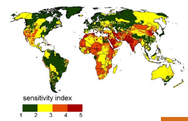
The irrigation-groundwater nexus at the global scale



http://water.usgs.gov/ogw/gwrp/photo_gallery/

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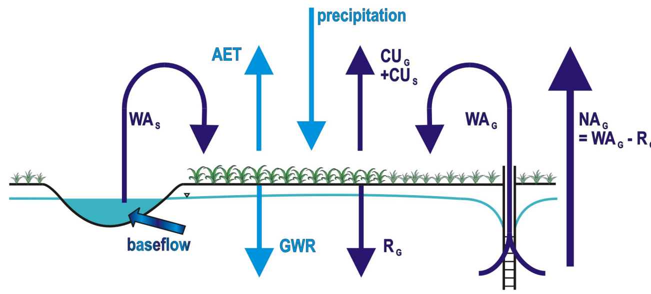
Conceptualization of the irrigation-groundwater nexus

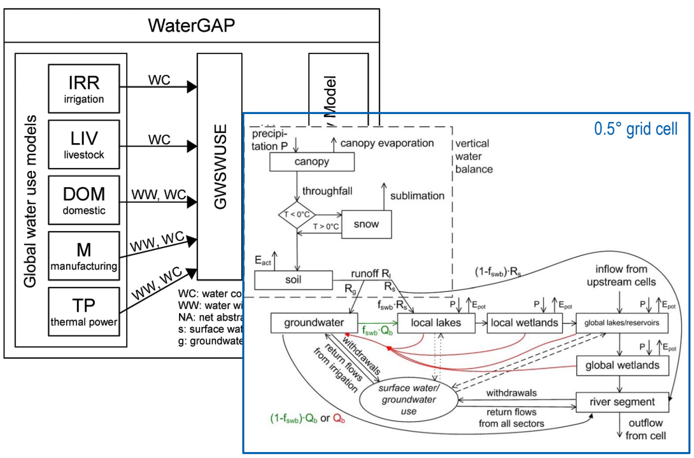


WA: water abstraction R: return flow

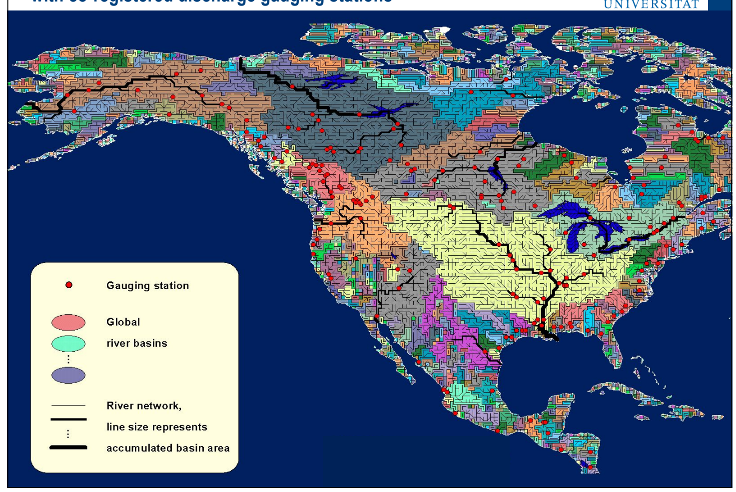
CU: consumptive use NA: net abstraction

The global water resources and use model WaterGAP

(developed since 1996 at University of Kassel and Goethe University Frankfurt)



Global drainage direction map DDM30 with co-registered discharge gauging stations



Quantification of the irrigation-groundwater nexus

Water use related flows

1. Consumptive water use of irrigated crops
2. Water abstractions for irrigation from groundwater (gw) and from surface water (sw)
3. Return flows to gw and to sw
4. Net abstractions from gw = gw abstractions (for all other sectors) – return flows from irrigation with sw and gw

Water resources related flows

1. (Natural) gw recharge
2. Baseflow (affected by gw use)

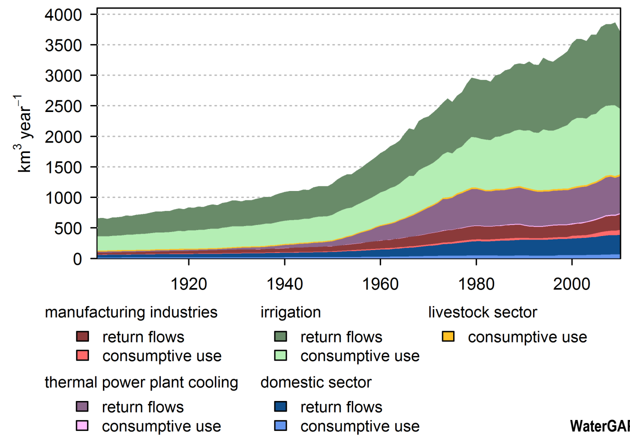
Uncertain data and assumptions used for computing irrigation water use components

