

Assessing the Effects of Watershed Management Projects on Enhancing Groundwater Resources, Hawai'i

Hawai'i Water Works Association
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U.S. Geological Survey

The Rain Follows the Forest Initiative

State of Hawaii (2011):

“Protecting forest watersheds is the most cost effective and efficient way to absorb rainwater and replenish ground water.”

Bailey (1851):

“It is a well established fact that rains are more frequent and copious where trees abound, than where they are wanting.”

The Rain Follows The Forest

Habai no ka ua i ka ululā`au

A Plan to Replenish Hawaii's Source of Water

Department of Land and Natural Resources - State of Hawaii

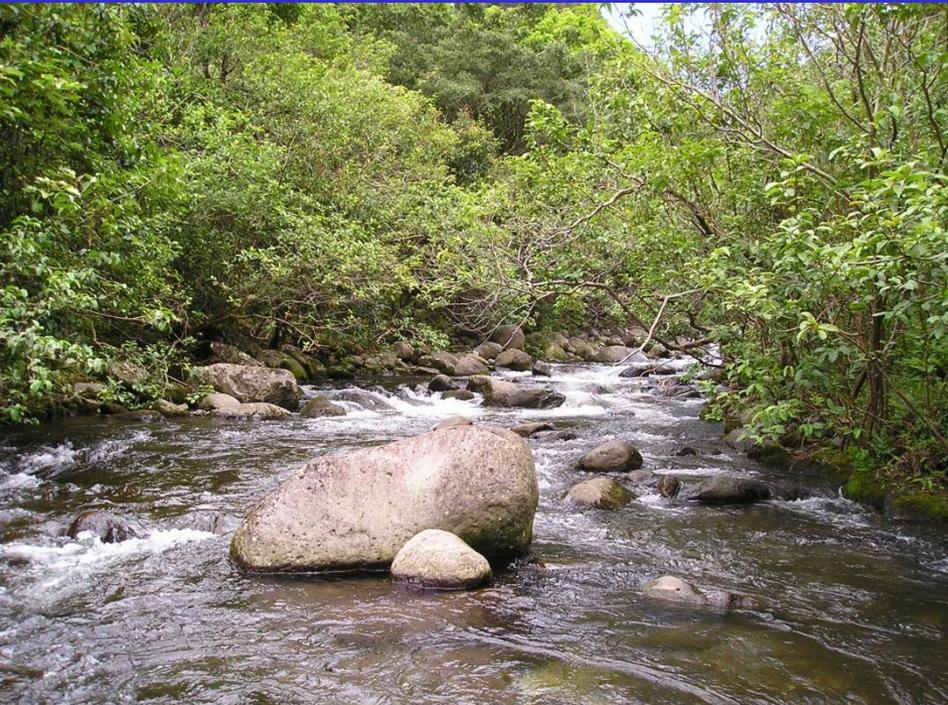
November 2011



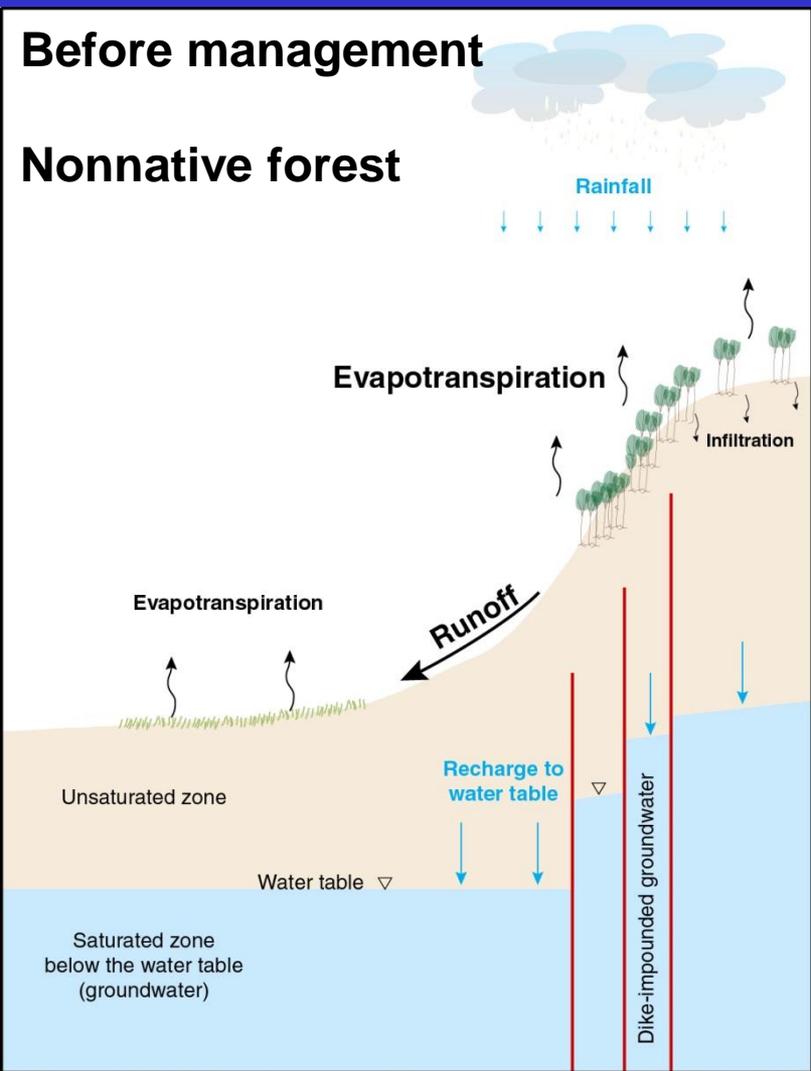
Photo: Air Maui

Motivation and Objective

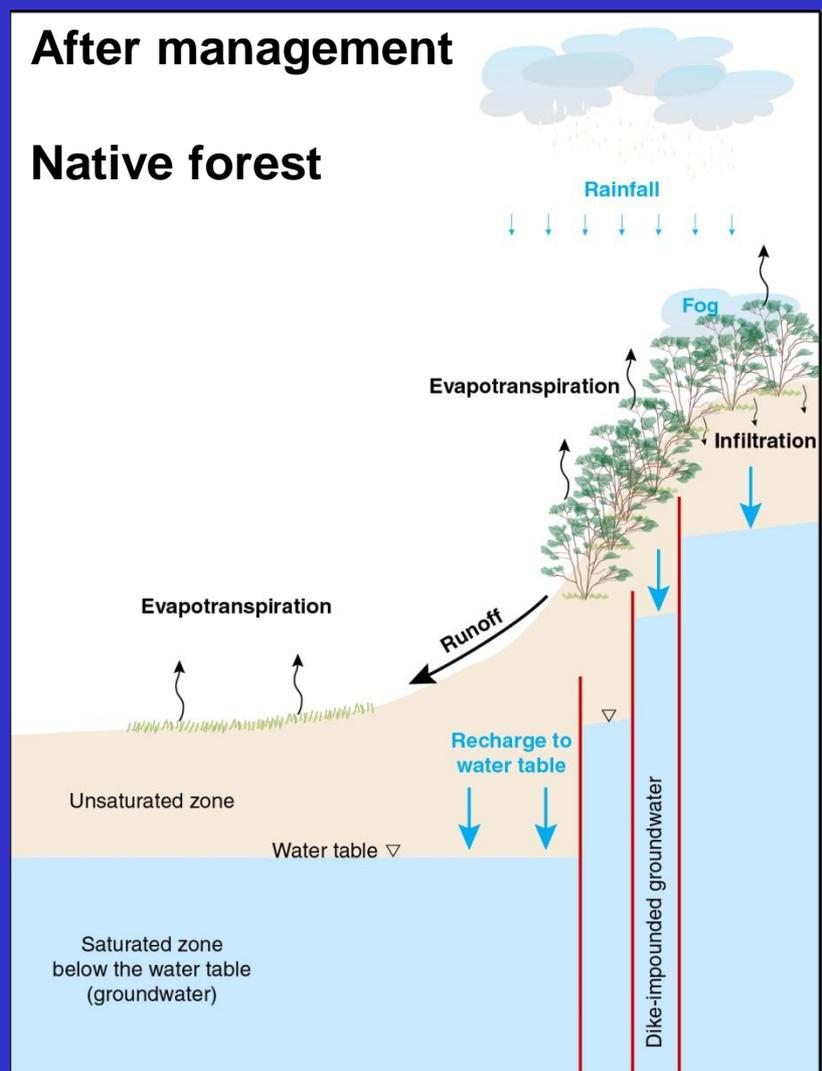
- Motivation: Although few would argue against the virtues of protecting forests, the hydrologic effects of watershed management projects have not been fully quantified
- Objective: To describe methods of quantifying the hydrologic response of a watershed to management projects



Watershed Management Projects May Affect Several Hydrologic Components

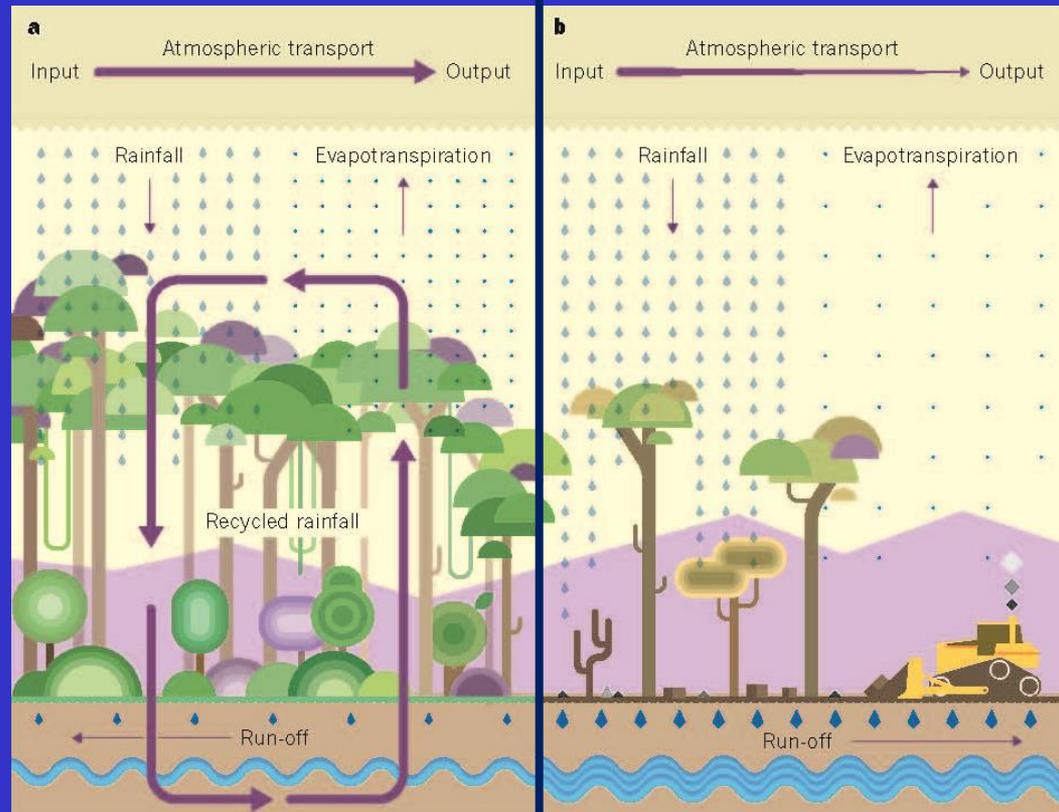


- Modify:**
- rainfall?
 - runoff
 - ET
 - fog drip
 - recharge



Does the Rain Follow the Forest?

