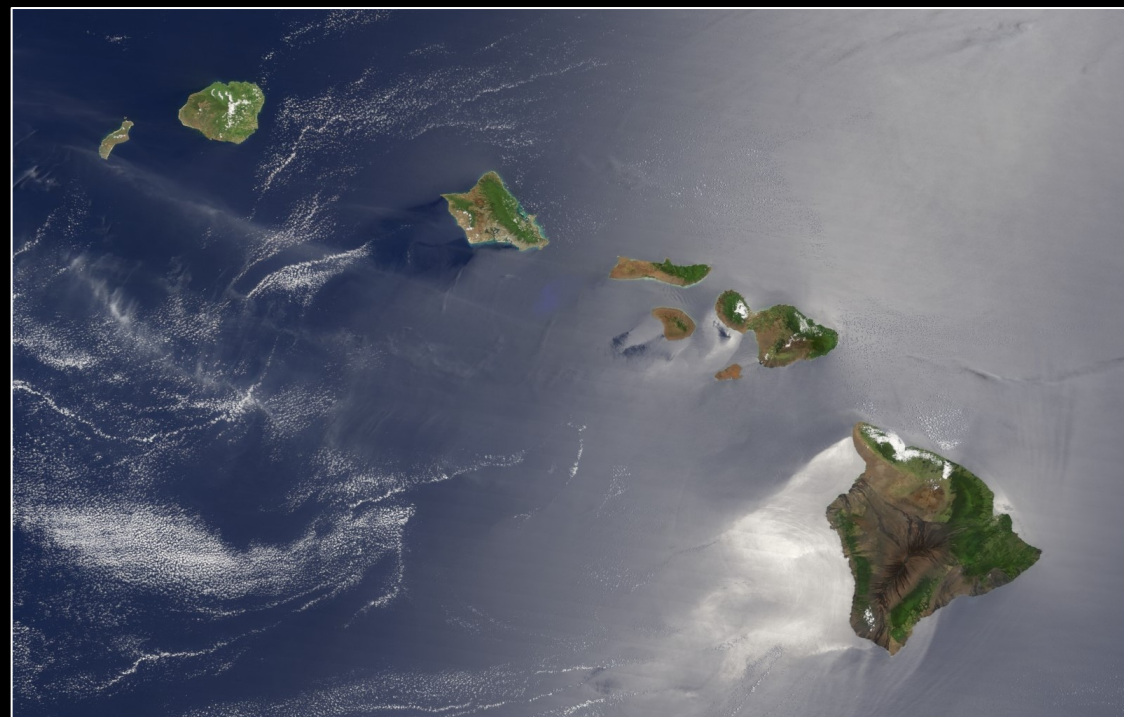


# The Water Cycle in Hawai'i

Alan Mair  
U.S. Geological Survey

EARTH 2023 Workshop  
July 11, 2023



# The Water Cycle: A Matter of Scale

## The Water Cycle

COMPLETED

By [Water Science School](#) October 2, 2022

• [Water Science School HOME](#) • [Water Cycle Diagrams](#) • [Glossary of Water Cycle Terms](#) • [Water Pools and Fluxes Data Tables](#)

### What is the water cycle?

The water cycle describes where water is on Earth and how it moves. Water is stored in the atmosphere, on the land surface, and below the ground. It can be a liquid, a solid, or a gas. Liquid water can be fresh or saline (salty). Water moves between the places it is stored. Water moves at large scales, through watersheds, the atmosphere, and below the Earth's surface. Water moves at very small scales too. It is in us, plants, and other organisms. Human activities impact the water cycle, affecting where water is stored, how it moves, and how clean it is.

### Pools store water

Oceans store 96% of all water on Earth. Ocean water is saline, meaning it's salty. On land, saline water is stored in saline lakes. The rest of the water on Earth is fresh water. Fresh water is stored in liquid form in [freshwater lakes](#), artificial reservoirs, [rivers](#), and wetlands. Water is stored in solid, frozen form in [ice sheets and glaciers](#), and in [snowpack](#) at high elevations or near Earth's poles. Water vapor is a gas and is stored as [atmospheric moisture](#) over the ocean and land. In the soil, frozen water is stored as permafrost and liquid water is stored as soil moisture. Deeper below ground, liquid water is stored as [groundwater](#) in aquifers. Water in groundwater aquifers is found within cracks and pores in the rock.

### Fluxes move water between pools

As it moves, water can change form between liquid, solid, and gas. Circulation mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the surface through [evaporation](#), [evapotranspiration](#), and [precipitation](#). Water moves across the surface through [snowmelt](#), [runoff](#), and [streamflow](#). Water moves into the ground through [infiltration](#) and groundwater recharge. Underground, [groundwater flows](#) within aquifers. Groundwater can return to the surface through natural discharge into rivers, the ocean, and from [springs](#).



### What drives the water cycle?

Water moves naturally and because of human actions. Energy from the [sun](#) and the force of gravity drive the continual movement of water between pools. The sun's energy causes liquid water to evaporate into water vapor. Evapotranspiration is the main way water moves into the atmosphere from the land surface and oceans. Gravity causes water to flow downward on land. It causes rain, snow, and hail to fall from clouds.

