The Water Cycle

CTB3300WCx: Introduction to Water and Climate

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What is hydrology?

*"The science of the **origin**, **occurrence** and **behaviour** of **water** in all its forms, on, above and under the Earth's surface"*

OR

*"The science of the **origin** and **fate** of **water**"*


Hydrology is beautiful!

The grand questions

- Origin of water
- Water availability
- Water threats
- Maintaining a healthy aquatic environment
- Effect of climatic change on hydrology
- Influence of human interventions on hydrology
- When to expect floods

The origin of water in our environment

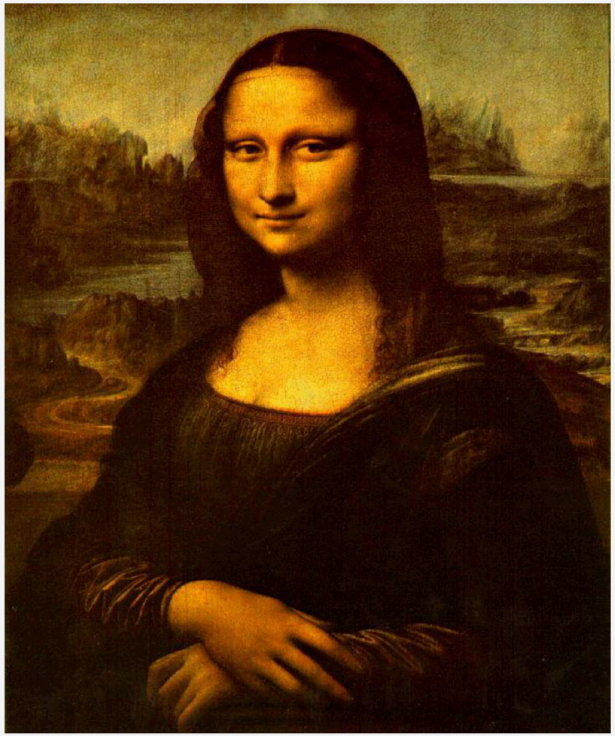
Plato *(427-348 BC) &* ***Aristoteles*** *(350 BC)*

- The rain feeds rivers and groundwater

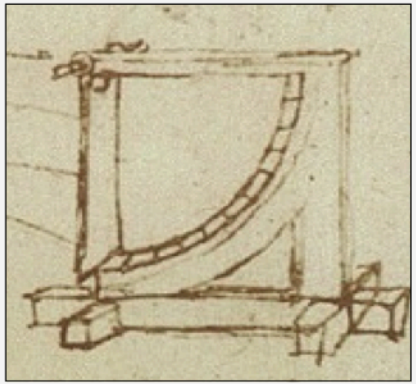
Leonardo da Vinci *(1452-1519)*

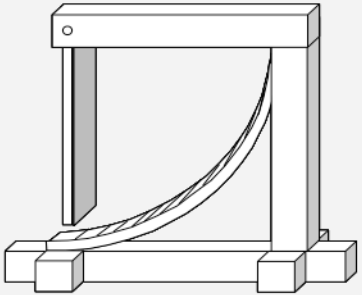
- Water cycles, but originates from underground feeding from the ocean

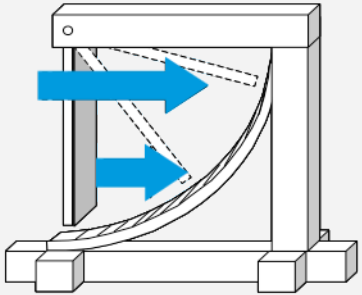
Leonardo da Vinci, a GREAT hydrologist

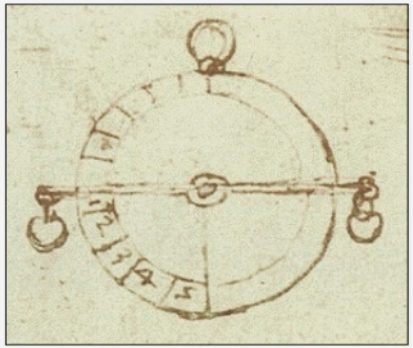


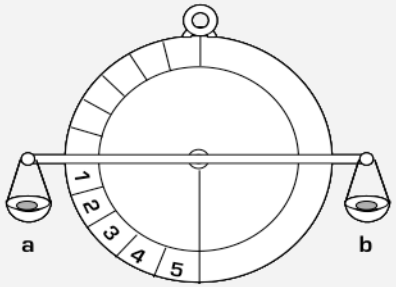
Meteorological instruments designed by Leonardo da Vinci

