Rain Forest Unit 1

Why is the Rain Forest Wet?

Overview

Water, of course, is one of the defining features of the rain forest environment. Rain forest plants and animals are adapted to living with high levels of rainfall and humidity year-round. And from the rain forest of East Maui comes the water supply for much of Upcountry, Central, and East Maui. In this unit, students examine rainfall patterns and their causes in the rain forest zone of windward Haleakalā and explore the rain forest as a source of water for human use.

Length of Entire Unit

Five class periods

Unit Focus Questions

1) How are climate and weather important in traditional Hawaiian culture?

2) What climatic forces influence the location of the rain forest on Haleakalā?

3) What are the environmental conditions for plants and animals in the rain forest?

4) How does the native Haleakalā rain forest protect the water supply for much of East, Central, and Upcountry Maui?

5) What effects do changes in the structure of the rain forest have on the function of the watershed?

Unit at a Glance

Activity #1
Climate Connections

Students identify signs of the importance of climate and weather in traditional Hawaiian society and in their lives. They use Hawaiian descriptions to help them describe the climate of a familiar location.

Length
One period, preceded and followed by homework

Prerequisite Activity
None

Objectives
- Make connections between water-related or weather-related Hawaiian place names and the weather patterns on the island.
- Describe the weather in a familiar location using Hawaiian rain descriptions.

DOE Grades 9-12 Science Standards and Benchmarks
None

Activity #2
Why Does It Rain on the Rain Forest?

Working with maps, students identify and explain weather patterns that influence the location of the rain forest on Haleakalā and the environmental conditions within it.

Length
Two periods

Prerequisite Activity
None

Objectives
- Explain trade wind patterns, orographic lifting, the lifting-condensation level, and the trade wind inversion.
- Relate these climatic phenomena to the location of the rain forest on Haleakalā and the environmental conditions within it.

DOE Grades 9-12 Science Standards and Benchmarks
DOING SCIENTIFIC INQUIRY: Students demonstrate the skills necessary to engage in scientific inquiry.
- Formulate scientific explanations and conclusions and models using logic and evidence.
- Communicate and defend scientific explanations and conclusions.

USING UNIFYING CONCEPTS AND THEMES: Students use concepts and themes such as system, change, scale, and model to help them understand and explain the natural world.
- Explain the function of a given system and its relationship to other systems in the natural world.

Activity #3
Rain Forest on a Budget

Students create a water budget for the Haleakalā rain forest and hypothesize about how changes in the rain forest structure might affect it. They simulate these changes on a rain forest model to test their hypotheses.

Length
Two class periods, preceded and followed by a homework assignment

Prerequisite Activity
Activity #2 "Why Does It Rain on the Rain Forest?"

Objectives
- Identify and describe the major components of a water budget.
- Analyze and graph data related to a water budget for East Maui.
- Hypothesize about the impact of altering the rain forest on the water budget.
- Manipulate a rain forest model to test these hypotheses.

DOE Grades 9-12 Science Standards and Benchmarks
DOING SCIENTIFIC INQUIRY: Students demonstrate the skills necessary to engage in scientific inquiry.
- Develop and clarify questions and hypotheses that guide scientific investigations.
- Design and conduct scientific investigations to test hypotheses.
- Organize, analyze, validate and display data/information in ways appropriate to scientific investigations, using technology and mathematics.
- Formulate scientific explanations and conclusions and models using logic and evidence.
- Communicate and defend scientific explanations and conclusions.

USING UNIFYING CONCEPTS AND THEMES: Students use concepts and themes such as system, change, scale, and model to help them understand and explain the natural world.
- Explain the function of a given system and its relationship to other systems in the natural world.
- Explain the effect of large and small disturbances on systems in the natural world.
- Design or create a model to represent a device, a plan, an equation, or a mental image.

Enrichment Ideas

- Find out where the water students drink at home comes from. How about at school? Research local issues related to water consumption. Look in local newspapers for stories related to water supply or water use.

- Write a paper about how altering the rain forest would likely affect human water supply or the impacts the loss of forests on Maui has already had on rainfall and human water supply.

- Find Hawaiian chants or hula about the Hāna, Kīpahulu, or Koʻolau areas, or about other parts of the rain forest on Haleakalā. Or create original chants and dance based on the information learned in this unit.

- Research the East Maui Watershed (which covers the whole windward side of Haleakalā). It is the single largest source of harvested surface water in the state. East Maui supplies drinking water to Upcountry and East Maui, and irrigation water to the Hawaiian Commercial & Sugar Company in Central Maui.

  One place to start looking for information—and another research topic in itself—is the East Maui Watershed Partnership. The partnership is a collaborative effort among six public and private landowners and Maui County to protect the 100,000-acre rain forest core of this critical watershed. Online information about the partnership can be found at <ice.ucdavis.edu/~robyn/mauimgt.html>. Students may also want to contact the major partners directly: The Nature Conservancy, East Maui Irrigation Company, Hawaiʻi Department of Land and Natural Resources, National Park Service, Haleakalā Ranch, Hāna Ranch, and Maui County.

- Instead of doing the condensation demonstration in Activity #2, have students do it as a lab.

Resources for Further Reading and Research

Giambelluca, Thomas, and Marie Sanderson, "The Water Balance and Climatic Classification," in Marie Sanderson (ed.), *Prevailing Trade Winds: Weather and Climate in Hawaiʻi*, University of Hawaiʻi Press, Honolulu, 1993, pp. 56-72.

Juvik, S. P., and J. O. Juvik, *Atlas of Hawaiʻi,* third edition, University of Hawaiʻi Press, Honolulu, 1998. (Page 59 provides general background about rainfall on the Hawaiian Islands.)

Juvik, J. O., and D. Nullet, "Relationships Between Rainfall, Cloud-Water Interception, and Canopy Throughfall in a Hawaiian Montane Forest," in Hamilton, L. S., J. O. Juvik, and F. N. Scatena (eds.), *Tropical Montane Cloud Forests*, New York, Springer-Verlag, 1995, pp. 165-182.

Kert, Harold Winfield, *Treasury of Hawaiian Words in One Hundred and One Categories,* Masonic Public Library of Hawaiʻi, Honolulu, 1986.

Loope, Lloyd L., and Thomas W. Giambelluca, "Vulnerability of Island Tropical Montane Cloud Forests to Climate Change, with Special Reference to East Maui, Hawaii," *Climatic Change,* Vol. 39, 1998, pp. 503-517. (Although this article focuses on the potential effects of climate change, it provides excellent background on the characteristics of the cloud forest climate on Haleakalā, as well as several points of comparison between the windward and leeward side climate.)

Maui Department of Water Supply at <www.mauiwater.org>.

Pukui, Mary Kawena, Samuel H. Elbert, and Esther T. Mookini, *Place Names of Hawaii*, University of Hawaiʻi Press, Honolulu, 1974.

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

Activity #1

Climate Connections

● ● ● In Advance *Student Assignment*

- Assign the Student Page "Climate Connections" (pp. 7-9) as homework.

● ● ● Class Period One *Climate Connections*

Materials & Setup

- *'Auhea wale ana oe - E ka ua 'Ulalena* acetate (master, p. 6)
- Overhead projector and screen
- Map of Maui

For each student

- Student Page "Climate Connections" (pp. 7-9)

Instructions

1) Show the *"'Auhea wale ana oe - E ka ua 'Ulalena"* acetate. Have one or more students read the Hawaiian chant, then read the English translation. Ask the class why they think Hawaiians would be strongly connected to the rains and weather of specific places. Ask if they know anyone who is a keen weather observer.

2) Ask students to share some of their responses to the questions on the "Climate Connections" homework assignment. Begin with the place names and their meanings. Locate each place on the map as you discuss it. Then ask several students to share their rain descriptions, and locate the places they describe on the map as well.

3) Allow students the rest of the class period to write on one or more of the journal topics suggested below.

Journal Ideas

- Why was it important for early Hawaiians to observe, understand, and be able to predict the weather?
- Why is observing and understanding—and even predicting—the weather important to you and the activities you do?
- Do you have friends or family who live in more severe climates than Hawai'i? How is knowing about the weather important to them?
- Have you ever lived in a place where it rained a lot? What was it like to live there?

Assessment Tools

- Student Page "Climate Connections"
- Participation in the class discussion
- Journal entries

Photo: Howard D Terry

ʻAuhea wale ana oe - E ka ua ʻUlalena

Auhea wale ana oe
E ka ua ʻUlalena
Kahiko mai la i uka
I ka nani o Piʻiholo
Ua like me Koʻopua
Noho mai la i ʻAwalau
Au aʻe nei ka manaʻo
E pili me ke aloha
Aloha o Makawao
I ka ua Ūkiukiu
He tiu na ka Nāulu
I ke tula o Kamaʻomaʻo
O ka loa kaʻu i ana
I ka oni o ka lihilihi
Ilihia iho nei loko
I ka ukana o ke aloha
Haina mai ka puana
Makaihiana he inoa.

Oh where are you,
ʻUlalena rain,
Beautiful one of the upland
The beauty of Piʻiholo
Is like the clouds
That nestle over ʻAwalau.
The mind reaches out
To be near the loved ones,
Beloved is Makawao
With its Ūkiukiu rain,
It is a scout for the Nāulu rain
On the plain of Kamaʻomaʻo
I measured its length
With a single glance,
A thrill possesses me
With this thing called love,
This ends my song,
In honor of Makaihiana.
—Bishop Museum Library

Climate Connections

Dependent upon their environment, early Hawaiians were great and careful observers of weather and climate. Understanding seasonal patterns of temperature, wind, and rainfall, linked with lunar cycles, helped Hawaiians know when to plant and harvest different crops, when and where to fish, and even where and how to build their homes.

In Hawaiian society, *kilo lani* were the seers who were able to predict the future by looking at the sky. Among their powers was the ability to look at the stars and moon, the atmosphere, the ocean, and what was happening on land and tie it all together.

Kilo lani and their students (*haumana*) were astute observers of the heavens and the weather, and over time built up personal storehouses of knowledge and experience about the connection between the two. They also relied on, and added to, the body of local weather knowledge that was passed on orally from generation to generation. Unlike the modern-day weather forecaster who can consult computers and satellite images, the *kilo lani* drew their knowledge from their surroundings and carried it in their heads.

Many Hawaiians were regional experts in the folklore and weather patterns of their home place. If you know someone who fishes a lot or farms or surfs, you probably know a modern-day regional weather expert. You may even be one yourself! Some people are good at observing weather patterns and knowing what those signs mean for weather conditions in the coming days.

Hawaiians have many names for the wind and rain, depending on characteristics such as temperature, how steady it is, where it comes from, and so forth. From ancient times, Hawaiians have given names to each variety of rain and wind that is particular to each part of the islands. If you live on Ukiu Street in Makawao, for example, you have personal experience with the cold, wet *ukiu* wind that is unique to Makawao.

Weather and water were important elements in the lives of early Hawaiians. This is reflected in the names of many places on the Hawaiian Islands. *Mauna Kea*, for example, means "white mountain." It is named for the snow that often caps the summit, especially in winter. *Waikamoi*, the name of a stream that flows out of the rain forest on Haleakalā is interpreted by many people to mean, "water of the *moi* taro."

For fun...

Hawaiian words often have more than one meaning.

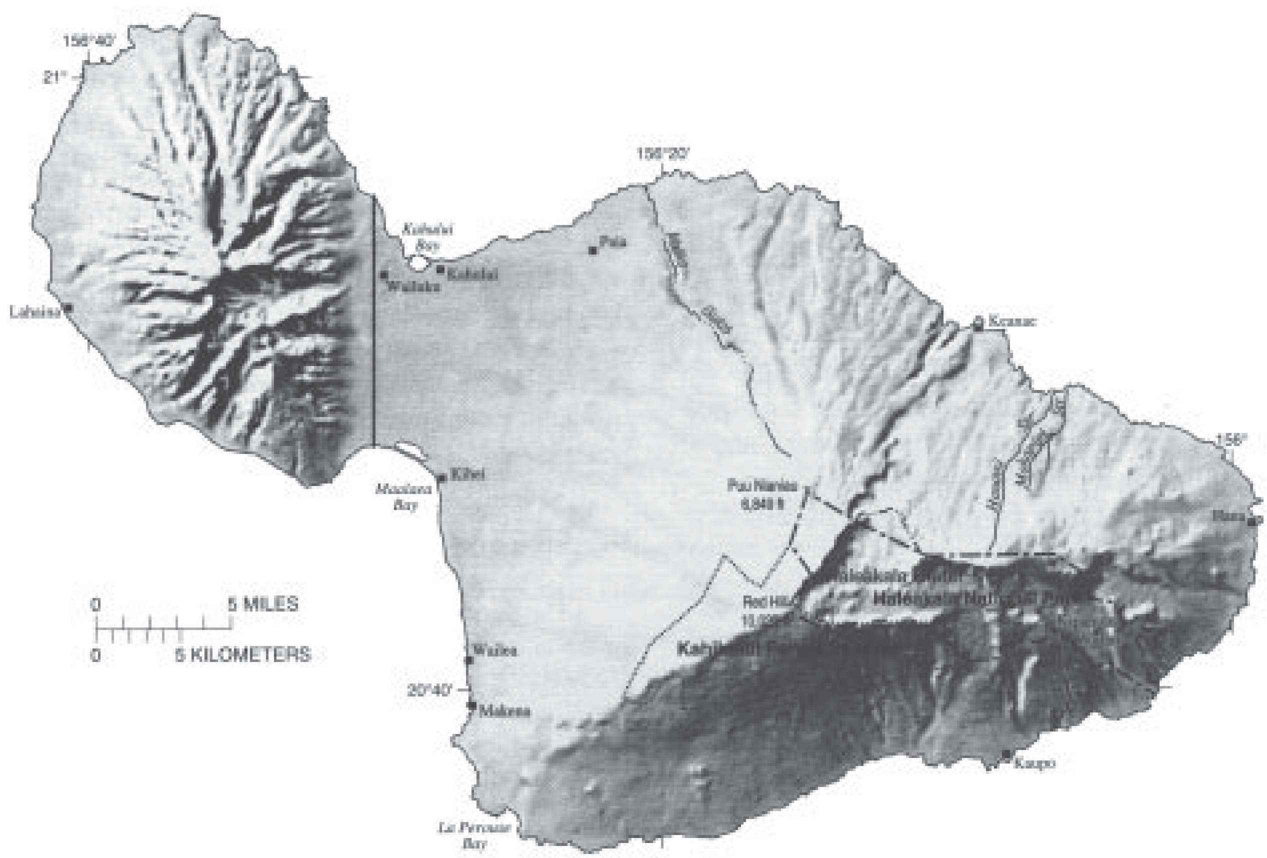
- Look up *kilo lani* in the Hawaiian dictionary, as well as *kilo* and *lani* separately. What different possible meanings of *kilo lani* can you come up with using the definitions offered in the dictionary?
- Talk to your parents, grandparents, aunts, or uncles to find out how they define *kilo lani*.
- What words have similar meanings in the English language?