<https://www.usgs.gov/special-topics/water-science-school/science/water-cycle>



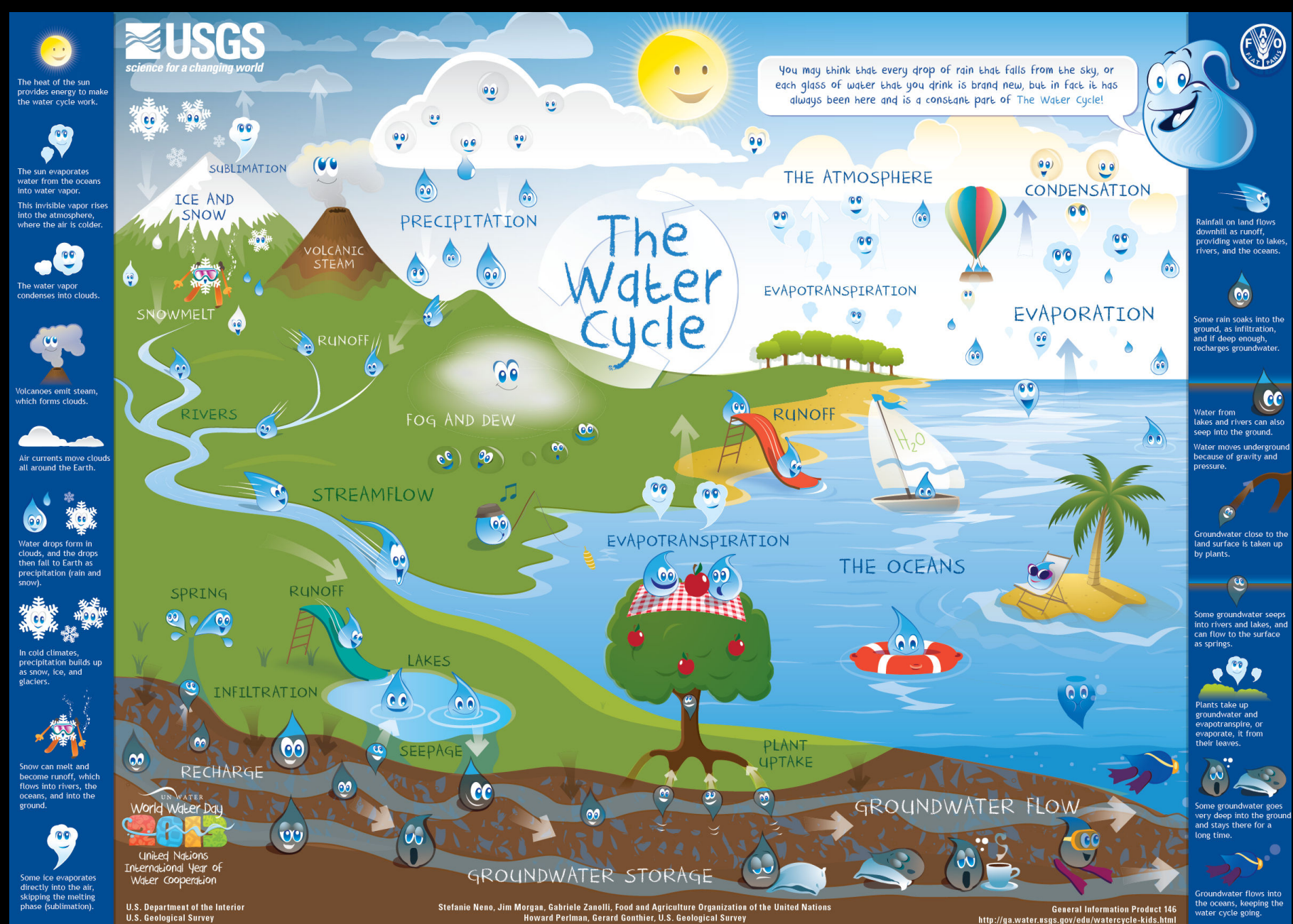
Sources/Usage: Public Domain.

Viewed from space, the most striking feature of our planet is the water. In both liquid and frozen form, it covers 75% of the Earth's surface. It fills the sky with clouds. Water is practically everywhere on Earth, from inside the planet's rocky crust to inside the cells of the human body (NASA). What's important to keep in mind is that all of this water is in constant motion across our planet.