- Tropical forests in continental areas can enhance rainfall by recycling water to the atmosphere through evapotranspiration (Spracklen and others, 2012)
- Deforested areas can enhance rainfall locally by enhancing convection (Negri and others, 2004)
- In Hawai'i, the effects of forests on rainfall have not been quantified



Aragão, 2012

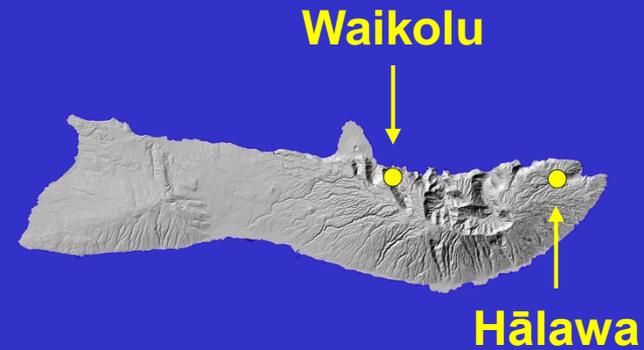
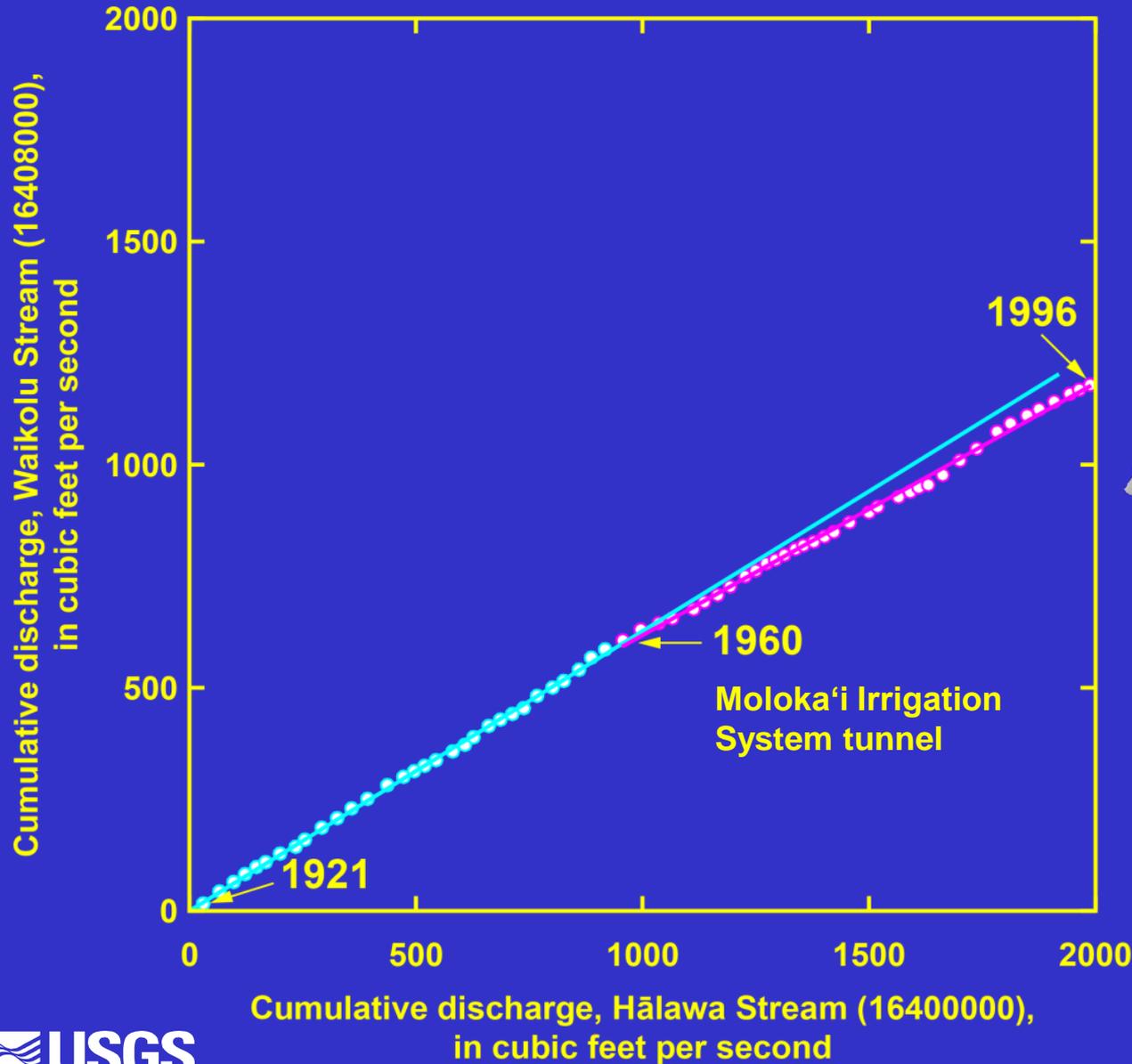
Forested:

ET recycles moisture to the atmosphere, enhancing rainfall

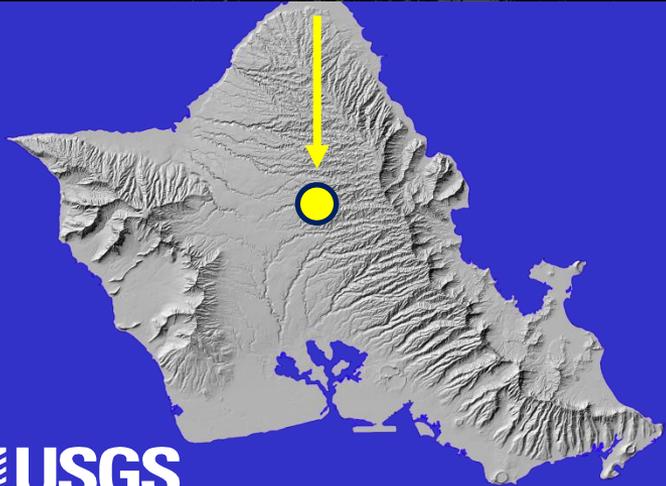
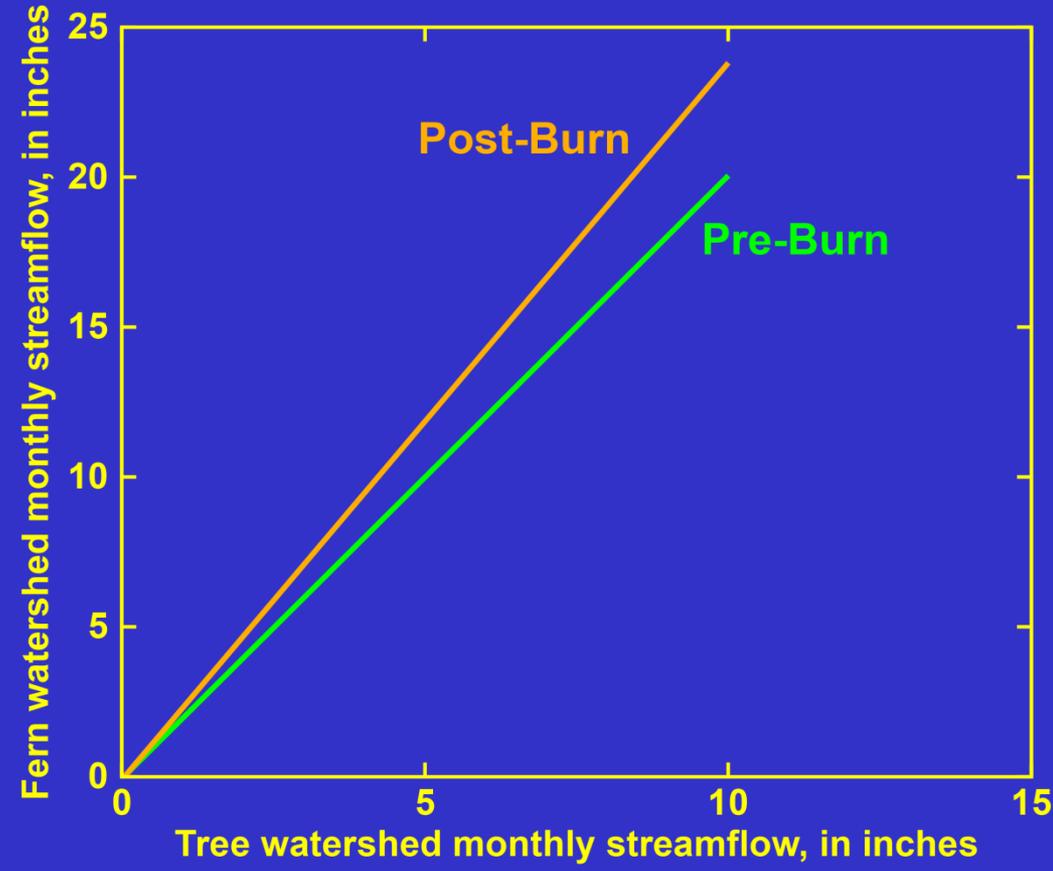
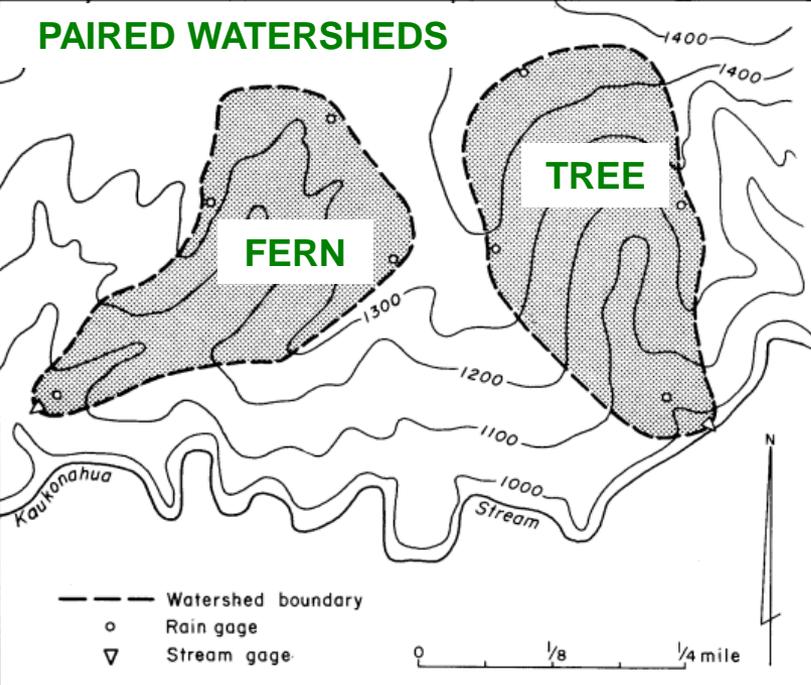
Deforested:

Reduced ET recycles less moisture to atmosphere, reducing rainfall

Streamflow — Double-Mass Curves



Streamflow — Effects of Vegetation



Transpiration — Effects of Vegetation

- Transpiration—process by which water is absorbed by plants and evaporated to the atmosphere
- Sap flow—transport of fluid in plant tissue

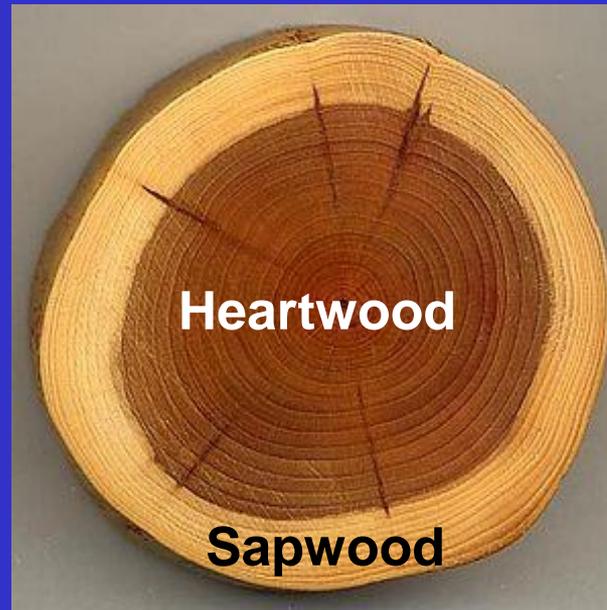
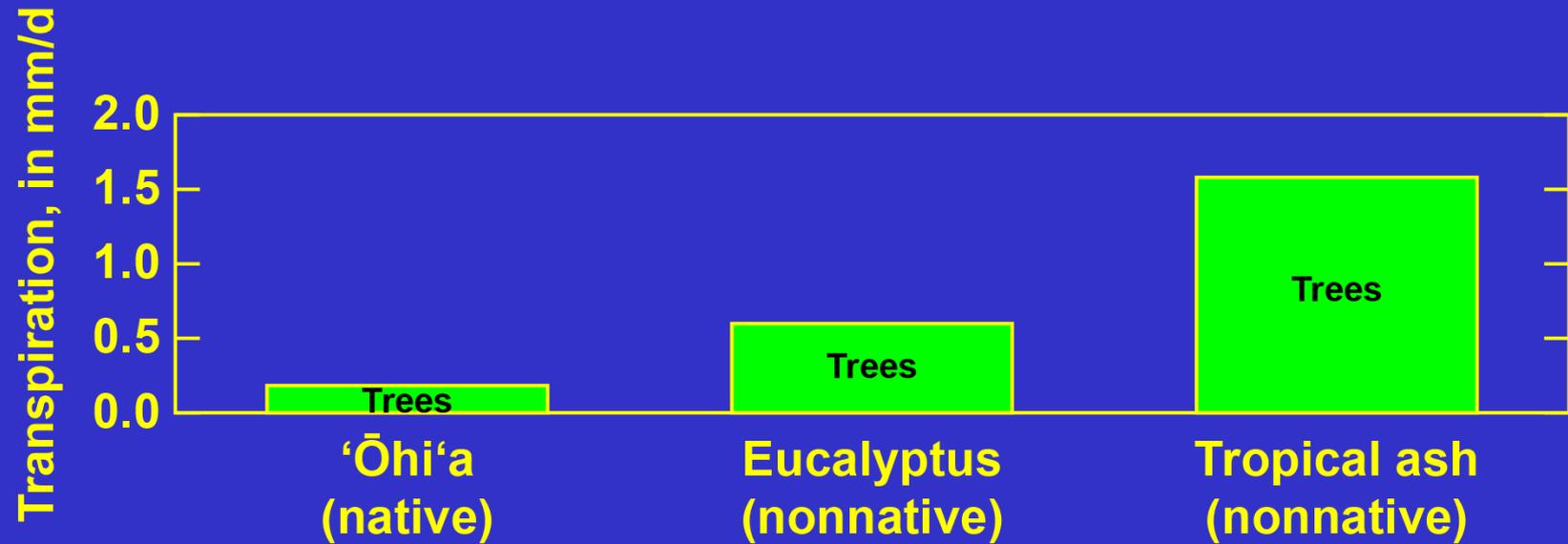
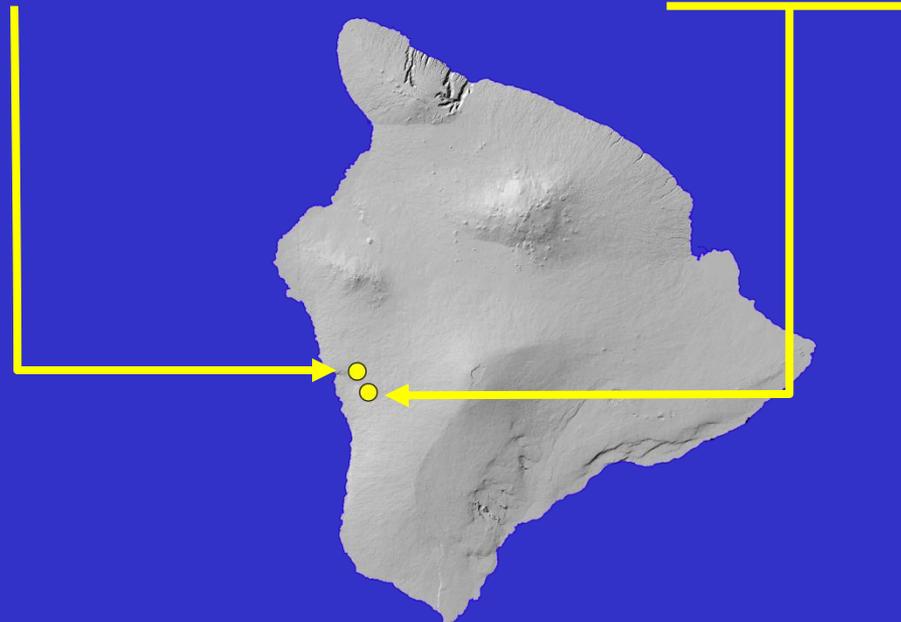


