DataFrame Operations in Pandas

```
+------------+---------+--------+
|            |  A      |  B     |
+------------+---------+---------
|      0     | 0.626386| 1.52325|----axis=1----->
+------------+---------+--------+
             |         |
             | axis=0  |
             ↓         ↓
```

ENVIRONMENTAL DATA SCIENCE

PRINCIPLES OF MASS BALANCE: HYDROLOGY & WATER RESOURCES

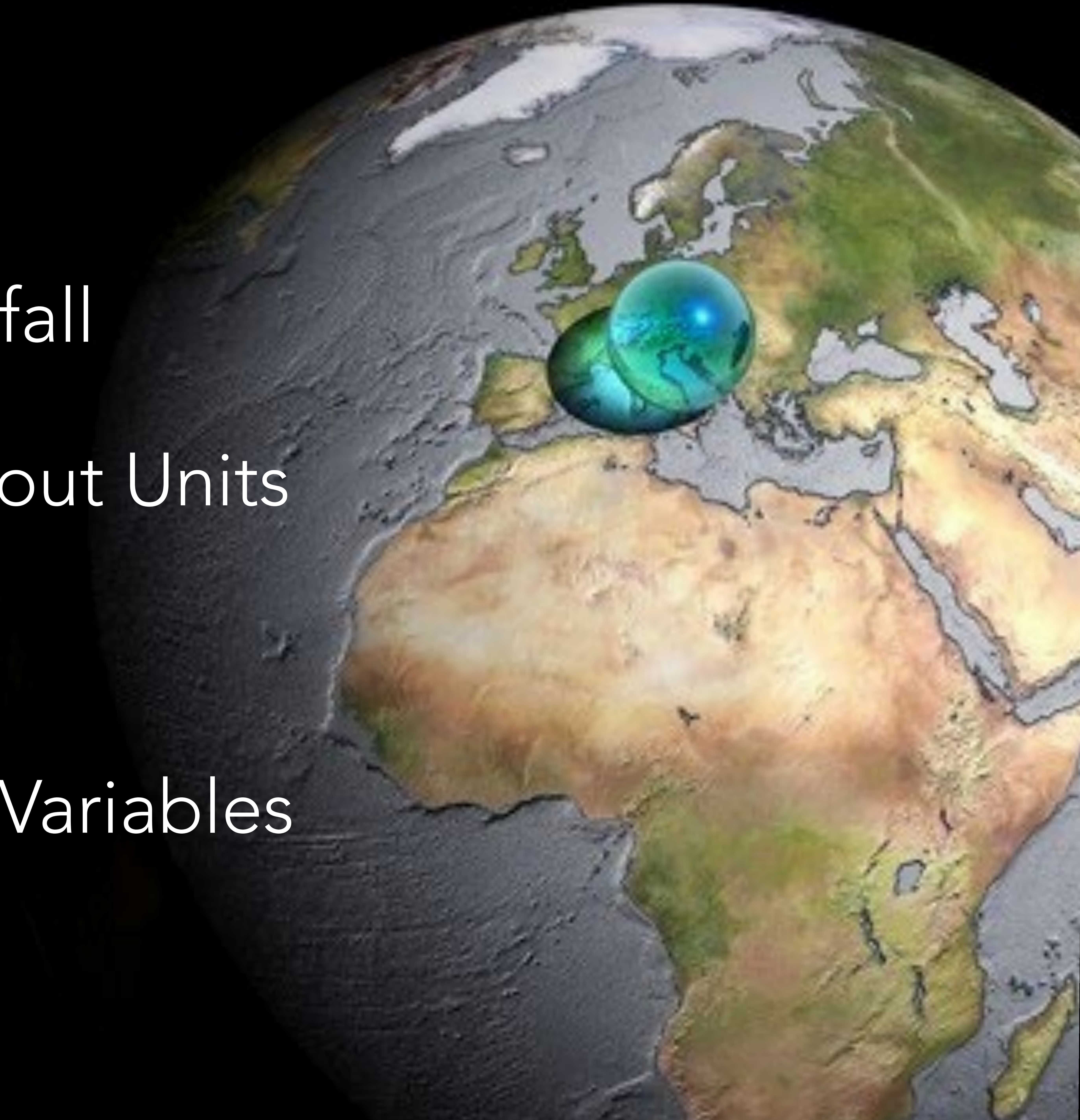
TOPICS

1. Global Patterns of Rainfall

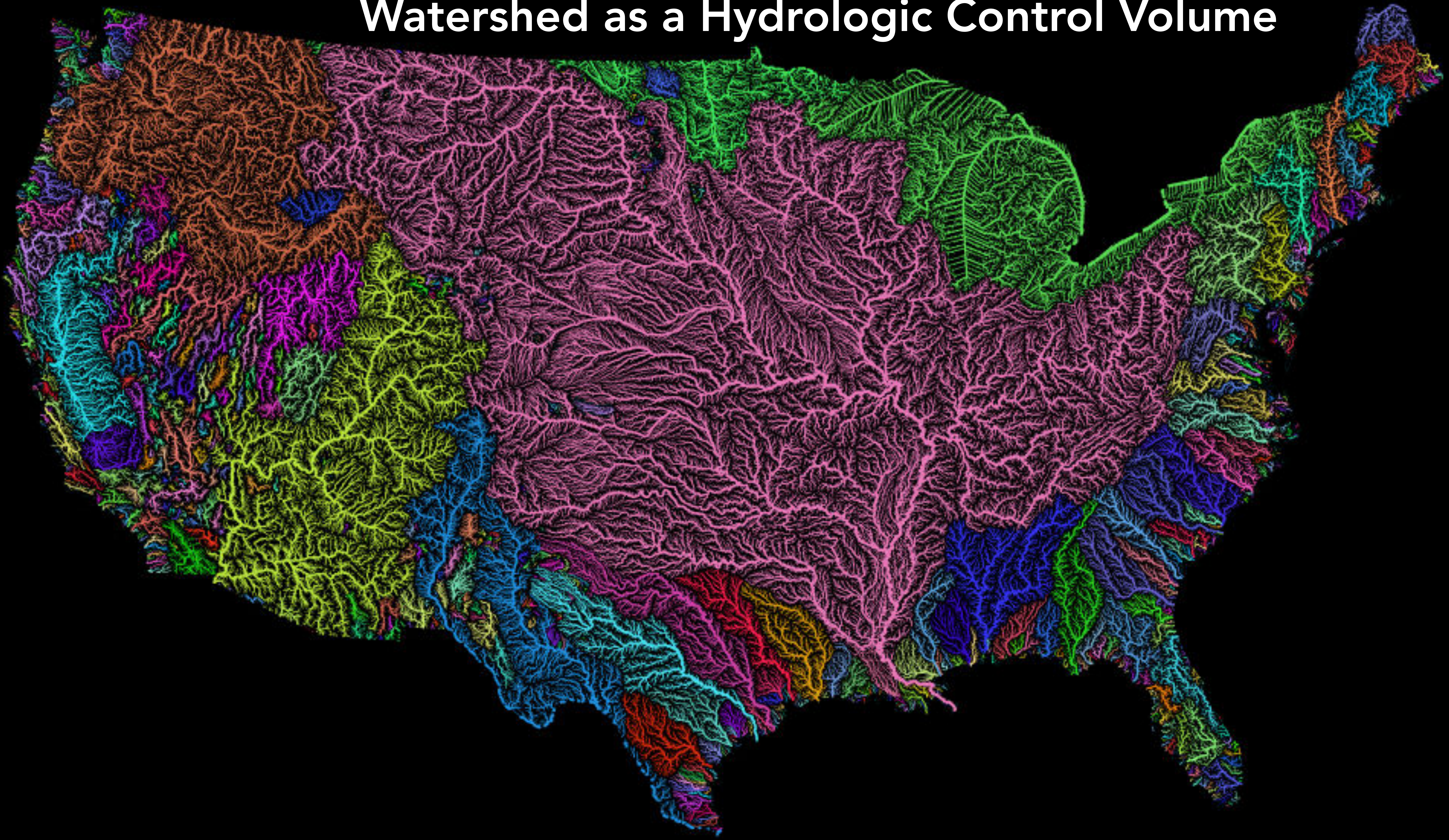