- Areas equipped for irrigation and areas actually irrigated (Global Map of Irrigation Areas GMIA v5.0, including spatial information on map quality, Siebert et al., with FAO)
- Areas equipped for irrigation with groundwater (Siebert et al. 2010 HESS)
- Irrigated crop calendars (Portmann et al. 2010 Global Biogeochemical Cycles)
- Climate data (WFDEI: reanalysis data that are bias-corrected with observations)
- Equation for computing potential evapotranspiration (Priestley-Taylor)
- Degree of deficit irrigation (70% in groundwater depletion areas, Döll et al. 2014 WRR)
- Ratio of consumption over abstraction (0.7 in case of groundwater use, otherwise country-specific)
- Fraction of return flows to gw (= 0.95–0.75*fdrain, with fdrain = fraction of grid cell that is artificially drained, Döll et al. 2014 WRR)

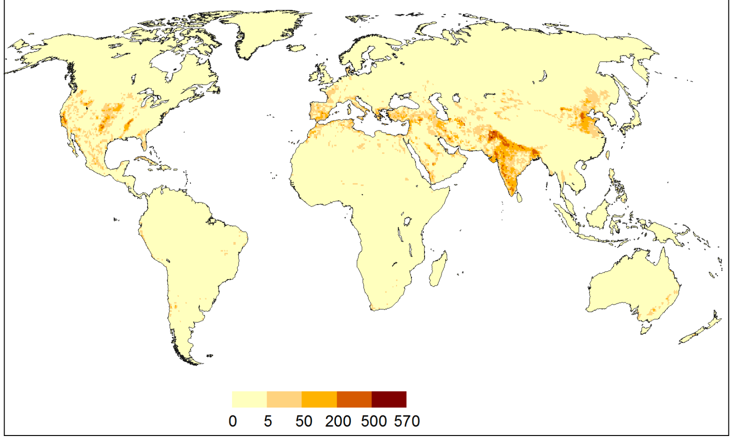
Uncertain data and assumptions used for computing gw resources and sw-gw interactions

- Climate data
- Equation for computing potential evapotranspiration
- Equation for computing actual evapotranspiration and runoff (calibrated against observed streamflow at 1319 gauging stations world-wide, Müller Schmied et al. 2014 HESS)
- Algorithm for partitioning total runoff into groundwater recharge and fast surface and subsurface runoff (function of relief, soil texture, hydrogeology and glaciers/permafrost)
- gw-sw interactions (baseflow from gw to sw except lakes and wetlands in dry areas that are assumed to recharge gw)

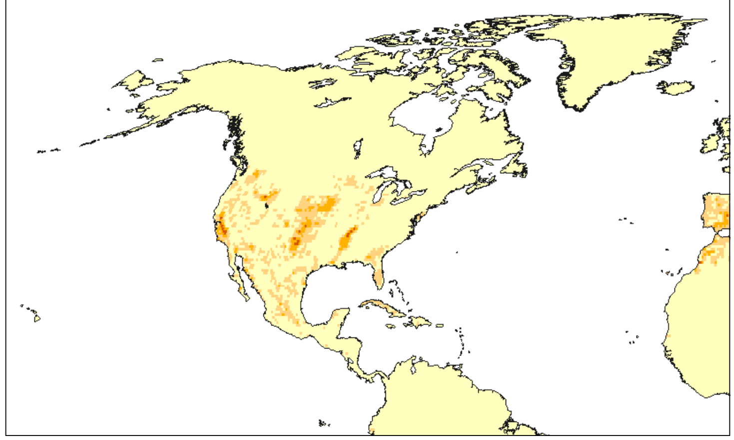
Global human water use (no distinction gw/sw)



