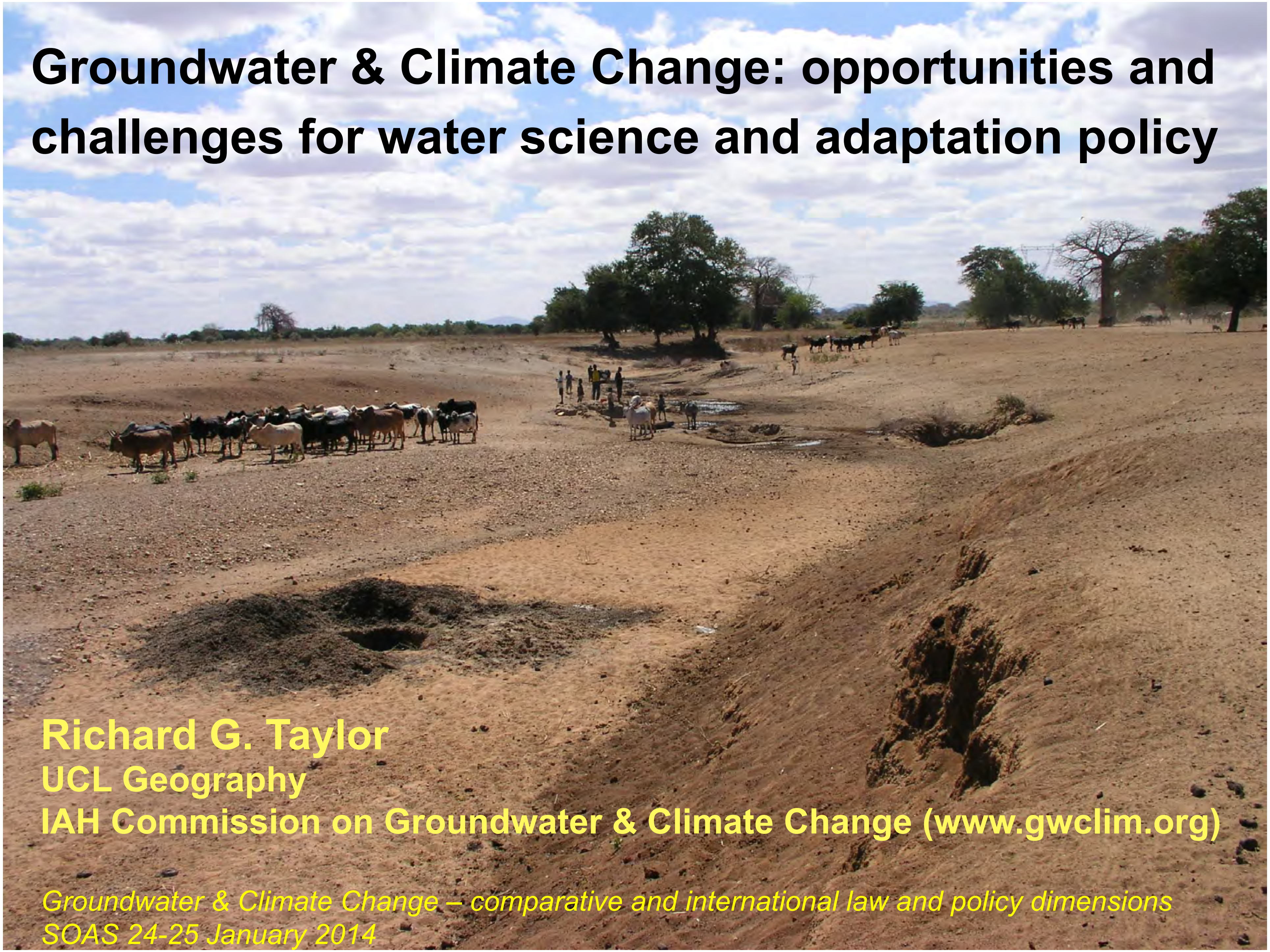
# Groundwater & Climate Change: opportunities and challenges for water science and adaptation policy




**Richard G. Taylor**
**UCL Geography**
**IAH Commission on Groundwater & Climate Change (www.gwclim.org)**


*Groundwater & Climate Change – comparative and international law and policy dimensions*
*SOAS 24-25 January 2014*

