Water in the Rain Forest--What Goes In and What Comes Out

Growing numbers of residents, tourists, and commercial developments mean an increasing demand for fresh water on Maui. Currently, the main source for water to supply most of the island's municipal uses is on West Maui, where wells pump water from the ʻĪao "aquifer" (an underground source of water). The ʻĪao aquifer is near its limit and cannot support much greater water withdrawals, so people are looking around for other sources of water for drinking, cooking, bathing, watering lawns and golf courses, filling pools, washing clothes and dishes, and all of our other daily activities that require fresh water.

One place people are looking is the windward side of East Maui, where large sources of ground water are still untapped. Sixty billion gallons of surface water per year from this part of East Maui already provide much of Upcountry and East Maui drinking water and most of the irrigation water that goes to the Hawaiian Commercial & Sugar Company in Central Maui. Some people, including the Board of Water Supply, want to tap the "ground water," too. (Ground water is the water that flows and is held in aquifers below the surface.) They look at that underground water as a key to providing fresh water for the entire island's future needs.

But the water that flows above the surface ("surface water") and the water that flows below it (ground water) are linked. Some people are concerned that pumping a lot of ground water and piping it off for use elsewhere on Maui would reduce the flow in the springs and streams that course down the flank of Haleakalā. They want more information about how the ground water and surface water interact on windward Haleakalā.

One effort to provide that information was a project completed in 1999 by the U.S. Geological Survey in partnership with the County of Maui Department of Water Supply and the State of Hawaiʻi Commission on Water Resource Management (Patricia J. Shade, *Water Budget of East Maui, Hawaii,* U.S. Geological Survey, Honolulu, 1999). Project investigators used existing data and models to calculate an average monthly "water budget" for East Maui. Part of that calculation focused specifically on the wet, windward side of East Maui between Māliko Gulch on the west and Makapipi Stream on the east, and from the shore to the north rim of the Haleakalā summit basin. (Figure 1, p. 46 shows the study area.)

A "water budget" is simply a model that estimates how much water enters and leaves a particular area, and through what mechanism. It is a first step in understanding a ground water system so that water resources can be managed well. Calculating a water budget is a complicated undertaking that involves many measurements, estimates, and calculations. The basic idea, however, is simple: What goes in must come out—or be stored somewhere within the system. Here is the basic equation:

$$G = P + F - R - ET - DSS$$

Where:

G = "ground water recharge"
P = rainfall
F = "fog drip"
R = "runoff"
ET = "evapotranspiration"
DSS = change in "soil-moisture storage"

(Figure 2, p. 47 illustrates the basic elements of the hydrologic cycle.)

Water Budget Equation Elements

Ground Water Recharge

This refers to the amount of water that filters into the soil, percolating through until it reaches