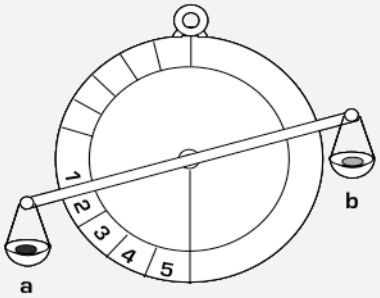




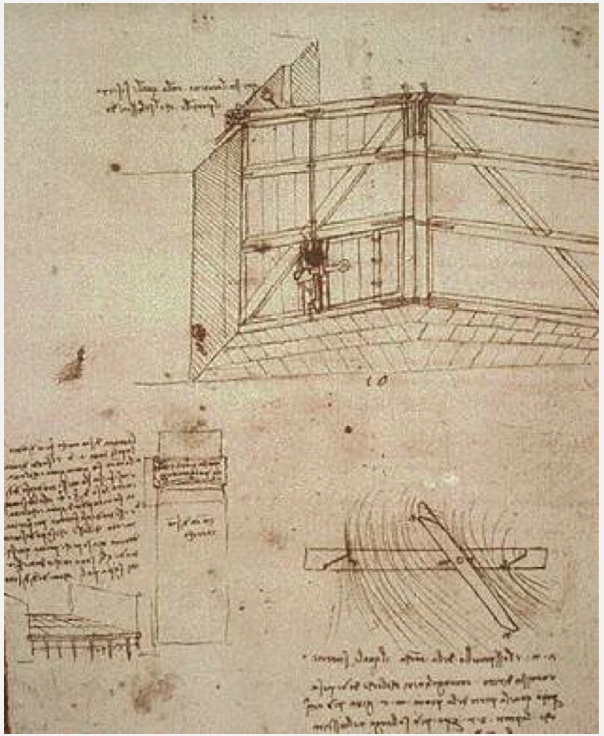


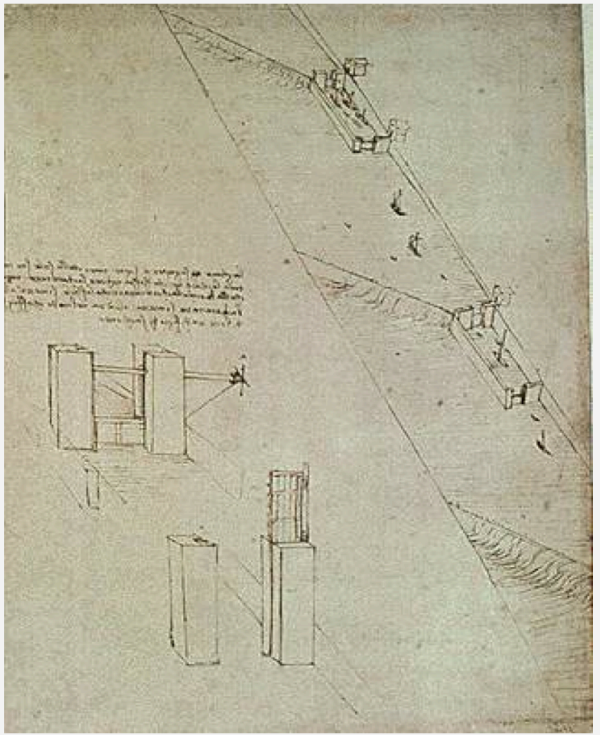




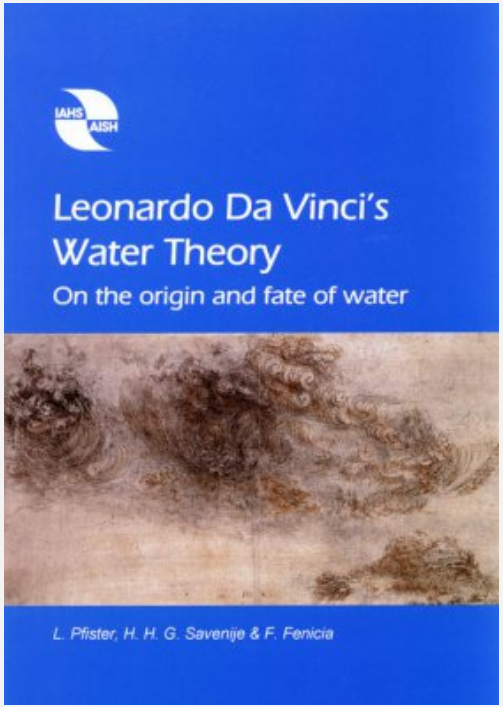


Sluice gate design by Leonardo da Vinci





Further reading



Leonardo da Vinci's Water Theory

On the origin and fate of water

by Laurent Pfister, Hubert Savenije and Fabrizio Fenicia

available at www.IAHS.info