# science overview

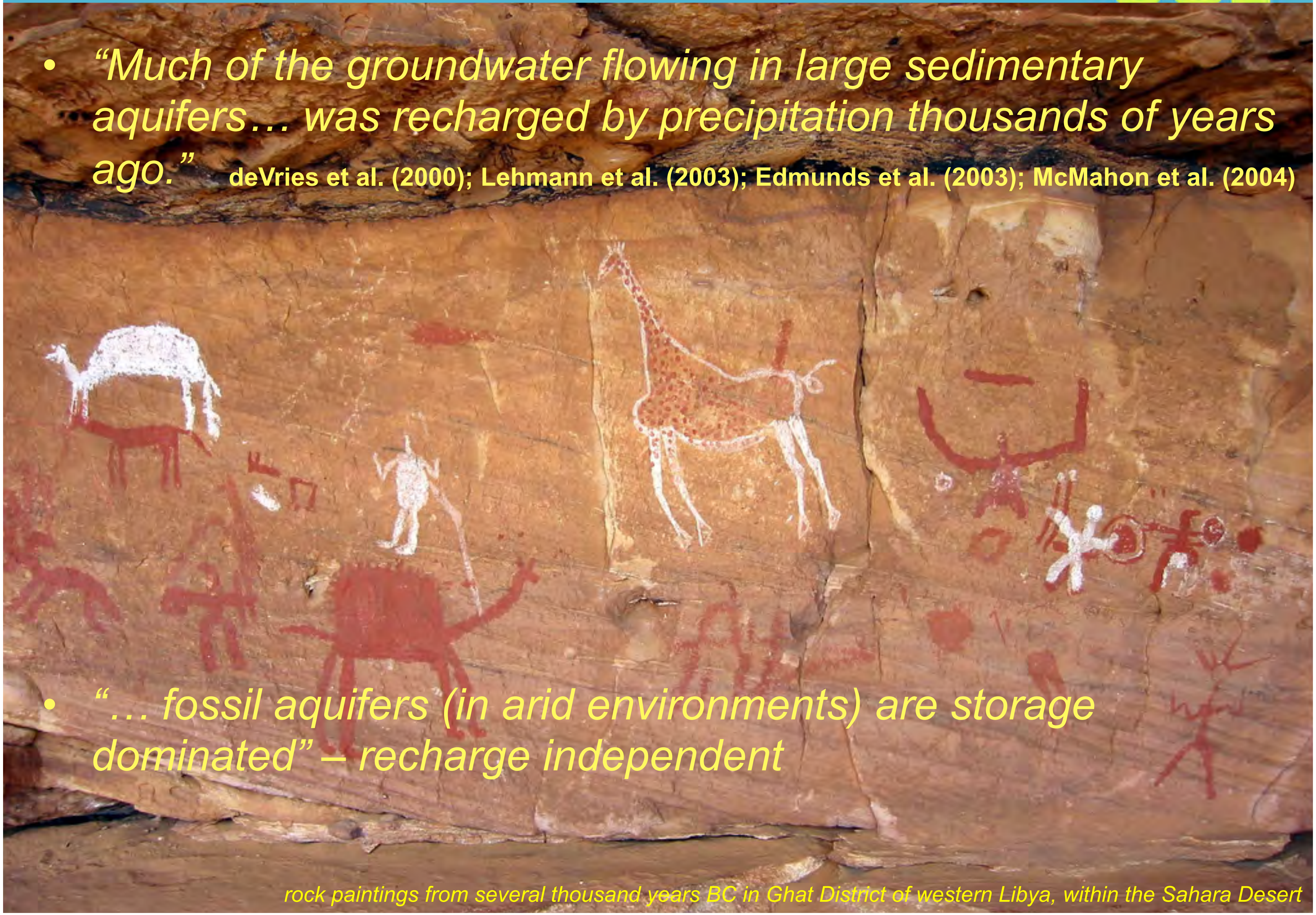
- substantial rise in research on direct and indirect impacts of climate forcing and feedbacks between groundwater and climate

- **uncertainty**
  – not just models but conceptual understanding

- **complexity**
  – diversity of groundwater-climate interactions

- **intractability**
  – indirect (climate change) vs direct human activity

# palaeohydrological evidence



- *"Much of the groundwater flowing in large sedimentary aquifers… was recharged by precipitation thousands of years ago."* **deVries et al. (2000); Lehmann et al. (2003); Edmunds et al. (2003); McMahon et al. (2004)**

- *"… fossil aquifers (in arid environments) are storage dominated" – recharge independent*

*rock paintings from several thousand years BC in Ghat District of western Libya, within the Sahara Desert*