Photo from Wikipedia

Transpiration — Effects of Vegetation

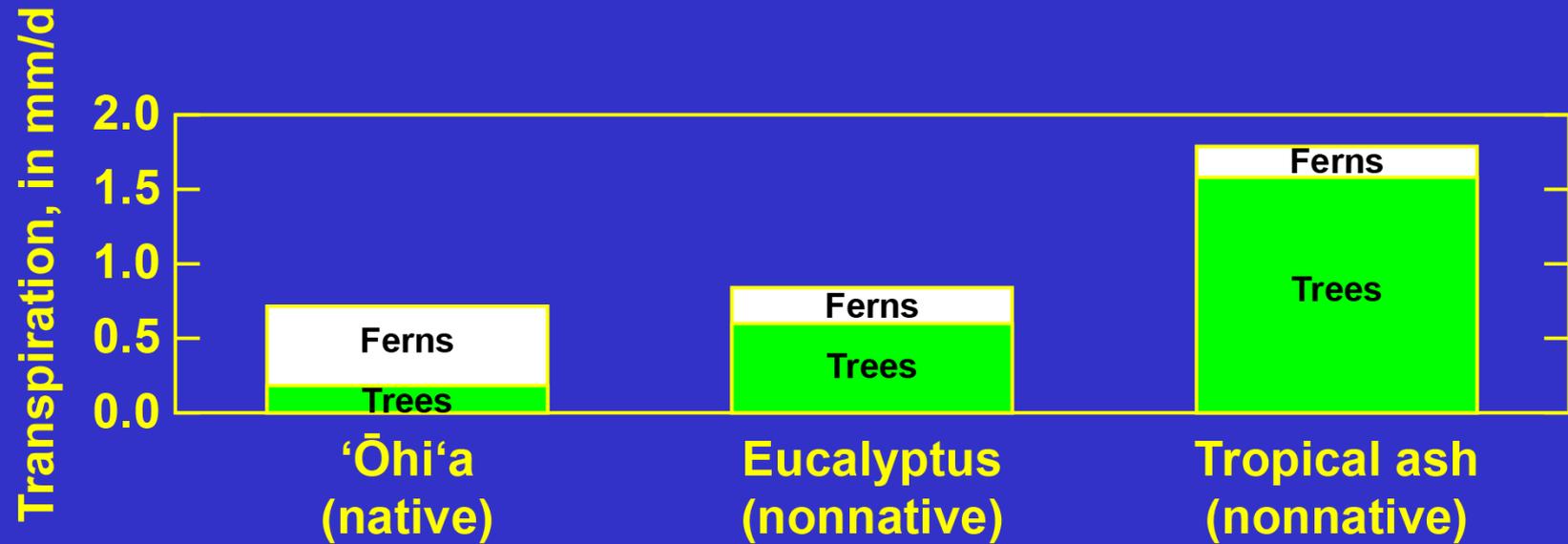


Old-growth 'ōhi'a

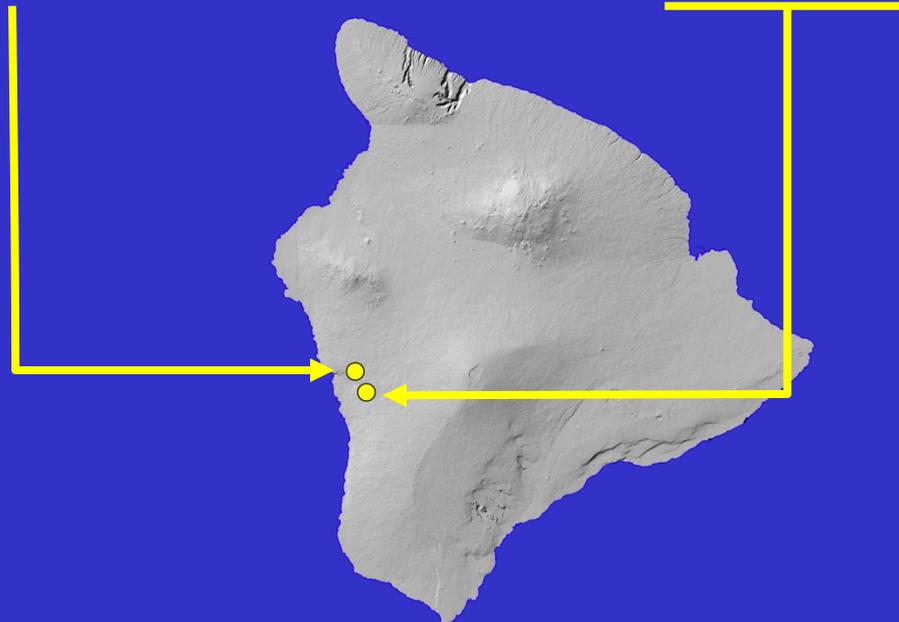


Nonnative plantation

Transpiration — Effects of Vegetation



Old-growth 'ōhi'a



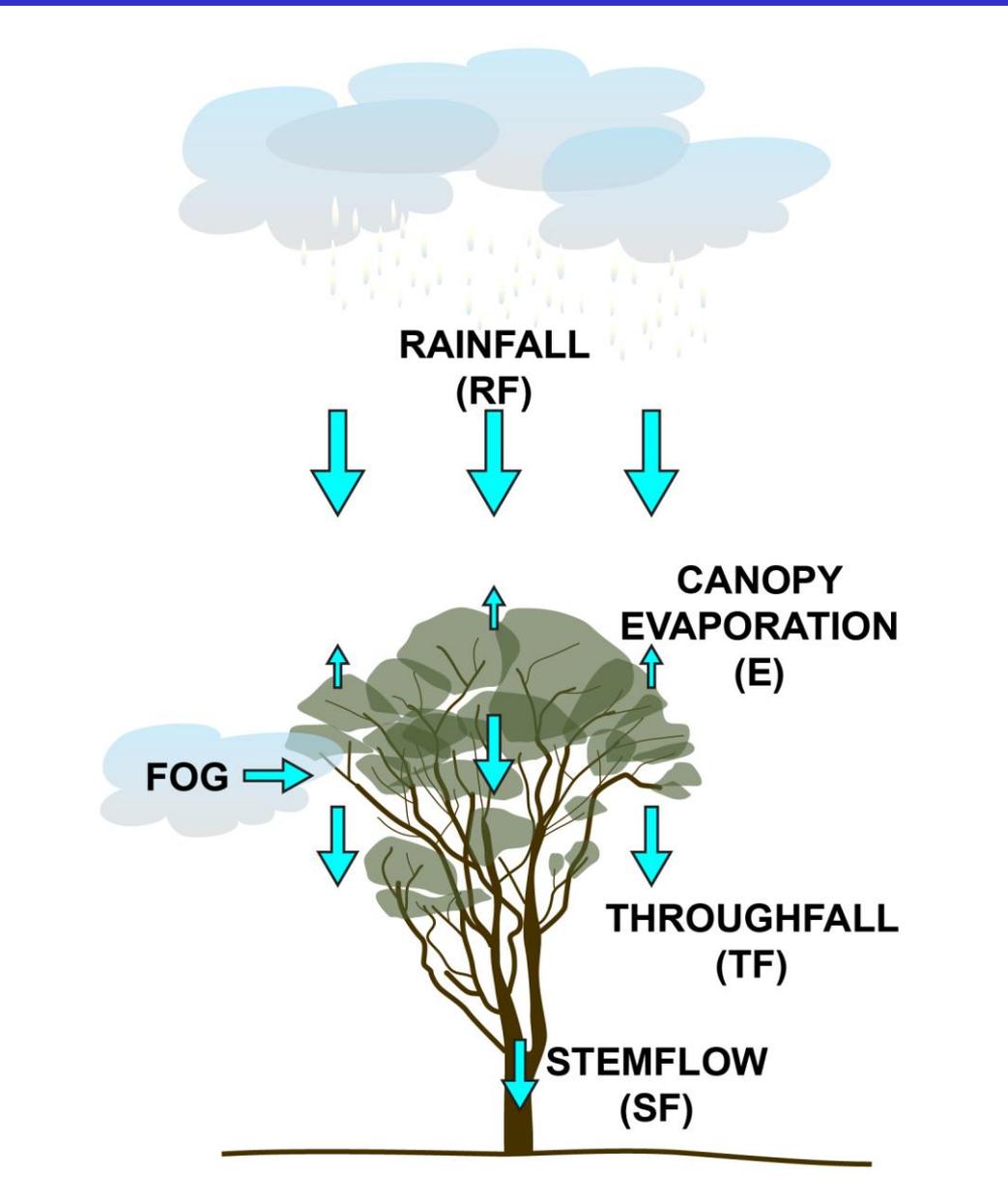
Nonnative plantation

Available Forest-Floor Water — Effects of Vegetation

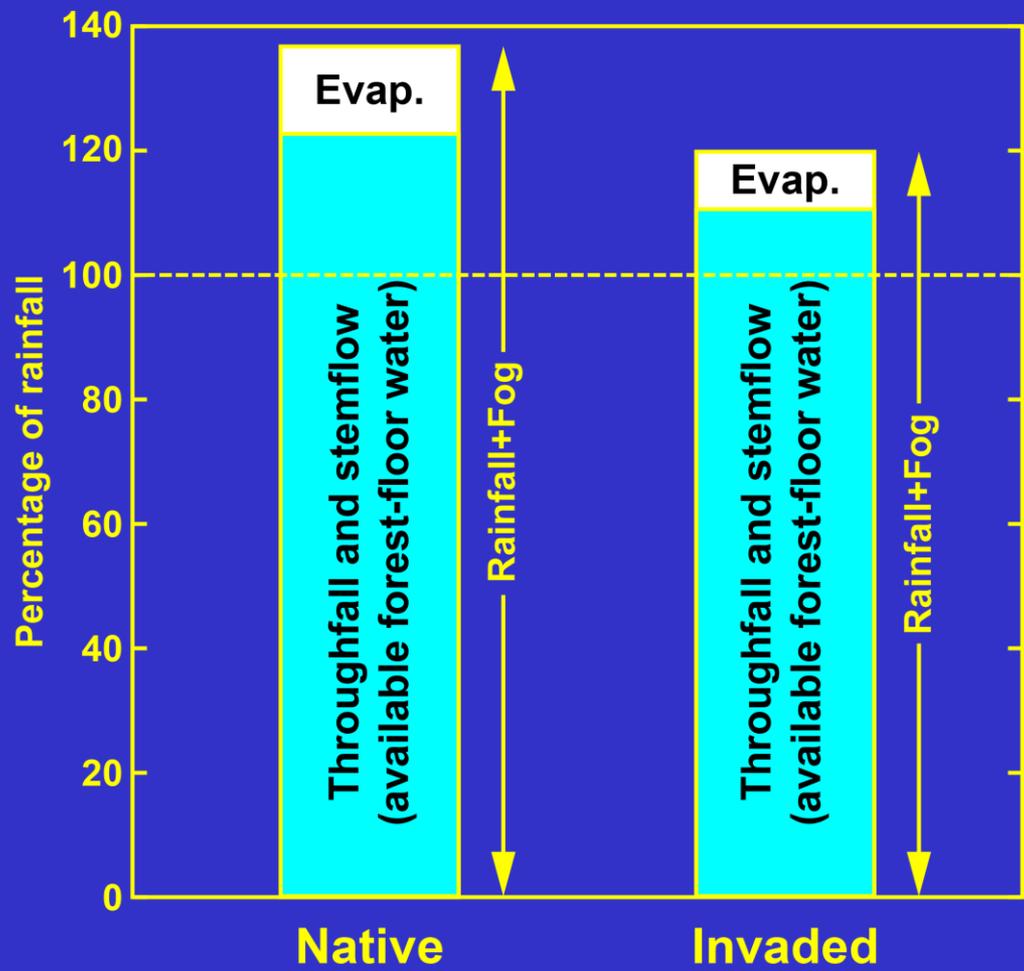
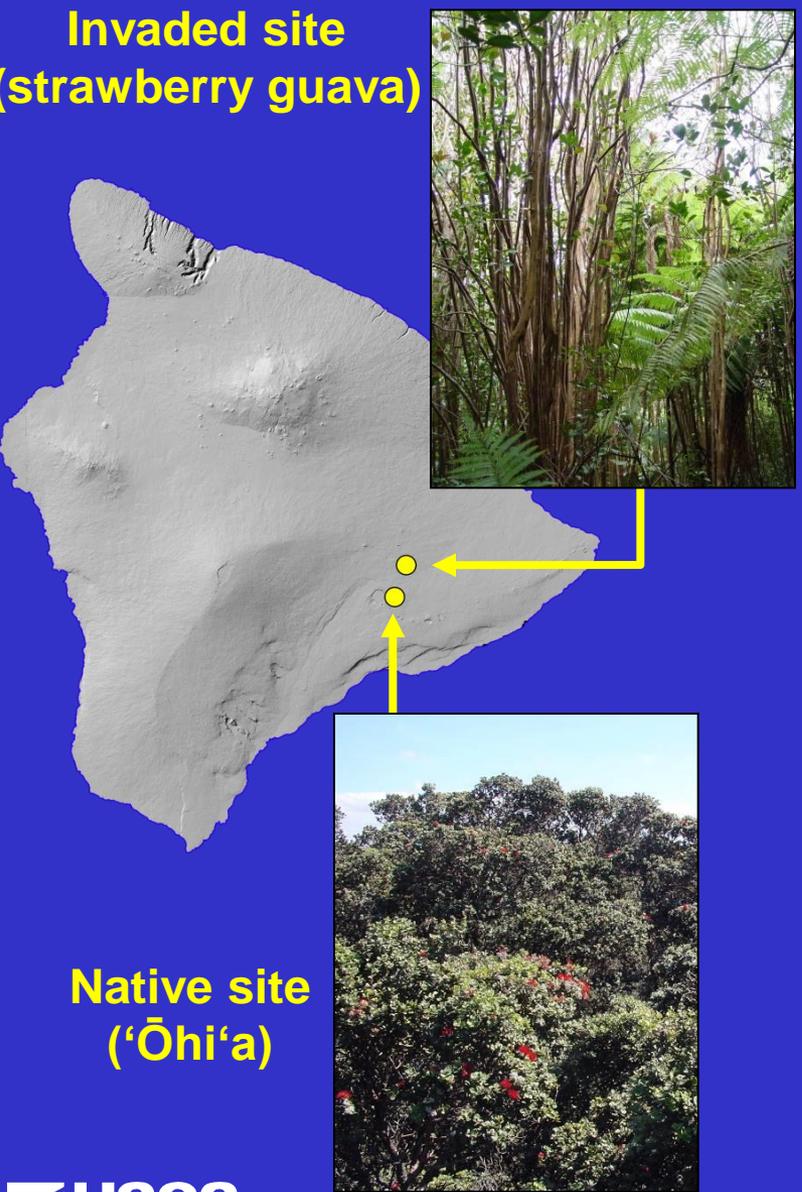
For the tree canopy, measure or compute each water input and output

