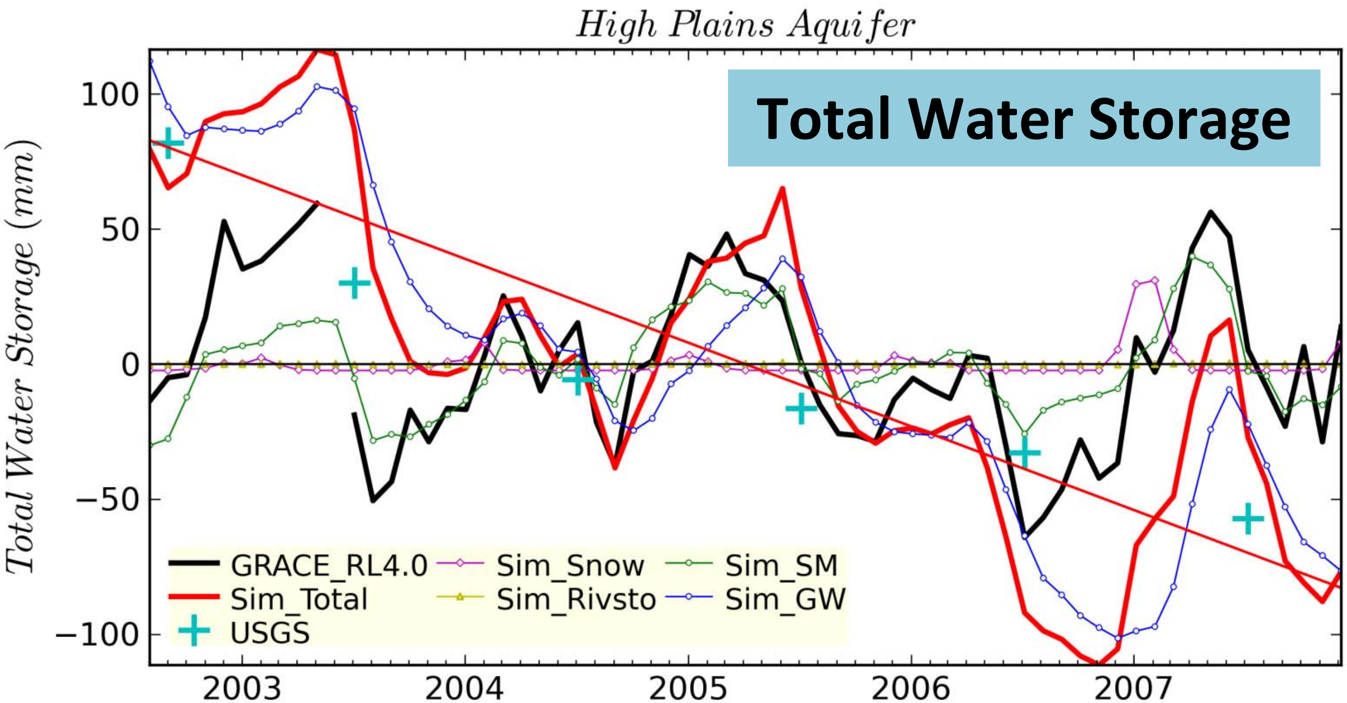
Almost 30% of GW withdrawals for irrigation in the US.
~97% of GW withdrawals from the aquifer are used for irrigation.





Groundwater levels have significantly **declined** since extensive GW **irrigation** started during 1950s.

Groundwater Depletion (High Plains Aquifer)



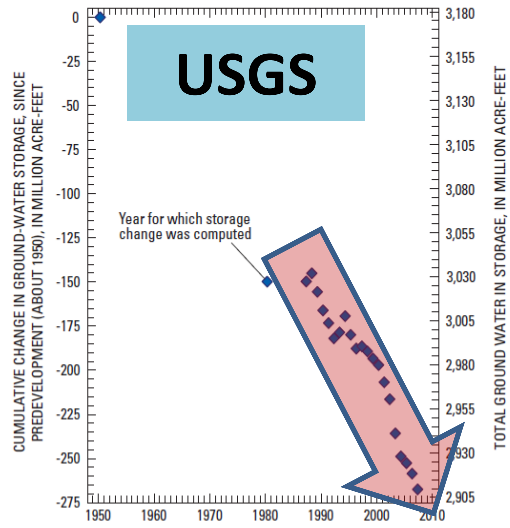
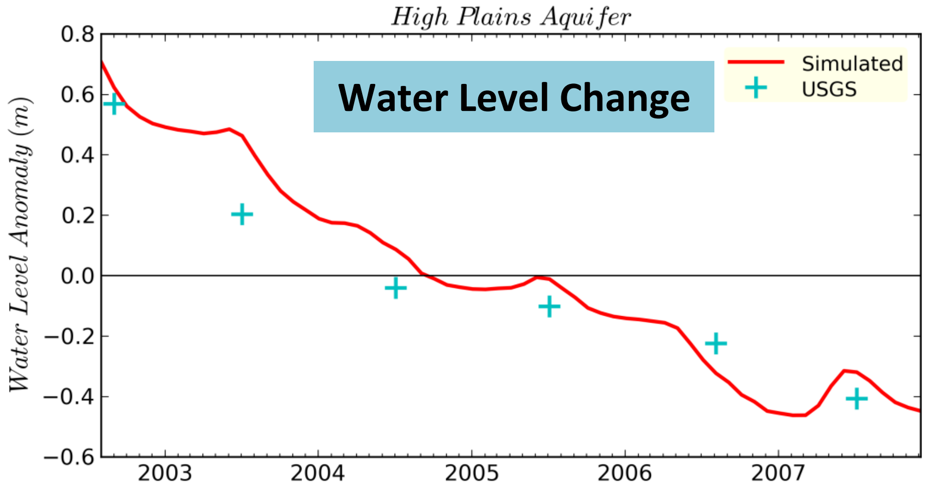


Figure 2. Cumulative change and total ground water in storage in the High Plains aquifer, predevelopment to 2007 (modified from McGuire, 2006).



USGS reports considerable decline in groundwater storage/levels in recent years.

Remarks

- **Integrated model of natural hydrology & anthropogenic activities is under development.**
  - **Capable of assessing the source and path of water withdrawals for agricultural productions**
  - **Can assess non-sustainable water usages**
- **Human activities are changing the hydrological cycles even on the global scale:**
  - **Storing in artificial reservoirs, exploiting fossil ground water, and the changes terrestrial water storages are changing the sea level.**

飲水思源

When you drink water,
think its origin.

飲食思水

When you eat,
think about water.

Thank You!