Credit: NASA

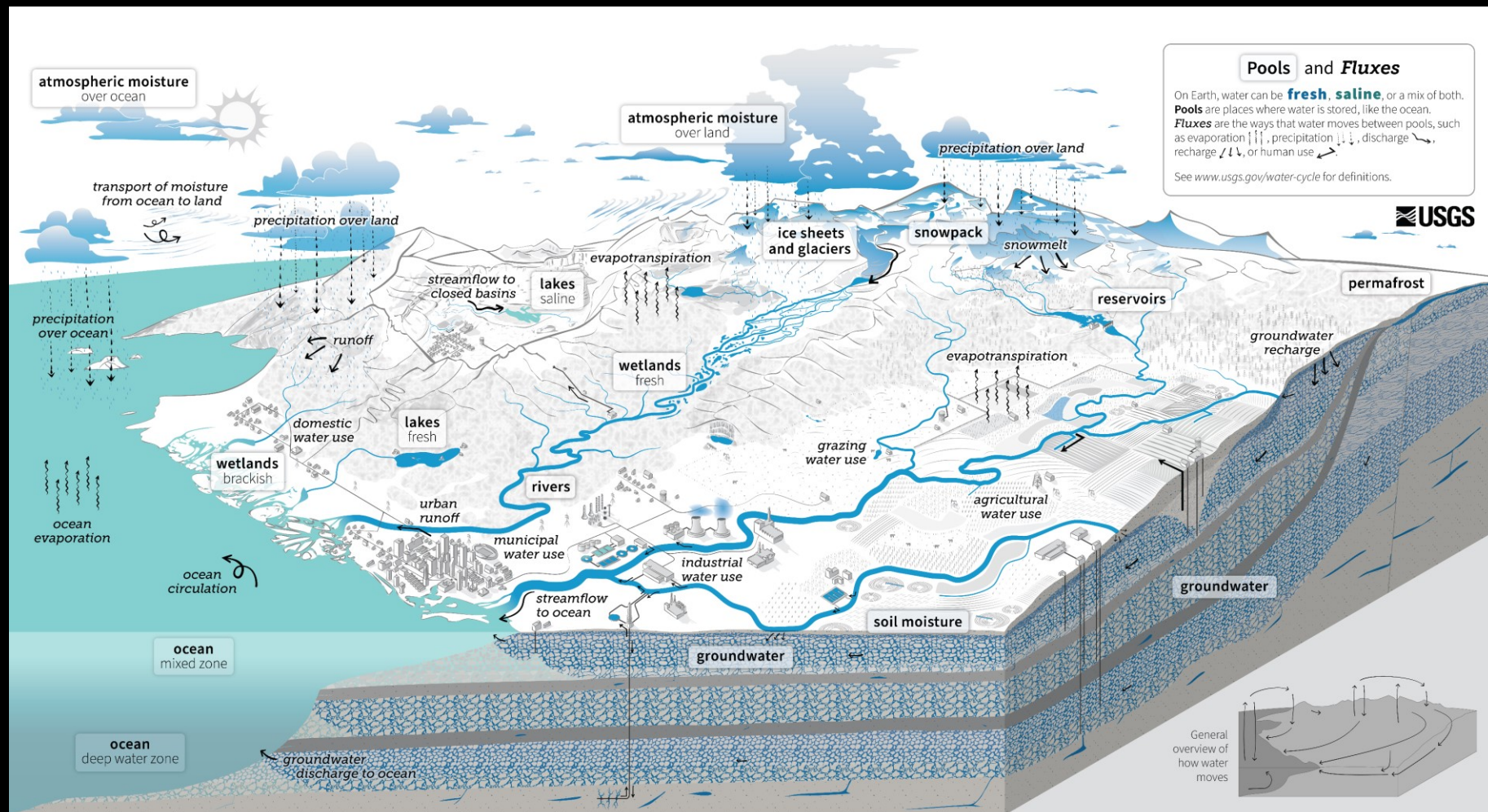


# The Water Cycle for Kids





# The Water Cycle: Continental Scale



## The Water Cycle

The water cycle describes where water is found on Earth and how it moves. Water can be stored in the atmosphere, on Earth's surface, or below the ground. It can be in a liquid, solid, or gaseous state. Water moves between the places it is stored at large scales and at very small scales. Water moves naturally and because of human interaction, both of which affect where water is stored, how it moves, and how clean it is.