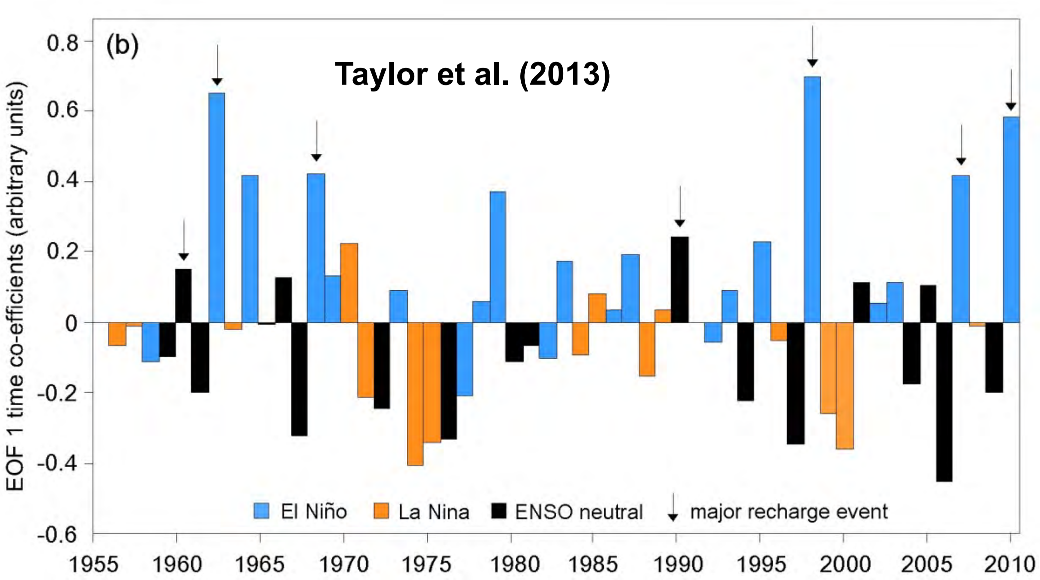
## groundwater storage

- low storage systems (*e.g.* deeply weathered crystalline rock aquifers) are especially *climate dependent* – requiring regular recharge

low-yielding well in Mbarara, Uganda

# direct impacts - precipitation

- historically, timing of recharge related to modes of climate variability historically (e.g. ENSO, PDO)




**Gurdak et al. (2012); Taylor et al. (2013)**

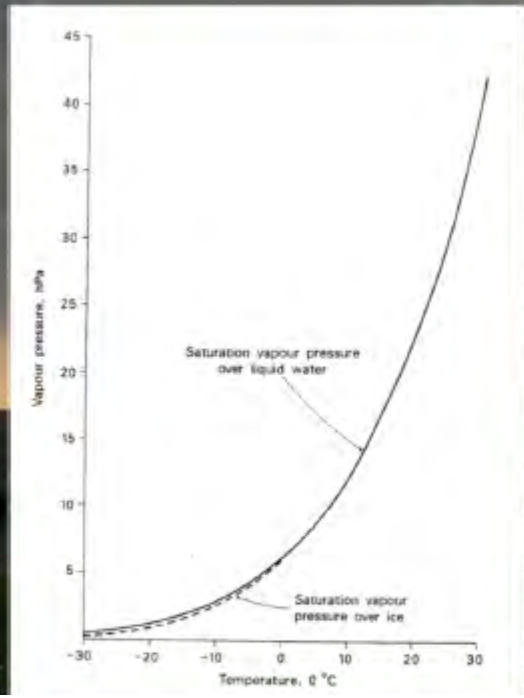
- projections of diffuse recharge are highly uncertain due to choice of GCM, downscaling, emissions, and recharge model **Döll (2009); Allen et al. (2010); Holman et al. (2011); Stoll et al. (2011); Jackson et al. (2011); Crosbie et al. (2012); Hiscock et al. (2012)**

# *intensification of precipitation under climate change*

- **fewer**, low and medium intensity precipitation events
- **more**, very heavy precipitation events (*i.e.*, “extreme events”)

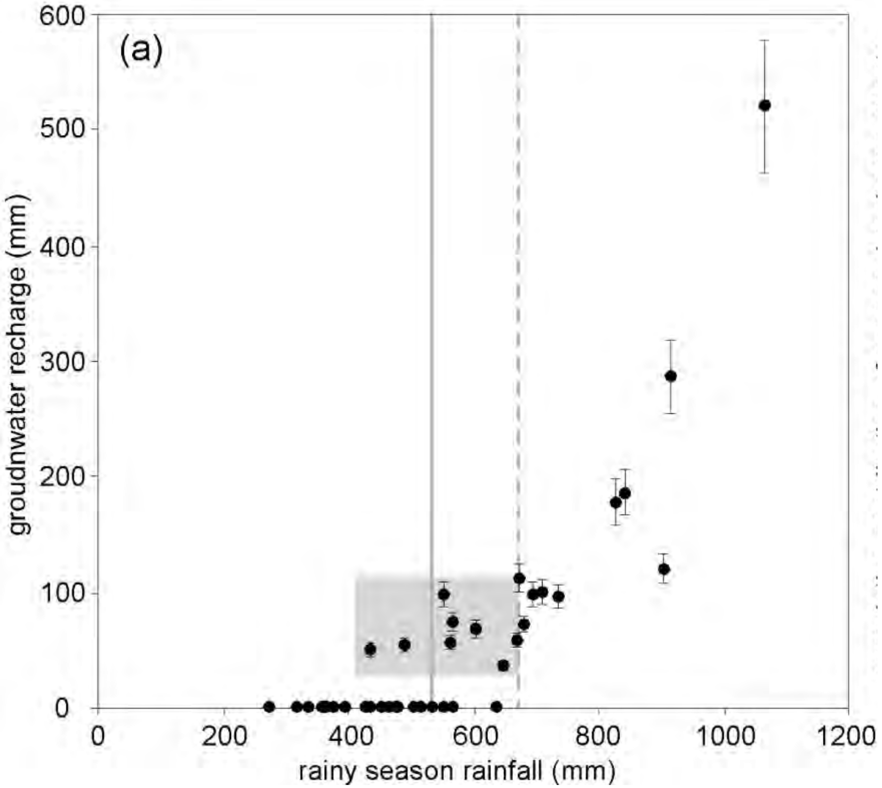
*Allan & Soden, 2008. Science 321: 1481-1484.*