In order to answer some of the questions below, you will need a map of Maui or Haleakalā National Park and a Hawaiian dictionary.

1) Using a map of Maui or Haleakalā National Park, find at least one place that is named for water or something associated with weather such as wind or clouds. You can use the Hawaiian dictionary to help you. Your school library may have helpful books such as:
   - Mary Kawena Pukui, Samuel H. Elbert, and Esther T. Mookini, *Place Names of Hawaii*, University of Hawaii Press, Honolulu, 1974, and
   - Kert, Harold Winfield, *Treasury of Hawaiian Words in One Hundred and One Categories,* Honolulu, Masonic Public Library of Hawai‘i, 1986.

   What is the name of the place? What does it mean?

2) On this map of Maui, place a dot where this place is located. Does the name of the place seem to tell you anything about that part of Maui? If so, what?



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

3) Think of a place that you are familiar with or that is near where you live. Write a paragraph, poem, or chant describing the rain that typically falls there. Include how hard the rain is, what direction it usually comes from, the time of day it generally falls, its temperature, or other characteristics that help to identify it. In your writing, incorporate at least one rain name in Hawaiian from the glossary below or another source.

Hawaiian Rain Names

‘awa — Fine rain or mist
‘awa‘awa — Fine, misty rain that frequently can be cold
hau — Snow, ice, frost
he ua lanipali — Shower reaching to heaven, i.e., a very heavy shower
ho‘okili — Fine, gentle rain, a form much beloved
ililani — Unexpected rain; rain from a seemingly clear sky
kahakikī — To pour down violently with a roar, as rain or rushing water
kēhau — Mist; cold, fine rain floating in the air, usually in the mountains
kēwai — Mist merging with rain some distance off
kili — Fine, light rain; peal of thunder; raindrops
kili hau — To fall gently, as a cold, soft shower; to stop falling and fade away, as rain at the end of a shower
ki‘o wao — Cool, mountain rain accompanied by wind and fog
ko‘iawe — Light moving shower
koko — Falling rain with light looking reddish as it shines through
līhau — Gentle, cool rain believed to bring luck to fishermen
ma‘au — Rain in the upland forest; rain forest
nākikiki‘i — Slanting rain
nāulu — Sudden shower of fine rain without seeming benefit of cloud or clouds
noe — Mist or fine rain, spray or fog; to sprinkle a little, as fine rain; to be damp, as fog; to rain, yet be scarcely discernible
pakakū — Rain falling in large drops
pakapaka — Heavy shower of large rain drops; spattering noise that such drops make on a hollow or dry substance, as on dry leaves
pāki‘o — Showery rain
pāki‘oki‘o — Showery rain; to rain in short showers and often
pīpinoke — To rain continuously
pulepe, pulu pē — To rain heavily; to be drenched
ua ‘awa — Chilly rain, cold and bitter
ua hānai — Rain that nurtures the earth
ua hō‘okina — Continuous rainfall
ua lanipili — Several-days downpour; heavy rain, cloudburst
ua poko — Short rain
ua po‘o nui — Light, steady rain (literally, big-head rain)

— *Kert, Harold Winfield,* Treasury of Hawaiian Words in One Hundred and One Categories*, Honolulu, Masonic Public Library of Hawai‘i, 1986, pp. 380-382.*

Activity #2

Why Does It Rain on the Rain Forest?

• • • Class Period One *Rain Forest Location and Characteristics*

Materials & Setup

- "Maui Map Pack" acetates (masters, pp. 21-26)
- Overhead projector and screen

For each group of 3 or 4 students

- Student Page "Maui Map Pack" (pp. 28-30)

For each student

- Student Page "Why Does It Rain on the Rain Forest?" (pp. 31-34)

Instructions

1) Draw a simple diagram on the board or overhead showing the ocean and Haleakalā. Ask students to predict what the average annual rainfall is over the open ocean. Then ask them to predict the highest annual rainfall ever measured at 1650 meters (5412 feet) in the Haleakalā rain forest. After gathering student ideas, share the actual data. Over the open ocean near Maui, an average of 56 to 71 centimeters (22-28 inches) of rain falls each year. In 1994, a rain gauge placed at 1650 meters in the Haleakalā rain forest measured more than 14 meters (46 feet or 551 inches) of rainfall in one year.

2) Ask students to hypothesize why there is such a huge difference in rainfall between the open ocean and the rain forest. Each student should write down a hypothesis. This activity will help students determine whether their hypotheses are correct.

3) Divide students into groups of three or four. Give each group a copy of the Student Page "Maui Map Pack." Have them look at these maps and answer the questions on the student page.

4) Bring the class back together and discuss the questions on the student page. Use the acetates as visual aids, and work from the teacher's notes to guide the discussion. (These are the same maps students received, along with a map of the location and extent of rain forests on Maui.)

5) Assign the Student Page "Why Does It Rain on the Rain Forest?" as homework.

● ● ● Class Period Two *Condensation Demonstration and Discussion*

Materials & Setup

- Three shiny metal cans
- Room temperature water to fill each can half full
- A tray of ice cubes
- Two thermometers (Celsius)
- A stirring tool
- “Condensation Demonstration Data Table” posted on the board or overhead (master, p. 27)
- “Condensation Demonstration Relative Humidity Table” posted on board or overhead, or handed out (master, p. 27)

Instructions

1) Ask students to discuss the factors that affect the rainfall pattern on the windward slopes of Haleakalā, where the East Maui rain forest is. (The factors include the interplay among topography, the prevailing wind patterns, and how water behaves at different temperatures.)

2) Ask students to discuss how condensation plays into the cycle of rainfall on the Haleakalā rain forest. (They should be able to link condensation to the formation of clouds and discuss the lifting condensation level.)

3) With the class, brainstorm a list of examples of condensation from daily life.

4) So that students may see the condensation of water in action, do the “Condensation Demonstration” following the instructions (pp. 16-17).

5) After the demonstration, go through the discussion questions in the teacher background (p. 18) with the class.

6) Discuss student responses to the questions in the Student Page “Why Does It Rain on the Rain Forest?” If you need more information to help students understand the atmospheric forces that form the trade winds and trade wind inversion see Marie Sanderson (ed.), *Prevailing Trade Winds,* University of Hawai‘i Press, Honolulu, 1993, or Alpine/Aeolian Unit 2 of this curriculum.

Journal Ideas

- What did you learn during this activity that confirms or refutes your original hypothesis about what explains the difference in rainfall between the open ocean and the Haleakalā rain forest?
- Have you ever been in the clouds or fog? What does it feel like compared to being in the rain?

Assessment Tools

- Participation in class discussion
- Student Page “Maui Map Pack” (teacher version, pp. 13-15)
- Student Page “Why Does It Rain on the Rain Forest?” (teacher version, pp. 19-20)
- Journal entries

Teacher Version

Maui Map Pack

Use the maps provided in this activity sheet to answer the following questions:

1) Where does most of the rainfall occur on Maui? on Haleakalā? What might explain that pattern?

   Most rainfall on Maui and Haleakalā occurs on the windward slopes of the mountains. (On the maps, the highest rainfall looks to be about 1/3-1/2 way up the mountain.) On Haleakalā, the heavy rainfall occurs in a band that runs across the northeast flank of the mountain and wraps around a bit toward the south.

   Students do not have a lot of information to work from yet to attempt to explain the pattern of rainfall. They might speculate that the winds pick up moisture from the ocean and dump it when they reach land.

2) Rain forests generally occur where annual rainfall is greater than 203 centimeters (80 inches) per year. According to the rainfall map, what parts of Maui get enough rain to support a rain forest? (Draw an outline on the rainfall map of where you would expect to find rain forests.)

   Note that this anticipated rain forest area goes all the way to the ocean for the majority of the northeast coast of East Maui.

3) Other than rainfall, what other characteristics do you expect to find in the area where you think the rain forests would be? (Use all of the maps provided for information.)

   From the wind map, students might speculate that a lot of the rain forest area would have light winds most of the time and that winds would tend to be blowing across the face of the mountain there.

   From the solar radiation map, they might speculate that the rain forest is cloudy.

Map Notes

(To accompany the map acetates, pp. 21-27)

Average Annual Rainfall on Maui (inches)

1) Notice that rainfall will support a rain forest all the way to the coastline on much of the northeast coast of East Maui. Driving the Hāna Highway will confirm that you are going through wet forest terrain. On maps of present day ecosystems, though, the native rain forest meets the coastline in very few areas. This is due to human disturbance in the lower reaches of the rain forest from Polynesian settlement onward.

2) Recent data suggest that average rainfall estimates for the rain forest on windward Haleakalā are low. Hawai‘i has many precipitation gages, but the rainfall of its more inaccessible reaches (e.g., much of the East Maui rain forest) is largely conjectural. Beginning in 1992, researchers began collecting climate information in this rain forest area, providing a new base of information.

New Estimates of Rainfall

Students do not have this information in their Maui Map Packs. Use it to show them the evolution of knowledge about the rain forest, comparing it to the rainfall map that is included in the student page.

In 1992, researchers established HaleNet II, a network of four microclimate sensing stations on windward Haleakalā. This network is currently providing data in an area where very little climatic data have been available. These measurements provide the first solid evidence to date of the extremely high rate of rainfall (Lloyd L. Loope and Thomas W. Giambelluca, “Vulnerability of Island Tropical Montane Cloud Forests to Climate Change, with Special Reference to East Maui, Hawaii,” *Climatic Change,* Vol. 39, 1998, pp. 503-517). In addition, the data collected are providing evidence of extreme spatial gradients for other climate variables such as humidity and solar radiation.

Based on these new data, as well as older and ongoing research and calculations, rainfall maps for East Maui are sure to change. The data from HaleNet II suggest that past maps probably underestimate the amount of precipitation within the wettest part of the Haleakalā rain forest.

Prevailing Wind Patterns on Maui

This map shows how Haleakalā diverts most air flow around its slopes. The prevailing trade winds from the east-northeast split and most of the airflow goes around the mountain rather than over the top of it.

In *Prevailing Trade Winds* (Marie Sanderson, (ed.), University of Hawai‘i Press, Honolulu, 1993), Thomas Schroeder explains that this effect has to do, in part, with the trade wind inversion:

> In Hawai‘i the combination of mountainous islands and persistent trade winds creates mesoscale systems that dominate local climate.
>
> If the mountains are below the inversion, a substantial amount of trade wind air will pass over the barrier. This is the case for O‘ahu, where the maximum elevation in the windward Ko‘olau Range is 960 m (3150 ft). On the island of Hawai‘i, Mauna Loa and Mauna Kea are more formidable barriers. Most trade winds are diverted around these mountains except for a small amount that penetrates the high, 2 km (6600 ft) saddle between them (p. 22).

See the teacher version of the Student Page “Why Does It Rain on the Rain Forest?” (pp. 19-20) and Alpine/Aeolian Unit 2 for more information about the trade wind inversion and its effect on the climate of Haleakalā.

Average Annual Solar Radiation Intensity (Watts/Meter^2)

Average annual solar radiation received on Maui differs from place to place. The highest levels occur along leeward coastal areas and at the tops of mountains.

Many factors can affect the amount of solar radiation that is absorbed and reflected before it can reach the ground. These include air pollutants, "vog" (smog-like air pollution caused by volcanic gases and particulates), particles of salt suspended in the air, and water vapor in the atmosphere.

Higher areas tend to receive more solar radiation because radiation traverses shorter distances through the atmosphere to reach them.

Clouds are the most important cause of variation in solar radiation intensity (based on *Atlas of Hawai'i,* 3rd ed., p. 50).

Limits of Native Ecosystems Before and After Human Settlement

Students do not have this information in their Maui Map Packs. Use it to show them the current location of the native rain forest on Haleakalā, as well as its past extent.