Input = Output (steady state):
 $RF + Fog = E + TF + SF$

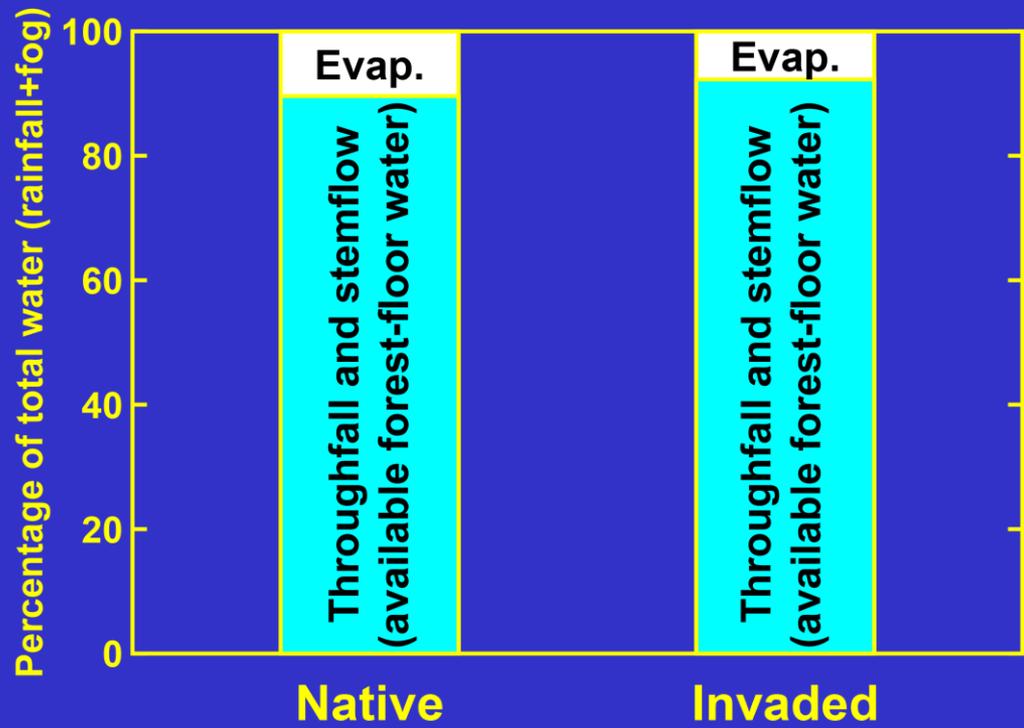
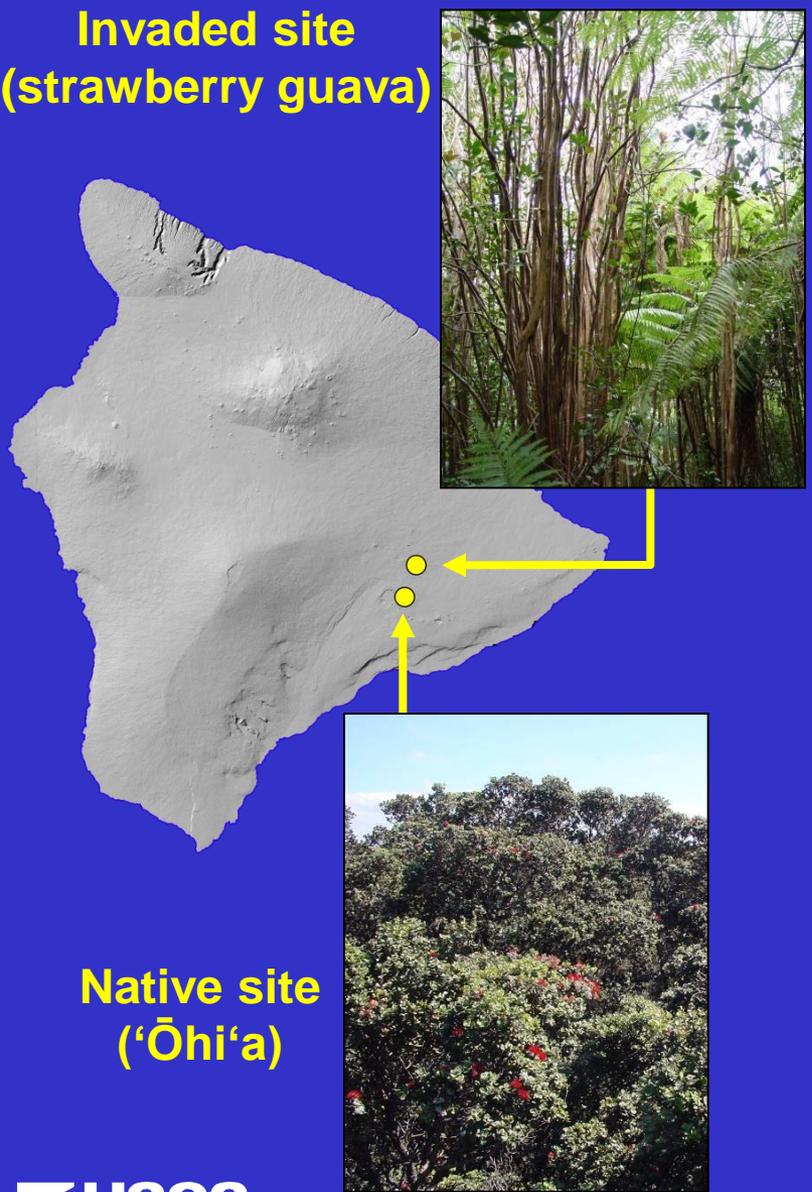
Outputs can exceed RF:
 $RF \leq E + TF + SF$



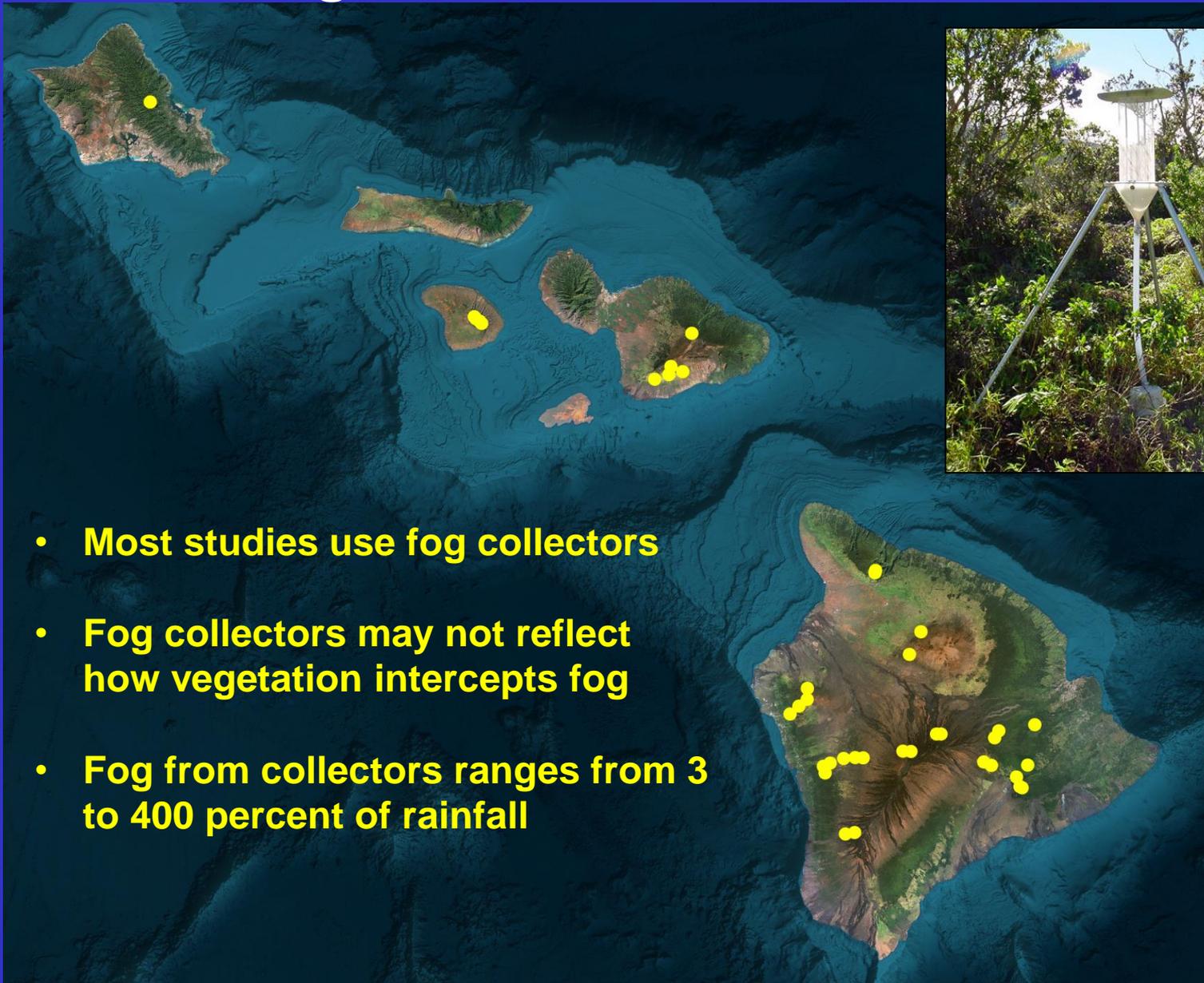
Available Forest-Floor Water — Effects of Vegetation