***“It is likely that the frequency of heavy precipitation… will increase in the 21st century over many areas of the globe. This is particularly the case in… tropical regions”*** *IPCC SREX (p. 10, 18 November 2011)*



# recharge and hydrological extremes

- in contrast to models, field observations suggest extreme (heavy) rainfall favours groundwater recharge **Owor et al. (2009); Favreau et al. (2009); Döll (2009); Crosbie et al. (2012); Taylor et al. (2013)**




- more intensive rainfall means longer droughts (more frequent floods) and more variable and lower soil moisture (food security?)

**Taylor et al. (2013)**

- heavy rainfall events have coincided with pathogenic contamination of groundwater & disease outbreaks

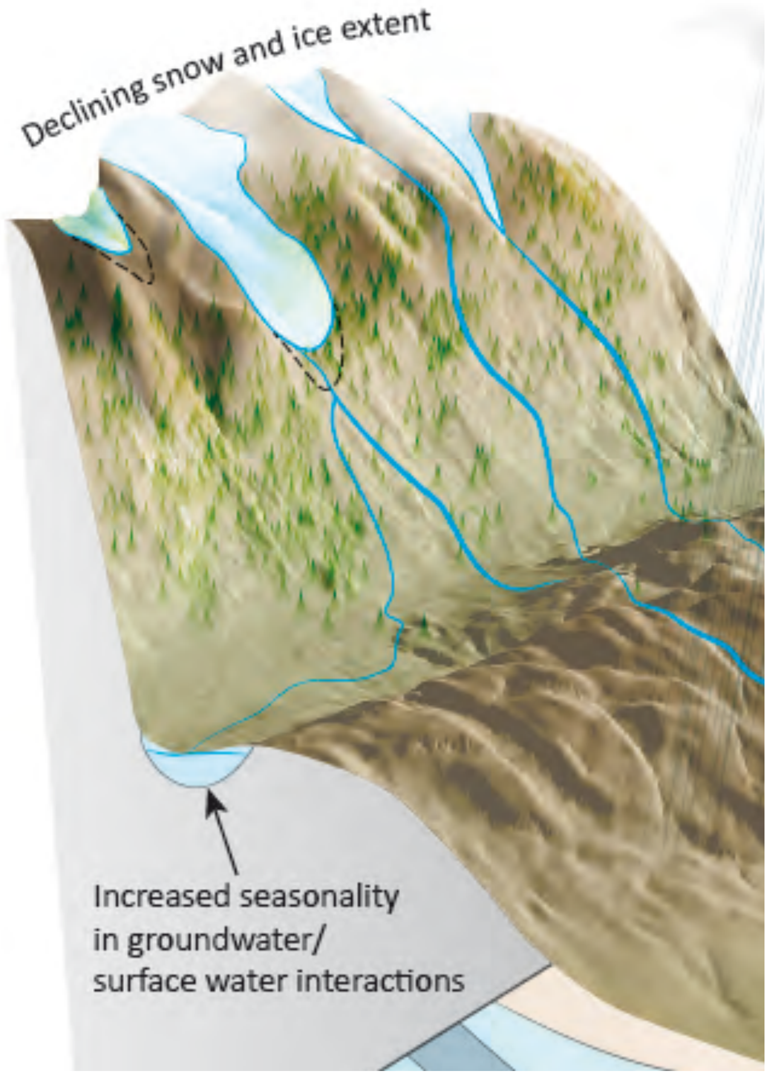
**Taylor et al. (2009)**

*protected spring in Bwaise (Kampala)*

# direct impacts – snow & ice

- “.. *changes in snowmelt regimes tend to reduce the seasonal duration and magnitude of recharge*”

