Global water cycle diagrams minimize human influence and over-represent water security

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Global water crisis

A large portion of the world’s population and ecosystems are threatened by human interference with the water cycle

- Human water use
  - Blue (withdrawals) 4,500 km$^3$ yr$^{-1}$
  - Green (crop use of soil moisture) 20,000 km$^3$ yr$^{-1}$
  - Grey (water needed to dilute pollution) 1,400 km$^3$ yr$^{-1}$
    - Heathwaite 2010; Hoekstra and Mekonnen, 2012

- Land-use change
  - Affected ¾ of ice-free land surface
  - Regional to continental effects on water cycle

- Climate change
  - Regional to global effects on water cycle
What hypotheses are implicit in our drawings of the water cycle?

P1. Depictions differ by discipline and audience

Falkenmark et al. 2003

P1. Depictions become more accurate and holistic through time

Oki and Kanae, 2006
Collection and analysis of diagrams

- 464 diagrams
- Classified by author and audience types
- Noted water use, land-use, and climate change
- Detailed extraction of 49 characteristics for 114 diagrams
  - Number and magnitude of pools and fluxes
  - Conservation of mass
  - Representation of ocean
Diagram format and general characteristics

- 4 formats
- Many similarities
  - 70% of diagrams flow from left to right
  - Copied elements
- 95% of diagrams show a single catchment
- 16 unique pools (mean = 6.4 ± 2.1)
- 26 unique fluxes (mean = 9.6 ± 3.2)
Representation of water pools

Pool size

- Ocean
- Ice caps and glaciers
- Saline groundwater
- Fresh groundwater
- Permafrost
- Fresh lakes
- Saline lakes
- Wetlands
- Soil water
- Ocean clouds
- Reservoirs
- Land clouds
- Rivers
- Intermittent rivers
- Biomass

Audience
- Public
  - n=39
- Scientific
  - n=66

Time period
- Pre 2006
  - n=52
- Post 2005
  - n=53

Percentage of diagrams depicting pool
Disciplinary differences

![Graph showing disciplinary differences in various parameters such as horizontal space occupied by ocean, precipitation over land, evapotranspiration from land, and evapotranspiration to precipitation ratio.]
### Depiction of human activity

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• Minimization of human influence
  • Omission of climate change and pollution
  • Complete exclusion of humans

• Overrepresentation of water availability
  • Accessible/inaccessible water
  • Saline/fresh groundwater and lakes

• Little sense of teleconnections
  • Inter-basin water movement
  • Ocean is an afterthought
    • Ocean currents
    • Ocean precipitation

Landscapes with abundant water, devoid of humans
Why do problems persist and do they matter?

- Not the first to bring up most of these issues
  - (Lvovitch, 1973; Linton, 2008; Schmidt, 2014)
- Author and reader preferences
  - Natural landscapes are prettier
- Change the format
  - Be quantitative
    - Actual numbers or a representation of proportions
  - Multiple catchments
    - Many small cycles
  - Integrate a temporal dimension
  - Make diagrams interactive
Major Pools in the Global Hydrological Cycle

Expressed in $10^3$ km$^3$

- Atmosphere over Land: $3.0 \pm 10\%$
- Snowpack (annual max.): $2.7 \pm 20\%$
- Ice Sheets and Glaciers: $26,000 \pm 10\%$
- Atmosphere over Ocean: $10 \pm 20\%$
- Reservoirs: $11 \pm 40\%$
- Permafrost: $210 \pm 100\%$
- Fresh Lakes: $110 \pm 20\%$
- Wetlands: $14 \pm 20\%$
- Surface Ocean: $130,000 \pm 30\%$
- Old Groundwater (mostly saline): $22,000 \pm 80\%$
- Modern Groundwater: $630 \pm 70\%$
- Biological Water: $0.94 \pm 30\%$
- Soil Moisture: $54 \pm 90\%$
Major Fluxes in the Global Hydrological Cycle

Human water appropriation is separated into green, blue, and grey water use. Expressed in $10^3$ km$^3$ yr$^{-1}$. 

- **Total Human Water Appropriation (Green + Blue + Gray)**: $24 \pm 20\%$
- **Ocean Precipitation**: $380 \pm 20\%$
- **Ocean Evaporation**: $420 \pm 20\%$
- **Interbasin Ocean Circulation**: $5,000 \pm 20\%$
- **Land Ice Discharge**: $3.1 \pm 40\%$
- **Land Evapotranspiration**: $69 \pm 10\%$
- **Land Precipitation**: $110 \pm 10\%$
- **Green Water Use**: $19 \pm 20\%$
- **Blue Water Use**: $4.0 \pm 30\%$
- **Endorheic Discharge**: $0.8 \pm 30\%$
- **Groundwater recharge**: $13 \pm 50\%$
- **Groundwater Discharge to Ocean**: $4.5 \pm 70\%$
- **Gray Water Use (pollution)**: $1.4 \pm 40\%$
- **River Discharge to Ocean**: $46 \pm 10\%$
- **Ocean to Land Atmospheric Flux**: $46 \pm 20\%$
- **Vertical Ocean Circulation**: $2,400 \pm 30\%$
Some Consequences of Human Interference with the Water Cycle

Consequences are colored by primary cause: human changes in **climate**, **land cover**, or **water use**.
Madeline Buhman
Undergraduate Seeking PhD program for Fall 2019
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