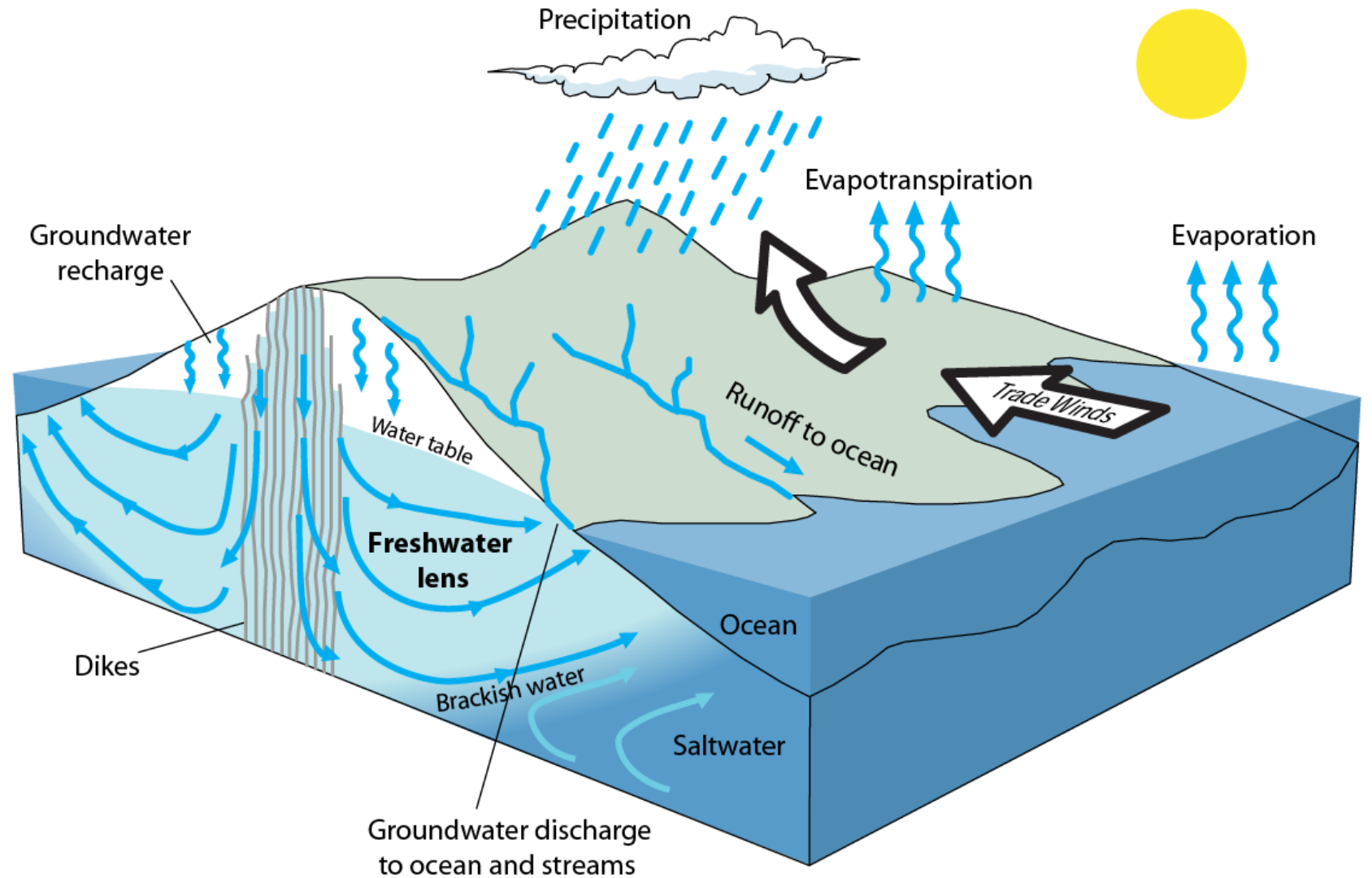
Liquid water can be fresh, saline (salty), or a mix (brackish). Ninety-six percent of all water is saline and stored in **oceans**. Places like the ocean, where water is stored, are called **pools**. On land, saline water is stored in **saline lakes**, whereas fresh water is stored in liquid form in **freshwater lakes**, artificial **reservoirs**, **rivers**, **wetlands**, and in soil as **soil moisture**. Deeper underground, liquid water is stored as **groundwater** in aquifers, within the cracks and pores of rock. The solid, frozen form of water is stored in **ice sheets**, **glaciers**, and **snowpack** at high elevations or near the Earth's poles. Frozen water is also found in the soil as **permafrost**. Water vapor, the gaseous form of water, is stored as **atmospheric moisture** over the ocean and land.

As it moves, water can transform into a liquid, a solid, or a gas. The different ways in which water moves between pools are known as **fluxes**. **Circulation** mixes water in the oceans and transports water vapor in the atmosphere. Water moves between the atmosphere and the Earth's surface through **evaporation**, **evapotranspiration**, and **precipitation**. Water moves across the land surface through **snowmelt**, **runoff**, and **streamflow**. Through infiltration and **groundwater recharge**, water moves into the ground. When underground, groundwater flows within aquifers and can return to the surface through **springs** or from natural **groundwater discharge** into rivers and oceans.

Humans alter the water cycle. We redirect rivers, build dams to store water, and drain water from wetlands for development. We use water from rivers, lakes, reservoirs, and groundwater aquifers. We use that water (1) to supply our **homes and communities**; (2) for **agricultural** irrigation and **grazing** livestock; and (3) in **industrial** activities like thermoelectric power generation, mining, and aquaculture. The amount of available water depends on how much water is in each pool (water quantity). Water availability also depends on when and how fast water moves (water timing), how much water is used (water use), and how clean the water is (water quality).

Human activities affect **water quality**. In agricultural and urban areas, irrigation and precipitation wash fertilizers and pesticides into rivers and groundwater. Power plants and factories return heated and contaminated water to rivers. Runoff carries chemicals, sediment, and sewage into rivers and lakes. Downstream from these types of sources, contaminated water can cause harmful algal blooms, spread diseases, and harm habitats. **Climate change** is also affecting the water cycle. It affects water quality, quantity, timing, and use. Climate change is also causing ocean acidification, sea level rise, and extreme weather. Understanding these impacts can allow progress toward sustainable water use.