   Some Shenanigans About Units

   Flows and Fluxes

   Extensive vs. Intensive Variables



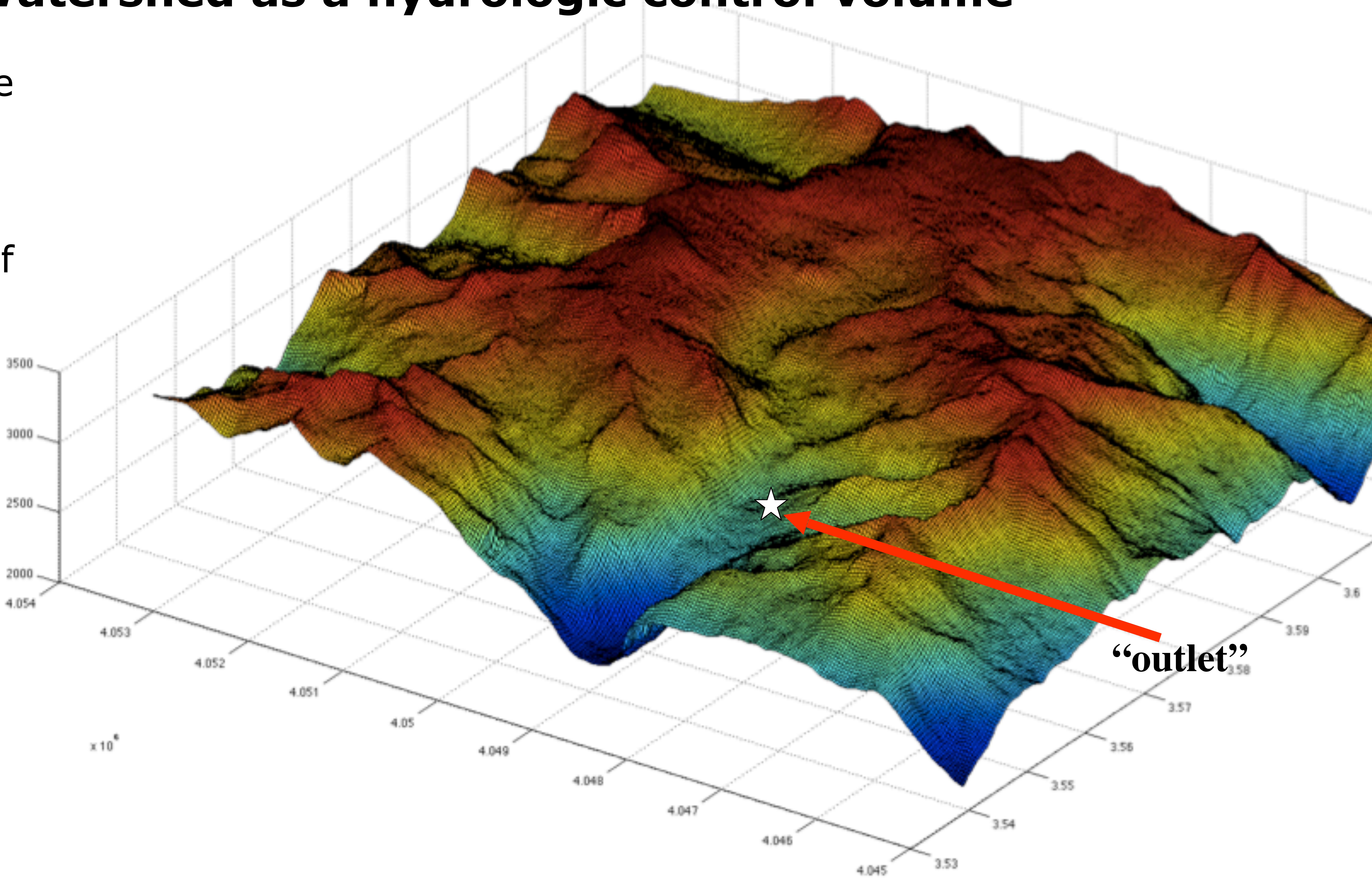
Watershed as a Hydrologic Control Volume



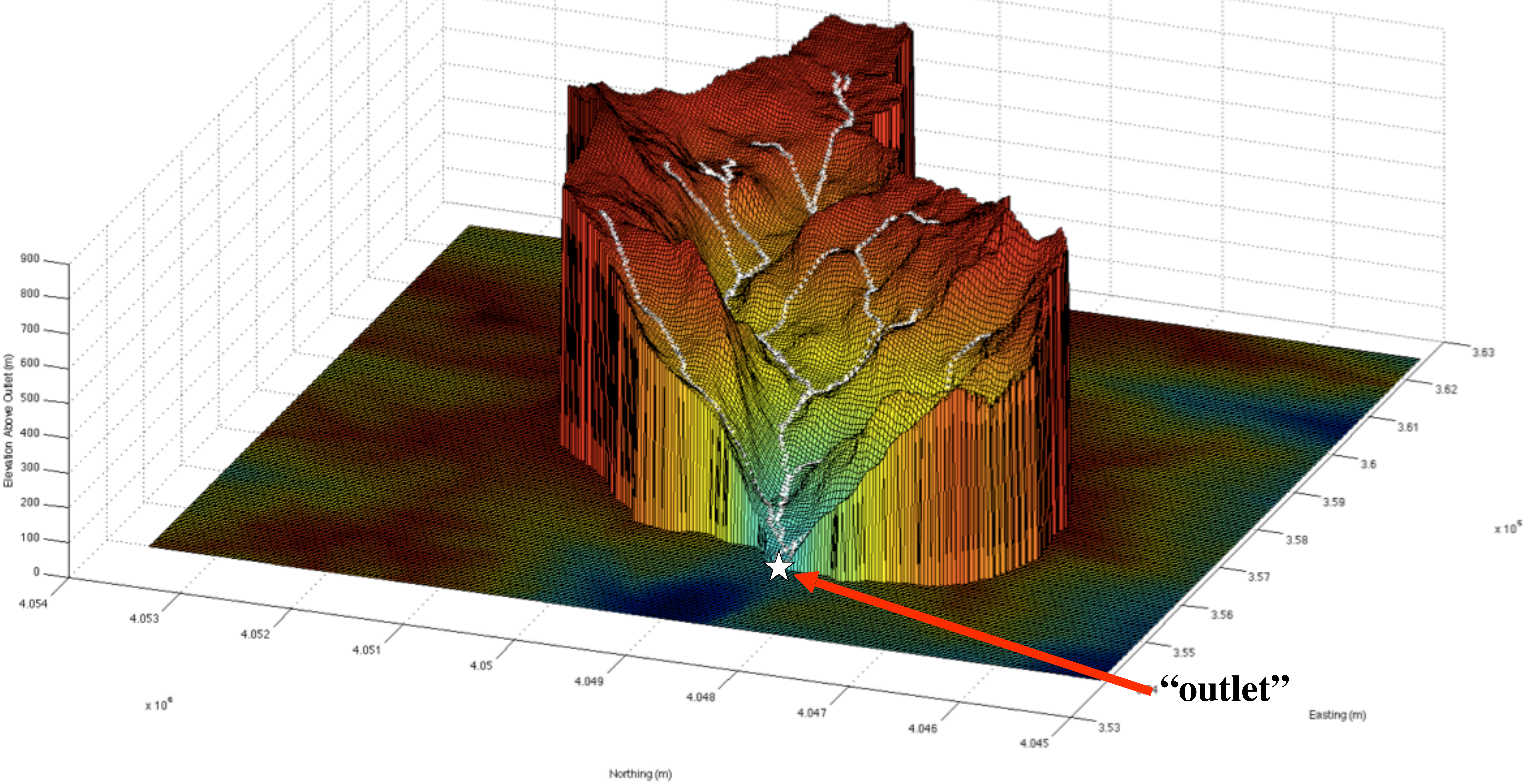
Watershed as a hydrologic control volume

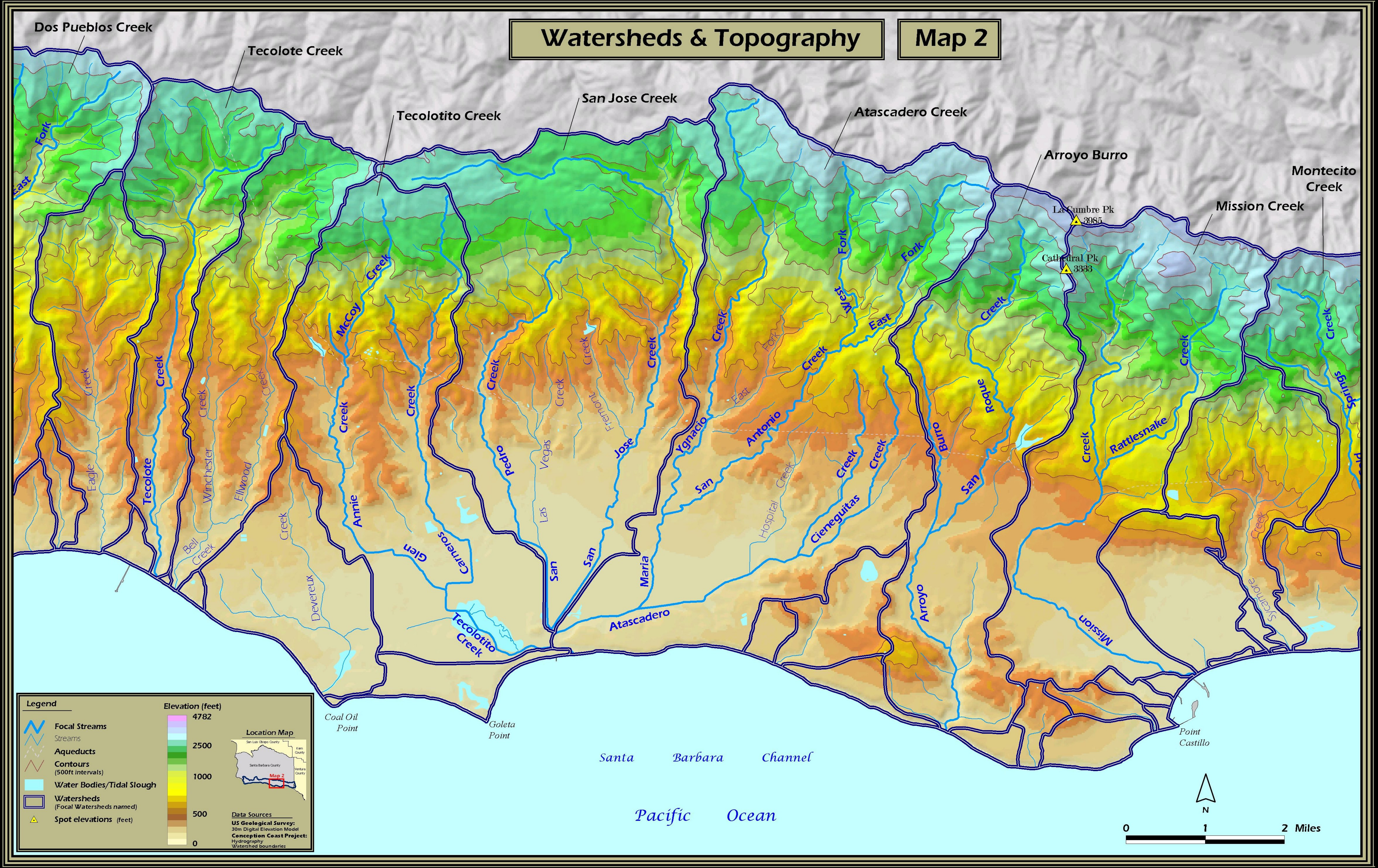
Topography can be a main driver of surface flow; topography often digitized in form of Digital Elevation Models (DEMs)

Basic question:
If standing in a stream channel, from what upstream area is the water coming from?