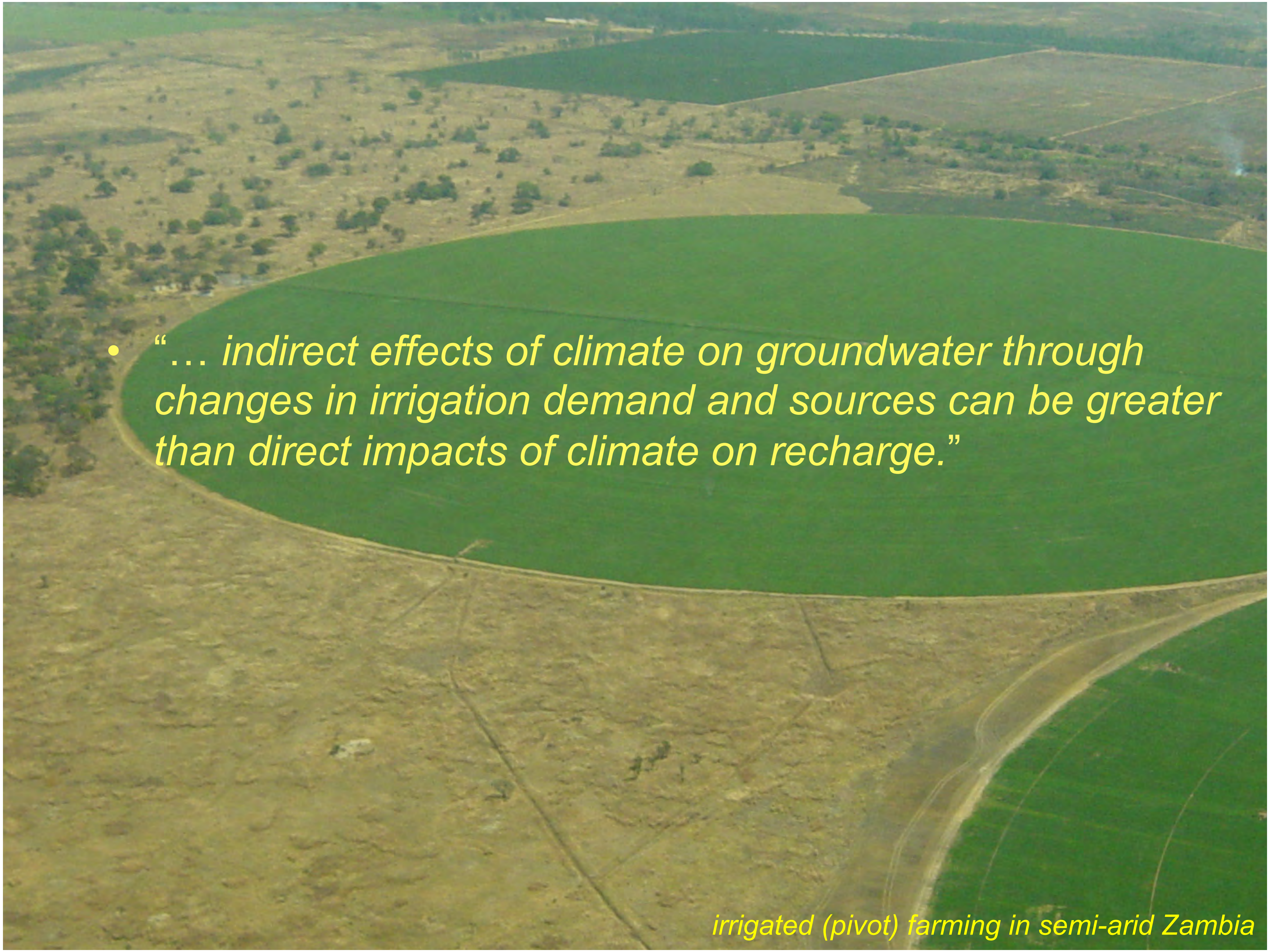
**Tague & Grant (2009); Sultana & Coulibaly (2010) Allen et al. (2010)**



# indirect impacts – land-use change

- *"… Land-Use Change may exert a stronger influence on terrestrial hydrology than climate change."* **Scanlon et al. (2006); Leblanc et al. (2008)**

- "… *recharge rates under cropland increased by one to two orders of magnitude compared with native perennial vegetation.*" **Cartwright et al. (2007); Scanlon et al. (2010); Leblanc et al. (2012)**