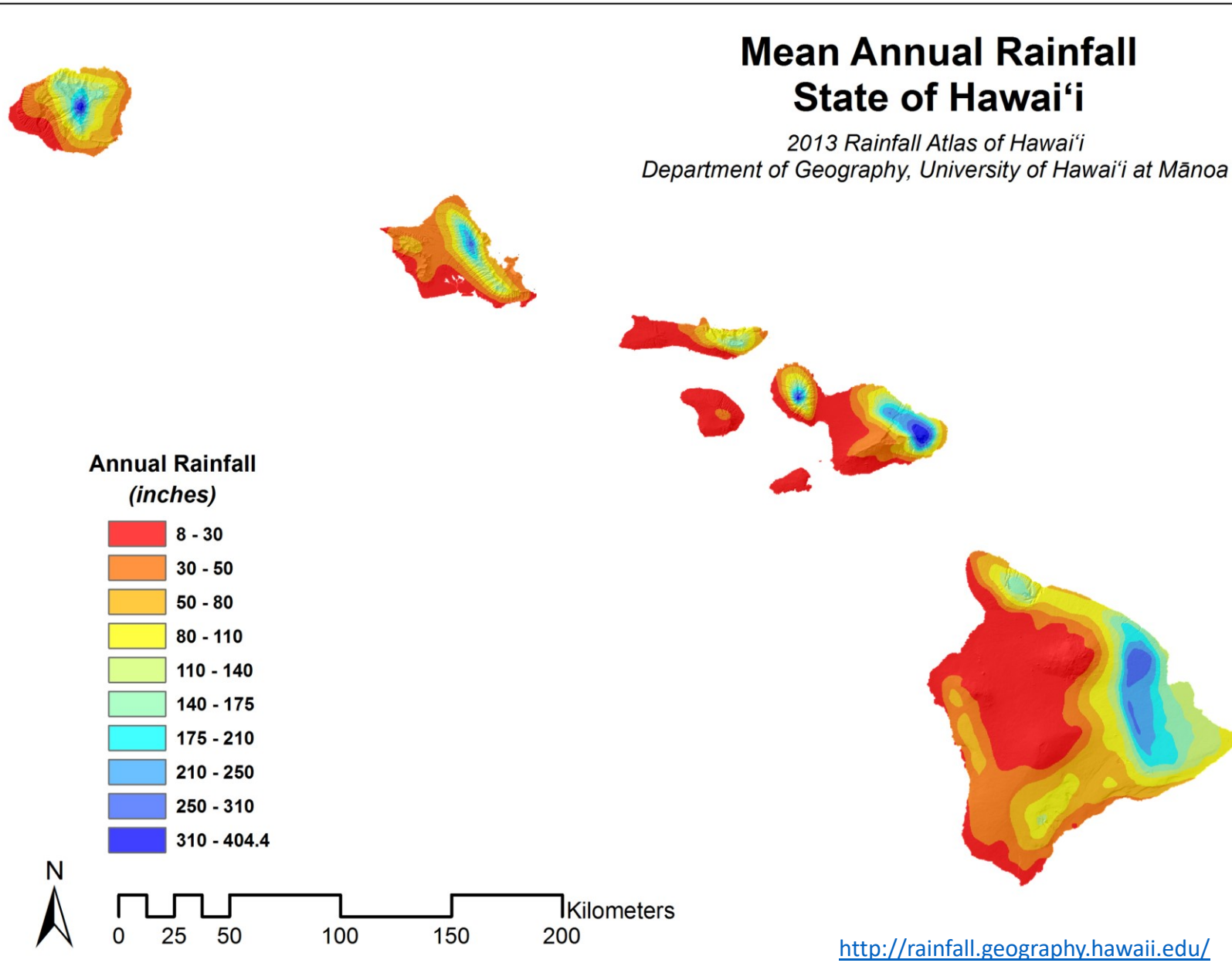
# The Water Cycle in Hawai'i: Island Scale