A **watershed** (or river basin or catchment) is the topographically derived set of points that drain to a specified "outlet"; boundaries formed by topographic ridgelines; all water falling within boundary will eventually drain to outlet.





Watersheds & Topography
Map 2
Dos Pueblos Creek
Tecolote Creek
Tecolotito Creek
San Jose Creek
Atascadero Creek
Arroyo Burro
Montecito Creek
Mission Creek
La Cumbre Pk
3985
Cathedral Pk
3333
Coal Oil Point
Goleta Point
Point Castillo
Santa Barbara Channel
Pacific Ocean
Legend
Focal Streams
Streams
Aqueducts
Contours
(500ft intervals)
Water Bodies/Tidal Slough
Watersheds
(Focal Watersheds named)
Spot elevations (feet)
Elevation (feet)
4782
2500
1000
500
0
Location Map
San Luis Obispo County
Kern County
Santa Barbara County
Ventura County
Map 2
Data Sources
US Geological Survey:
30m Digital Elevation Model
Conception Coast Project:
Hydrography
Watershed boundaries
0
1
2 Miles
N

Catchment Water Balance

P: Precipitation
ET: Evapotranspiration
Q: Streamflow
S: Soil Water Storage

$$\frac{dS}{dt} = P - ET - Q$$

Assumes no groundwater flows between basins

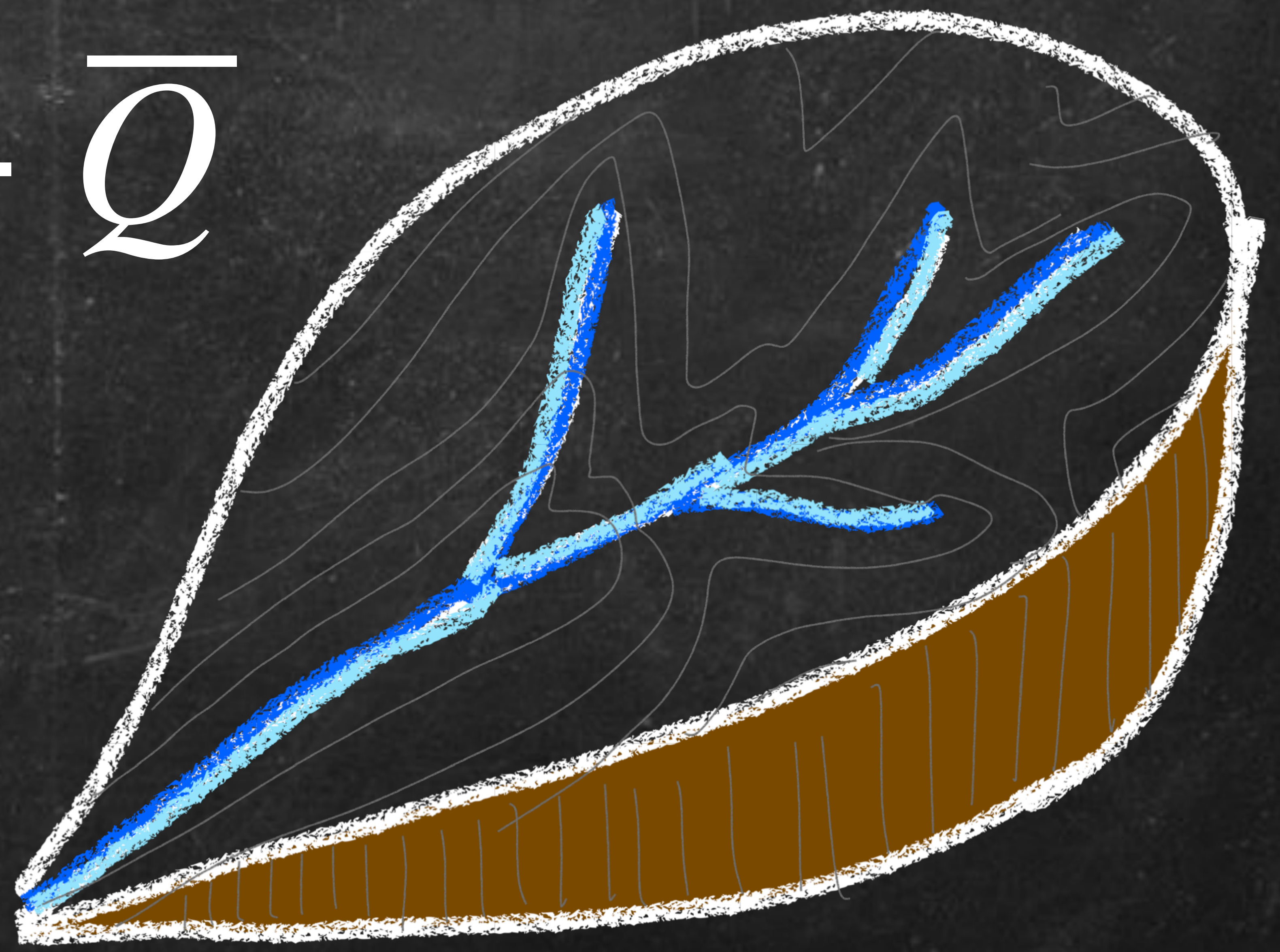
Evaporation From Mass Balance

Over long (annual, or multi-year) time-scales,

$$\frac{dS}{dt} \text{ is zero:}$$

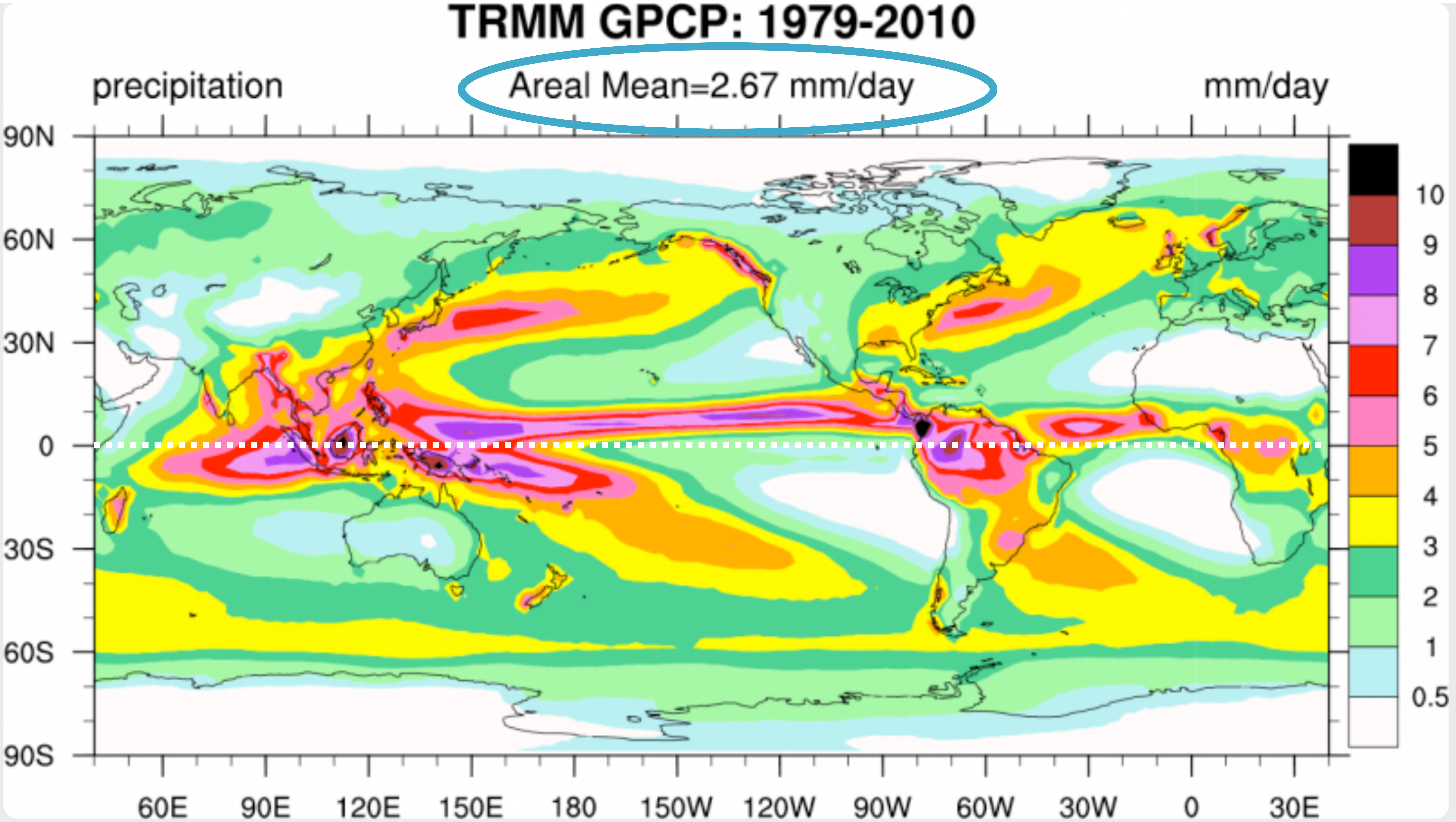
$$\overline{\frac{dS}{dt}} = 0 = \overline{P} - \overline{ET} - \overline{Q}$$