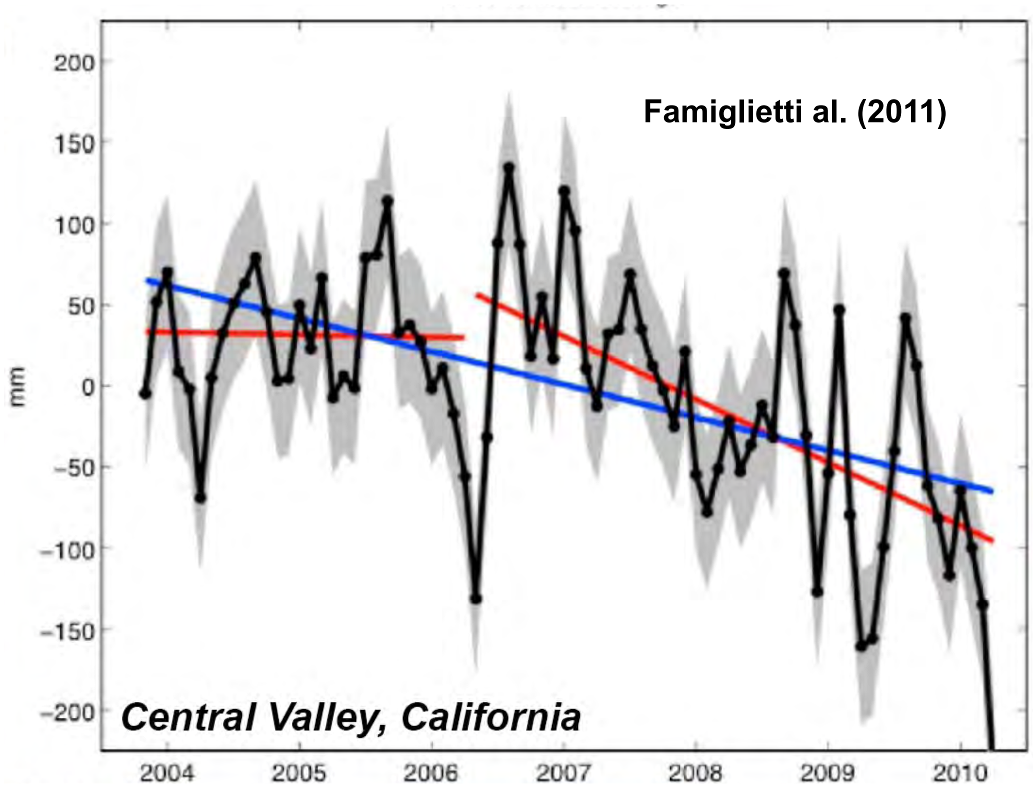
- *"… indirect effects of climate on groundwater through changes in irrigation demand and sources can be greater than direct impacts of climate on recharge."*