The origin of water in our environment

Perrault *(1608-1680)*

- Rainfall is sufficient to feed river discharge (Seine)

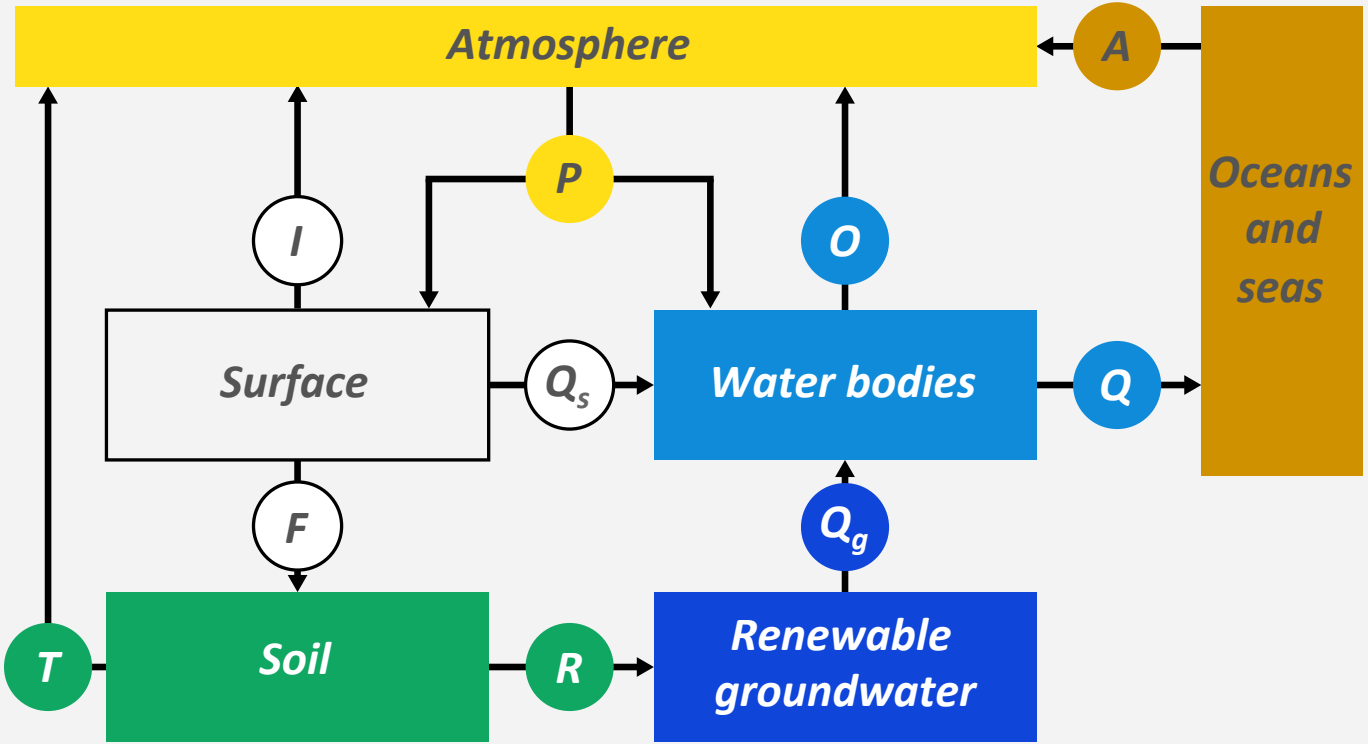
Edmund Halley *(1656-1742)*

- Condensation in caves makes a substantial contribution

John Dalton *(1760-1844)*

- Closed the water balance of England and Wales

Global water resources



Where is the world's water located?