As background, you may want to look on pages 122-123 of *Atlas of Hawai'i*, 3rd ed., for generalized maps of the extent of native ecosystems before human settlement and today. These maps help to show patterns in where rain forests are located on all of the islands (i.e., windward mountain slopes) and that rain forests once extended to the ocean on Maui. (Sonia P. Juvik and James O. Juvik, editors, University of Hawai'i Press, Honolulu, 1998.)

Human disturbance of the lower reaches of the rain forest, from the time of Polynesian settlement onward, has converted most of the low-elevation native rain forest into a rain forest dominated by nonnative species. This effect is clear on the acetate maps "Native Ecosystems on Maui Before Human Habitation" and "Limits of Native Ecosystems on Maui Today." Native rain forests still exist over much of their historic extent, where climate conditions are conducive, but the lower elevations are now dominated by nonnative species.

Teacher Background

Condensation Demonstration

This demonstration is designed to help students visualize the behavior of water vapor in the trade winds that are pushed upslope on the windward side of Haleakalā. You may also use it to demonstrate the concept of a microclimate created when moist air is trapped in a steep valley such as Kīpahulu. As this air is pushed upward through the valley, it reaches the "lifting-condensation level" the altitude at which water vapor condenses out of rising air, forming clouds and/or rain), and the water vapor condenses, forming clouds and rain.

In this demonstration, you will determine the dew point of the air in your classroom and calculate the relative humidity. "Dew point" is the temperature at which water vapor in the air begins to condense. "Relative humidity" is the ratio between the amount of water vapor in the air and the highest amount of water vapor possible in the current air temperature.

Materials

Listed in the activity instructions

Instructions

1) Measure the air temperature in the classroom.

2) Fill one can half full of room temperature water.

3) Slowly stir the water with a stirring rod, adding small amounts of ice. Ask the class to help you watch for condensation to appear on the outside of the can. Record the water temperature when that happens, being careful not to let the thermometer touch any ice. This is the dew point.

4) Subtract the dew point temperature from the air temperature. Use the relative-humidity table to determine the relative humidity in the air around the beaker. (For a more accurate calculation, use the equations that follow at the end of the questions for discussion.)

	A = Outside air temperature (°C)	B = Water temperature when condensation forms on the outside of the can (°C)	Difference between readings (A-B)	Relative humidity (percent)
Trial 1				
Trial 2				
Trial 3				

Data Table
Relative-Humidity Table

Air Temp. (°C)	Temperature Difference (°C)											
	1	2	3	4	5	6	7	8	9	10	12	14
10	88	76	65	54	44	33	23	14	4			
12	89	78	67	57	47	39	29	20	11	3		
14	89	79	69	60	51	42	33	25	17	9		
15	90	80	71	62	54	45	37	29	22	14		
18	91	81	73	64	56	48	41	33	26	19	6	
20	91	82	74	66	58	51	44	37	30	24	11	
22	91	83	75	68	60	53	46	40	34	27	16	5
24	92	84	76	69	62	55	49	43	37	31	20	9
26	92	85	77	70	64	57	51	45	39	34	23	14
28	92	85	78	72	65	59	53	47	42	37	26	17
30	93	86	79	73	67	61	55	49	44	39	29	20
32	93	86	80	74	68	62	56	51	46	41	32	23

———Relative Humidity Around Beaker———

Questions for Discussion

1) Why did we have to wait for condensation to form?

The water temperature (and therefore the temperature of the outside surface of the can) had to drop to the dew point.

2) When condensation formed, was the air right around the can saturated?

Yes. Relative humidity is the ratio of the actual amount of moisture in the atmosphere to the amount of moisture the atmosphere can hold. At the dew point, condensation begins to form because the air can hold no more moisture.

3) Why would there be a relationship between relative humidity and the dew point temperature?

At lower temperatures, the atmosphere can hold less moisture (under constant pressure conditions).

4) As the moist trade winds are pushed up along the windward slopes of Haleakalā, what is happening to their temperature? At some point, would you expect the air temperature to reach its condensation point? What factors could influence the elevation at which that happens?

• As air rises, temperature drops.

• Yes, depending upon the moisture level in the air

• Air pressure, moisture level in the winds

5) The level at which water vapor in a rising air mass begins to condense is called its "lifting-condensation level." How does the lifting-condensation level relate to cloud formation?

The lifting-condensation level is the altitude at which clouds begin to form.

Teacher Version

Why Does It Rain on the Rain Forest?

Use the information and graphics provided in this article along with what you learned in class to answer the following questions:

1) On Figure 1:
   a) Indicate the approximate altitude of the inversion layer.
   b) Draw a line indicating the approximate lower limits of the rain forest.

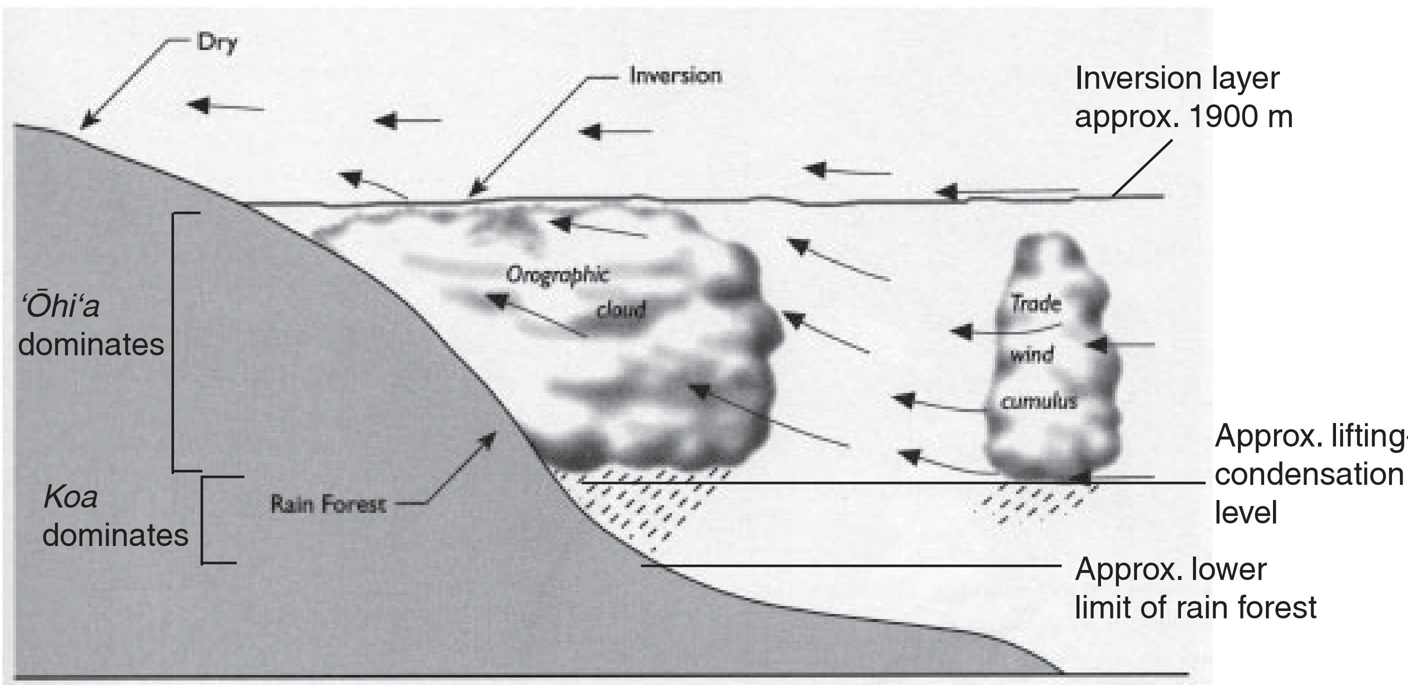


***Figure 1: General weather patterns on windward Haleakalā** From Marie Sanderson (ed.),* Prevailing Trade Winds*, University of Hawai'i Press, Honolulu, 1993.*

2) Would the native rain forest extend all the way to sea level in this image? Why or why not?

Look for well-reasoned responses. In this image, the rain forest would probably not extend all the way to the coast. The rain falling from the orographic cloud stops well short of the coastline, leaving a broad coastal bench without orographically generated rainfall. However, if the orographic cloud regularly gets bunched up and extends further over the coastal bench, then there could be enough rain to support a rain forest to the coastline.

3) Part of the rain forest on Haleakalā is a zone called the "cloud forest." The cloud forest zone is almost always enshrouded in clouds that hug the side of the mountain. It gets moisture from the clouds as well as rainfall. On Haleakalā, the cloud forest zone is between about 1000 meters (3280 feet) and 1900 meters (6232 feet).

How do you think the lower limit of the cloud forest relates to the lifting-condensation level? Explain your reasoning.

The lower limit of the cloud forest is approximately the same as the usual lifting-condensation level. The lower limit of the cloud forest would not be below the lifting-condensation level because there are not clouds below that level. At and above the lifting-condensation level, clouds are continually generated in the rising and cooling air being pushed by the prevailing trade winds.

4) On Figure 1, draw a line that indicates the approximate lifting-condensation level. If you are able to estimate the elevation of that level, do so on Figure 1 and explain your reasoning below. If you are not able to estimate its elevation, what additional information do you need?

The lifting-condensation level should correspond with the bottom of the cloud layer because that is where condensation/cloud formation begins. The lifting-condensation level should roughly correspond with the lower limit of the cloud forest, or approximately 1000 meters (3280 feet).

5) Would the lifting-condensation level always be at exactly the same elevation? Explain your reasoning.

No. As we learned in the dew point demonstration, air pressure and atmospheric moisture content can affect the dew point (lifting condensation level).

While the lifting-condensation level would not always be exactly the same, it should be relatively constant, reflecting the usual range of atmospheric conditions.

6) *'Ōhi'a* (*Metrosideros polymorpha*) and *koa* (*Acacia koa*) are the two main tree species in the rain forest canopy on Haleakalā. *'Ōhi'a* tends to dominate in the wettest part of the rain forest. *Koa* tends to dominate where it is drier, sometimes in a mixed-species canopy along with *'ōhi'a*. More commonly, the koa will grow taller than the *'ōhi'a*, sometimes forming a distinct upper canopy layer above the *'ōhi'a*.

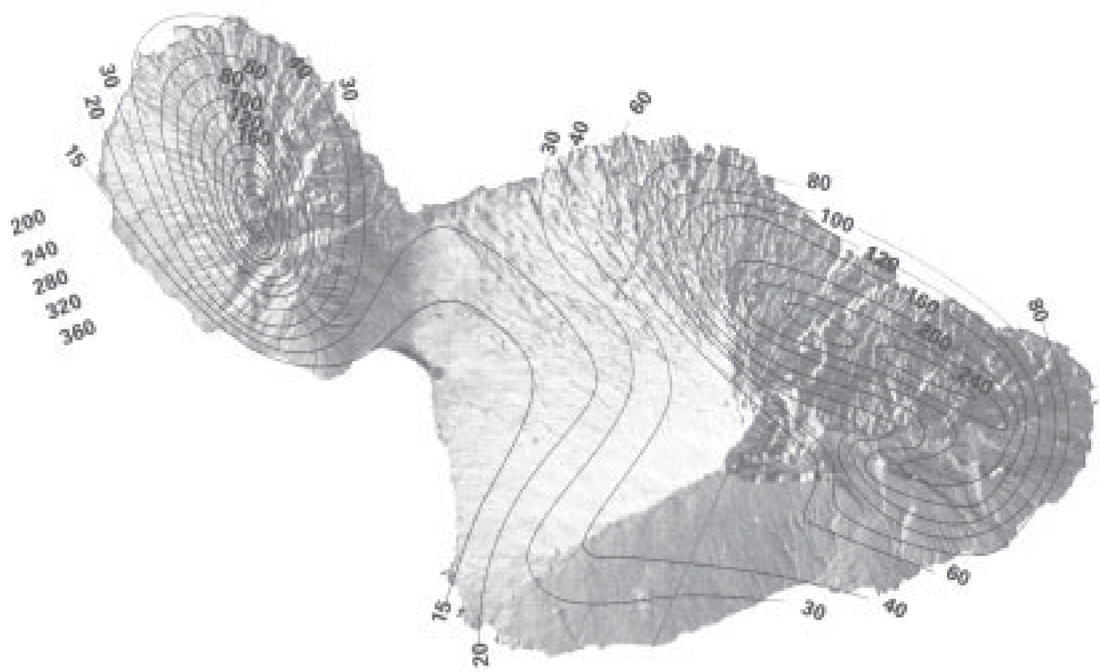
On Figure 1, indicate where you expect *'ōhi'a* to be the dominant tree in the rain forest and where you would expect *koa* to dominate. Is there any place where the two species might co-dominate? Explain your reasoning below.

See the graphic (p. 19) for the expected range of *'ōhi'a* and *koa*.

One might expect *koa* and *'ōhi'a* to codominate at the lower limit of the cloud forest, where rainfall is still relatively high but lessening with loss of elevation.