$$\overline{ET} = \overline{P} - \overline{Q}$$

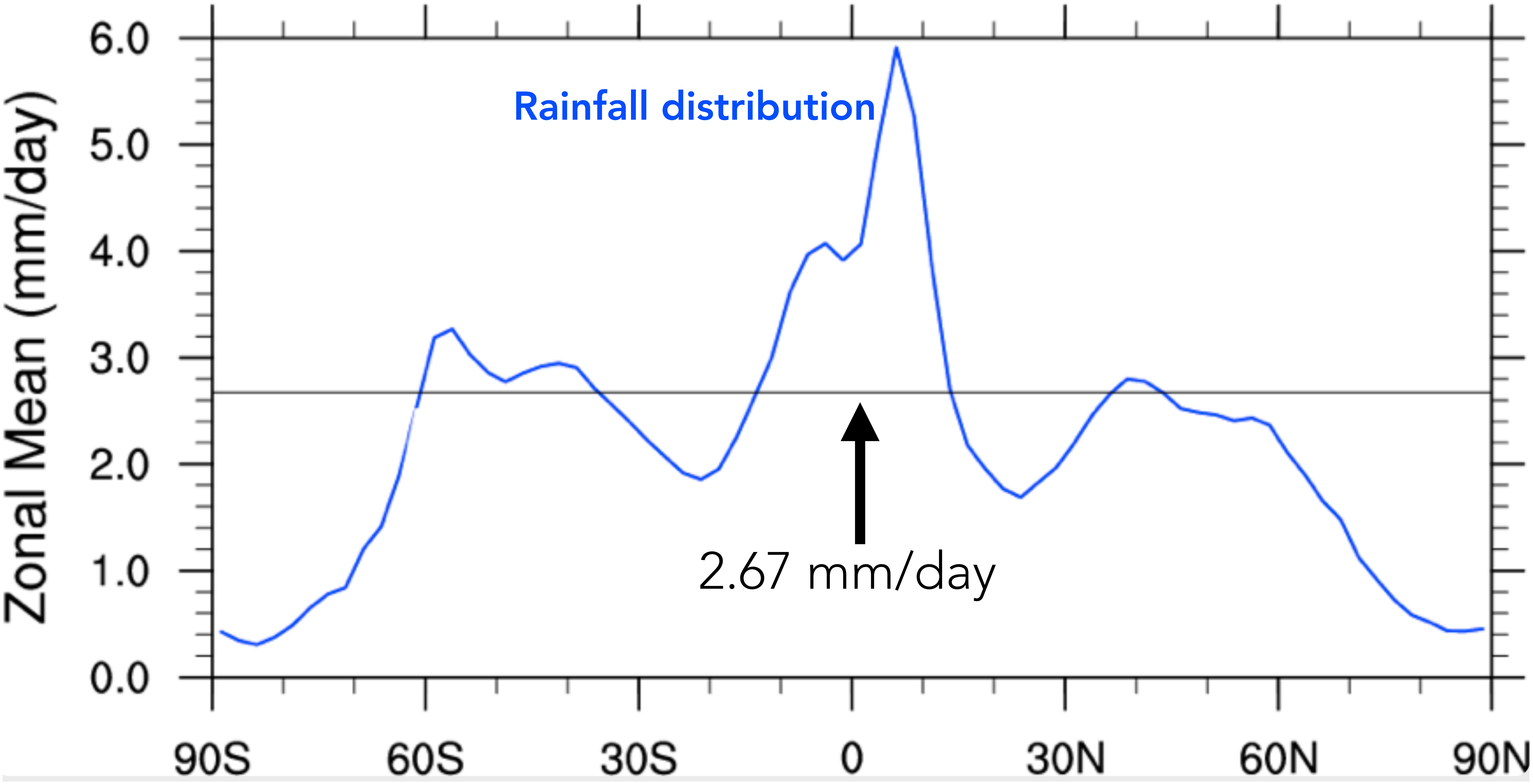



Average Annual Precipitation
California
Copyright 2000 by Spatial Climate Analysis Service, Oregon State University
Legend (in inches)
Under 5
5 to 10
10 to 15
15 to 20
20 to 30
30 to 40
40 to 60
60 to 80
80 to 120
Above 120

Global Rainfall Patterns



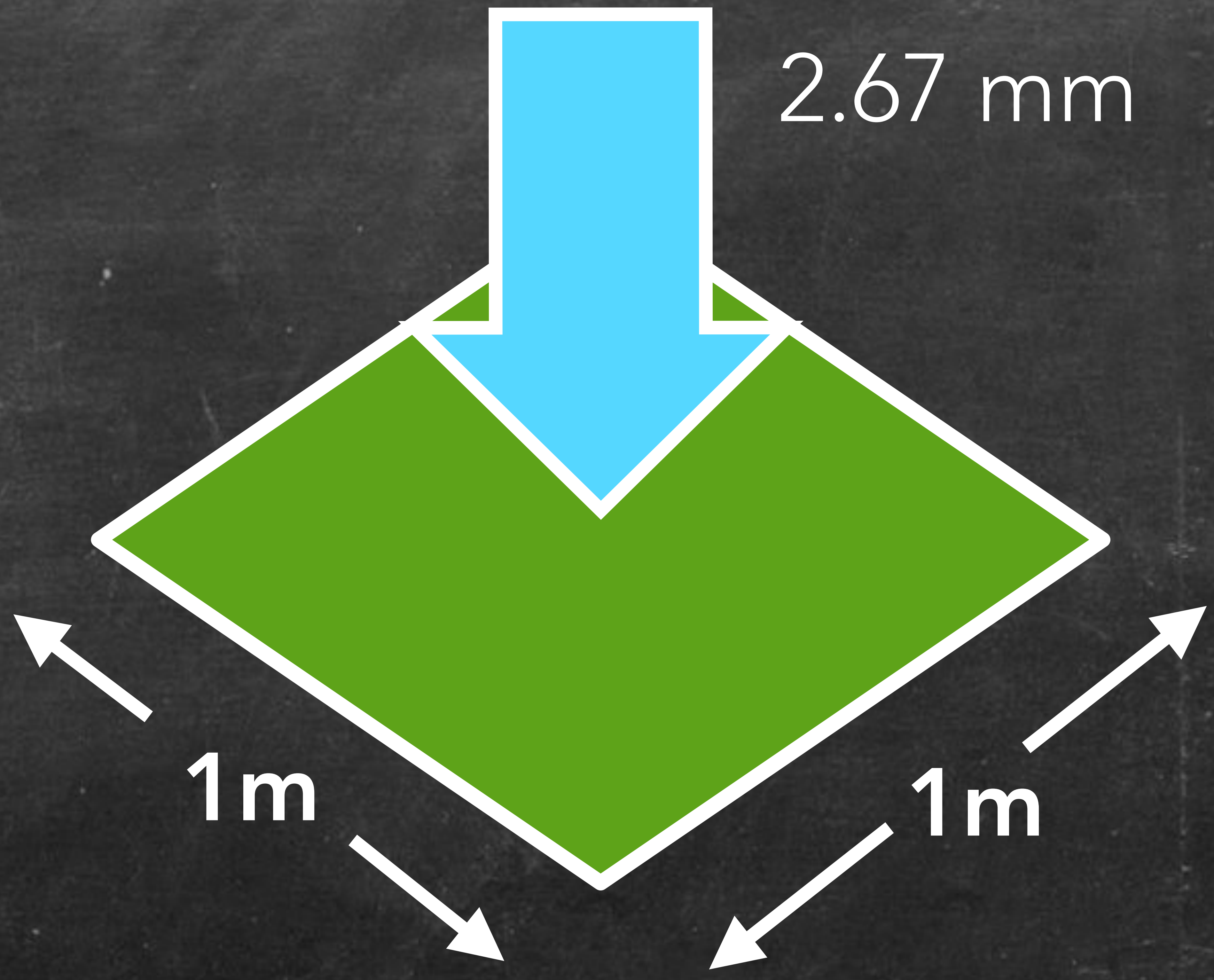
Latitudinal Distribution of Rainfall



Global Average Rainfall: 2.67 mm per day

Consider a single square meter:

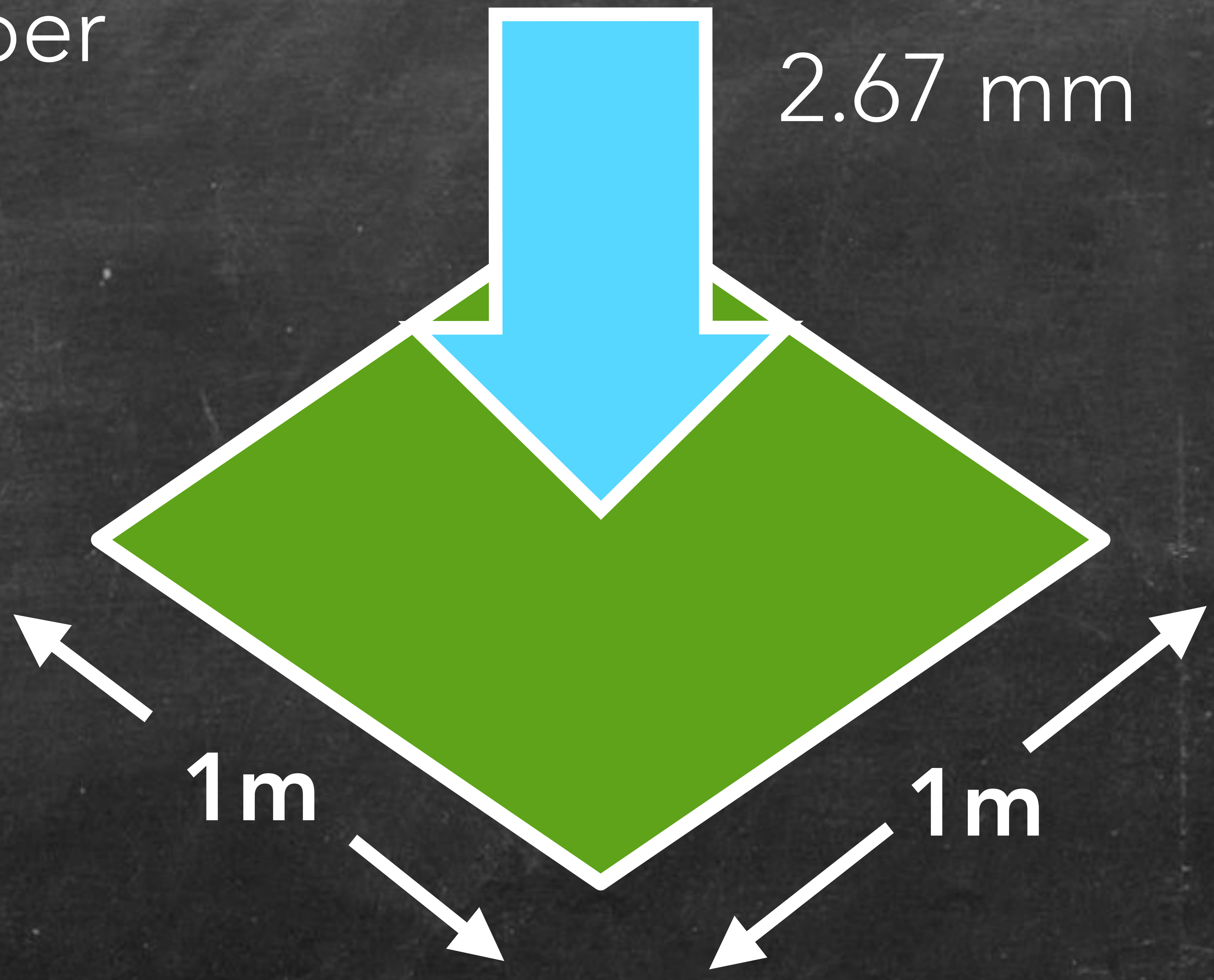
Each day, there is an average of 2.67 mm of rainfall onto each m^2 of the planet



Global Average Rainfall: $2.67 \dfrac{mm}{m^2}$ per day

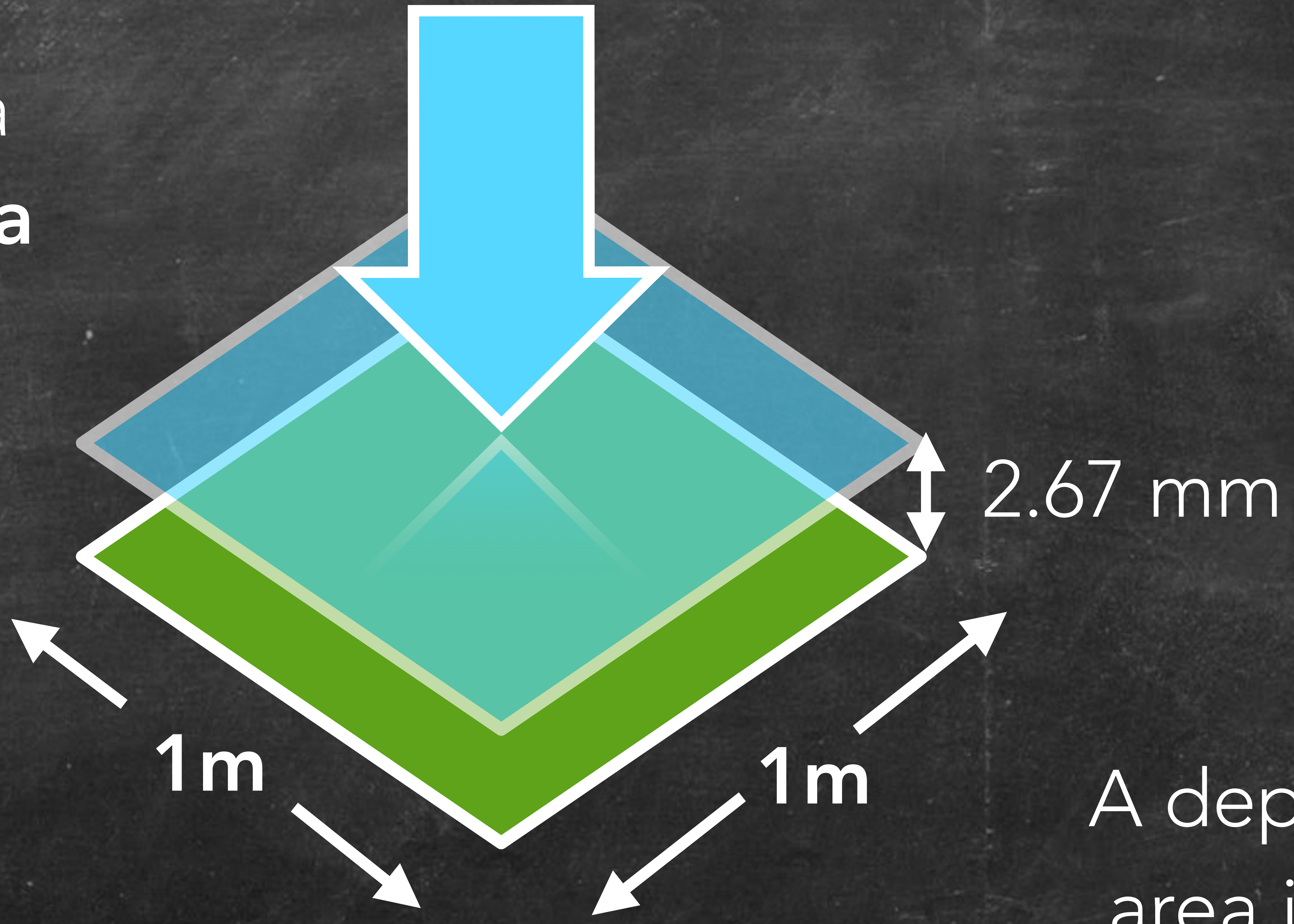
So. Daily rainfall is a **depth** per unit area per day… right?

2.67 mm of rainfall on average per m^2 each day



Global Average Rainfall: $2.67 \dfrac{\text{mm}}{\text{m}^2}$ per day

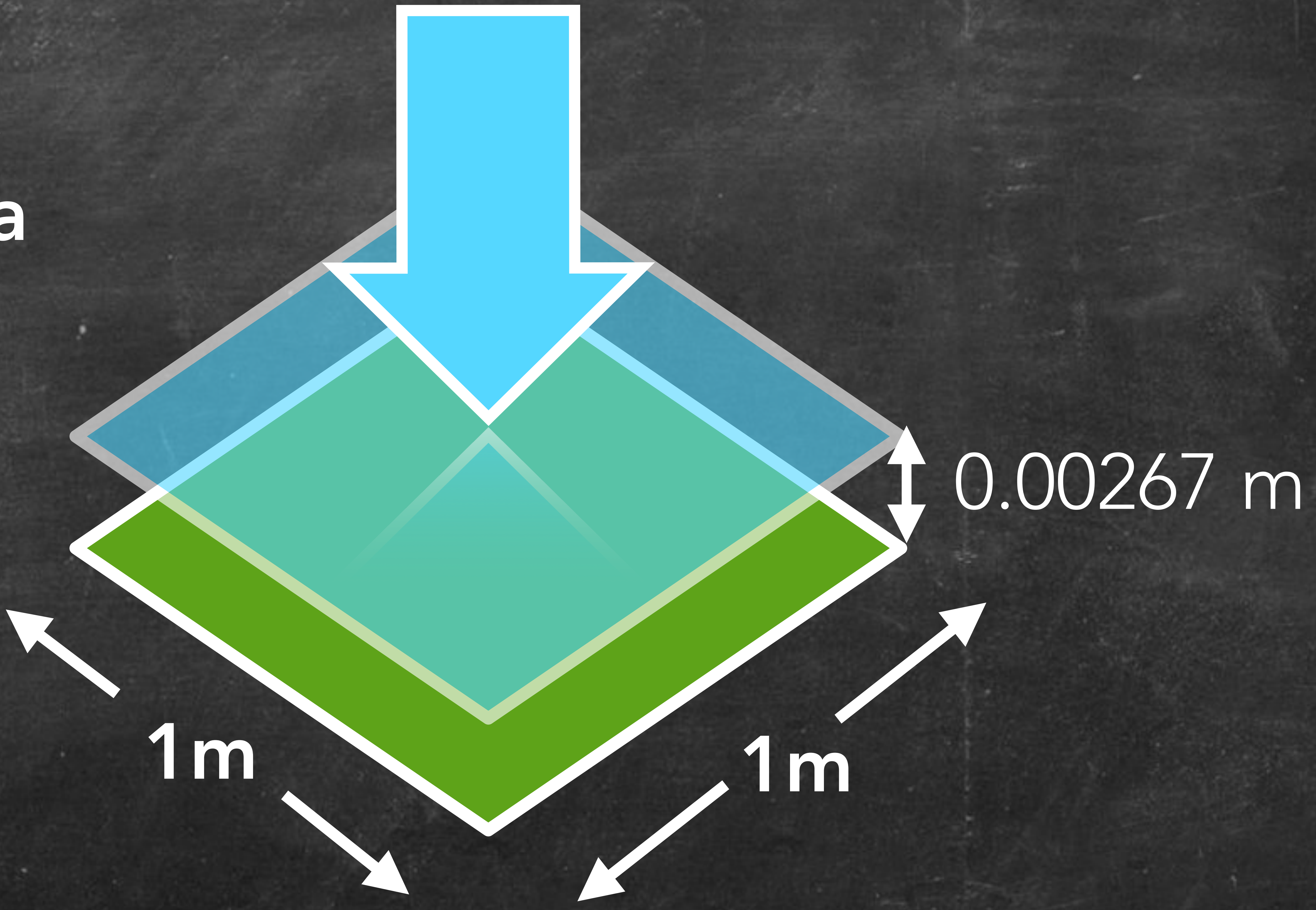
So. Daily rainfall is a **depth times an area** per unit area.