Water occurrence	Volume (10^{12} m^3)	% of water	% of fresh water
World oceans	1.300.000	97	-
Salt lakes / seas	100	0,008	-
Polar ice	28.500	2,14	77,6
Atmospheric water	12	0,001	0,035
Water in organisms	1	0,000	0,003
Fresh lakes	123	0,009	0,335
Water courses	1	0,000	0,003
Unsaturated zone	65	0,005	0,18
Saturated zone	8000	0,60	21,8
Total fresh water	36.700	2,77	100
Total water	1.337.000	100	-

Where is fresh water located?

- Water bodies (light blue)
- Ground water (deep blue)
- Soil (green) (coined by Malin Falkenmark)

see e.g.: http://www.hydrol-earth-syst-sci.net/9/15/2005/hess-9-15-2005.html

- Direct evaporation (white water)

Global water resources

Resource	Flux	[L / T]	Stock	[L]	Residence time	[T]
Soil	T	210 mm/a	S_u	100 mm	S_u / T	6 months
Surface	I	200 mm/a	S_s	1 mm	S_s / I	2 days
Water bodies	Q	310 mm/a	S_w	830 mm	S_w / Q	2,7 years
Renewable groundwater	Q_g	30 mm/a	S_g	5000 mm	S_g / Q_g	160 years
Atmosphere	P	720 mm/a	S_a	20 mm	S_a / P	0,3 months
Oceans and seas	A	130 mm/a	S_o	3600 m	S_o / A	28.000 years

See e.g.: Savenije, H.H.G., “Water Scarcity Indicators; the Deception of the Numbers”, *Physics and Chemistry of the Earth(B)*, Vol.25, No. 3, pp 199-204, 2000.
(http://www.sciencedirect.com/science/article/pii/S1464190900000046)

Water balance

$$\frac{\mathrm{d}S}{\mathrm{d}t} = I - O$$

The residence time

Average residence time *or*
Process time scale (T_R)

$$= \frac{\text{Stock (S)}}{\text{Flux (O)}}$$

Global water resources

Resource	Flux	[L / T]	Storage	[L]	Residence time	[T]
Soil	T	210 mm/a	S_u	100 mm	S_u / T	6 months
Surface	I	200 mm/a	S_s	1 mm	S_s / I	2 days
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Annual average precipitation and evaporation