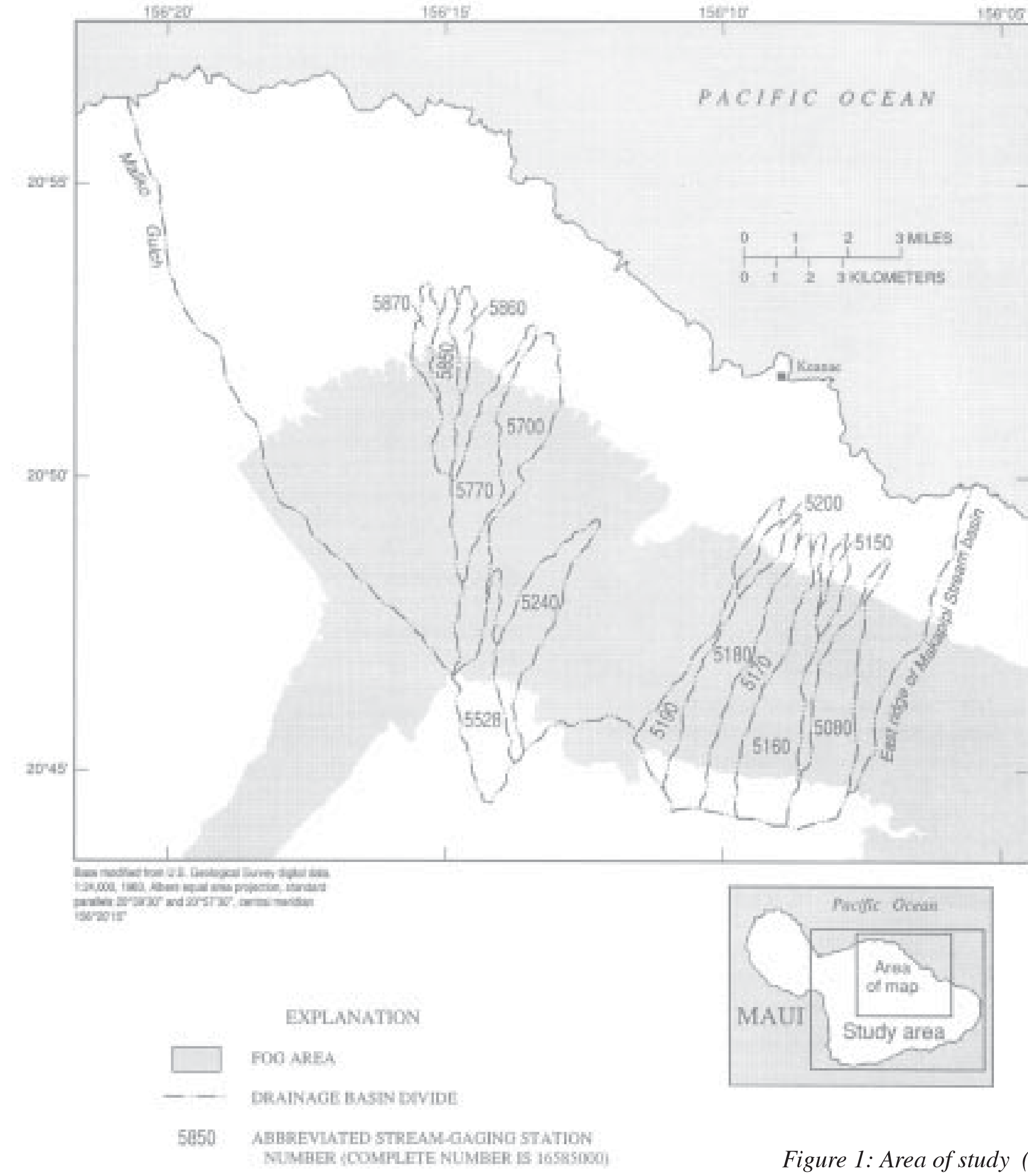


Figure 1: Area of study (Patricia J. Shade, Water Budget of East Maui, Hawaii*, U.S. Geological Survey, Honolulu, 1999, p. 13.)*

the underground reservoirs and flow-ways called aquifers. To calculate this amount, the other variables need to be known or estimated.

Rainfall

As you have learned in this unit, the rainfall distribution on windward Haleakalā is influenced by the orographic effect. Rainfall is abundant at most elevations as the prevailing trade winds are forced to rise and cool, condensing into clouds and rain. Monthly mean rainfall levels were calculated based on interpreting collected data to create maps denoting different rainfall levels across the study area.