A depth times an area is a volume

Global Average Rainfall: $2.67 \frac{\text{mm}}{\text{m}^2}$ per day

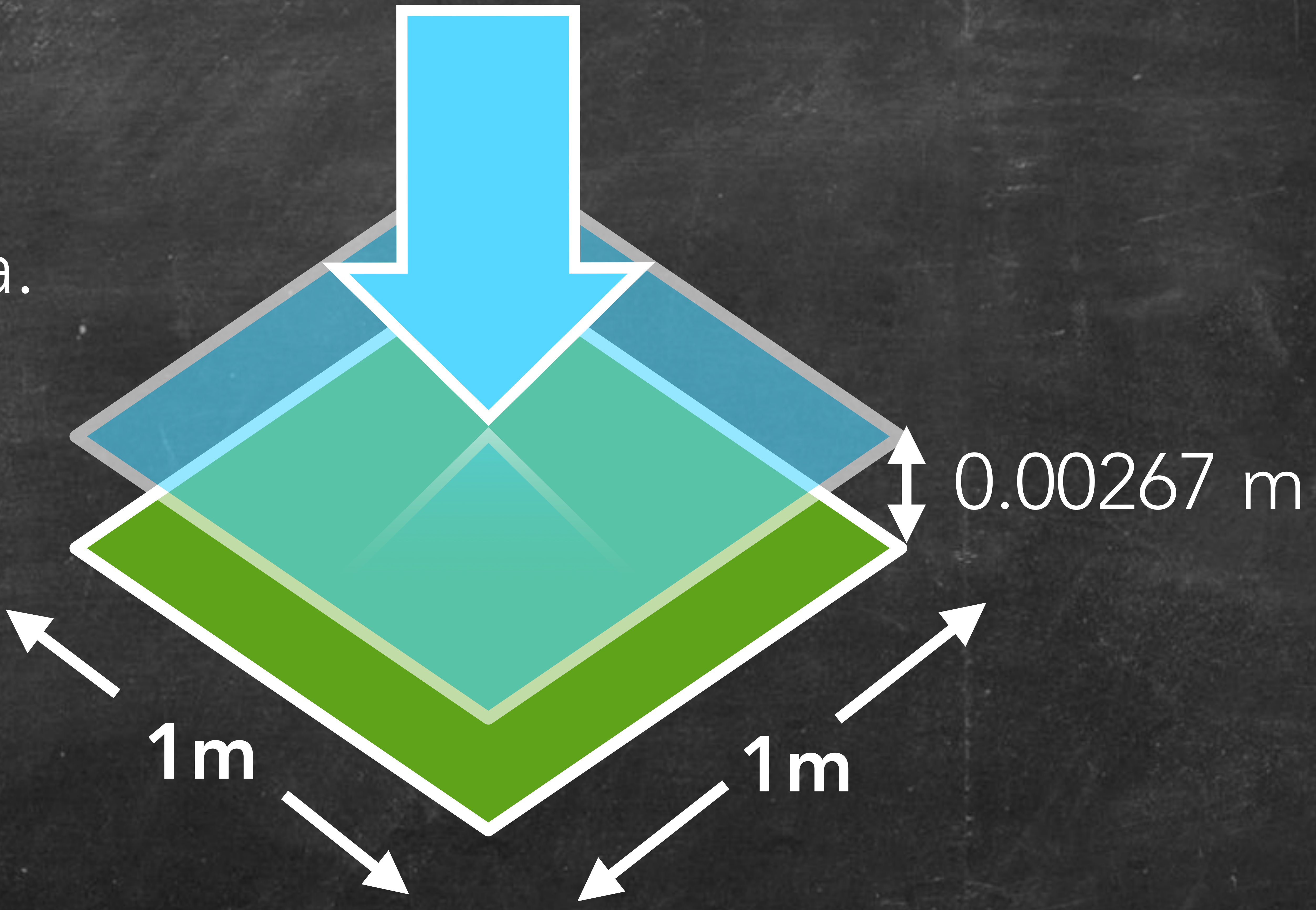
So. Daily rainfall is a **depth times an area** per unit area.



$$R_v = \left(2.67 \frac{\text{mm}}{\text{m}^2} \text{day}^{-1} \times \frac{1 \text{ m}}{1000 \text{ mm}}\right) \times 1 \text{ m}^2 = 0.00267 \frac{\text{m}^3}{\text{m}^2} \text{day}^{-1}$$

Global Average Rainfall: $0.00267 \dfrac{m^3}{m^2}$ per day

So. Daily rainfall is a **volume** per unit area.



$$R_v = \left(2.67 \frac{mm}{m^2}\,\mathrm{day}^{-1} \times \frac{1\ \mathrm{m}}{1000\ \mathrm{mm}} \right) \times 1\ \mathrm{m}^2 = 0.00267 \frac{m^3}{m^2}\,\mathrm{day}^{-1}$$

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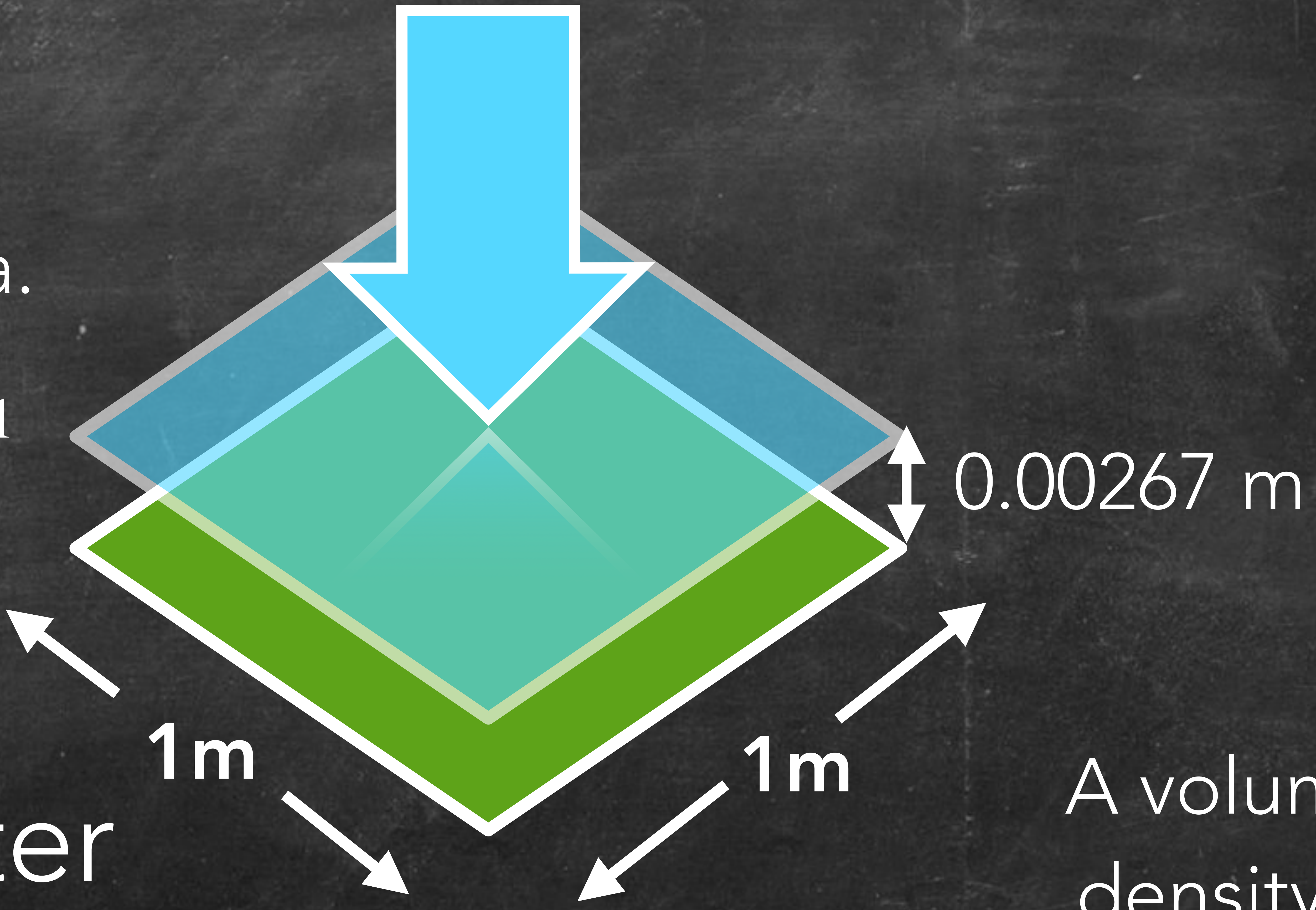
So. Daily rainfall is a **volume** per unit area.