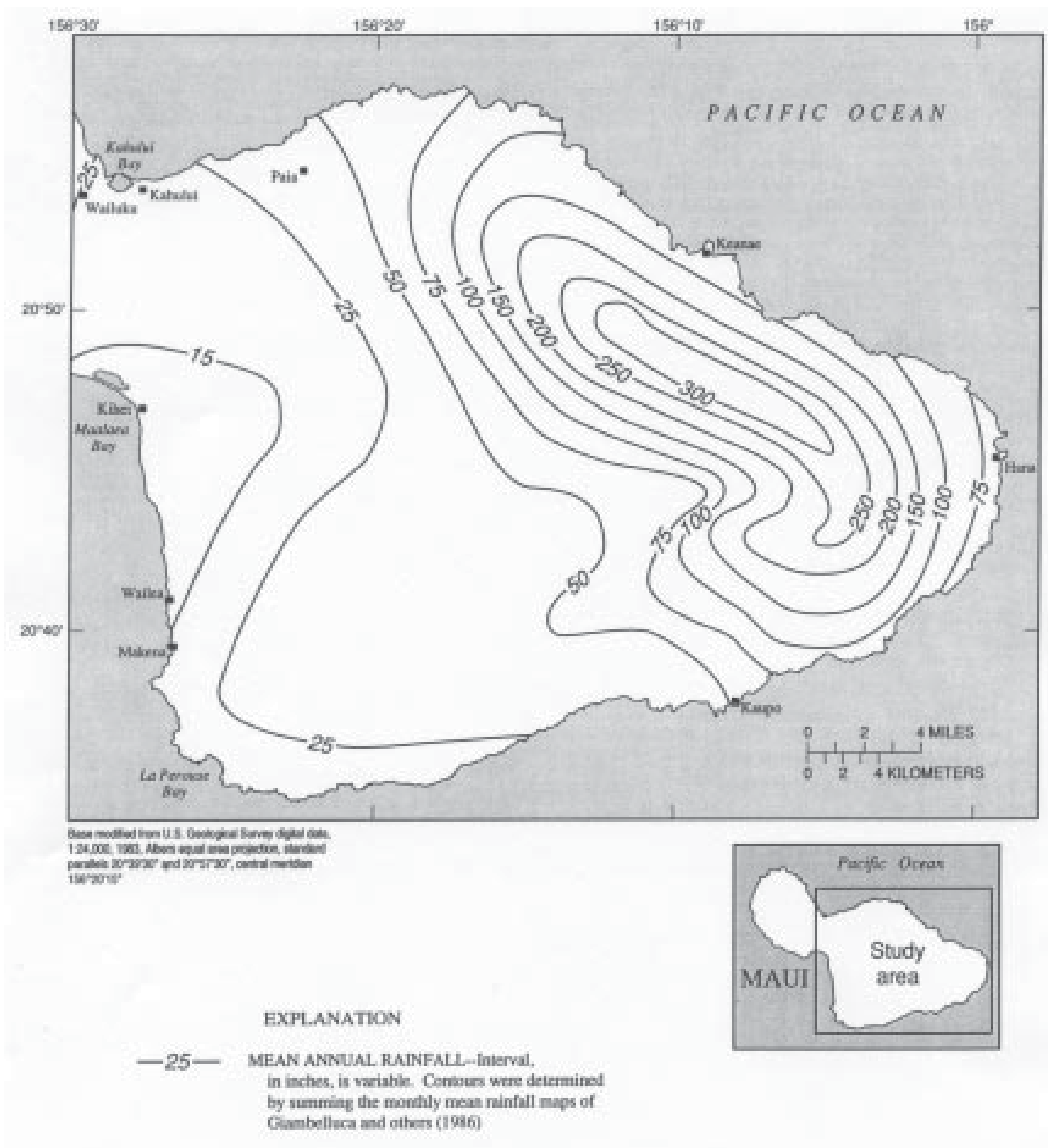
Maui Map Pack Acetate Masters

Average Annual Rainfall on Maui (inches)



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

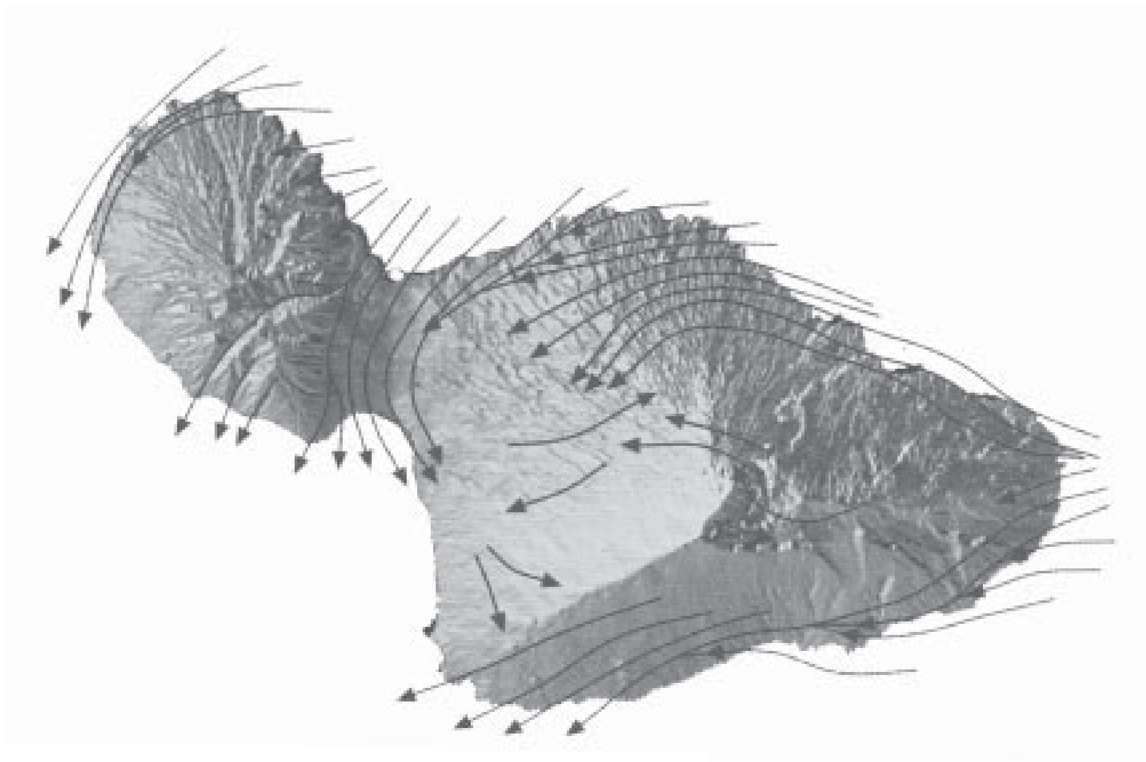
New Estimates of Rainfall



P. J. Shade, Water Budget of East Maui, Hawaii,
U.S. Geological Survey, Honolulu, 1999.

Prevailing Wind Patterns on Maui

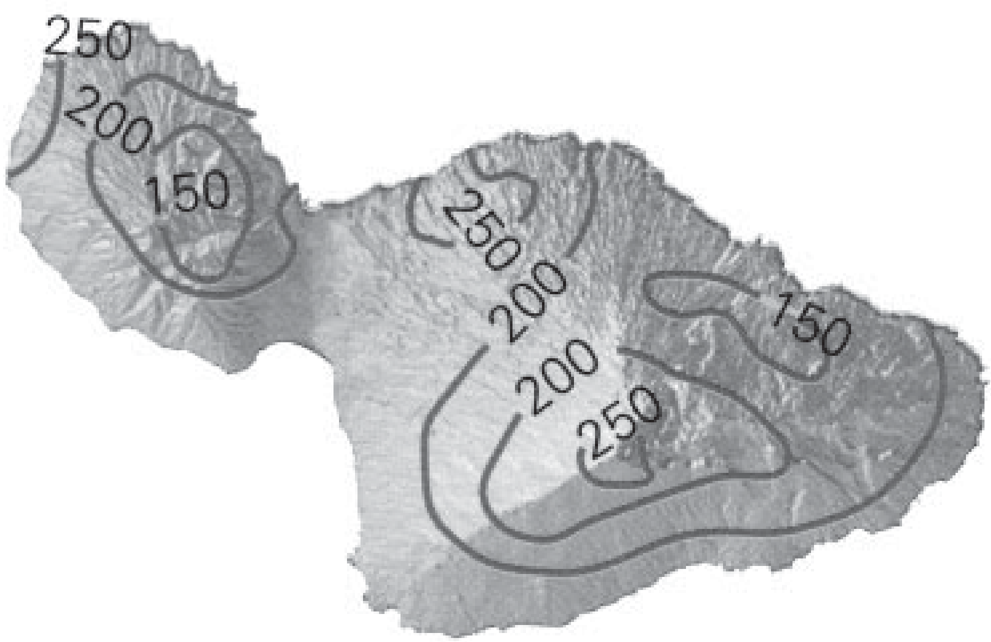
Lines and arrows represent flow lines of the prevailing winds.



Sonia P. Juvik and James O. Juvik (eds.), Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

Average Annual Solar Radiation Intensity (Watts/Meter^2)

Solar radiation is the amount of energy from the sun
that reaches the surface of the earth.