Available Forest-Floor Water — Effects of Vegetation

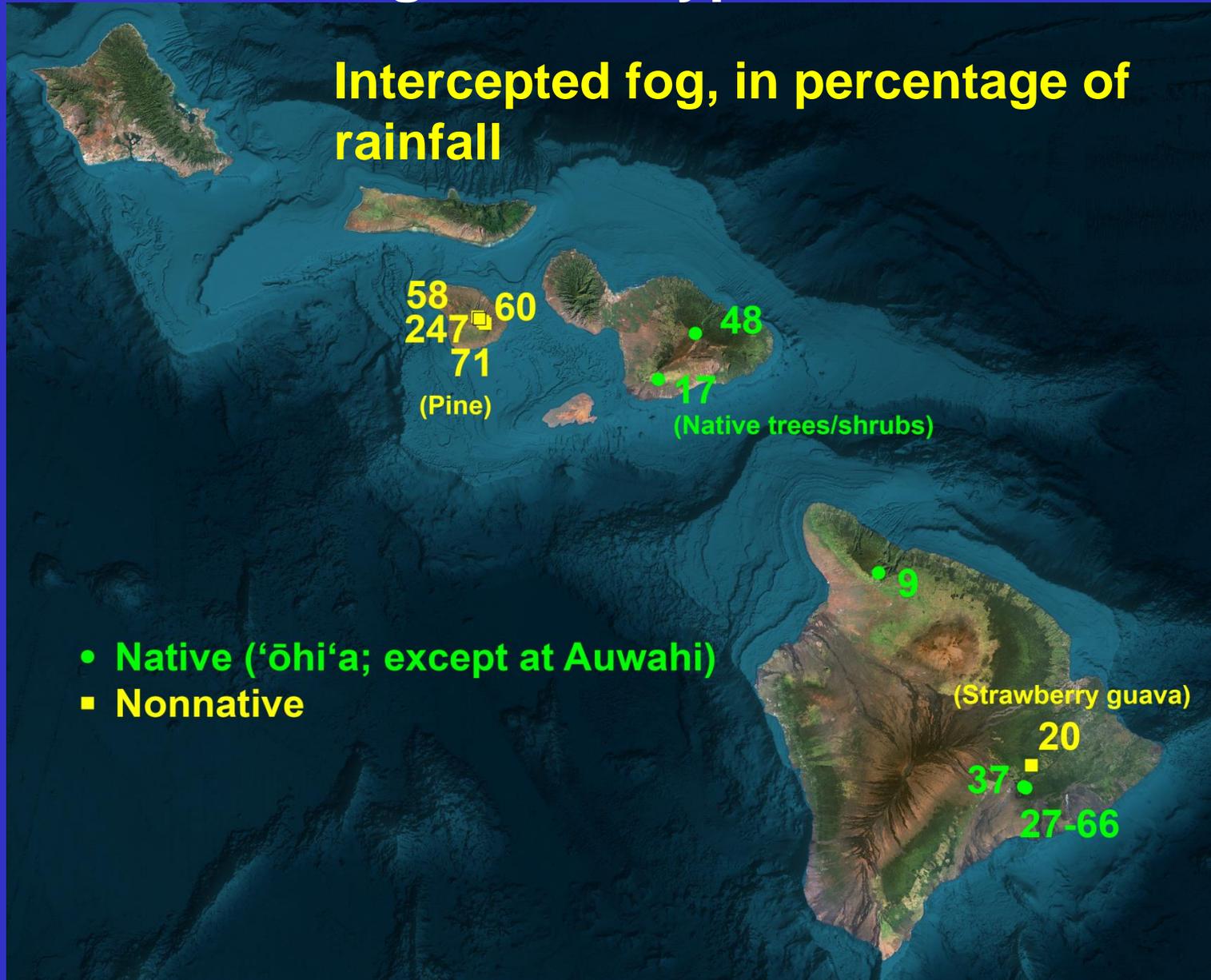


Fog Studies in Hawai'i



- Most studies use fog collectors
- Fog collectors may not reflect how vegetation intercepts fog
- Fog from collectors ranges from 3 to 400 percent of rainfall

Fog — Effects of Vegetation Type, Stature, Location



Ekern, 1964; Heath and Huebert, 1999; Delay, 2005; Schlappa, 2006; Delay and Giambelluca, 2010; Giambelluca and others, 2011; Juvik and others, 2011; Takahashi and others, 2011

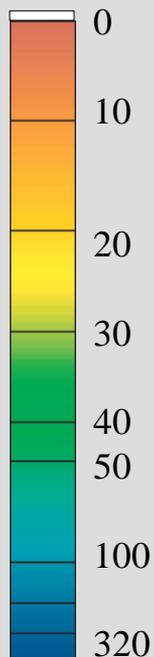
Selected Recharge-Estimation Methods

Method	Description
Water budget	Account for daily changes in soil moisture and daily recharge
Watershed model	Model rainfall-runoff process to est. recharge
SGD	Measure submarine groundwater discharge (SGD)
Lysimeter	Measure recharge in soil zone
Groundwater levels	Monitor water-level changes that reflect recharge changes
Gravity	Monitor gravity changes that reflect recharge changes
Tracers	Monitor tracer movement/concentration to est. recharge
Seepage runs	Measure changes in groundwater discharge to stream
Double-mass curves	Analyze base flow at gaging stations
Numerical model	Model changes in soil moisture in root zone and recharge
Darcy's law	Multiply hydraulic conductivity and head gradient to est. recharge

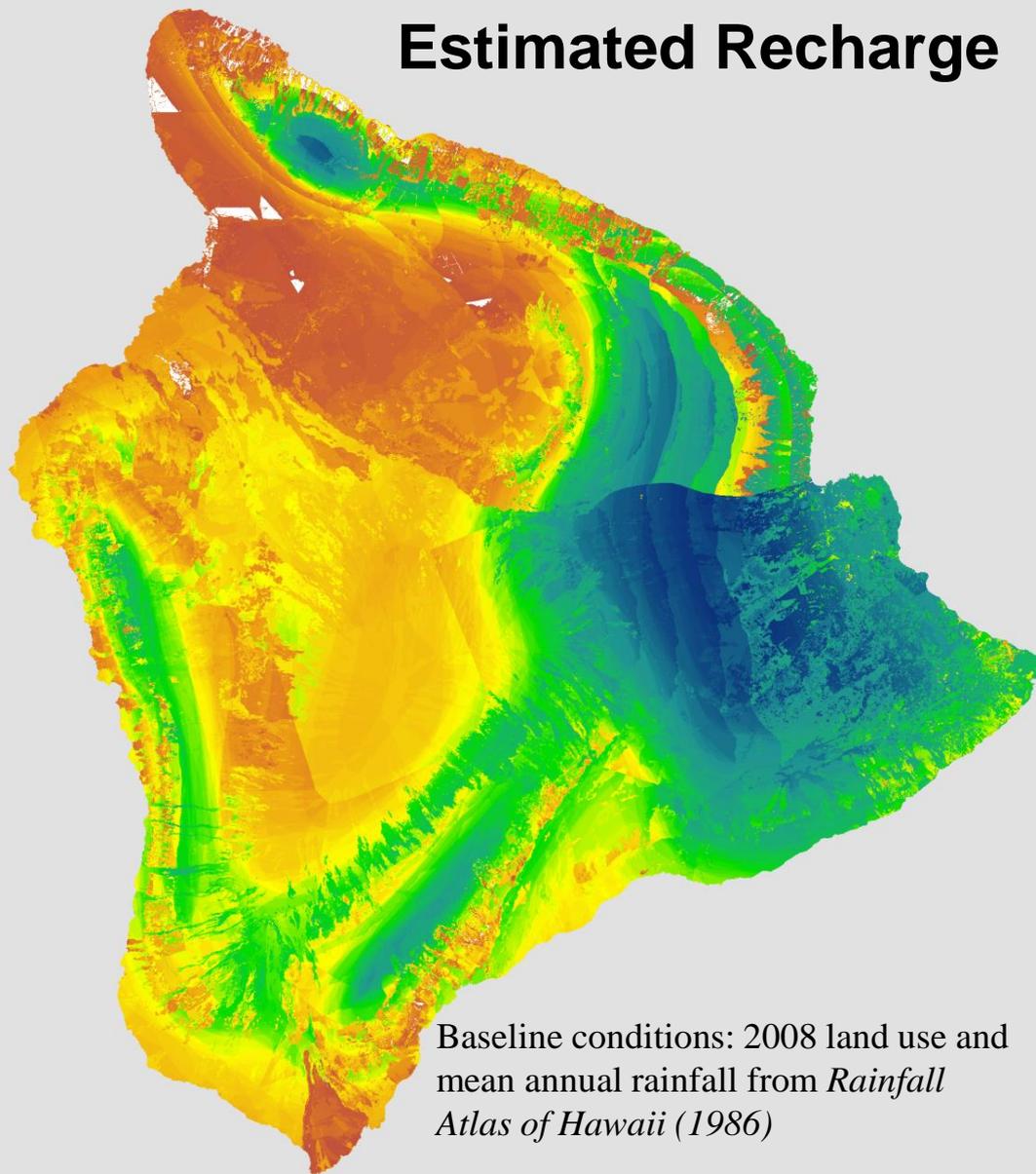
Recharge — Water Budget

For each area, account for the water inputs to and outputs from the root zone to estimate recharge