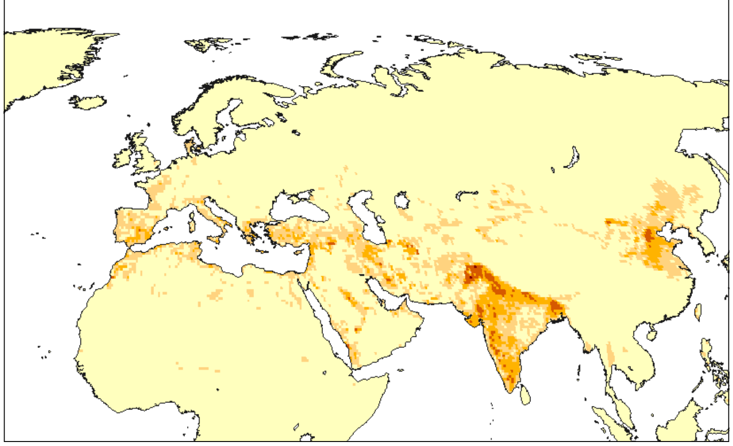
Irrigation water abstractions from groundwater 2003-2009, in mm/yr



Irrigation water abstractions from groundwater 2003-2009, in mm/yr

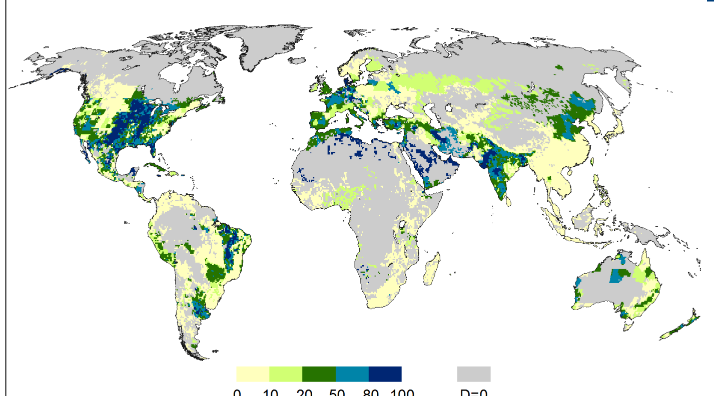


Irrigation water abstractions from groundwater 2003-2009, in mm/yr



How important is groundwater as a source for irrigation?

Irrigation water abstractions from gw in % of total irrigation water abstractions



How important is irrigation use among all other groundwater user?

Irrigation water abstractions from gw in % of total gw abstractions

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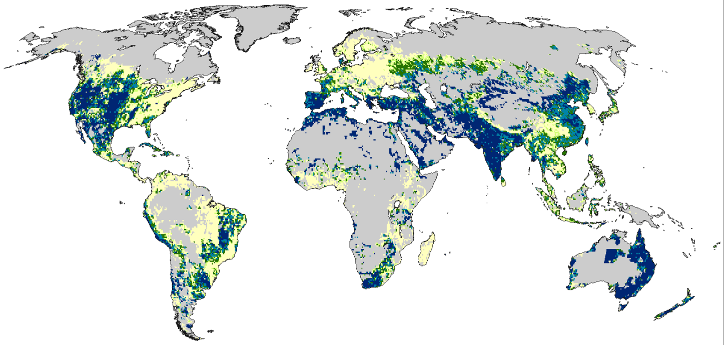

Net water abstractions 2003-2009 (mm/yr)

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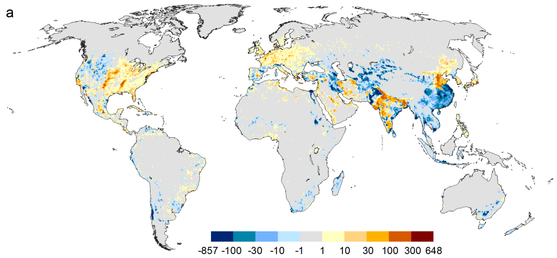
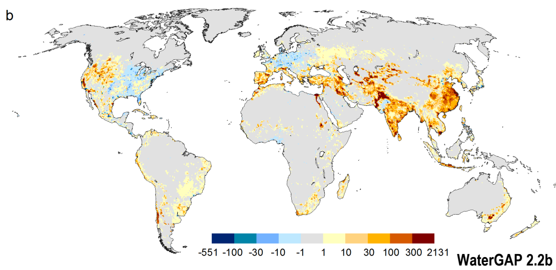
from groundwater



from surface water bodies



WaterGAP 2.2b

Global water use 2003-2009 as computed by WaterGAP 2.2b

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	Total Abstractions (km^3/yr)	GW Fraction (%)	Consumptive use (km^3/yr)	GW Fraction (%)
Irrigation (70% of optimum in gw depletion areas)	**2492**	**24**	**1149**	**37**
Livestock	30	0	30	0
Domestic	362	36	60	37
Manufacturing	289	27	62	26
Thermal power	615	0	17	0
Total	**3788**	**22**	**1317**	**35**