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

Native Ecosystems on Maui Before Human Habitation

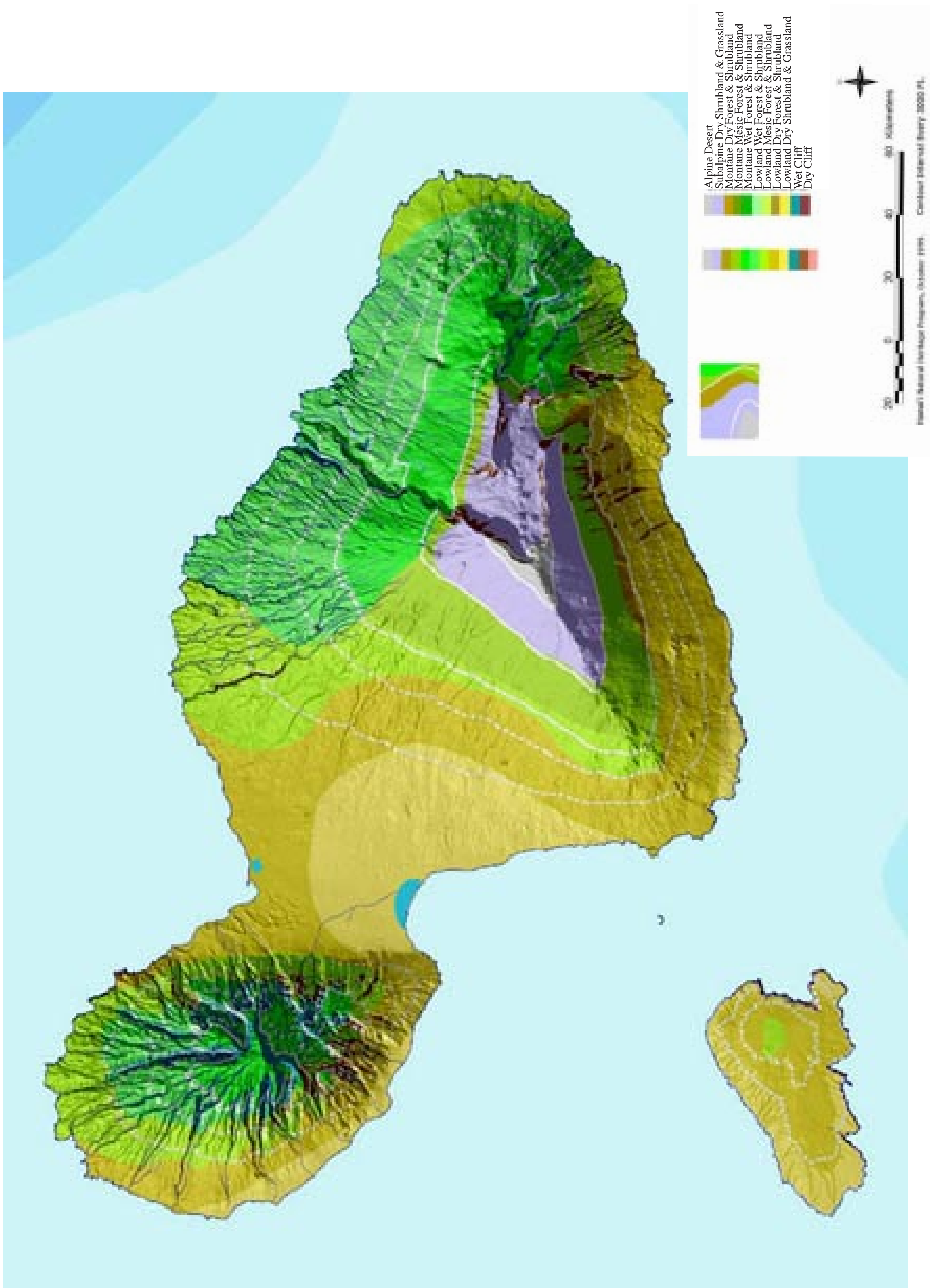


Image: Hawai'i Natural Heritage Program

Limits of Native Ecosystems Today

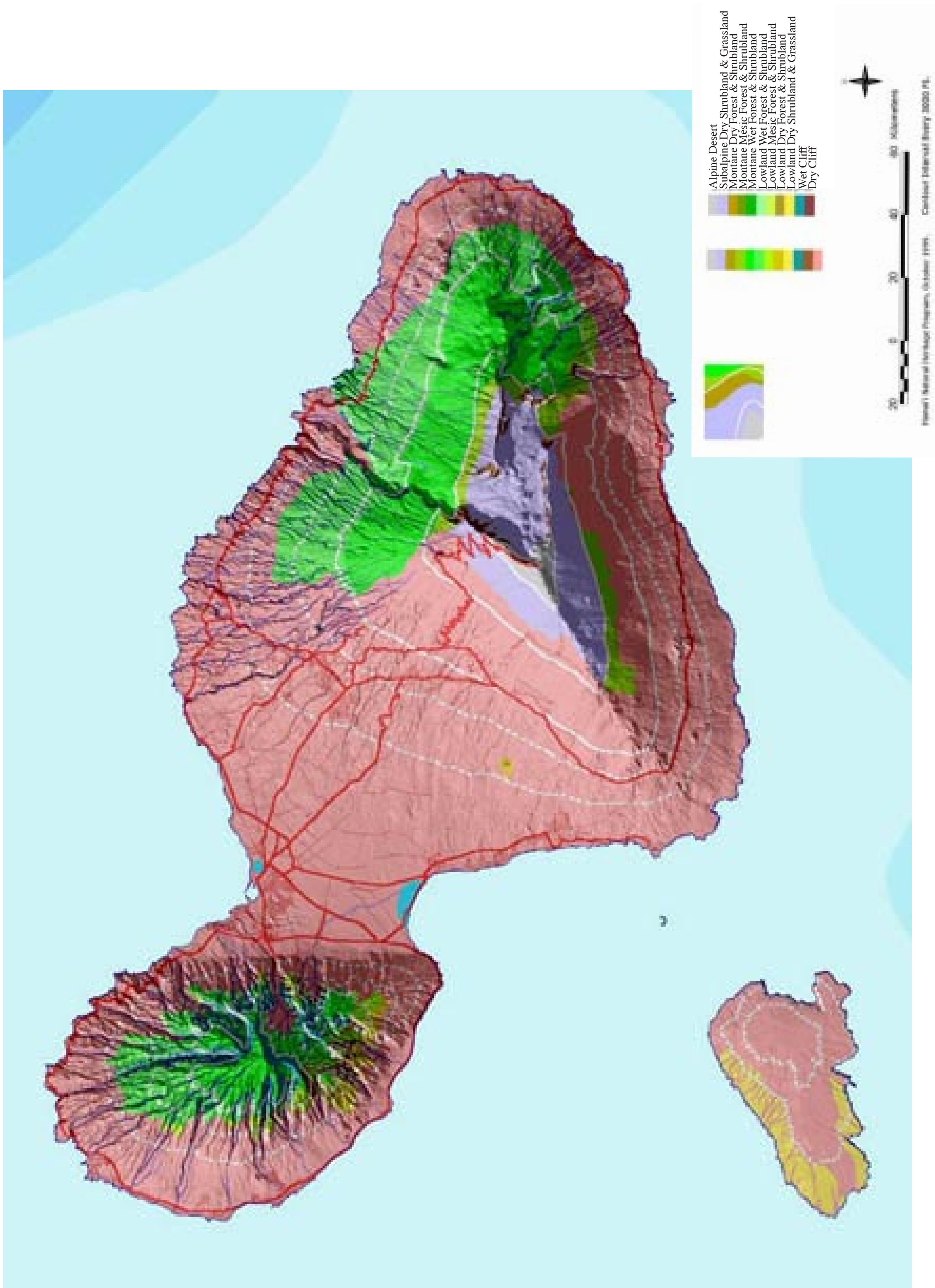


Image: Hawai'i Natural Heritage Program

Data Table

	A = Outside air temperature (°C)	B = Water temperature when condensation forms on the outside of the can (°C)	Difference between readings (A-B)	Relative humidity (percent)
Trial 1				
Trial 2				
Trial 3				

Relative-Humidity Table

Air Temp. (°C)	**Temperature Difference (°C)**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**14**
10	88	76	65	54	44	33	23	14	4			
12	89	78	67	57	47	39	29	20	11	3		
14	89	79	69	60	51	42	33	25	17	9		
15	90	80	71	62	54	45	37	29	22	14		
18	91	81	73	64	56	48	41	33	26	19	6	
20	91	82	74	66	58	51	44	37	30	24	11	
22	91	83	75	68	60	53	46	40	34	27	16	5
24	92	84	76	69	62	55	49	43	37	31	20	9
26	92	85	77	70	64	57	51	45	39	34	23	14
28	92	85	78	72	65	59	53	47	42	37	26	17
30	93	86	79	73	67	61	55	49	44	39	29	20
32	93	86	80	74	68	62	56	51	46	41	32	23

———Relative Humidity Around Beaker———

Maui Map Pack

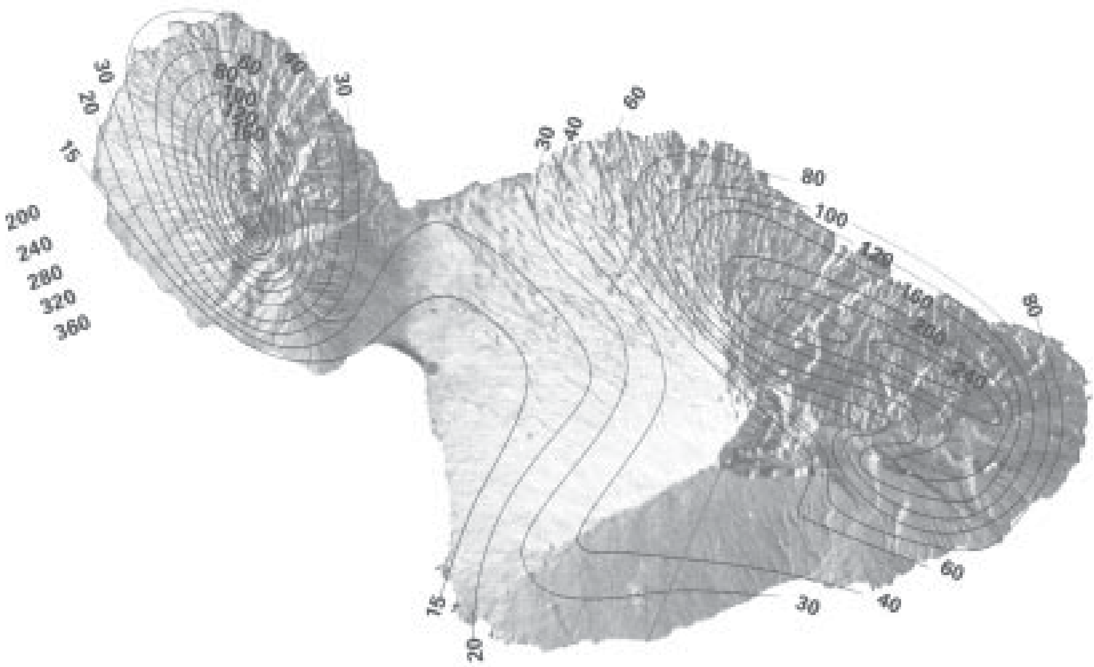
Use the maps provided in this activity sheet to answer the following questions:

1) Where does most of the rainfall occur on Maui? on Haleakalā? What might explain that pattern?

2) Rain forests generally occur where annual rainfall is greater than 203 centimeters (80 inches) per year. According to the rainfall map, what parts of Maui get enough rain to support a rain forest? (Draw an outline on the rainfall map of where you would expect to find rain forests.)

3) Other than rainfall, what other characteristics do you expect to find in the area where you think the rain forests would be? (Use all the maps provided for information.)

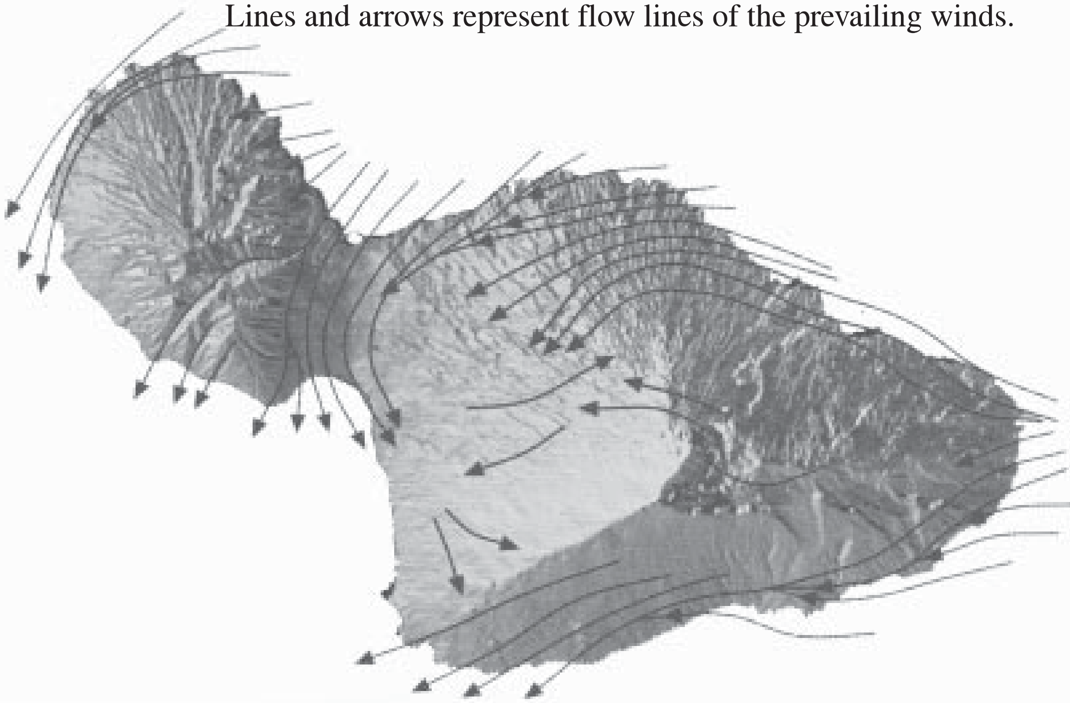
Average Annual Rainfall on Maui (inches)



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of*
Hawai'i Press, Honolulu, 1998.

Prevailing Wind Patterns on Maui

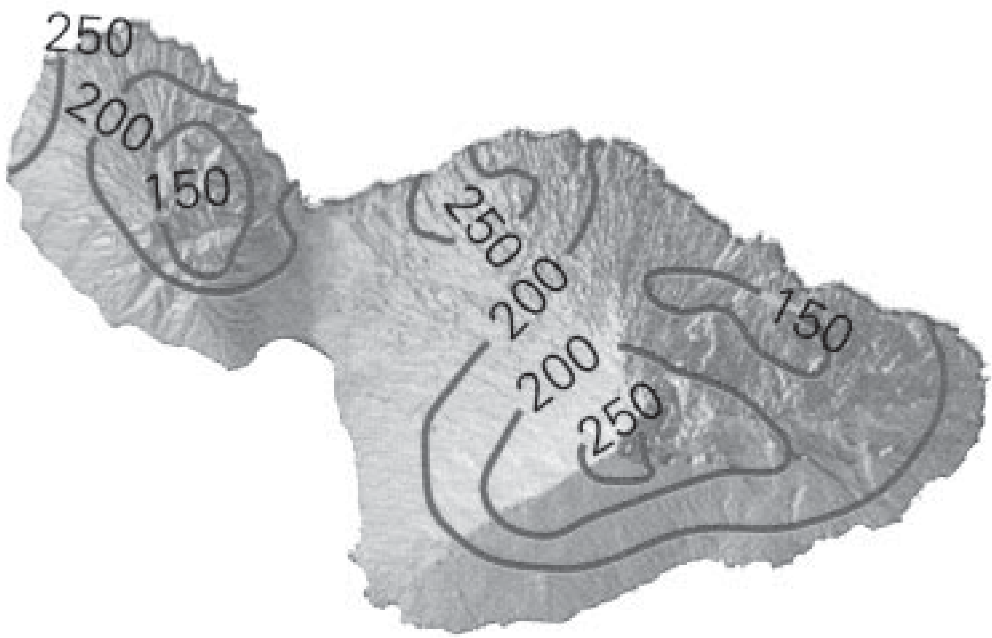
Lines and arrows represent flow lines of the prevailing winds.



Sonia P. Juvik and James O. Juvik (eds.),
Atlas of Hawai'i, *3rd ed., University of*
Hawai'i Press, Honolulu, 1998.

Average Annual Solar Radiation Intensity (Watts/Meter^2)

Solar radiation is the amount of energy from the sun
that reaches the surface of the earth.



Sonia P. Juvik and James O. Juvik (eds.), Atlas of Hawai'i, *3rd ed., University of Hawai'i Press, Honolulu, 1998.*

Why Does It Rain on the Rain Forest?

Over the open ocean near Maui, between 56 and 71 centimeters (22-28 inches) of rain falls in an average year. In 1994, a rain gauge placed at 1650 meters (5412 feet) in the rain forest on the windward flank of Haleakalā measured more than 14 meters (45.92 feet or 551 inches) of rainfall *in one year*! What accounts for this difference?

One factor that accounts for this difference is Haleakalā itself. Trade winds blowing across the ocean from the northeast hit the mountain broadside and are forced upward. Some of the wind is deflected to the sides, flowing around the mountain. But much of the moist air is forced up the mountain's steep slopes in a phenomenon known as "orographic lifting." As the air travels upward it cools. As it reaches the "dew point," or condensation point, clouds form along the mountain slope. The moisture from these clouds and the "orographic rain" that falls from them is what accounts for the rain forest climates on windward Haleakalā.

The elevation at which clouds begin to form is called the "lifting-condensation level." In other words, this is the level at which air that is orographically lifted reaches its condensation point.