Fog Drip

Also known as cloud-water interception, fog drip contributes water to the water budget

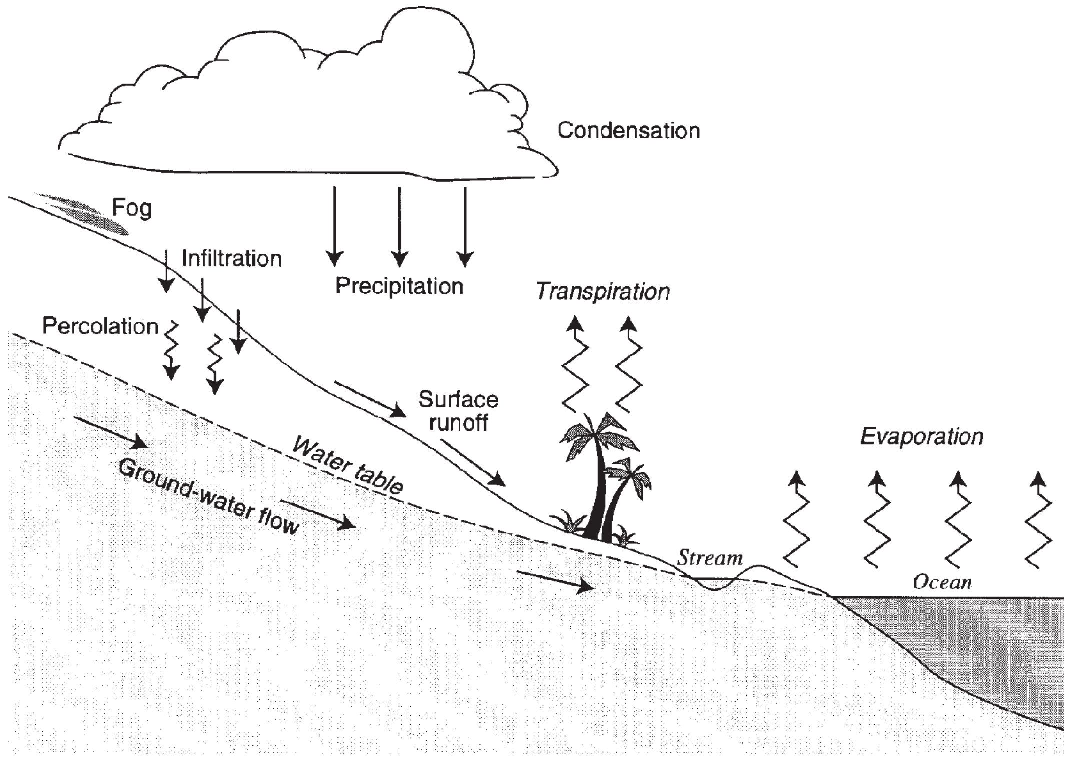


Figure 2: The hydrologic cycle (Patricia J. Shade, Water Budget of East Maui, Hawaii*, U.S. Geological Survey, Honolulu, 1999, p. 6.)*

through condensation that accumulates on the surfaces of plants and the ground. Limited data are available for calculating this part of the equation on East Maui. So its contribution was estimated based on research done on the windward slopes of Mauna Loa on the island of Hawai'i. As you have also learned in this unit, the cloud (or fog) zone on windward Haleakalā is influenced by the interaction of the orographic lifting effect and the trade wind inversion. In this area, fog drip makes a significant contribution to the water budget.

Runoff

Runoff is the water that flows across the land surface and into stream channels promptly after rainfall. It is calculated using data gathered about streamflow in fourteen different drainage basins on windward Haleakalā. Stream flow has two components: runoff and "base flow." Base flow is the part of stream flow that is sustained through dry weather by the discharge of ground water into the stream. So runoff can be estimated by subtracting the base flow from the total stream flow.

Evapotranspiration

This is the quantity of water evaporated from soil and water surfaces added to the amount of water evaporated as plants "transpire" (vaporize water through their leaf surfaces). For this study, evapotranspiration rates were estimated using two sets of data.

Soil characteristics

Soils of East Maui have been analyzed and mapped according to several characteristics that affect their ability to store moisture that would then be available to plants. These characteristics include "permeability rate" (how quickly water filters through the soil), how many inches of water each inch of soil can store, and the average depth of plant roots in that soil type. A maximum soil-moisture storage value was calculated for each soil type using these values, and the results were plotted on a soils distribution map. The maximum soil-moisture storage affects evapotranspiration because it can limit the amount of water available for plants to take up from the soil and transpire through their leaves.