410 mm/a

720 mm/a

1250 mm/a

1120 mm/a

310 mm/a over land

130 mm/a over sea

$46*10^{12}$ m^3/a

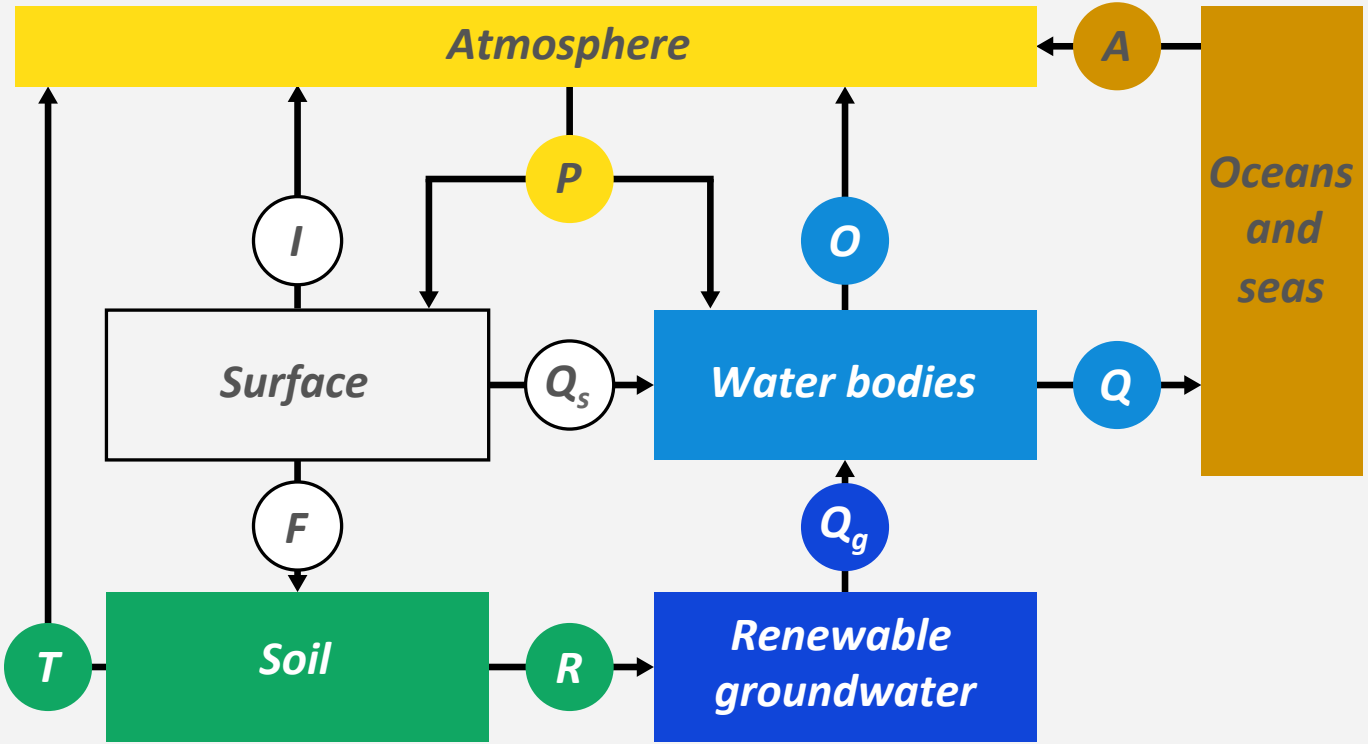
30% of Earth's surface

$149*10^{12}$ m^2

70% of Earth's surface

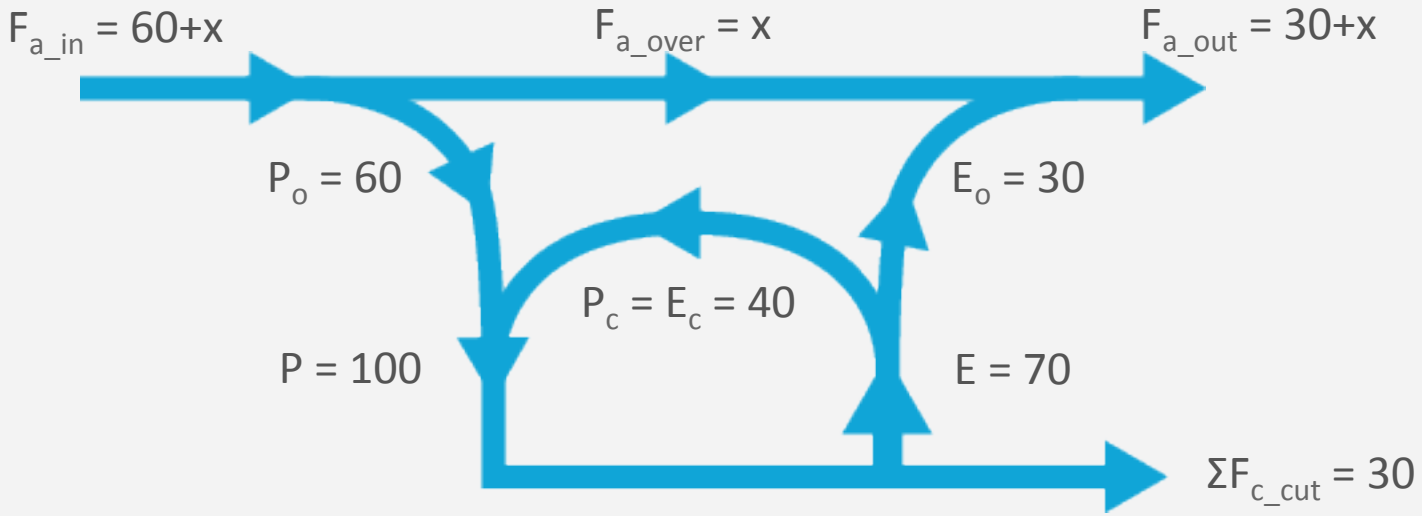
$361*10^{12}$ m^2

Global water resources



Does all precipitation come from the ocean?