So now you know how the clouds are formed that make the rain that enables the rain forest to thrive. There is more to the picture, though, if you want to understand why the rain forest occurs in a belt along the northeastern flank of Haleakalā. Why isn't there rain forest all the way to the summit?

The answer to that question has to do with the trade wind "inversion layer." When the rising and cooling clouds meet the warm descending air in the Hadley Cell (see Figure 2, p. 31), the inversion layer is formed. The warm air overlying the

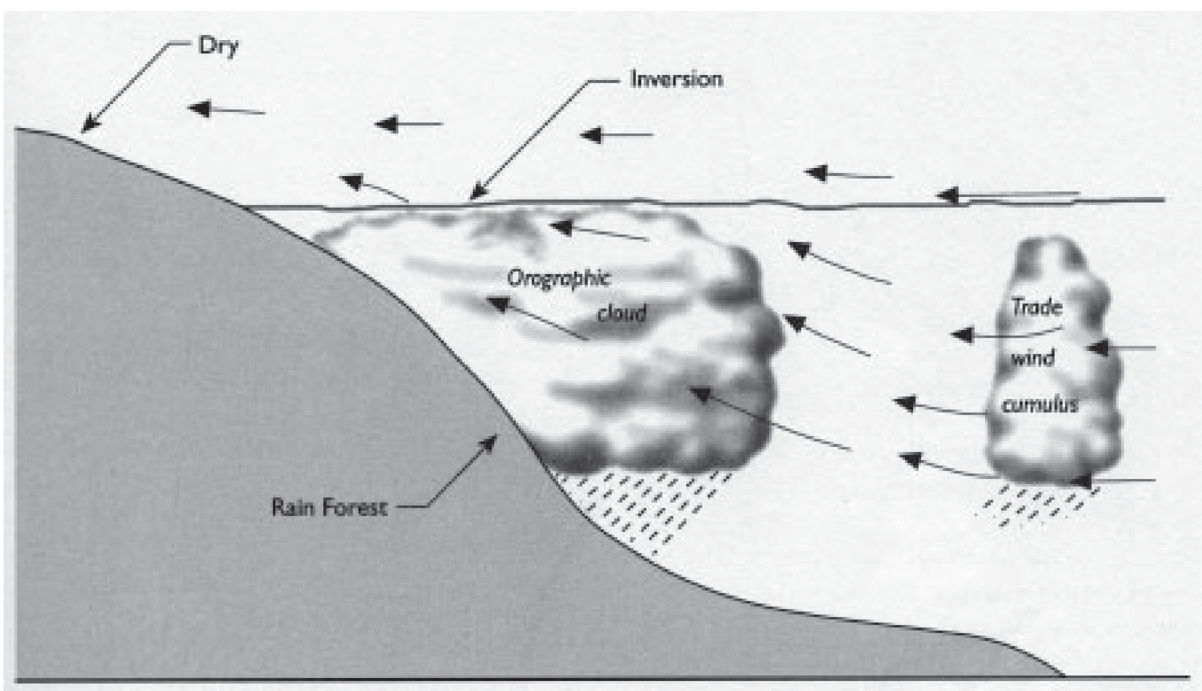


Figure 1: General weather patterns on windward Haleakalā (Marie Sanderson (ed.), Prevailing Trade Winds, *University of Hawai'i Press, Honolulu, 1993.)*

cooler air forms a barrier to clouds—any cloud that is forced through the inversion layer rapidly evaporates in the dry air above it.

Figure 1 (p. 30) illustrates the general pattern of trade wind weather on windward Haleakalā.

The clouds and rainfall are restricted to elevations below the level of the inversion layer. On windward Haleakalā, a good way to estimate the typical elevation of the inversion layer is to look at the upper limits of the rain forest, which are at about 1900 meters (6232 feet).

Before humans settled on Maui, the native rain forest extended all the way to the coastline along much of the northeast coast of Haleakalā. This entire area receives more than enough rain to support a rain forest. Now, however, in most of the lower elevation areas, there are only scattered remnants of native rain forest. It is still wet and lush, as a drive along the Hāna Highway will prove. But ever since the time of Polynesians, these lower reaches of the rain forest have been favored for human settlement, farming, and other activities. This activity has dramatically changed the ecosystem from one dominated by native rain forest species to one dominated by nonnative rain forest species. In some areas, such as around Hāna, the native rain forest did not extend all the way to the coast, even before human settlement. Looking at the rainfall map will show you one reason why this is the case.

Use the information and graphics provided in this article along with what you already know to answer the following questions about how the interaction of climate and topography forms the limits to the rain forest on Haleakalā.

The Hadley Cell

The Hadley Cell is a part of the large-scale circulation of the earth's atmosphere. Warm air rises near the equator and moves toward the north pole at high altitudes. As it reaches 30° N latitude, the air sinks and circulates back toward the equator completing the Hadley Cell.

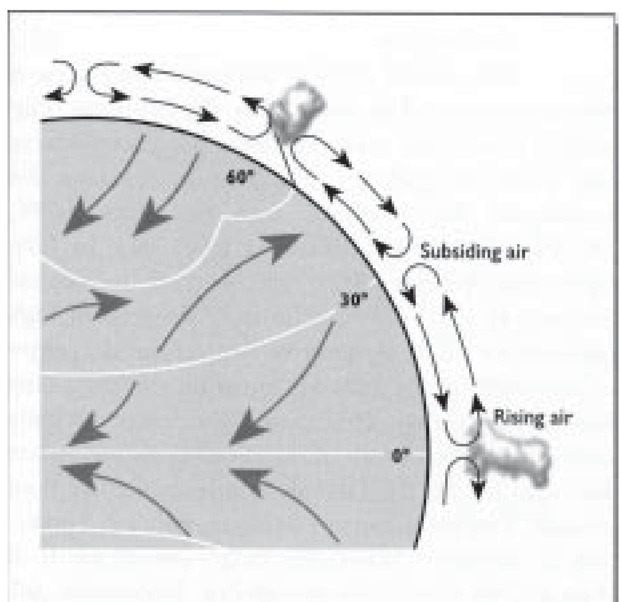


Figure 2: Idealized Hadley Cell, showing vertical and horizontal wind patterns (Marie Sanderson (ed.), Prevailing Trade Winds, *University of Hawai'i Press, Honolulu, 1993.)*

Questions

1) On Figure 1of the reading (p. 30):
   a) Indicate the approximate altitude of the inversion layer.
   b) Draw a line indicating the approximate lower limits of the rain forest.

2) Would the native rain forest extend all the way to sea level in this image? Why or why not?

3) Part of the rain forest on Haleakalā is a zone called the "cloud forest." The cloud forest zone is almost always enshrouded in clouds that hug the side of the mountain. It gets moisture directly from the clouds as well as from rainfall. On Haleakalā, the cloud forest zone is between about 1000 meters (3280 feet) and 1900 meters (6232 feet).
   How do you think the lower limit of the cloud forest zone relates to the lifting-condensation level?

4) On Figure 1 of the reading (p. 30), draw a line that indicates the approximate lifting condensation level. If you are able to estimate the elevation of that level, do so on Figure 1 and explain your reasoning below. If you are not able to estimate its elevation, what additional information do you need?

5) Would the lifting-condensation level always be at exactly the same elevation? Explain your reasoning.

6) *‘Ōhi‘a* (*Metrosideros polymorpha*) and *koa* (*Acacia koa*) are the two main tree species in the rain forest canopy on Haleakalā. *‘Ōhi‘a* tends to dominate in the wettest part of the rain forest. *Koa* tends to dominate where it is drier, sometimes in a mixed-species canopy along with *‘ōhi‘a*. More commonly, the *koa* will grow taller than the *‘ōhi‘a*, sometimes forming a distinct upper canopy layer above the *‘ōhi‘a*.

On Figure 1 of the reading (p. 30), indicate where you expect *‘ōhi‘a* to be the dominant tree in the rain forest and where you would expect *koa* to dominate. Is there any place where the two species might co-dominate? Explain your reasoning below.

Activity #3

Rain Forest on a Budget

● ● ● In Advance *Student Assignment*

- Assign the Student Page "Water in the Rain Forest—What Goes In and What Comes Out" (pp. 45-53) as homework.

● ● ● Class Period One *Rain Forest Water Budget & Demonstration*

Materials & Setup

- "Water Budget for Windward Haleakalā" acetate (master, p. 44)
- Overhead projector and screen

For each student

- Student Page "Water in the Rain Forest—What Goes In and What Comes Out" (pp. 45-53)

Four sets of the following materials for the demonstration

- Cardboard box, 17 inches long x 12.5 inches wide x 12.5 inches high (or similar)
- 33-gallon garbage bag
- Scissors
- Household sponges—enough to cover the bottom of the box
- Stapler
- Soil
- Board or dish drainer to put under box
- Leafy branches (leaves one to two inches long)
- Plastic 1/2-gallon jug with small holes drilled into the side (not the bottom, because you have to put water in it without letting it run out) or a garden watering can
- Timer
- Catchment container at open end of box
- Four measuring beakers of the same size

Instructions

1) Discuss student responses to the Student Page "Water in the Rain Forest—What Goes In and What Comes Out." Use the "Water Budget for Windward Haleakalā" acetate as you are discussing question #3.

2) After the discussion, show the water budget acetate again, and ask students what they think would happen to each of the water budget elements if the understory and forest floor vegetation and/or canopy layers were disturbed or removed from the rain forest.

3) Do the "Rain Forest in a Box" demonstration following instructions in the teacher background (pp. 40-42). This demonstration helps students visualize what happens to the forest soil layer as rain falls in an intact rain forest, as well as one in which the understory and forest floor vegetation and/or the canopy layers have been removed.

4) After the demonstration, divide the class into four groups. Each group should select one water budget element and design an experiment to test their hypothesis about the effects of clearing the rain forest on that element. They will be conducting these experiments during the next class period. Encourage students to use the same materials as you used for the demonstration. If a group needs additional materials, students should bring them to the next class.

● ● ● Class Period Two *Testing the Effects of Rain Forest Clearing*

Materials & Setup

For each student

- Student Page "The Waters of Kāne" (pp. 54-55)

For the demonstration

- Same four sets of materials from Class Period One

Instructions

1) Provide each group with one set of "Rain Forest in a Box" materials. Have them conduct their experiments by:
   a) Writing the question they are trying to answer, as well as their hypothesis;
   b) Writing a description of the methods they will use to test their hypothesis;
   c) Setting up and conducting the experiment;
   d) Recording results; and
   e) Writing their conclusions.

2) Have groups share their methods and results with the rest of the class.

3) As homework, assign the Student Page "The Waters of Kāne" and/or one or more of the journal writing topics.

Journal Ideas

- What is the likely effect of rain forest degradation on human water supply from the Haleakalā rain forest?
- What do you think would happen to the rain forest if people started pumping large volumes of ground water from the East Maui Watershed? How could you test this hypothesis?
- What are some ways to reduce the growing demand for water from the Haleakalā rain forest? What can you do personally to contribute?
- Do you think surface water should be diverted from East Maui streams for agricultural and household use in Central, Upcountry, and East Maui? West and South Maui? Why or why not?

Assessment Tools

- Student Page "Water in the Rain Forest—What Goes In and What Comes Out" (teacher version, pp. 37-39)
- Participation in class discussion and demonstration
- Design, conduct, record-keeping, and reporting of experiment
- Student Page "The Waters of Kāne" (teacher version, p. 43)
- Journal entries

Teacher Version

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

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.