Mean annual recharge, in/yr



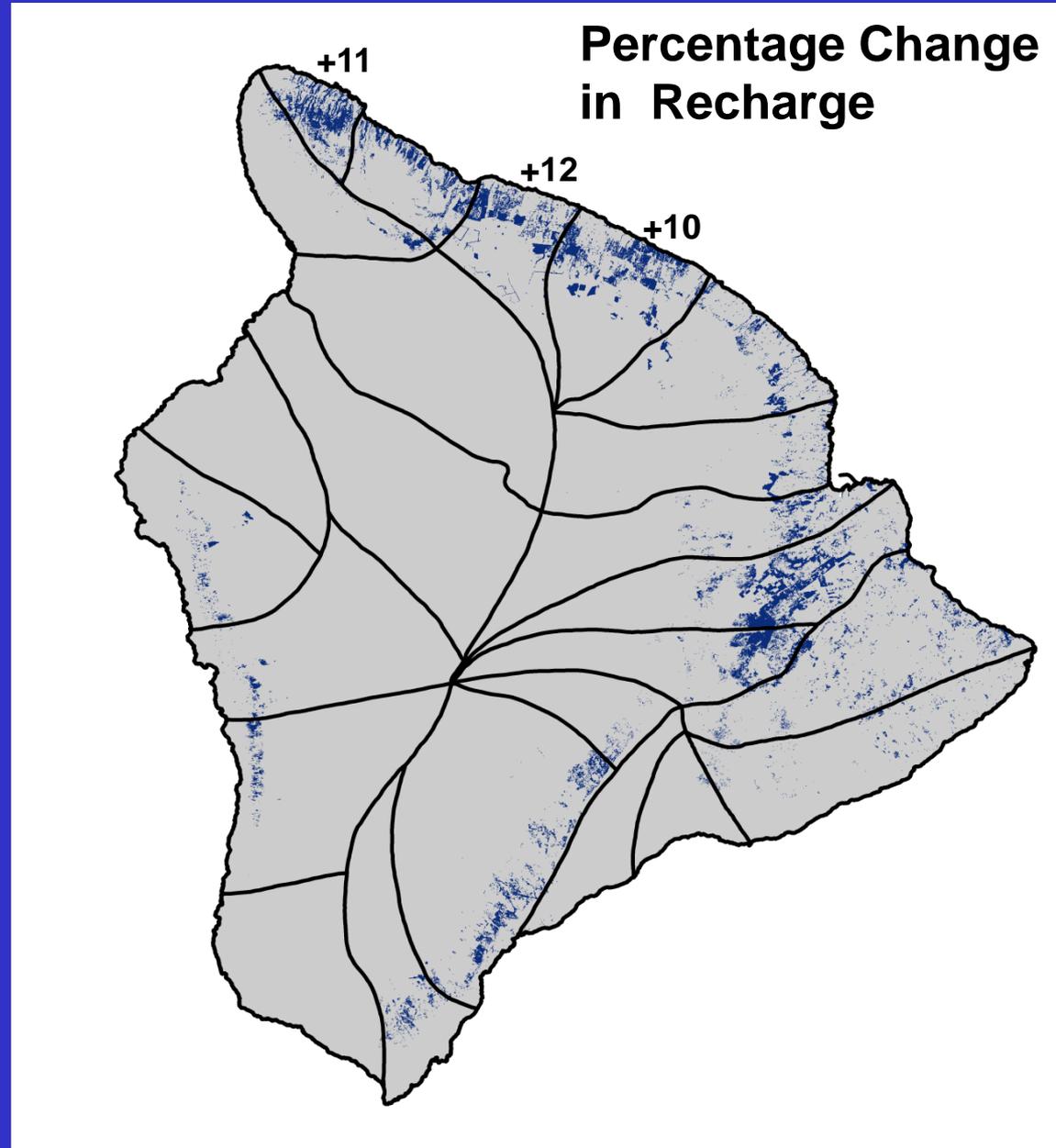
Estimated Recharge



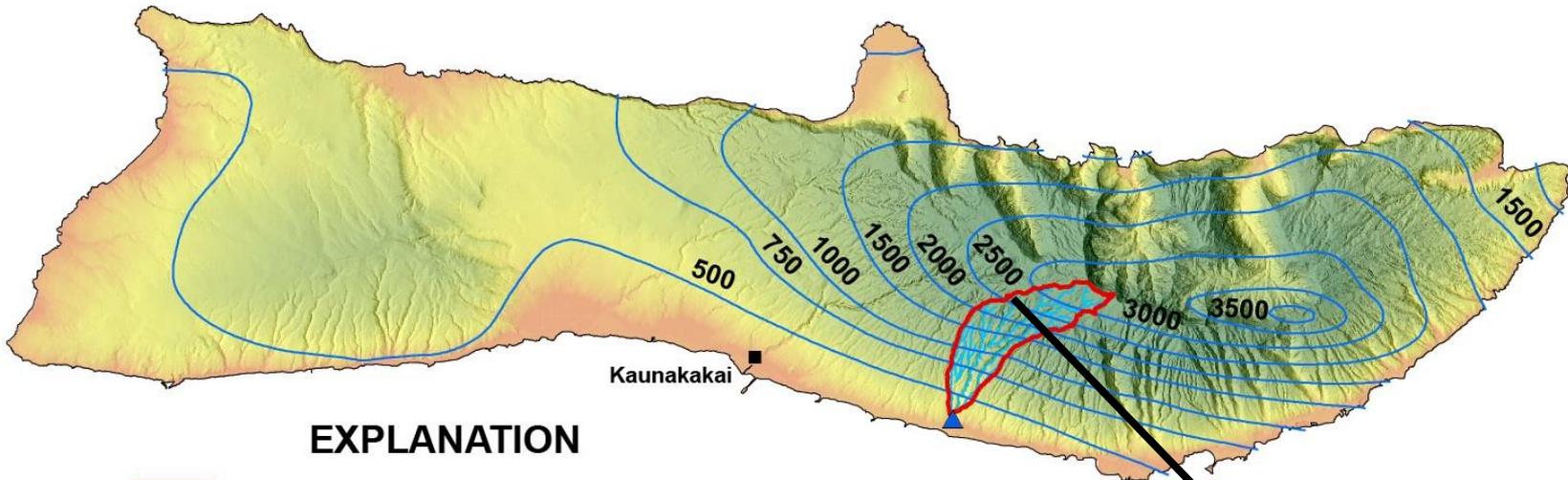
Baseline conditions: 2008 land use and mean annual rainfall from *Rainfall Atlas of Hawaii (1986)*

Recharge — Effect of Vegetation

Replace nonnative forest with native forest in water budget model

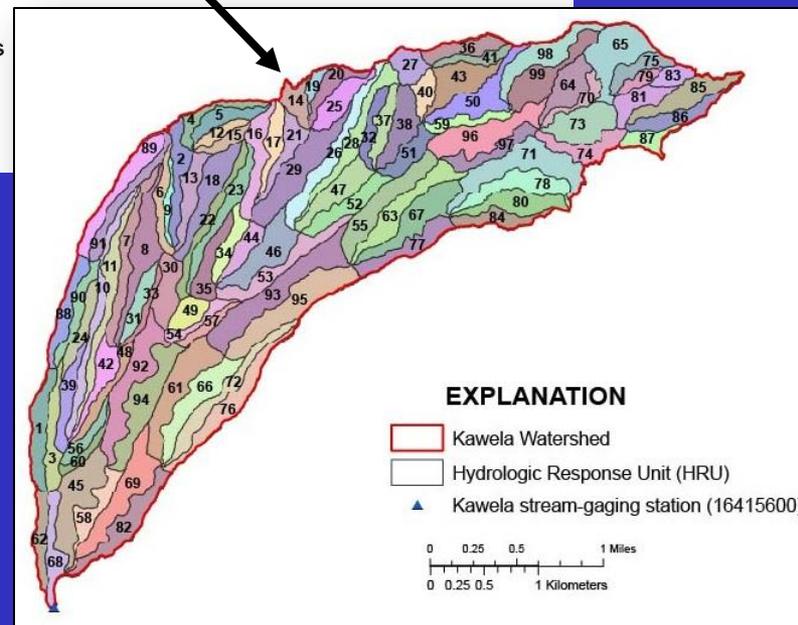
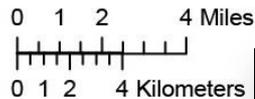


Watershed Model



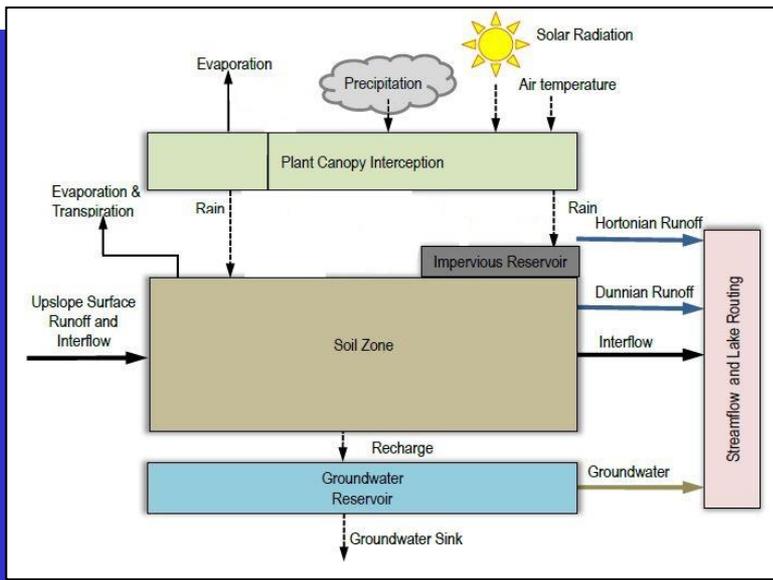
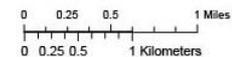
EXPLANATION

- Kawela Watershed
- Kawela Watershed Streams
- Average Annual Rainfall (mm)
- ▲ Kawela stream-gaging station (16415600)