- How important is terrestrial evaporation?
- Is moisture recycled? And if so, how much?



Water resources research

WATER RESOURCES RESEARCH, VOL. 46, W09525, doi:10.1029/2010WR009127, 2010

Origin and fate of atmospheric moisture over continents

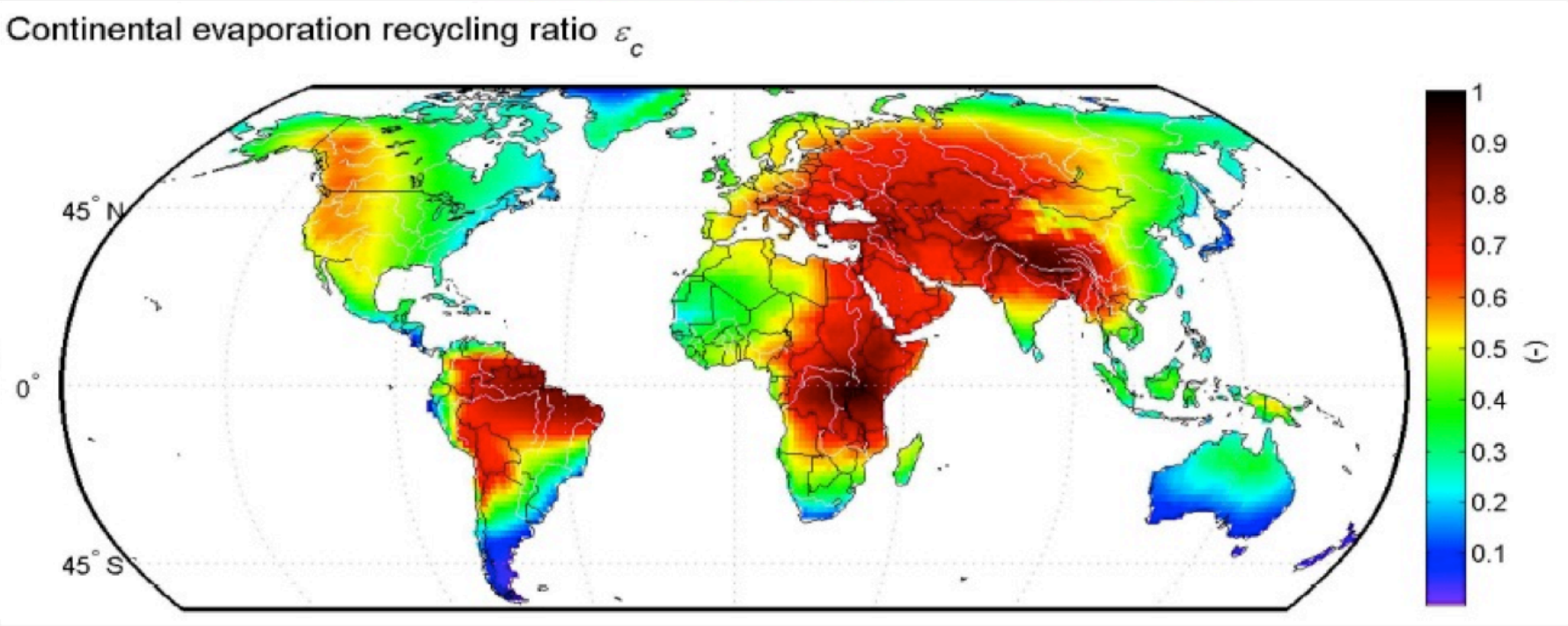
Rudi J. van der Ent,[1] Hubert H. G. Savenije,[1] Bettina Schaefli,[1]
and Susan C. Steele-Dunne[1]

Received 19 January 2010; revised 6 April 2010; accepted 24 May 2010; published 22 September 2010.