$$R_v = 0.00267 \frac{\mathrm{m}^3}{\mathrm{m}^2}\ \mathrm{day}^{-1}$$



$$R_m = R_v \times \rho_{\mathrm{water}}$$

A volume times a density is a mass

$$\rho_{\mathrm{water}} = \frac{1000\mathrm{kg}}{\mathrm{m}^3}$$

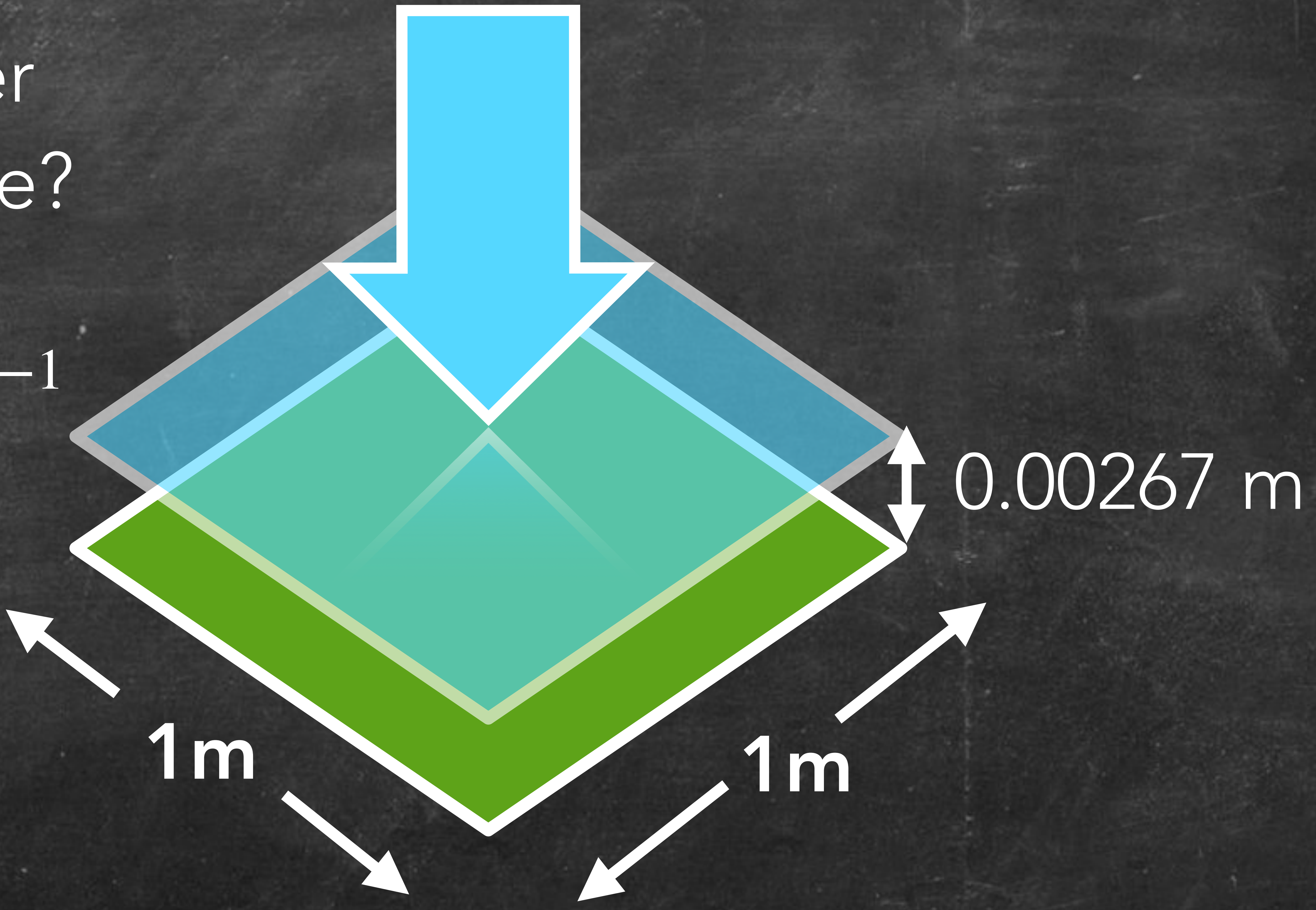
Global Average Rainfall: $0.00267\dfrac{\mathrm{m}^3}{\mathrm{m}^2}$ per day

Rainfall is a **mass** per unit area per unit time?

$$R_v = 0.00267\frac{\mathrm{m}^3}{\mathrm{m}^2}\mathrm{day}^{-1}$$

$$R_m = R_v \times \rho_{\mathrm{water}}$$

$$\rho_{\mathrm{water}} = \frac{1000\mathrm{kg}}{\mathrm{m}^3}$$



$$R_m = \left(0.00267\frac{\mathrm{m}^3}{\mathrm{m}^2}\,\mathrm{day}^{-1}\right) \times \frac{1000\mathrm{kg}}{\mathrm{m}^3}$$

Global Average Rainfall: $2.67\dfrac{\text{kg}}{\text{m}^2}$ per day

Rainfall is a **mass** per unit area per unit time?

$$R_v = 0.00267\frac{\text{m}^3}{\text{m}^2}\text{day}^{-1}$$

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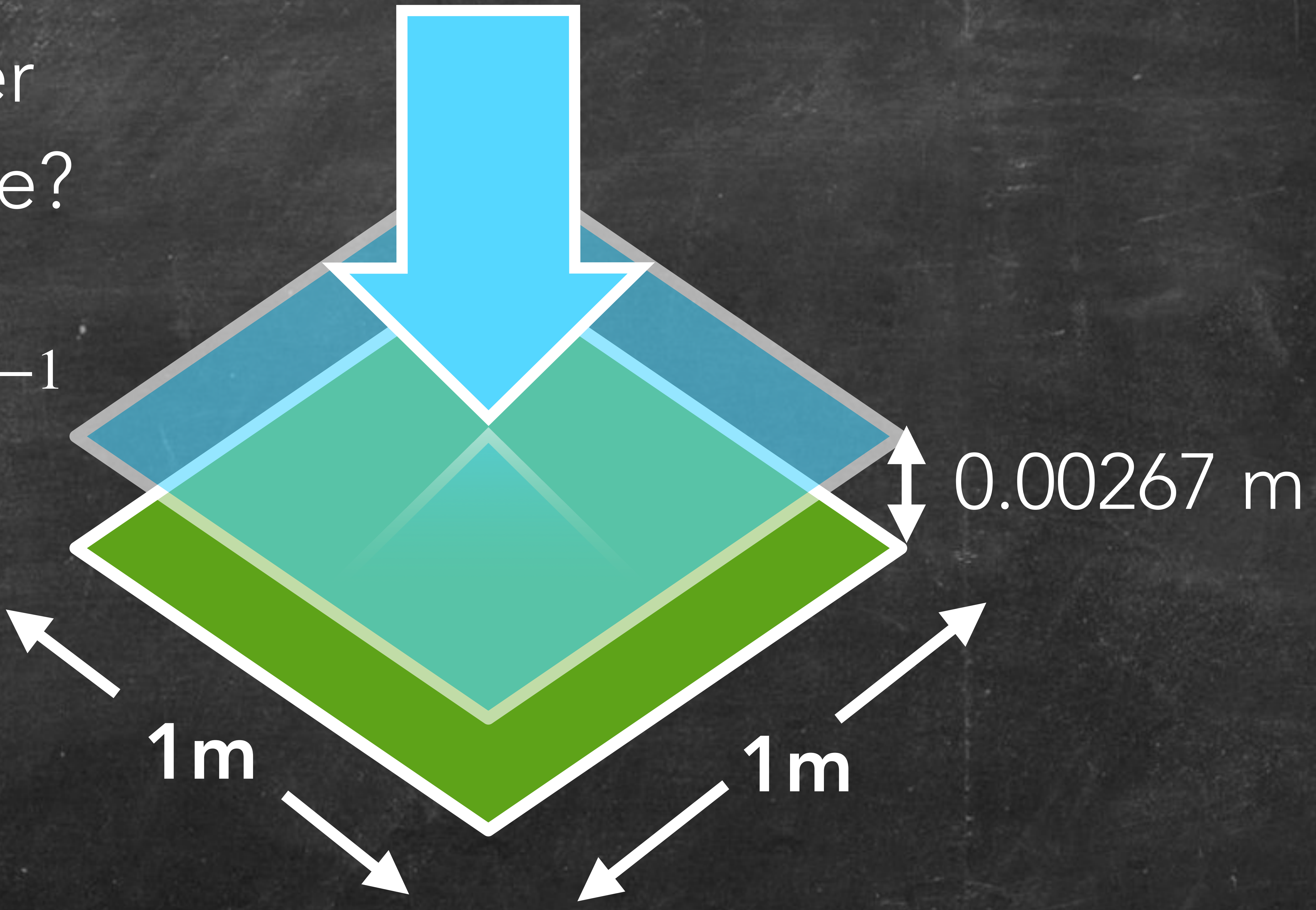
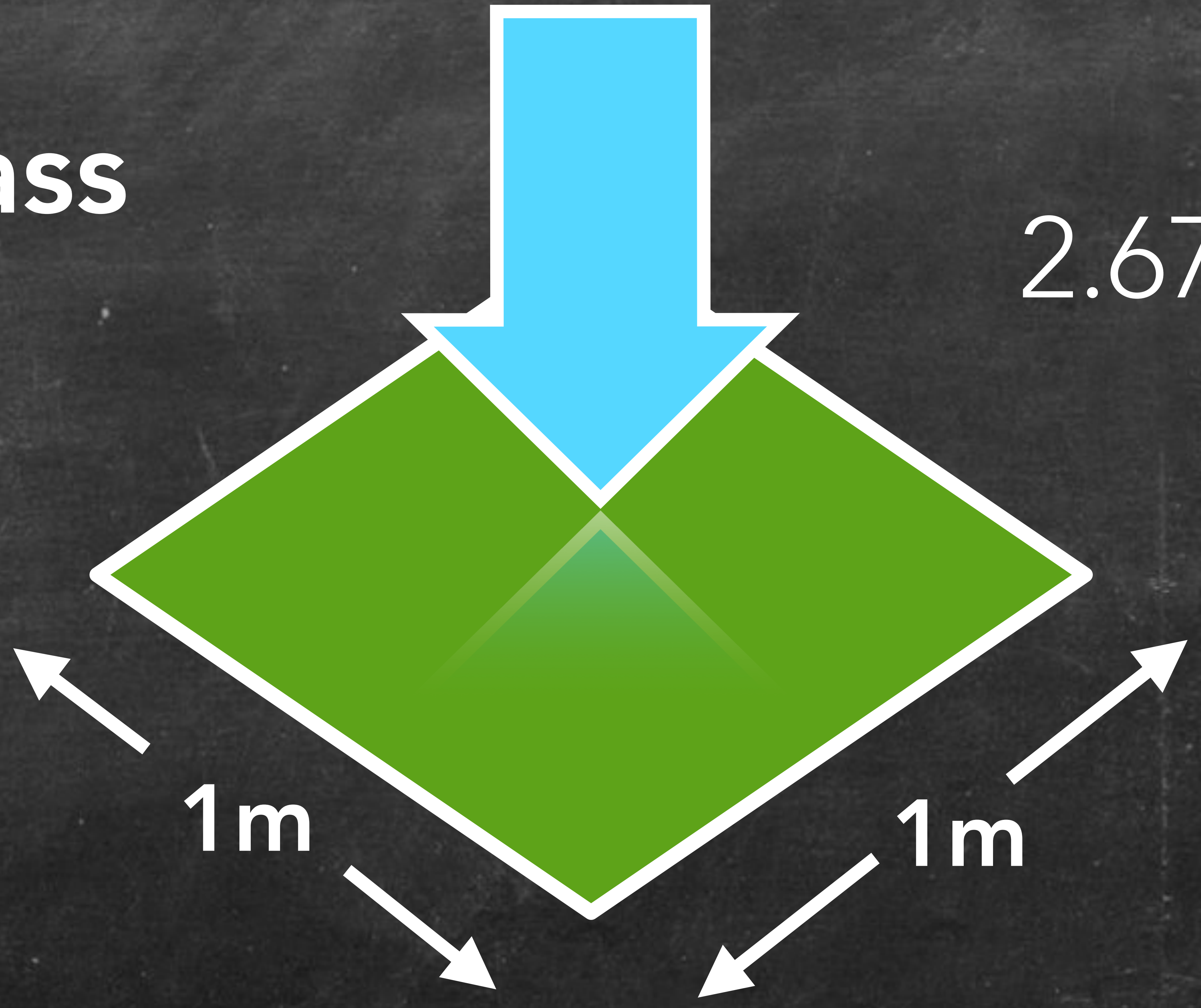
$$\rho_{\text{water}} = \frac{1000\text{kg}}{\text{m}^3}$$