*irrigated (pivot) farming in semi-arid Zambia*


*irrigated (pivot) farming in semi-arid Zambia*

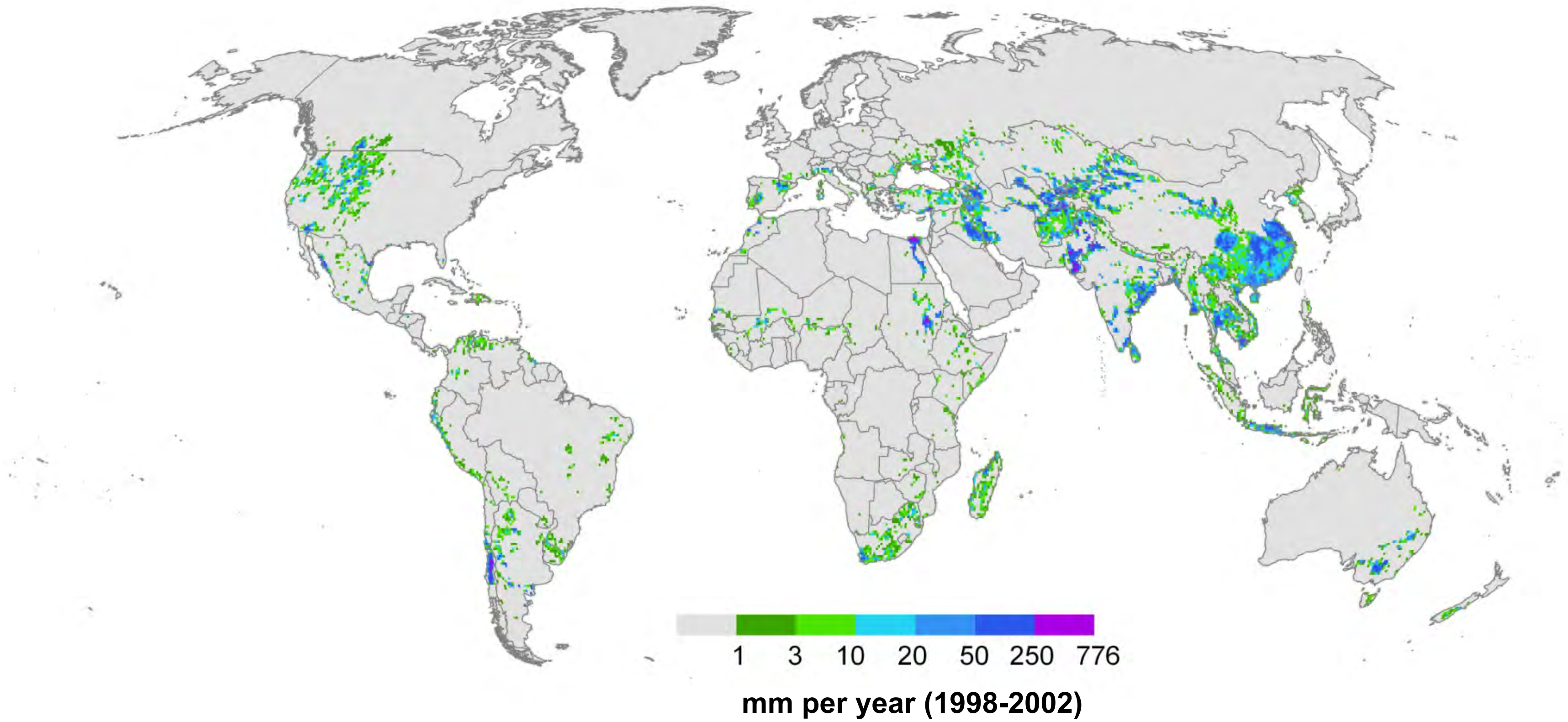
# groundwater depletion

- groundwater depletion detected from *in situ* and satellite data in California Central Valley, North China Plain, High Plains Aquifer, NW India and Bangladesh **Rodell et al. (2009); Chen et al. (2010); Longuevergne et al. (2010); Famiglietti et al. (2011); Scanlon et al. (2012); Shamsudduha et al. (2012)**



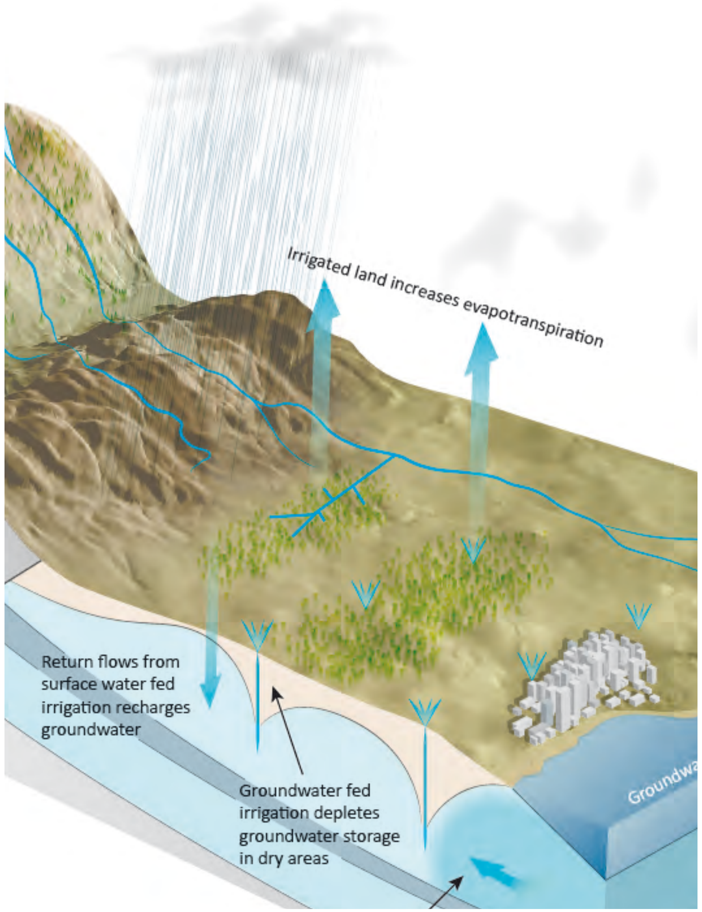
# groundwater accumulation

- irrigation return flows from surface-water fed irrigation provide "anthropogenic recharge" to: Nile Basin, Tigris-Euphrates, lower Indus, and SE China **Döll et al. (2012)**



# groundwater feedbacks to climate

- "… *groundwater primarily influences climate through contributions to soil moisture. Irrigation can transform areas from moisture-limited to energy-limited evapotranspiration thereby influencing water and energy budgets.*"