Potential evapotranspiration

This is an estimate of the maximum evapotranspiration from an extensive area of well-watered, actively growing vegetation. It is estimated using data from standardized evaporating pans, which are easier to collect and have been shown to closely correspond with actual potential evapotranspiration. Where these data were not available, potential evapotranspiration was estimated based on research done on the windward slopes of Mauna Kea on the island of Hawai'i.

Change in Soil-Moisture Storage

This variable is an estimate of the amount of water actually being stored in the soil across the study area. The volume of water stored in the soil changes from month to month and is approximated based on an estimated initial value, monthly changes in the other variables, and the maximum soil-moisture storage values.

Arriving At the Water Budget

Using this basic equation, a lot of complex modeling, and some well-calculated estimates, researchers produced a mean monthly water budget for East Maui. Table 1: "Mean Monthly Water Budget for Windward Haleakalā" shows the main results for windward Haleakalā. Use it to answer the questions that follow.

Table 1: Mean Monthly Water Budget for Windward Haleakalā

Water budget component	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Fog drip	70	77	89	174	129	103	316	322	241	161	237	183
Rainfall	1018	1090	1300	1261	881	713	897	917	671	792	1104	1228
Runoff	-475	-493	-598	-684	-378	-175	-286	-346	-193	-285	-509	-569
Evapotranspiration	-203	-230	-169	-185	-239	-272	-230	-222	-276	-238	-204	-177
Ground water recharge	-417	-445	-608	-571	-428	-394	-678	-667	-471	-417	-596	-651

Data in million gallons per day

Questions

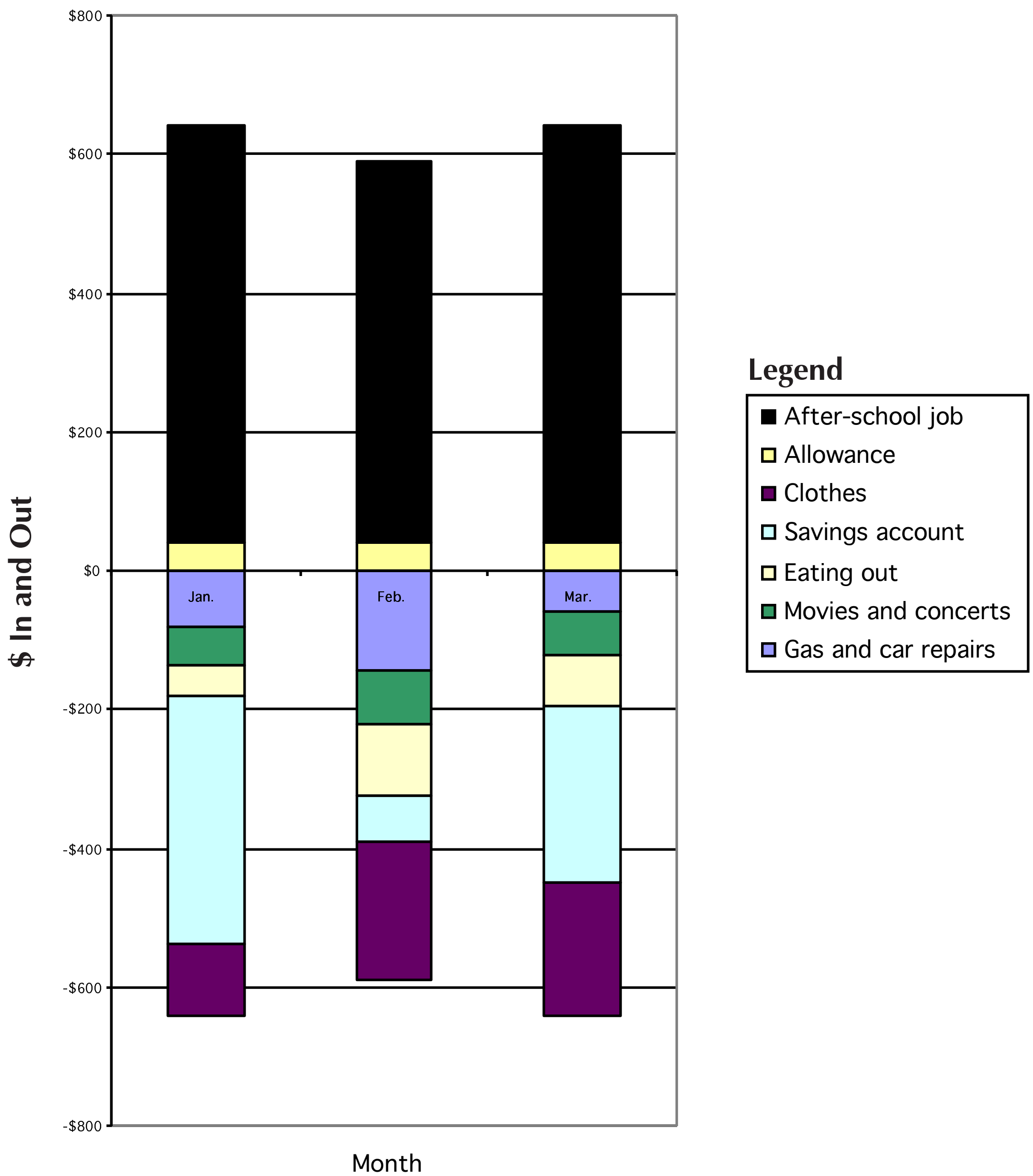
1) Using the data in Table 1: Mean Monthly Water Budget for Windward Haleakalā for your calculations, identify the three months in which the ratio of fog drip to rainfall is the highest. Below, list these three months and the contribution of fog drip to the water budget as a percentage of total moisture input (fog drip + rainfall). Express percentages using two decimal places.