<https://doi.org/10.3133/sir20155164>

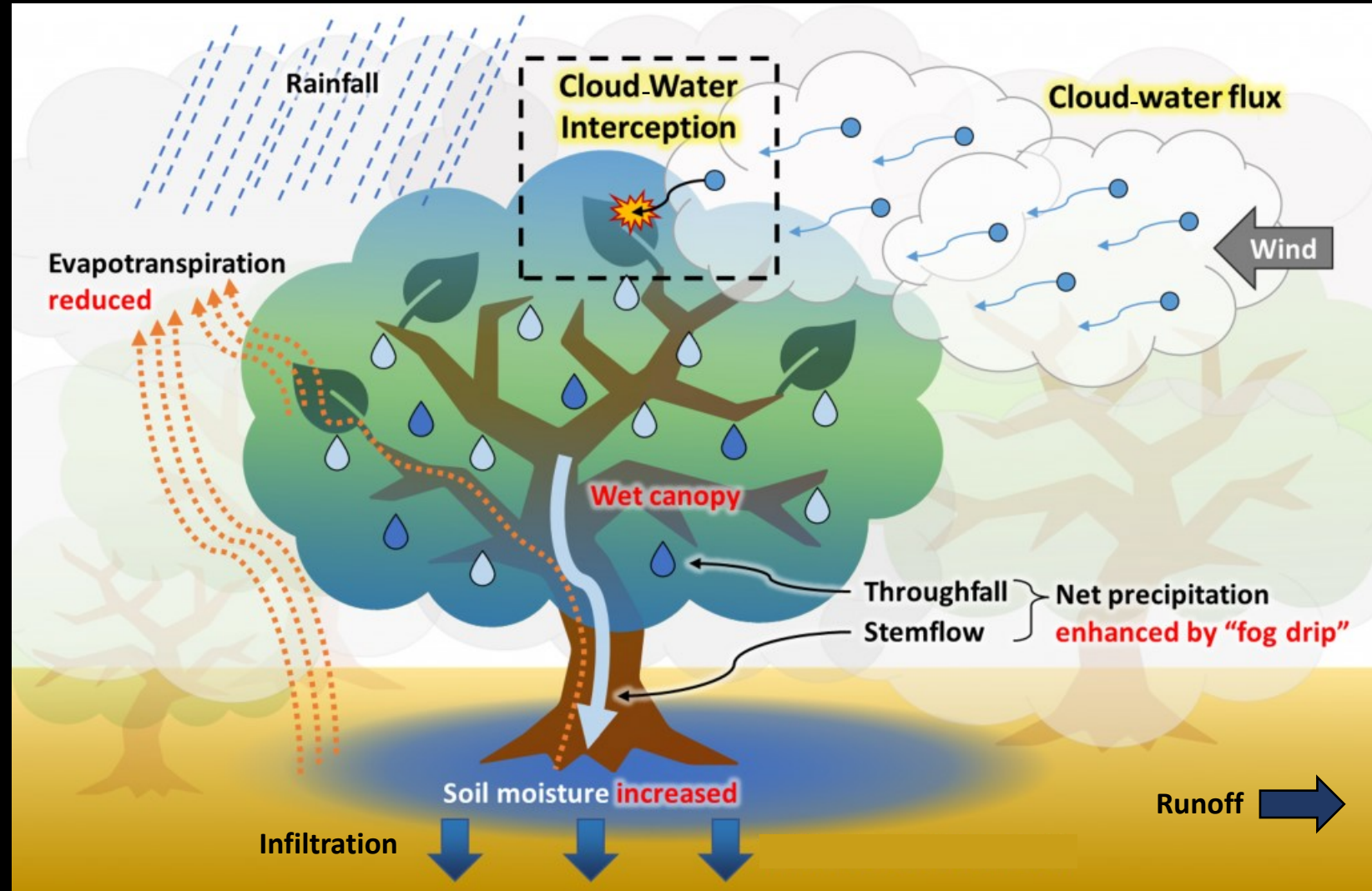
# Mean Annual Rainfall State of Hawai'i

*2013 Rainfall Atlas of Hawai'i*  
*Department of Geography, University of Hawai'i at Mānoa*





# The Water Cycle in Hawai'i: Forest-Plot Scale



Modified from <https://www.hawaii.edu/climate-data-portal/cloud-water-interception-in-hawaii/>



# Selected High Priority Non-Native Species of Concern



Himalayan ginger  
(*Hedychium gardnerianum*)



Tropical ash  
(*Fraxinus uhdei*)



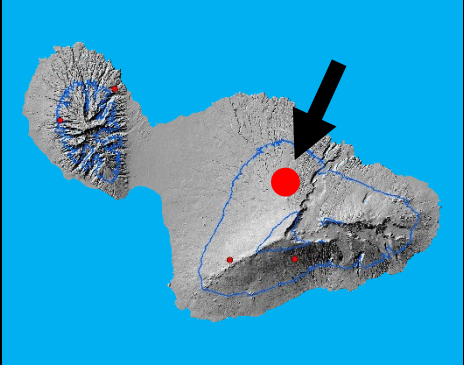
Strawberry guava  
(*Psidium cattleianum*)



Kikuyu grass  
(*Pennisetum clandestinum*)