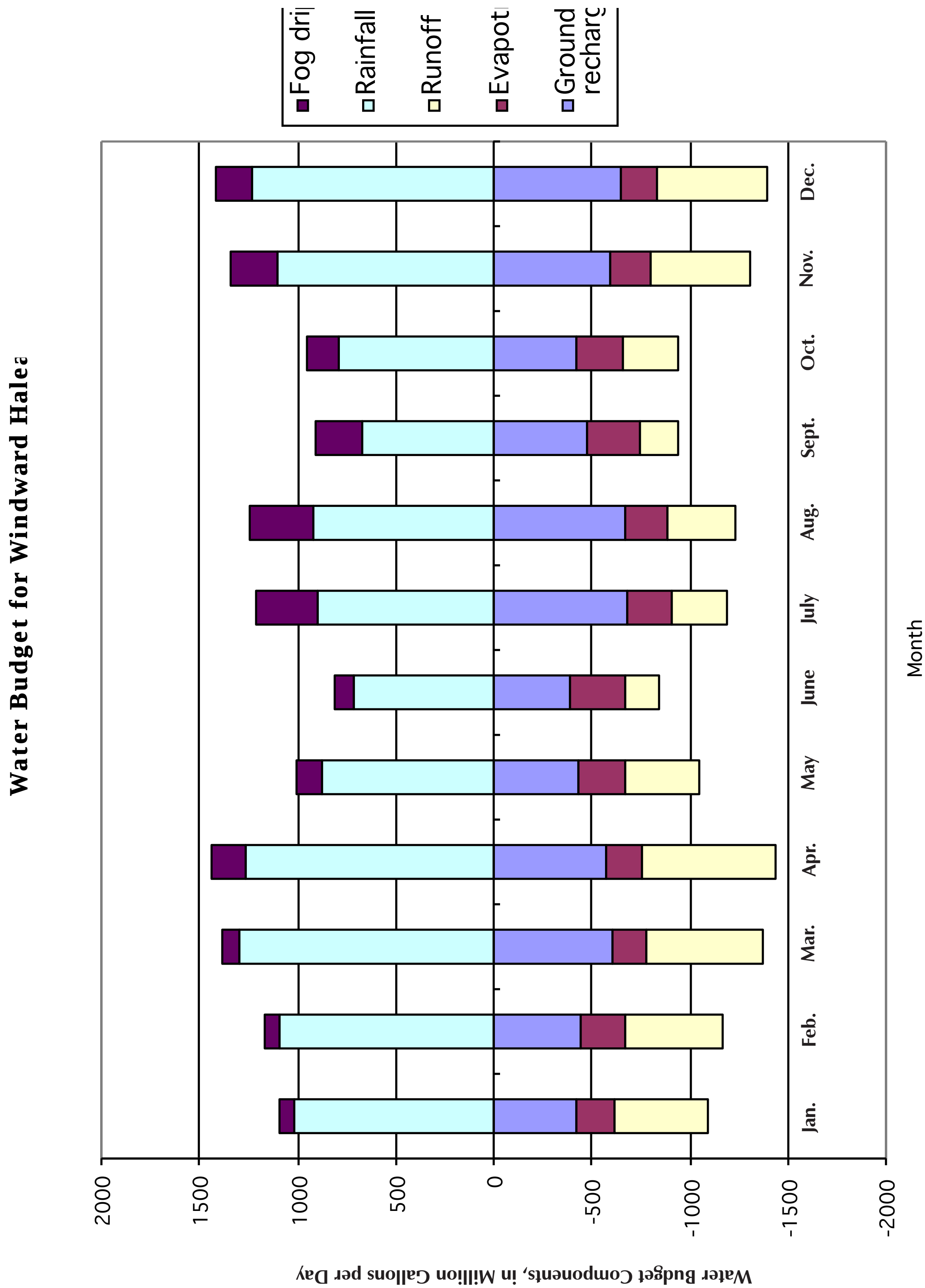
Top three months for fog-drip contribution	Percent of total moisture input
July	26.05%
August	25.99%
September	26.43%

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.

   The fog zone on the windward (north) side of Haleakalā volcano extends from the mean cloud base level, at about 600 meters (1970 feet), to the lower limit of the most frequent temperature inversion base height at about 2000 meters (6560 feet). The high July to September ratio of fog drip to rainfall is the result of a well-developed atmospheric temperature inversion and strong trade winds. As the moist air is forced upslope, cloud height is restricted by the inversion, thus favoring fog rather than raindrop formation.

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 relative proportion of water-budget components for windward Haleakalā. A sample stacked-column chart is shown below.
   Give this chart a title, labels for each axis, and a legend.

   See the completed chart on p. 38.


Water Budget for Windward Halea
Fog drip
Rainfall
Runoff
Evapot
Ground recharg
Water Budget Components, in Million Gallons per Day
2000
1500
1000
500
0
-500
-1000
-1500
-2000
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Month

4) Using the following data, calculate the mean monthly contribution of rainfall and fog drip (in millions of gallons per day) to the water budgets of leeward Haleakalā (zone C on the map) and windward Haleakalā (zone F on the map--see student version for map).

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

Answers:

Windward rainfall	989
Windward fog drip	176
Leeward rainfall	170
Leeward fog drip	10

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.

The basic answer is that there is, proportionately, a much smaller fog zone on leeward Haleakalā than there is on the windward side. The windward side is subject to the prevailing trade winds, which bring moisture-laden air from across the ocean. Haleakalā forces these winds upward (the orographic effect), forming clouds that hug the mountainside, capped by a temperature inversion layer.

The same temperature inversion layer caps the cloud/fog layer on leeward Haleakalā. But the winds coming around the mountain and onshore from the south tend not to be as strong, constant, or moist as the trade winds.

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.

Well-reasoned responses are acceptable.

Teacher Background

Rain Forest in a Box

Overview

This demonstration illustrates the importance of the layer of mosses and other vegetation that covers the ground (and many trees) in the rain forest. This thick layer acts as a sponge in the capture and slow release of water in the rain forest. It also illustrates how trees and vegetation slow the speed of water onto the ground.

Materials

- Cardboard box, 17 inches long x 12.5 inches wide x 12.5 inches high (or similar)
- 33-gallon garbage bag
- Scissors
- Household sponges—enough to cover the bottom of the box
- Stapler
- Soil
- Board or dish drainer to put under box
- Leafy branches (leaves one to two inches long)
- Plastic 1/2-gallon jug with small holes drilled into the side (not the bottom, because you have to put water in it without letting it run out) or a garden watering can
- Timer
- Catchment container at open end of box
- Four measuring beakers of the same size

Preparation

In advance of the class period, assemble the four sets of materials in the following manner:

1) Cut away the narrow (12.5 inches) end of the box.

2) Cut open the plastic garbage bag, and line the inside of the box with it. Staple the edges to the box.

3) Support the underside of the box with a board or dish drainer.

4) Put soil into the box to a depth of approx. 1 1/2 inches; pack it down.

5) Completely cover the soil with sponges.

6) Prop the back of the box up two inches, so it is on a slight slope.

7) Place leafy branches in the box so that it looks like a forest inside.

8) Place one quart of water into the 1/2-gallon jug.

Procedure

Experiment 1 - How much water drains out with the forest vegetation intact?

1) Explain to students what you are about to do, and have them write down hypotheses about what will happen.

2) On one "rain forest in a box," slowly sprinkle the quart of water onto the leafy branches. Note the length of time this takes.

3) Let the box drain into the catchment container for one minute.

4) Pour the water and any soil into a measuring beaker or cup. If there is soil in it, let it stand awhile so the soil can settle out. Then measure the volume of soil and water, and record the results.

5) Squeeze out the sponges and measure the water they hold. Record the results.

6) Have students compare the results to their hypotheses.

Experiment 2 — Simulating understory destruction

Using a different "rain forest in a box," do exactly the same as above, but without the sponges.

Experiment 3 — Simulating canopy opening

Using a new "rain forest in a box," repeat the procedure, but without the leafy vegetation.

Experiment 4 — Simulating canopy opening and understory destruction

Carry this investigation one step further by taking both the leafy branches and the sponges out and sprinkling the water on the bare soil.

Interpretation

1) Measure the height of the soil layer in all beakers.

2) Measure the height of the water layer in all beakers.

3) Measure the height of the water taken from the sponges.

4) Make a bar graph for comparison.

Discussion

1) Did the sponge layer do anything to retard the flow of water and soil as runoff?

2) How does the sponge layer appear to be valuable in the forest?

   It slows the water getting to the ground, so the soil isn't washed away and releases the moisture slowly into the ground to recharge the aquifers.

3) What acts like a sponge in the rain forest?

   The forest floor is covered with a mat of mosses, lichens, and low-growing plants, along with a layer of soil and decaying plant matter that act as a sponge.

4) In nature, where does the runoff go?

   Into streams and then to the ocean

5) What destroys the sponge layer in the forest?

   Pigs root in the forest floor for fern roots and earthworms; the hooves of wild cattle break up the sponge; people walking over the same area break down the sponge.

6) Discuss the role that vegetation plays in slowing down the flow of water onto the ground.

   Leaves and branches provide surface area, which forces the rain water to slow as it falls.

7) Why is it important that the rain falls slowly onto the ground?

   Soil isn't washed away.

8) Why is the topsoil valuable?

   Most of the decomposition in the forest happens in the top soil layer, so all the nutrients are here.

Teacher Version

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 great 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.

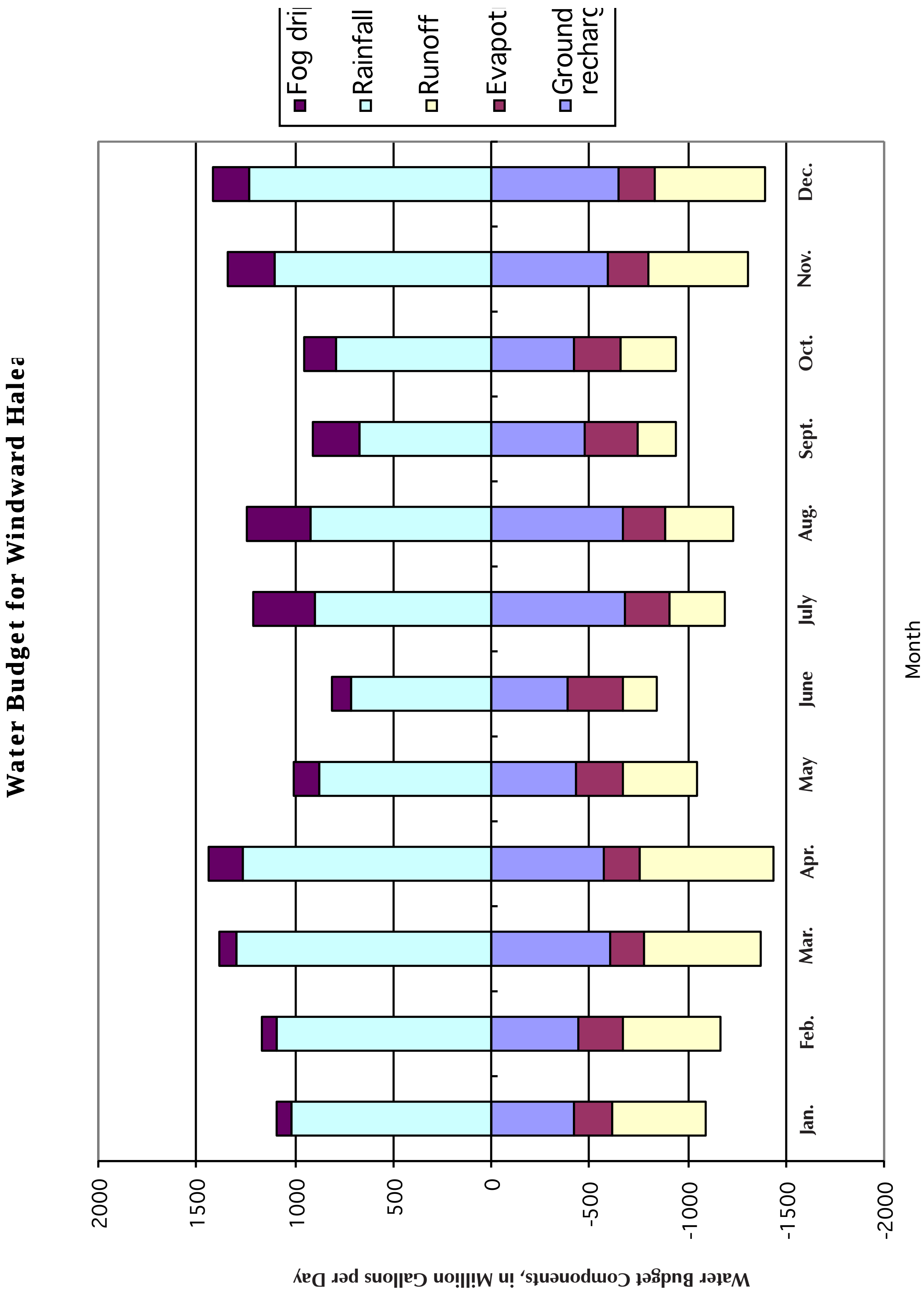
Other ideas for your *mele* include:

- 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.

Basic parameters for evaluating the students’ *mele* include:

- Accurate inclusion of the main water budget components (rainfall, fog drip, runoff, evapotranspiration, soil-moisture storage, and groundwater recharge),
- Accuracy in describing/including other concepts related to the hydrologic cycle, and
- Accurately locating places on Maui with respect to the hydrologic cycle.

You may also want to account for creativity, evidence of additional research, the range of additional information included beyond the six components of the water budget.