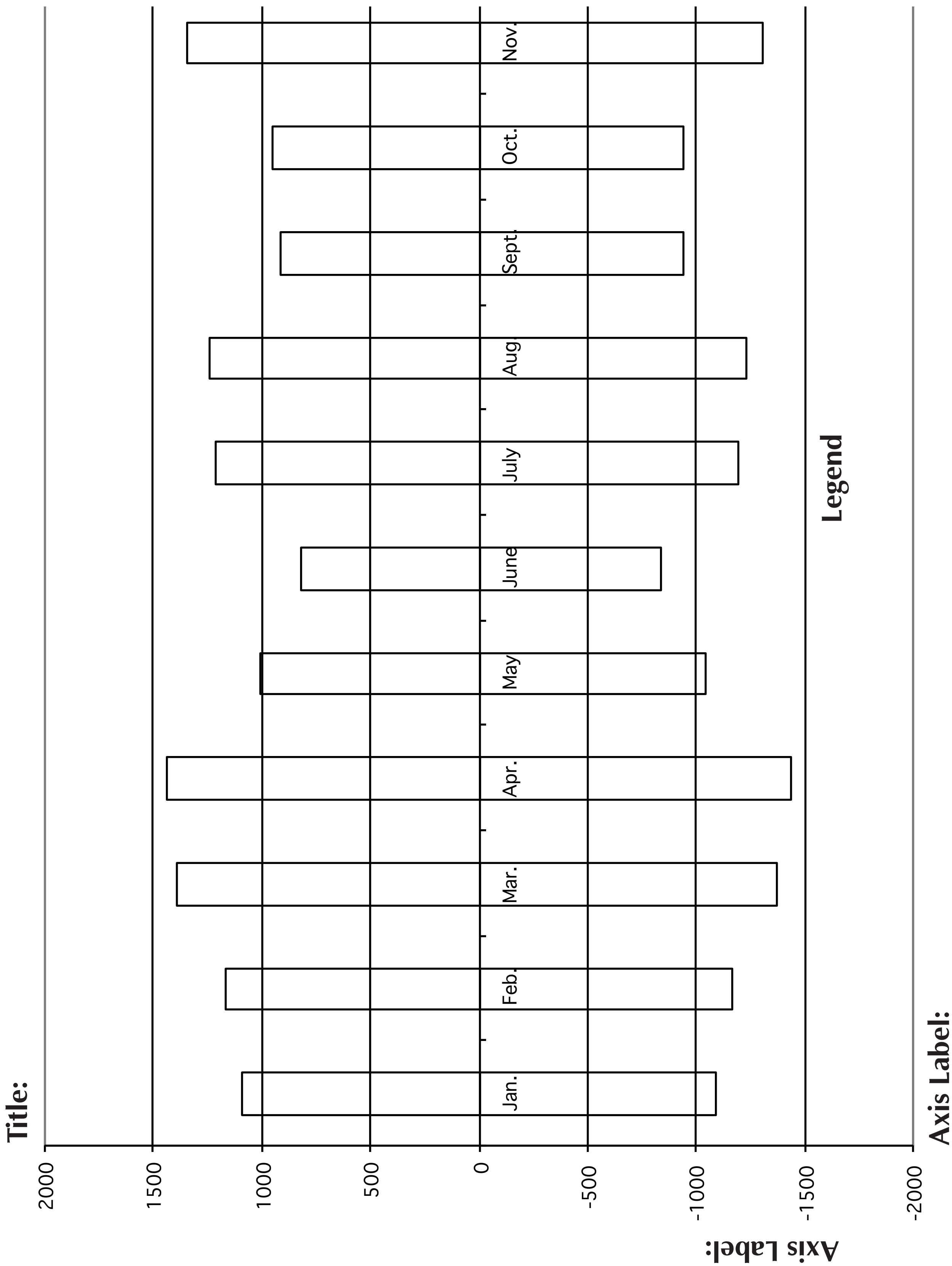
Top three months for fog-drip contribution	Percent of total moisture input
______________________________	________________
______________________________	________________
______________________________	________________