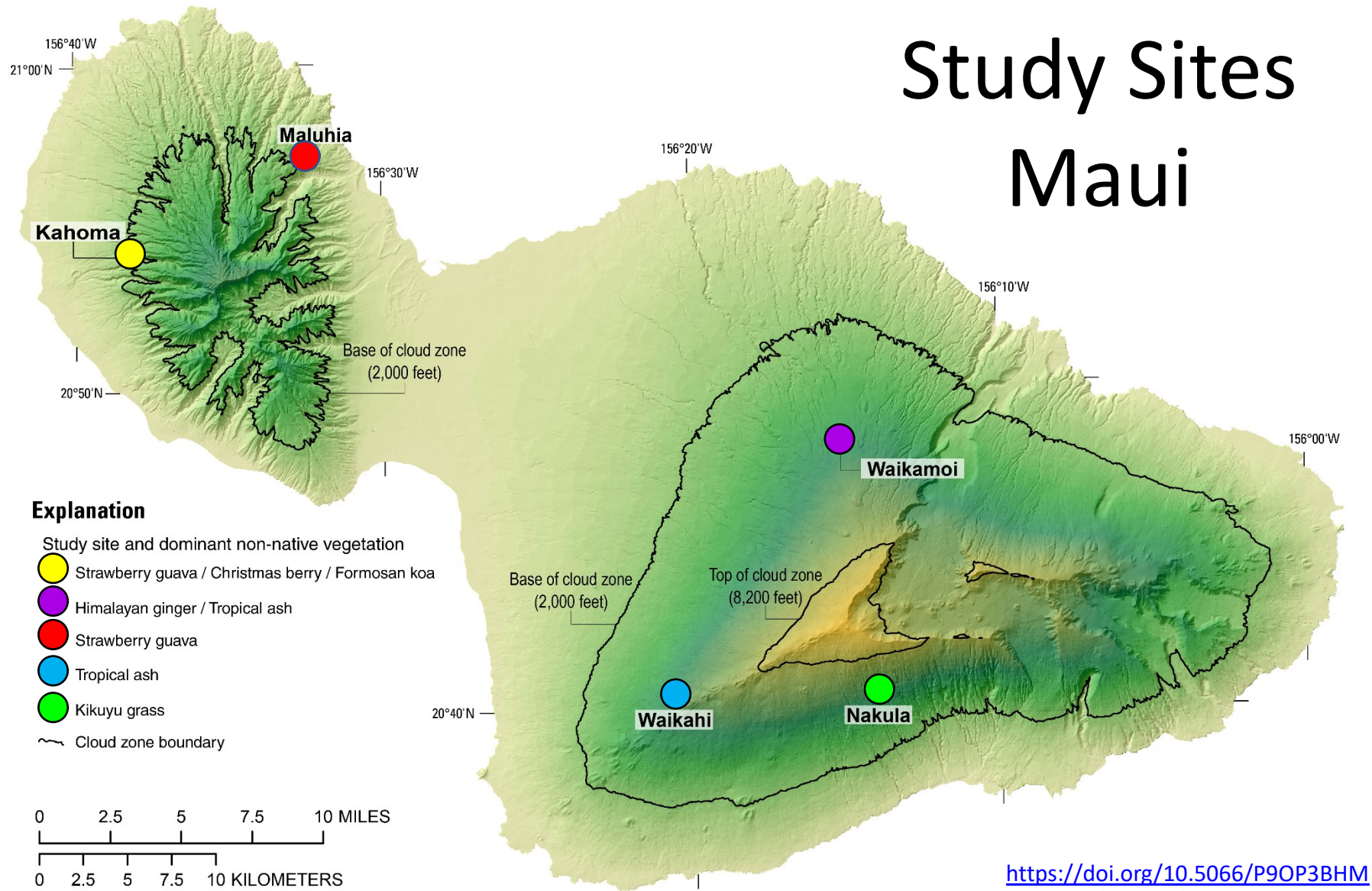


# Waikamoi, Maui





# Study Sites Maui



<https://doi.org/10.5066/P9OP3BHM>  
<https://doi.org/10.5066/P9J5SESD>



# Infiltration-Rate Testing



Single-ring infiltrometer

Strawberry guava plot  
Maluhia, Maui



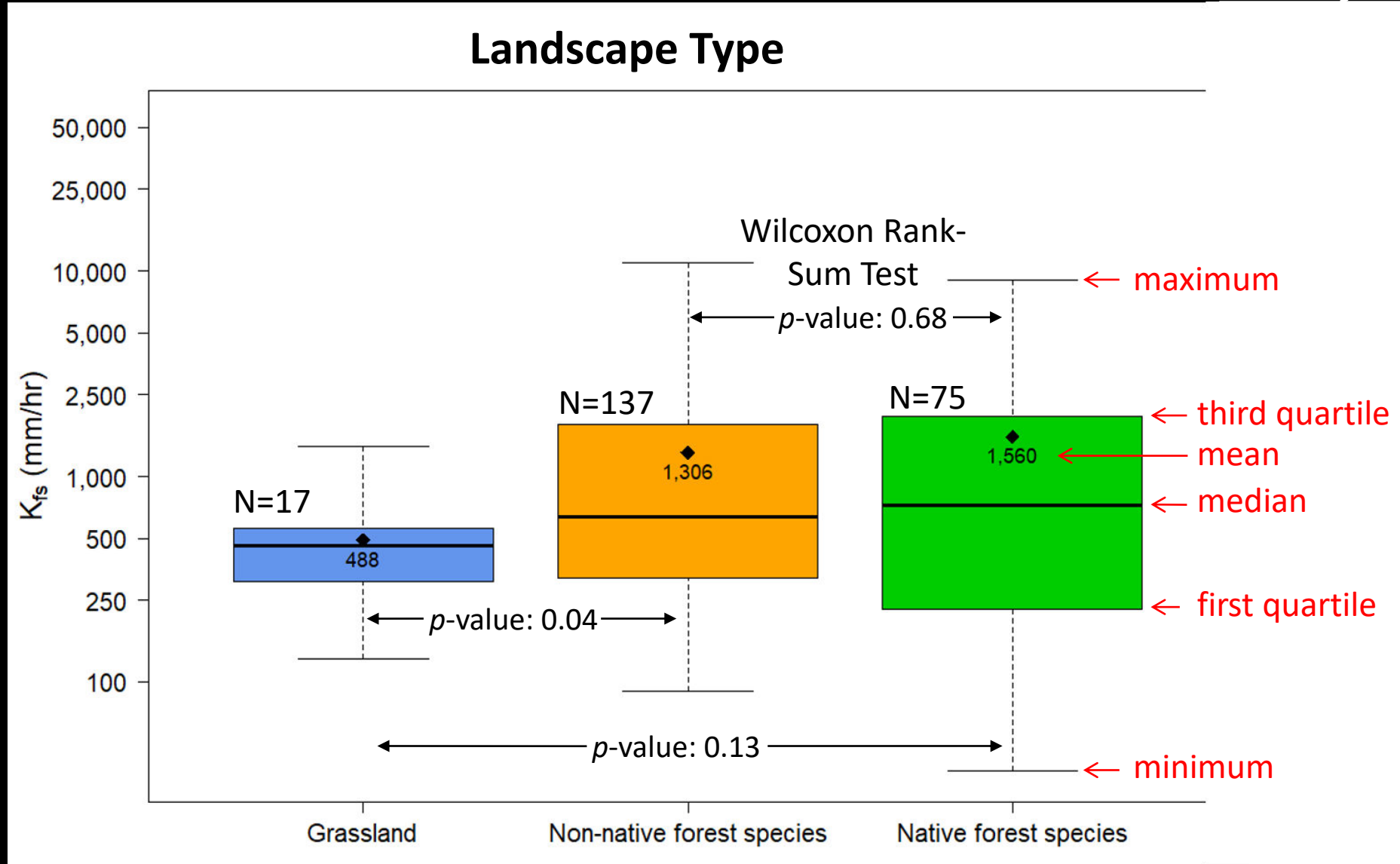
Himalayan ginger-Tropical ash plot  
Waikamoi, Maui



Strawberry guava plot  
Kahoma, Maui



# Field-Saturated Hydraulic Conductivity ( $K_{fs}$ )



Excludes data collected from Maluhia plots



# ScienceBase Digital Repository

**USGS**  
science for a changing world

ScienceBase-Catalog Communities Help Log in

ScienceBase Catalog → USGS Pacific Islands Water ... → Ecohydrology → Soil Characteristics → Summary of soil field-saturat...