[1] There has been a long debate on the extent to which precipitation relies on terrestrial evaporation (moisture recycling). In the past, most research focused on moisture recycling within a certain region only. This study makes use of new definitions of moisture recycling to study the complete process of continental moisture feedback. Global maps are presented identifying regions that rely heavily on recycled moisture as well as those that are supplying the moisture. An accounting procedure based on ERA-Interim reanalysis data is used to calculate moisture recycling ratios. It is computed that, on average, 40% of the terrestrial precipitation originates from land evaporation and that 57% of all terrestrial evaporation returns as precipitation over land. Moisture evaporating from the Eurasian continent is responsible for 80% of China's water resources. In South America, the Río de la Plata basin depends on evaporation from the Amazon forest for 70% of its water resources. The main source of rainfall in the Congo basin is moisture evaporated over East Africa, particularly the Great Lakes region. The Congo basin in its turn is a major source of moisture for rainfall in the Sahel. Furthermore, it is demonstrated that due to the local orography, local moisture recycling is a key process near the Andes and the Tibetan Plateau. Overall, this paper demonstrates the important role of global wind patterns, topography and land cover in continental moisture recycling patterns and the distribution of global water resources.

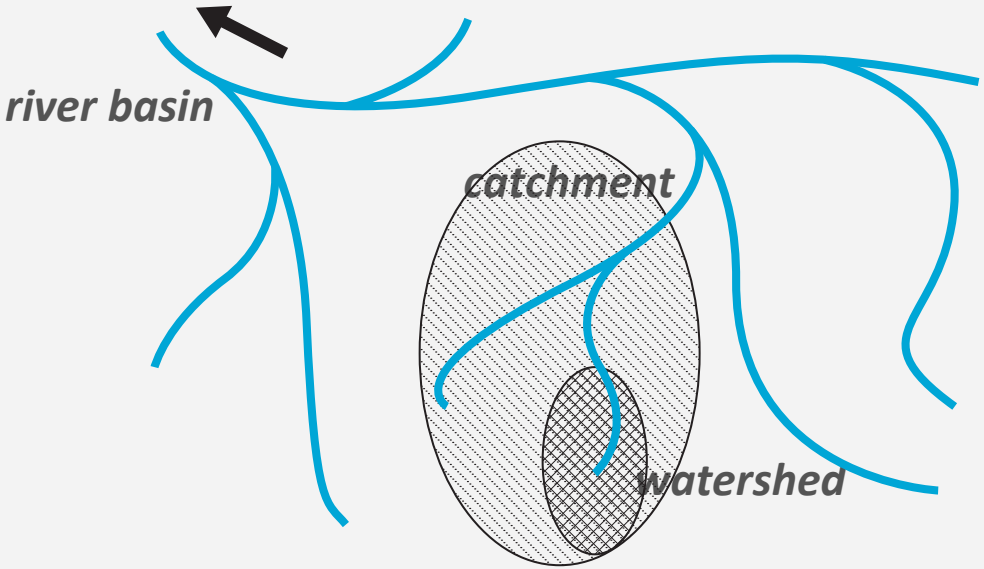
Citation: van der Ent, R. J., H. H. G. Savenije, B. Schaefli, and S. C. Steele-Dunne (2010), Origin and fate of atmospheric moisture over continents, *Water Resour. Res.*, *46*, W09525, doi:10.1029/2010WR009127.