2) In the summer months, trade winds tend to be stronger and more reliable than at other times of the year. This pattern produces a well-developed trade wind inversion. How would this seasonally stronger atmospheric inversion help to explain the patterns in high fog-drip contribution you identified in question #1? Explain your reasoning.

3) Using the data in Table 1: Mean Monthly Water Budget for Windward Haleakalā and the blank chart on the following page, create a stacked-column chart representing the water-budget components for windward Haleakalā. A sample stacked-column chart is shown below.
Give your chart a title, labels for each axis, and a legend.

SAMPLE STACKED COLUMN CHART: Monthly Cash Flow

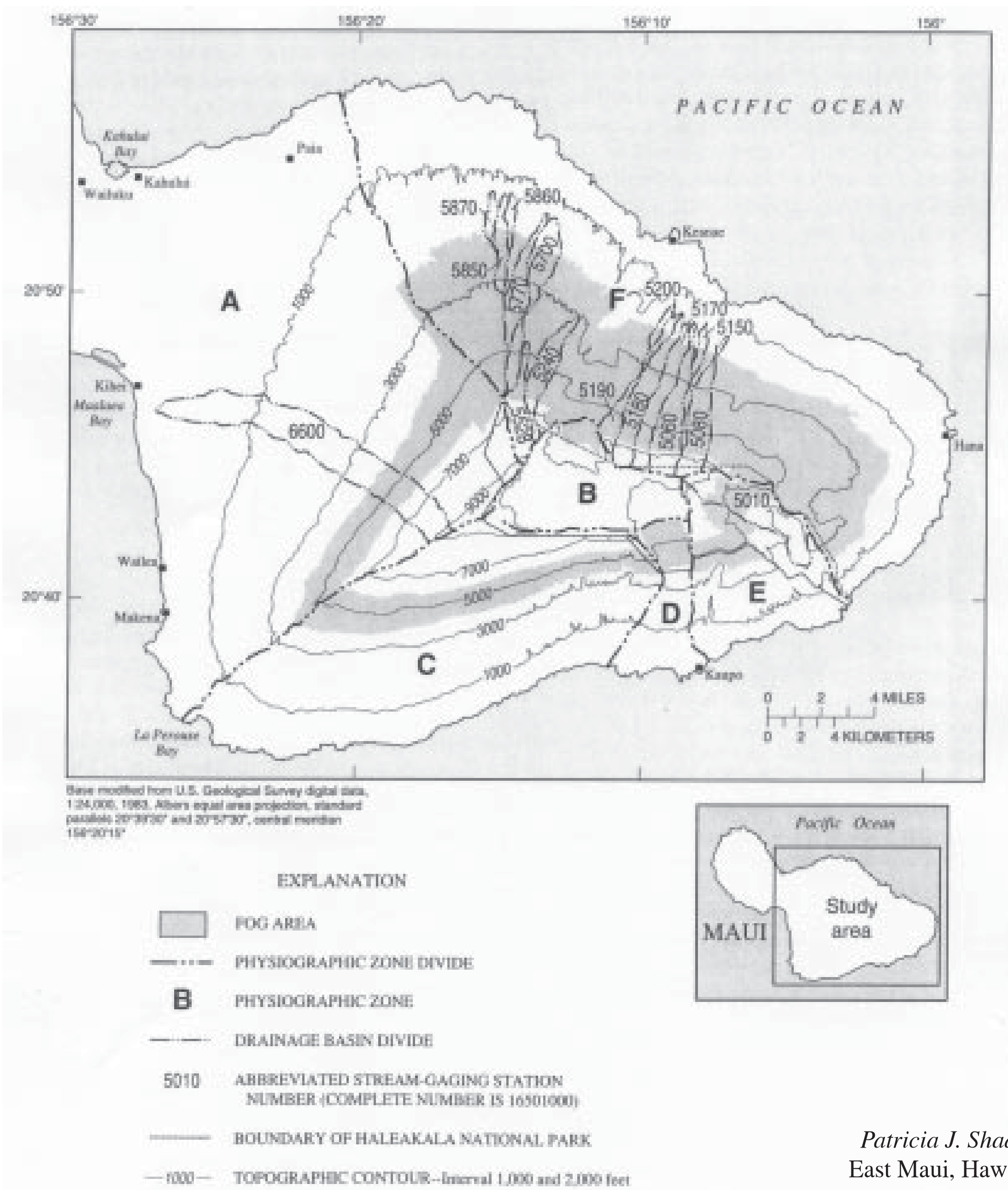



Title:
Legend
Axis Label:
Axis Label:
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
2000
1500
1000
500
0
-500
-1000
-1500
-2000

4) Using the following data, calculate the average contribution of rainfall and fog drip (in million gallons per day) to the water budgets of leeward Haleakalā (zone C on the map below) and windward Haleakalā (zone F on the map below). Show your calculations on the next page.

Water budget component	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Windward Haleakalā												
Rainfall	1018	1090	1300	1261	881	713	897	917	671	792	1104	1228
Fog drip	70	77	89	174	129	103	316	322	241	161	237	183
Leeward Haleakalā												
Rainfall	336	268	247	205	107	49	49	82	80	146	192	282
Fog drip	8	7	7	12	6	3	7	12	11	12	16	15

Data in Million Gallons per Day



This map shows where the windward and leeward fog zones are so you can picture the areas for which you are performing calculations. It is not used in your calculations.

Patricia J. Shade, Water Budget of East Maui, Hawaii, *U.S. Geological Survey, Honolulu, 1999, p. 13.*

4) (continued) Show calculations here.