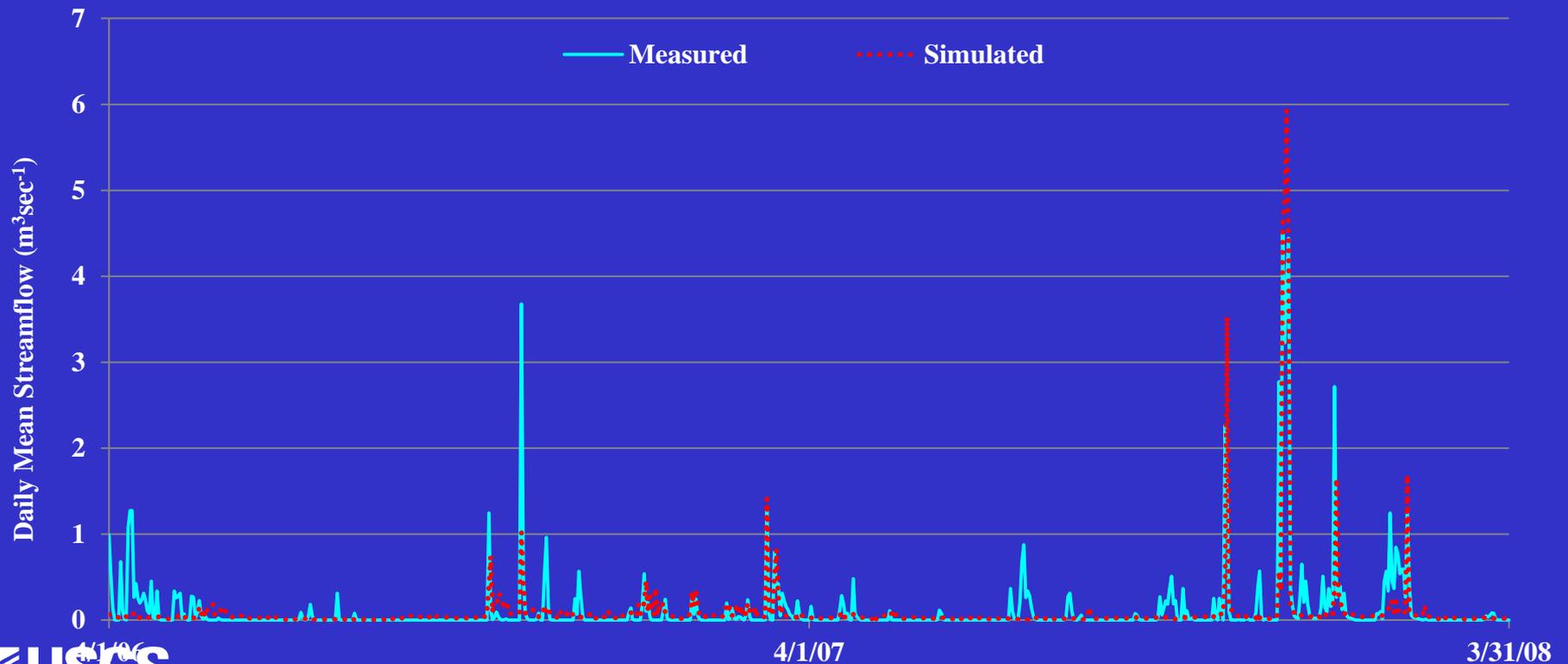
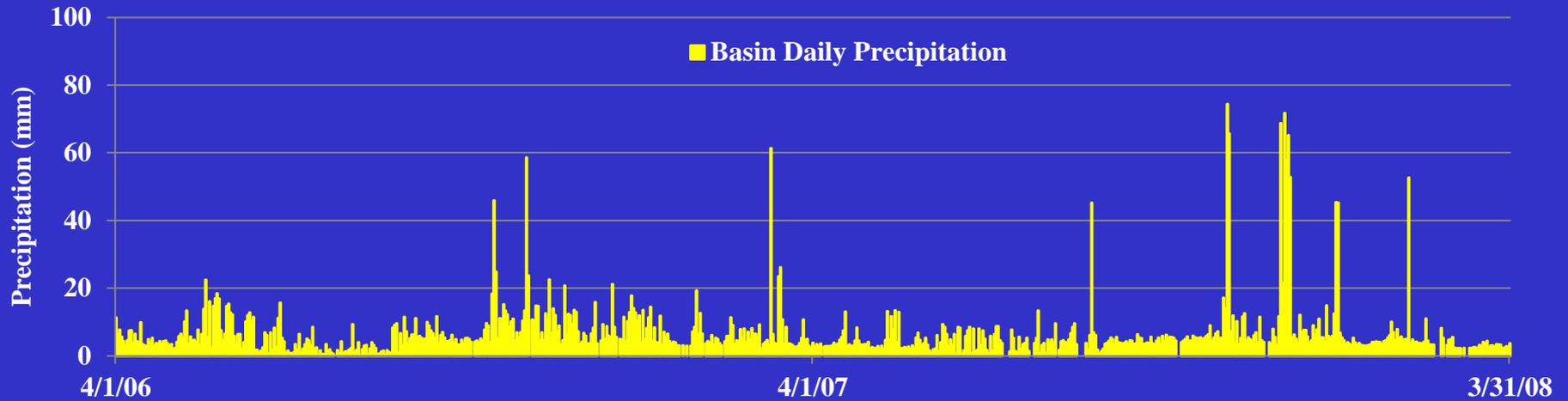


EXPLANATION

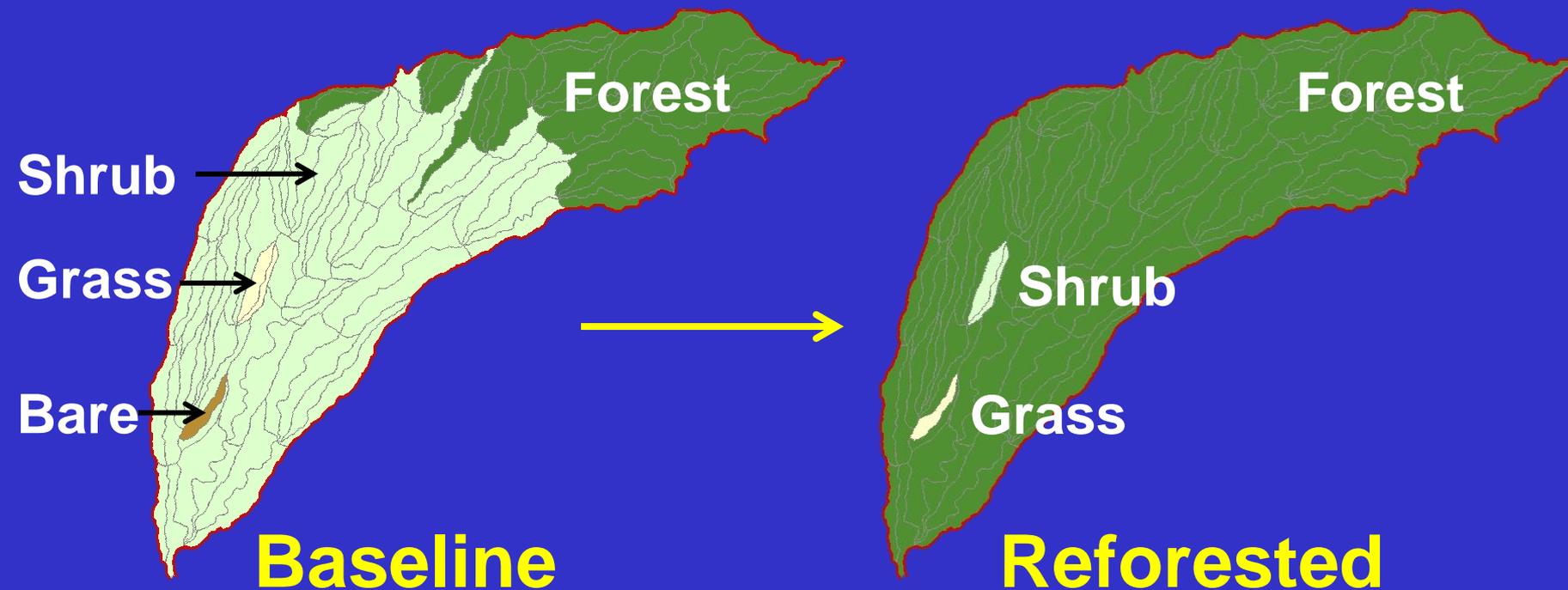
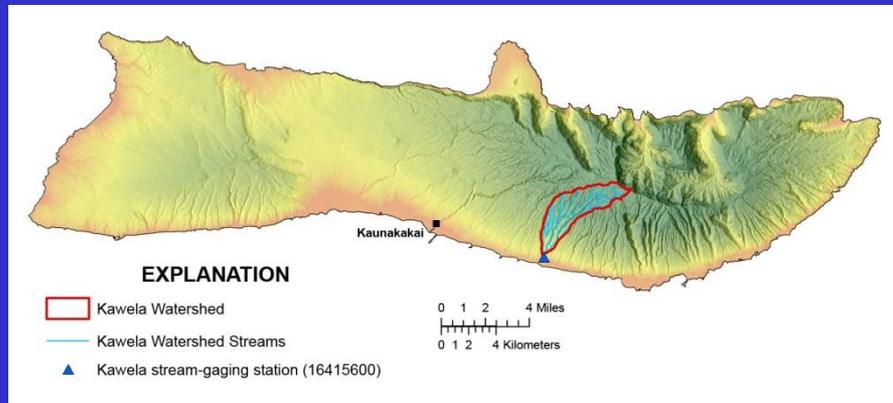
- Kawela Watershed
- Hydrologic Response Unit (HRU)
- ▲ Kawela stream-gaging station (16415600)



Watershed Model — Simulate Runoff



Watershed Model — Effects of Reforestation



Watershed Model — Effects of Reforestation

Average Annual Water Budget				
Scenario	Precipitation (in/yr)	ET (in/yr)	Runoff (in/yr)	Recharge (in/yr)
Baseline	79	34	7	38
Reforested	80	39	6	35

- Rainfall not changed in model
- Precipitation increases—forests intercept more fog
- Recharge decreases—forests utilize more water

CONCLUSIONS

- No known studies in Hawai'i to evaluate whether the rain follows the forest or the forest follows the rain
- Studies on how vegetation affects individual hydrologic components (runoff, ET, fog) are necessary but not sufficient to evaluate impact of land management on water resources
- Water budgets and watershed models are needed to synthesize information on individual hydrologic components and provide a method to evaluate regional impact of land management on water resources

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