$$R_m = \left(0.00267\frac{\text{m}^3}{\text{m}^2}\,\text{day}^{-1}\right) \times \frac{1000\text{kg}}{\text{m}^3} = 2.67\frac{\text{kg}}{\text{m}^2}\,\text{day}^{-1}$$

Global Average Rainfall: $2.67 \dfrac{\text{kg}}{\text{m}^2}$ per day

Rainfall is a **mass** flux!



$2.67 \dfrac{\text{kg}}{\text{m}^2}$ per day

FLOWS VS. FLUXES

	DESCRIPTION	MASS EXAMPLE	MASS UNITS	ENERGY EXAMPLE	ENERGY UNITS
Flow	A **quantity** per unit time	Streamflow	$\frac{kg}{s}$	Heat Flow	$\frac{J}{s}$
Flux	A **quantity** per unit time per unit area	Evaporation	$\frac{kg}{m^2 s}$	Evaporation	$\frac{J}{m^2 s}$ or $\frac{W}{m^2}$

Extensive Vs. Intensive

Extensive Measures

Extensive measures are properties that depend on the size or extent of a system

Intensive Measures

Intensive measures are properties that do not depend on the size or extent of a system

Extensive Vs. Intensive

Extensive Measures

Extensive measures are properties that depend on the size or extent of a system

- Heat content (J)
- Mass (kg)
- Volume (m^3)
- Area (m^2)
- Flow (kg/s)

Intensive Measures

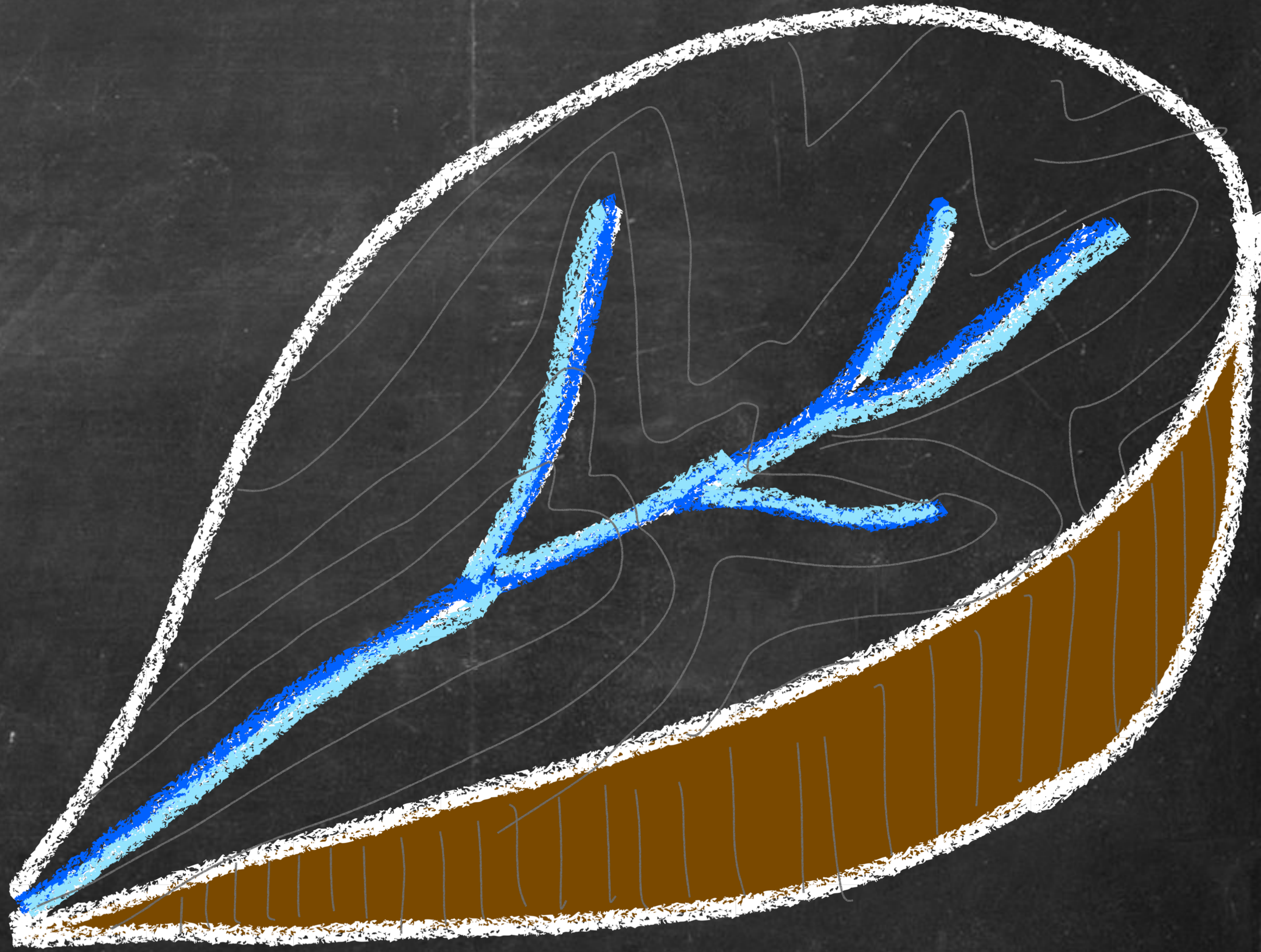
Intensive measures are properties that do not depend on the size or extent of a system

- Mass density (kg/m^3)
- Temperature
- Soil Moisture (kg/m^3)
- Flux ($kg/m^2/s$)

Catchment Water Balance

P: Precipitation
ET: Evapotranspiration
Q: Streamflow
S: Soil Water Storage

R_c: **Runoff Coefficient** $= \dfrac{Q}{P}$



Assumes no groundwater flows between basins

$$\frac{dS}{dt} = P - ET - Q$$