NAs = 1479 km^3/yr, NAg = -162 km^3/yr

Impact of irrigation on groundwater

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- Irrigation with sw: additional recharge
- Irrigation with gw:
  - Initial decrease of groundwater storage and decrease of baseflow
  - If gw recharge and decrease in baseflow cannot balance water abstraction: gw depletion with continuously dropping water storage and no more baseflow

Impact of human water use (predominantly irrigation) on baseflow (1980–2009)

Base flow as a fraction of total natural gw recharge

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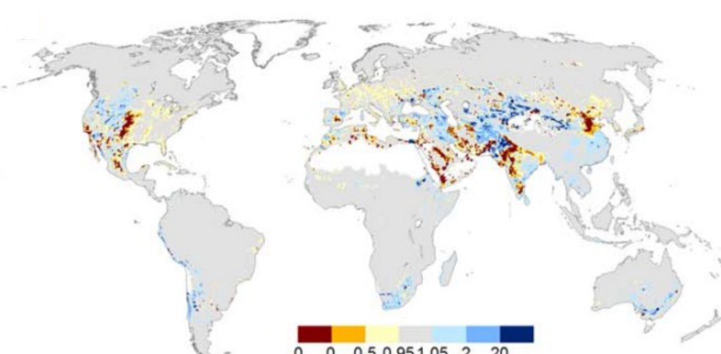

Döll et al. 2014 WRR

Groundwater development stress (1971-2000)

Mean annual net groundwater abstraction divided by mean annual natural groundwater recharge in % per grid cell

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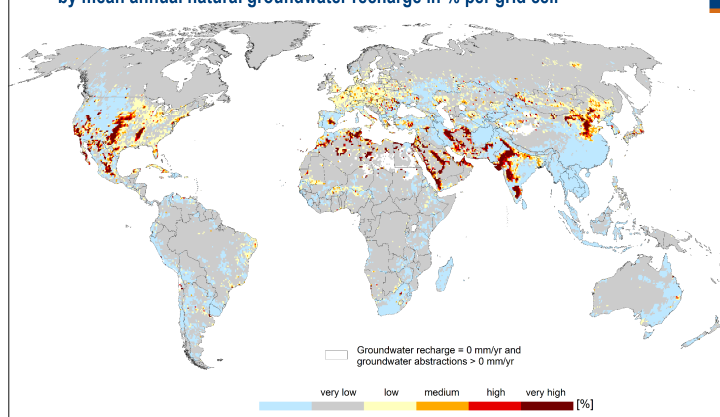
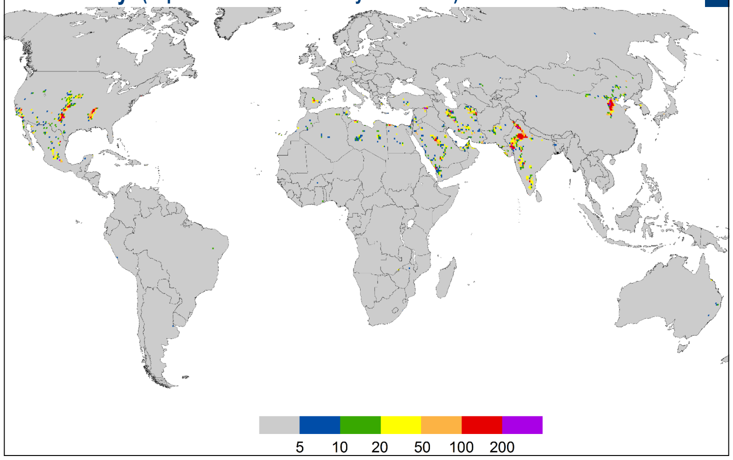


Groundwater depletion by human water use 2000-2009, in mm/yr (impact of climate variability subtracted)



Relevance of groundwater for global food production

- Irrigation (total/with groundwater) accounts for 18%/ 7% of total (blue and green) water use for crop production.
- Reducing food supply chain losses by half and changing to a diet recommended by WHO would reduce both blue and green water requirement by more than 15% (Jalava et al. 2016 Earth's Future)

Conclusions

- Globally, irrigation is the most important gw user (70% of human gw abstractions, 90% gw consumptive use)
- Irrigation with gw leads to baseflow reductions and often gw depletion, exacerbating sea level rise caused by climate change.
- Irrigation with surface water leads to increased gw recharge, gw storage and baseflow *(but often to water pollution by pesticides, nutrients and salts)*
- In a world with free global exchange of food, we could avoid environmentally damaging (gw) irrigation that only contributes to about 20% (7%) of global food production by reducing food losses and changing diets.