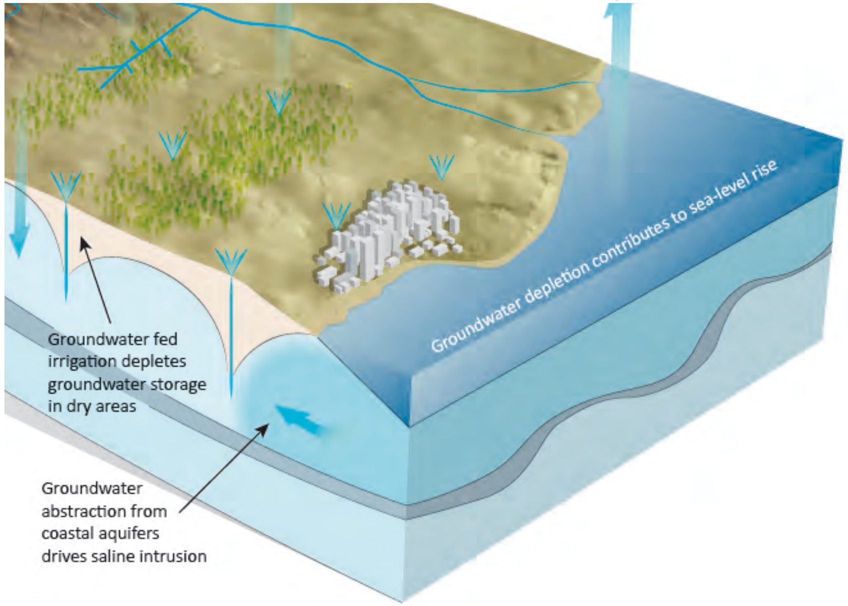



- increases downwind precipitation

**Douglas et al. (2009); DeAngelis et al. (2010); Kustu et al. (2011); Lo & Famiglietti (in review)**

# groundwater & sea-level rise (SLR)

- "*The impacts of seawater intrusion have been observed most prominently in association with intensive groundwater abstraction around high population densities*" **Taniguchi (2011)**




- "*Coastal aquifers under very low hydraulic gradients such as the Asian mega-deltas are theoretically sensitive to SLR but, in practice, are expected in coming decades to be more severely impacted by saltwater inundation from storm surges than SLR.*" **Ferguson & Gleeson (2012)**

# groundwater depletion & SLR

- *“Groundwater depletion contributes to SLR through a net transfer of freshwater from long-term terrestrial groundwater storage to active circulation near the earth’s surface and its eventual transfer to oceanic stores.”*

- 204 ± 30 $km^3$/year (0.57 ± 0.09 mm/year) flux-based method

**Wada et al. (2012)**

- 145 ± 39 $km^3$/year (0.4 ± 0.1 mm/year) volume-based method

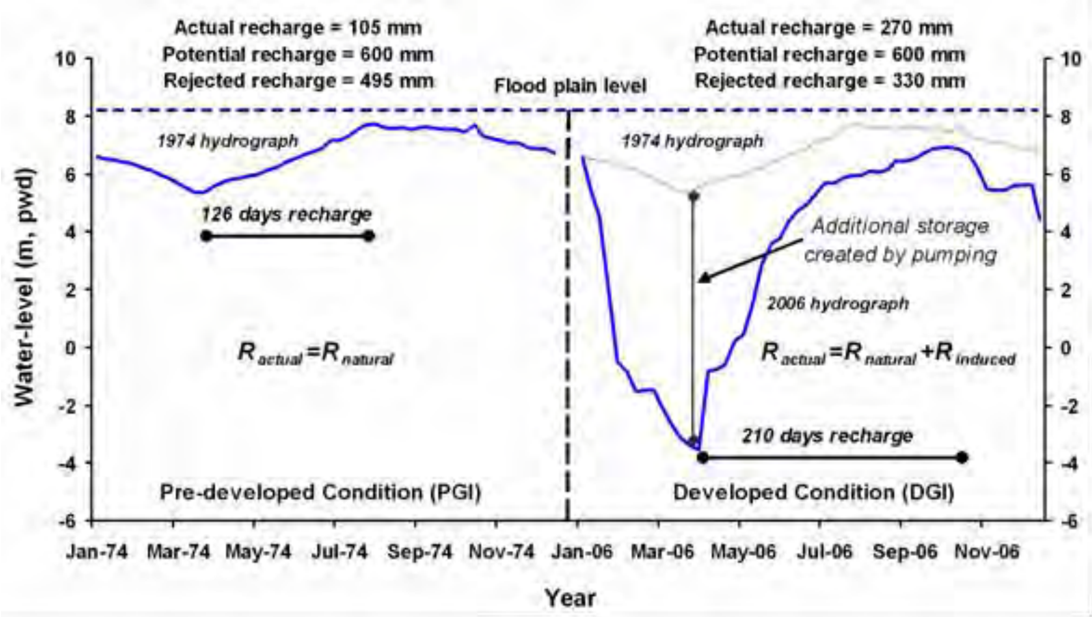
**Konikow (2011)**

# legal and policy questions/challenges

- Groundwater represents an invaluable distributed store of freshwater to enable adaptation to climate variability and change… but for whom?

- Substantial uncertainty in predictive models – how to assess impact or assign responsibility?

- How to untangle direct impacts of human activity (over-abstraction, land-use change) from indirect (climate change) impacts on groundwater?




- increased dry-season groundwater abstraction induces greater recharge during the monsoon

*groundwater-fed irrigation of Boro rice (Bangladesh)*