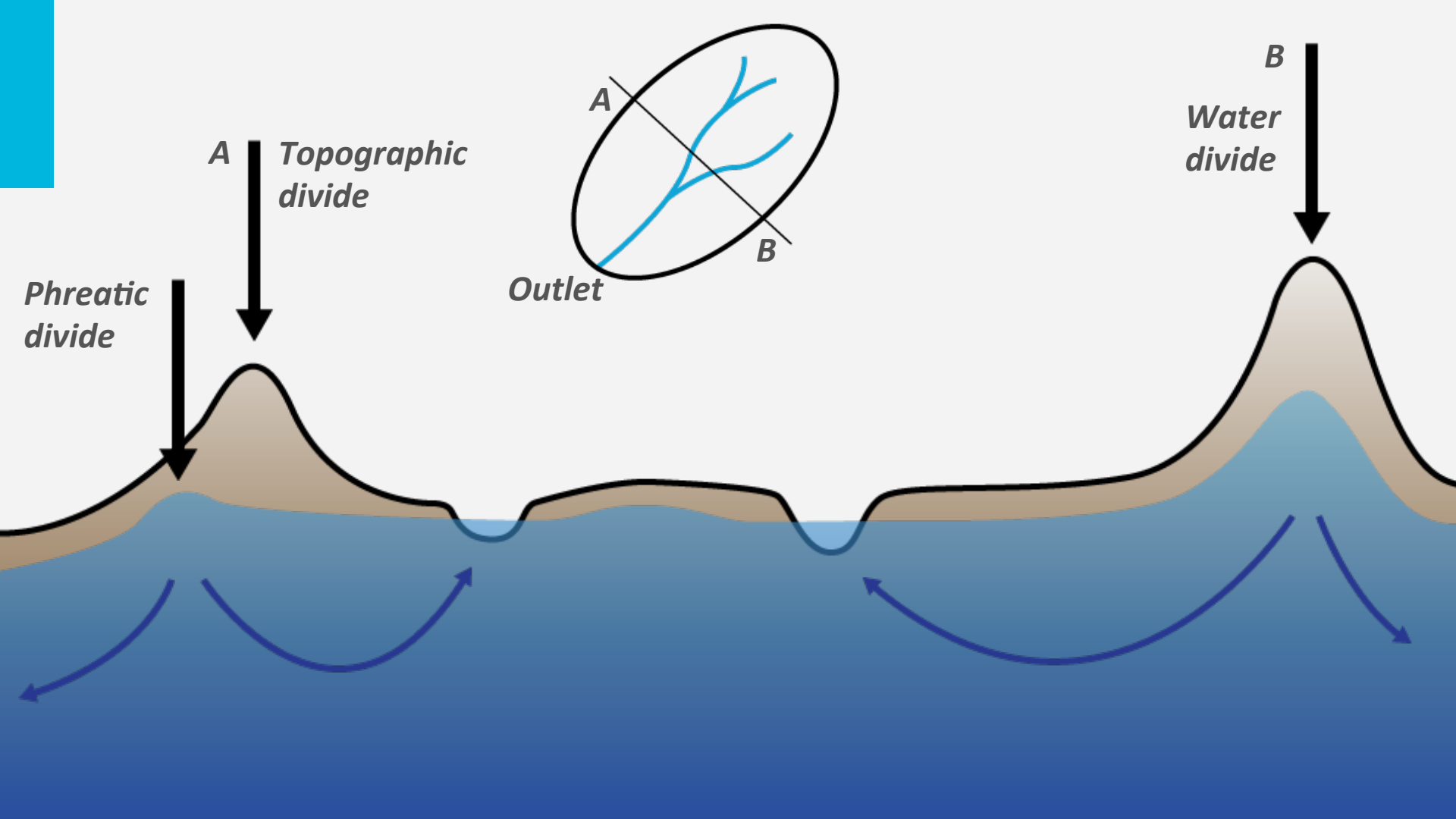
Global effects



Water balance of a drainage basin

$$\frac{\mathrm{d}S}{\mathrm{d}t} = (P - E)A - Q$$




A
Topographic divide
Phreatic divide
A
B
Outlet
B
Water divide

River	Area	Precipitation		Evaporation		Runoff		C_R
	10^9 m^2	mm/a	10^9 m^3/a	mm/a	10^9 m^3/a	mm/a	10^9 m^3/a	%
Nile	2803	220	620	190	534	30	86	14
Mississippi	3924	800	3100	654	2540	142	558	18
Parana	975	1000	980	625	610	382	372	38
Orinoco	850	1330	1150	420	355	935	795	70
Mekong	646	1500	970	1000	645	382	325	34
Amur	1730	450	780	265	455	188	325	42
Lena	2430	350	850	140	335	212	514	60
Yenisei	2440	450	1100	220	540	230	561	51
Ob	2950	450	1350	325	965	131	385	29
Rhine	200	850	170	500	100	350	70	41
Zambezi	1300	990	1287	903	1173	87	114	12

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Falkenmark M., and M. Lannerstad, Consumptive water use to feed humanity - curing a blind spot, *Hydrol. Earth Syst. Sci.*, 9, 15-28, 2005.
http://www.hydrol-earth-syst-sci.net/9/15/2005/hess-9-15-2005.html