5) Explain the difference in relative contribution of fog drip to total moisture input between the leeward and windward zones using the information on the map and what you know about the climate of windward and leeward Haleakalā.

6) A water budget is a model based on past averages. Some people believe that a series of extremely dry years in the late 1990s may be a sign that East Maui is entering into a prolonged period of reduced average rainfall. If East Maui is indeed beginning a long drought, do you think this estimated water budget should be used as a tool for determining how much surface or ground water can be safely withdrawn from the watershed? Explain your response.

The Waters of Kāne

On the following page is a translation of a *mele* from Kaua‘i that describes elements of the hydrologic cycle. It is entitled “*Ka Wai a Kāne*” or “The Waters of Kāne.” (Kāne is one of the four major Hawaiian gods.)

Read “*Ka Wai a Kāne.*” Then, on this page or a separate piece of paper, write your own *mele* that reflects the hydrologic cycle on windward Haleakalā. Be sure to include the water budget components you worked with in this unit.

Other ideas for your *mele* include:

- Rain forest alterations that can or have changed the water budget,
- Specific places on East Maui,
- Inversion layer and lifting-condensation levels,
- Seasonal differences,
- Orographic lifting,
- Differences between the windward and leeward sides,
- Other climate characteristics you studied in this unit, and
- How people can help keep the “waters of Kāne” flowing on East Maui.

Ka Wai a Kāne (The Waters of Kāne)

He ui, he ni nau,
E ui aku ana au iā ʻoe:
Aia i hea ka wai a Kāne?
Aia i ka hikina a ka lā,
Puka i Haʻehaʻe
Aia i laila ka wai a Kāne.
E ui aku ana au iā ʻoe,
Aia i hea ka wai a Kāne?
Aia i Kaulanakalā
I ka pae ʻōpua i ke kai,
Ea mai ana ma Nihoa
Ma ka mole mai o Lehua,
Aia i laila ka wai a Kāne.
E ui aku ana au iā ʻoe:
Aia i hea ka wai a Kāne?
Aia i ke kuahiwi, i ke kualono,
I ke awāwa, i ke kahawai,
Aia i laila ka wai a Kāne.
E ui aku ana au iā ʻoe:
Aia i hea ka wai a Kāne?
Aia i kai, i ka moana,
I ke Kaulau, i ke anuenue,
I ka pūnohu, i ka uakoko
I ka ʻālewalewa
Aia i laila ka wai a Kāne.
E ui aku ana au iā ʻoe:
Aia i hea ka wai a Kāne?
Aia i luna ka wai a Kāne,
I ke ʻōuli, i ke ao ʻeleʻele,
I ke ao panopano,
I ke ao popolohua mea a Kāne la e!
Aia i laila ka wai a Kāne.
E ui aku ana au iā ʻoe:
Aia i hea ka wai a Kāne?
Aia i lala, i ka honua, i ka wai hu,
I ka wai kau a Kāne me Kanaloa
He waipuna, he wai e inu,
He wai e mana, he wai e ola,
E ola nō, ʻeā!

A question, a query
I put to you:
Where is the water of Kāne?
At the eastern gate
Where the sun comes in at Haʻehaʻe
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
Out there with the floating sun
Where cloud-forms rest of the ocean
Uplifting their forms at Nihoa
This side the base of Lehua
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
There on the mountain peak, on the ridges steep,
In the valleys deep, where the rivers sweep,
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
There at sea, on the ocean
In the driving rain, in the rainbow arch,
In the misty spray, in the blood-red rainbow
In the ghost-pale cloud form,
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
High up is the water of Kāne,
In the heavenly blue, in the black-piled cloud,
In the thick dark cloud,
In the dark sacred cloud of the gods, indeed!
There is the water of Kāne.
A question, a query I put to you:
Where is the water of Kāne?
Deep in the ground, in the gushing spring
In the place of Kāne and Kanaloa,
A wellspring of water, water to drink
A water of power, the water of life!
Life indeed!