## Summary of soil field-saturated hydraulic conductivity, hydrophobicity, preferential-flow, and particle-size measurements collected at four study sites on the island of Maui, Hawaii, September 2017–August 2018

View

### Dates

Start Date : 2017-09-19  
End Date : 2018-08-01  
Publication Date : 2019-02-01

### Citation


Kennedy, J.J., Mair, A., and Perkins, K.S., 2019, Summary of soil field-saturated hydraulic conductivity, hydrophobicity, preferential-flow, and particle-size measurements collected at four study sites on the island of Maui, Hawaii, September 2017–August 2018: U.S. Geological Survey data release, <https://doi.org/10.5066/P9OP3BHM>.

### Summary

The U.S. Geological Survey and the University of Hawaii at Manoa, in cooperation with the County of Maui Department of Water Supply and the State of Hawaii Commission on Water Resource Management, initiated a field data-collection program to provide information for evaluating how infiltration rates and soil hydrophobicity are dependent on plant species type within forested areas on the island of Maui. The field data collection is part of a study to quantify the impacts of high-priority non-native and dominant native plant species on freshwater availability throughout the State of Hawaii ([https://archive.usgs.gov/archive/sites/hi.water.usgs.gov/studies/maui\\_eco/index.html](https://archive.usgs.gov/archive/sites/hi.water.usgs.gov/studies/maui_eco/index.html)). The overall objective of the study is to provide needed information for (1) assessing species-specific impacts on freshwater availability and (2) reducing uncertainty in regional recharge estimates associated with forested areas.

This dataset includes a summary of measurements of soil field-saturated hydraulic conductivity, hydrophobicity, and preferential flow collected at four study sites on the island of Maui, Hawaii between September 2017 and August 2018. The dataset also includes a summary of soil particle-size analyses made on a subset of soil samples collected from the four sites.

### Map »



### Spatial Services

ScienceBase WMS :  
<https://www.sciencebase.gov/catalog>

### Communities

- USGS Data Release Products
- USGS Pacific Islands Water Science Center

### Tags

<https://doi.org/10.5066/P9OP3BHM>

**USGS**  
science for a changing world

ScienceBase-Catalog Communities Help Log in

ScienceBase Catalog → USGS Pacific Islands Water ... → Ecohydrology → Soil Characteristics → Summary of soil field-saturat...

## Summary of soil field-saturated hydraulic conductivity, hydrophobicity, and preferential-flow measurements and soil laboratory-testing results collected at three sites on the islands of Maui and Hawaii, Hawaii, July 2016–January 2018

View

### Dates

Publication Date : 2019-03-20  
Time Period : 2016-07-15  
Time Period : 2017-04-14  
Time Period : 2017-07-26  
Time Period : 2018-01-24  
Time Period : 2018-01-25

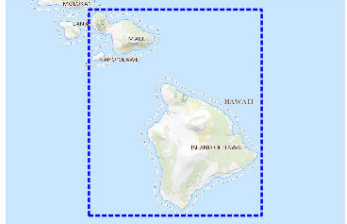
### Citation

Kennedy, J.J., Mair, A., Perkins, K.S., Nullet, M.A., Tseng, H., and Miyazawa, Y., 2019, Summary of soil field-saturated hydraulic conductivity, hydrophobicity, and preferential-flow measurements and soil laboratory-testing results collected at three sites on the islands of Maui and Hawaii, Hawaii, July 2016–January 2018: U.S. Geological Survey data release, <https://doi.org/10.5066/P9J5SESD>.

### Summary

The U.S. Geological Survey Pacific Islands Water Science Center and the University of Hawaii at Manoa Department of Geography, in cooperation with the U.S. Department of Interior Pacific Islands Climate Adaptation Science Center initiated a field data-collection program as part of a study to quantify the impacts of drought on water resources and the importance of cloud-water interception in mitigating the impacts of drought (see Related External Resources link below). The goal of the data-collection program is to provide information for evaluating the role that cloud-water interception in Hawaii's rain forests has in providing moisture for plants, reducing wildfire risk within the fog zone, and contributing to groundwater recharge to aquifers that supply drinking water and persistent groundwater discharge to streams even during dry periods. The overall objective of the study is to provide needed information (1) to estimate changes in soil moisture, evapotranspiration, and groundwater recharge during periods of drought for current and projected climate conditions, and (2) to estimate the combined impact of drought and reduced cloud-water interception

### Map »



### Communities

- National and Regional Climate Adaptation Science Centers
- Pacific Islands CASC
- USGS Data Release Products
- USGS Pacific Islands Water Science Center

### Tags

Categories : Data  
Harvest Set : USGS Science Data Catalog (SDC)  
Theme : bulk density, gravimetric water content,

<https://doi.org/10.5066/P9J5SESD>

# Mahalo!



Native forest plot  
Kahoma, Maui

Alan Mair

[dmair@usgs.gov](mailto:dmair@usgs.gov)

U.S. Geological Survey

Pacific Islands Water Science Center

Honolulu, Hawai'i