Water Budget for Windward Halea
Fog drip
Rainfall
Runoff
Evapot
Ground recharg
2000
1500
1000
500
0
-500
-1000
-1500
-2000
Water Budget Components, in Million Gallons per Day
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Month

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

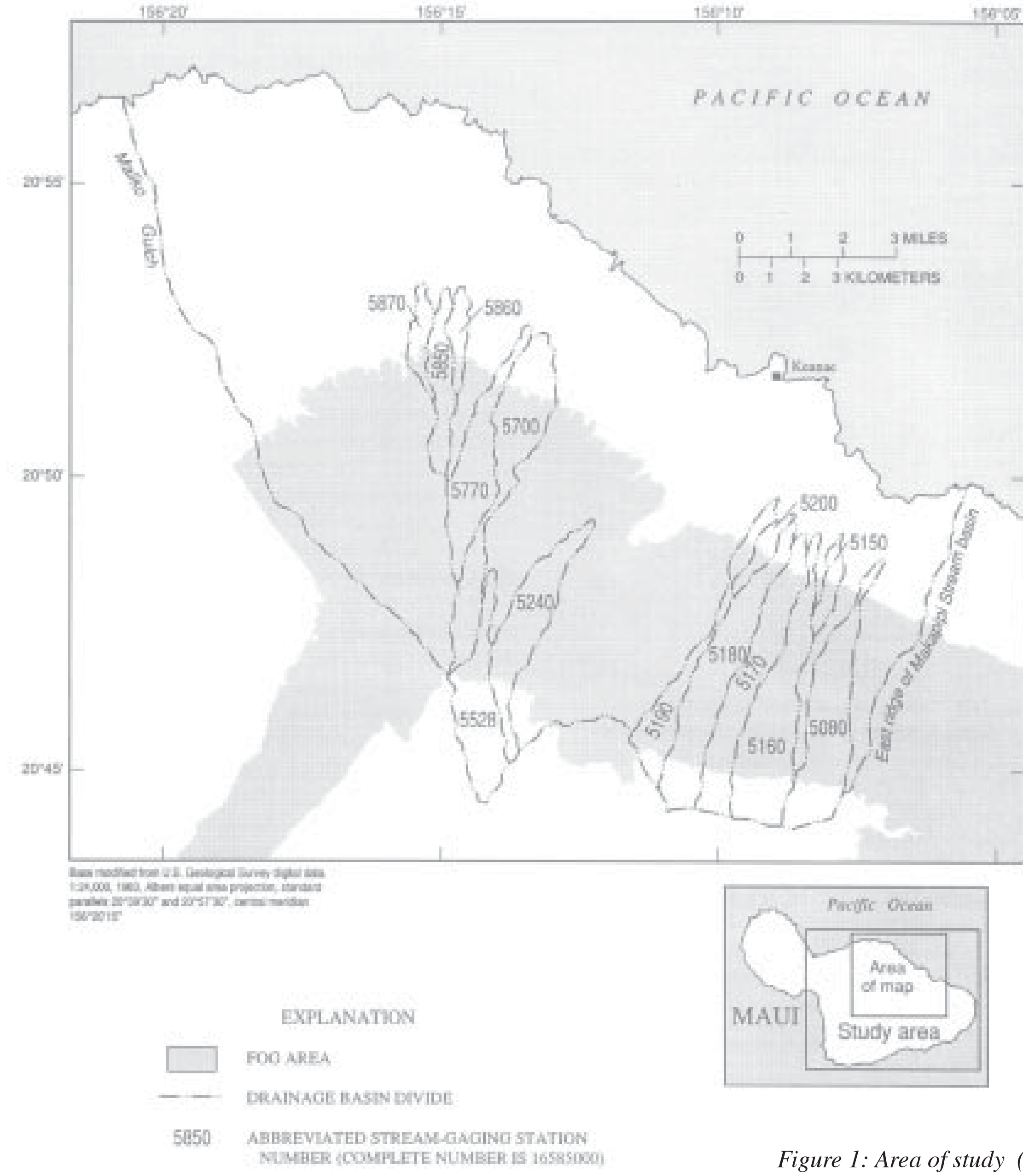


Figure 1: Area of study (Patricia J. Shade, Water Budget of East Maui, Hawaii*, U.S. Geological Survey, Honolulu, 1999, p. 13.)*

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

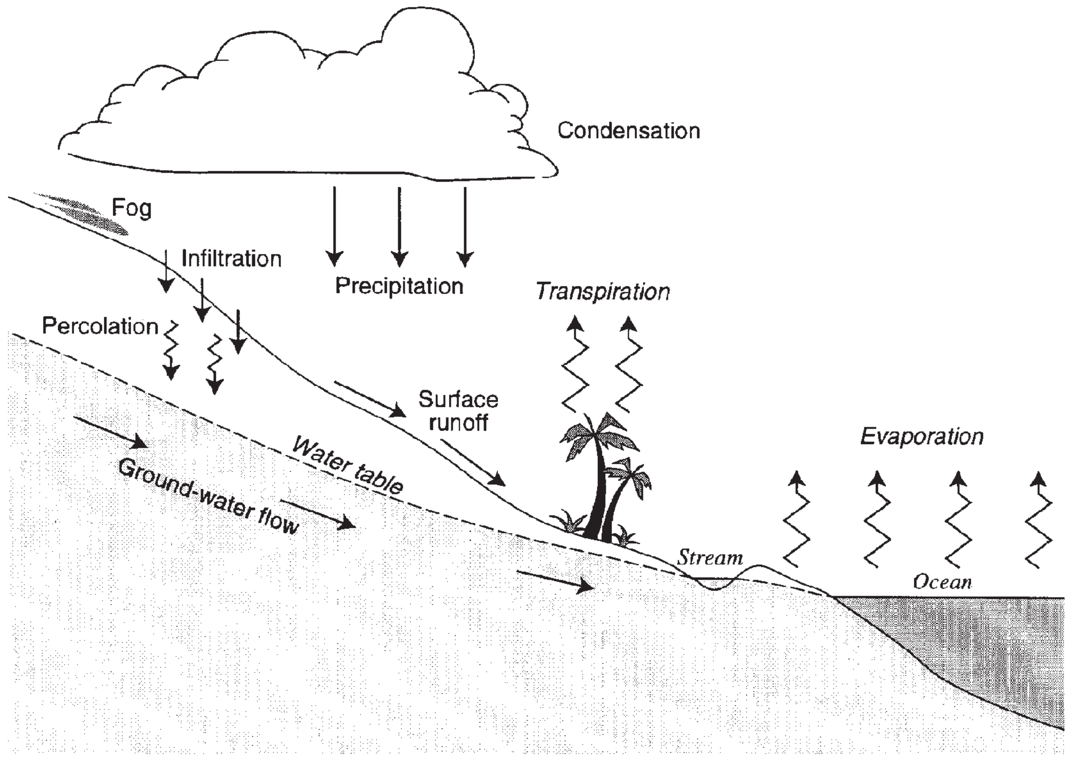


Figure 2: The hydrologic cycle (Patricia J. Shade, Water Budget of East Maui, Hawaii*, U.S. Geological Survey, Honolulu, 1999, p. 6.)*

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

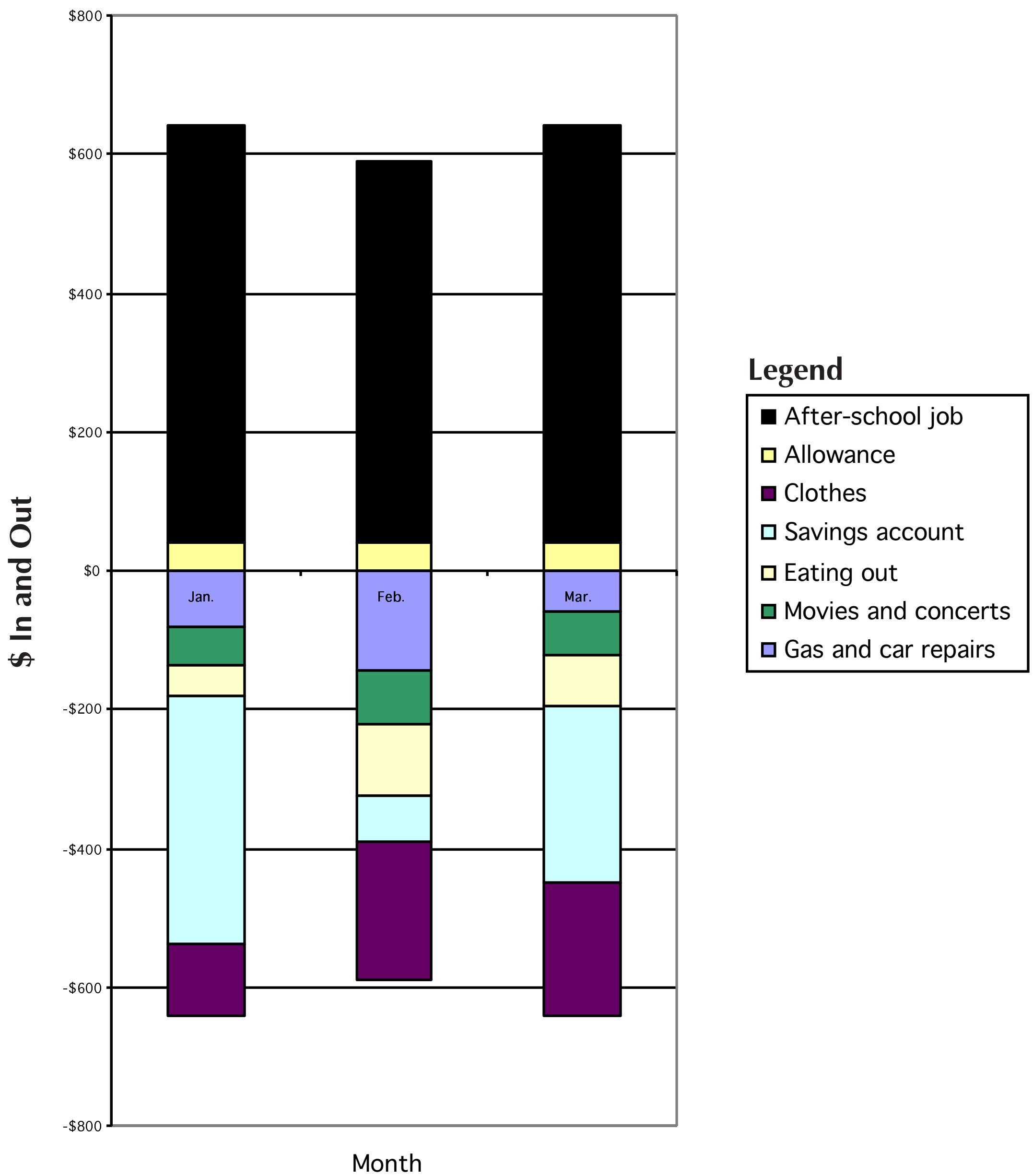
1) Using the data in Table 1: Mean Monthly Water Budget for Windward Haleakalā for your calculations, identify the three months in which the ratio of fog drip to rainfall is the highest. Below, list these three months and the contribution of fog drip to the water budget as a percentage of total moisture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

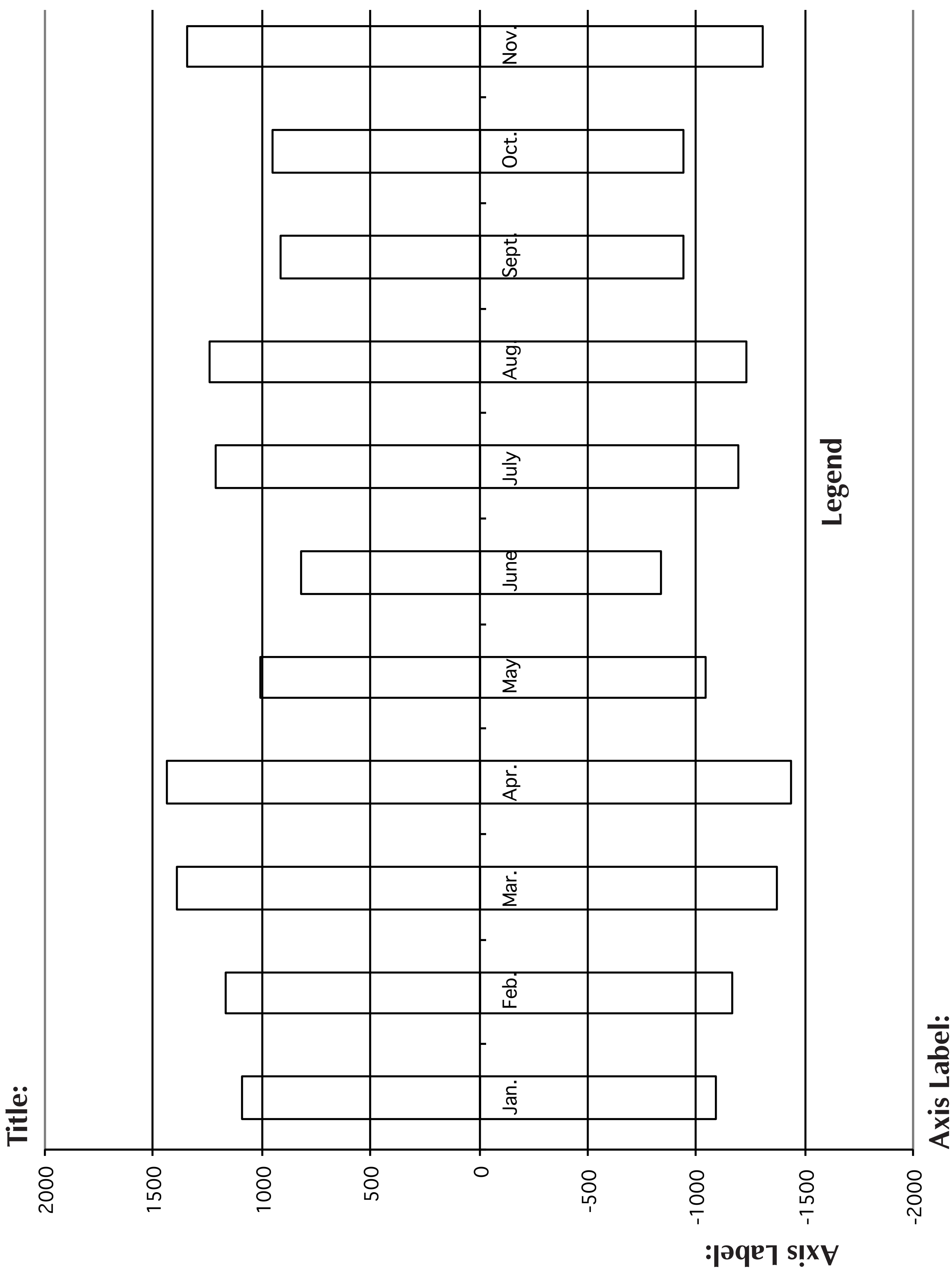
Top three months for fog-drip contribution	Percent of total moisture input
______________________	____________
______________________	____________
______________________	____________

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

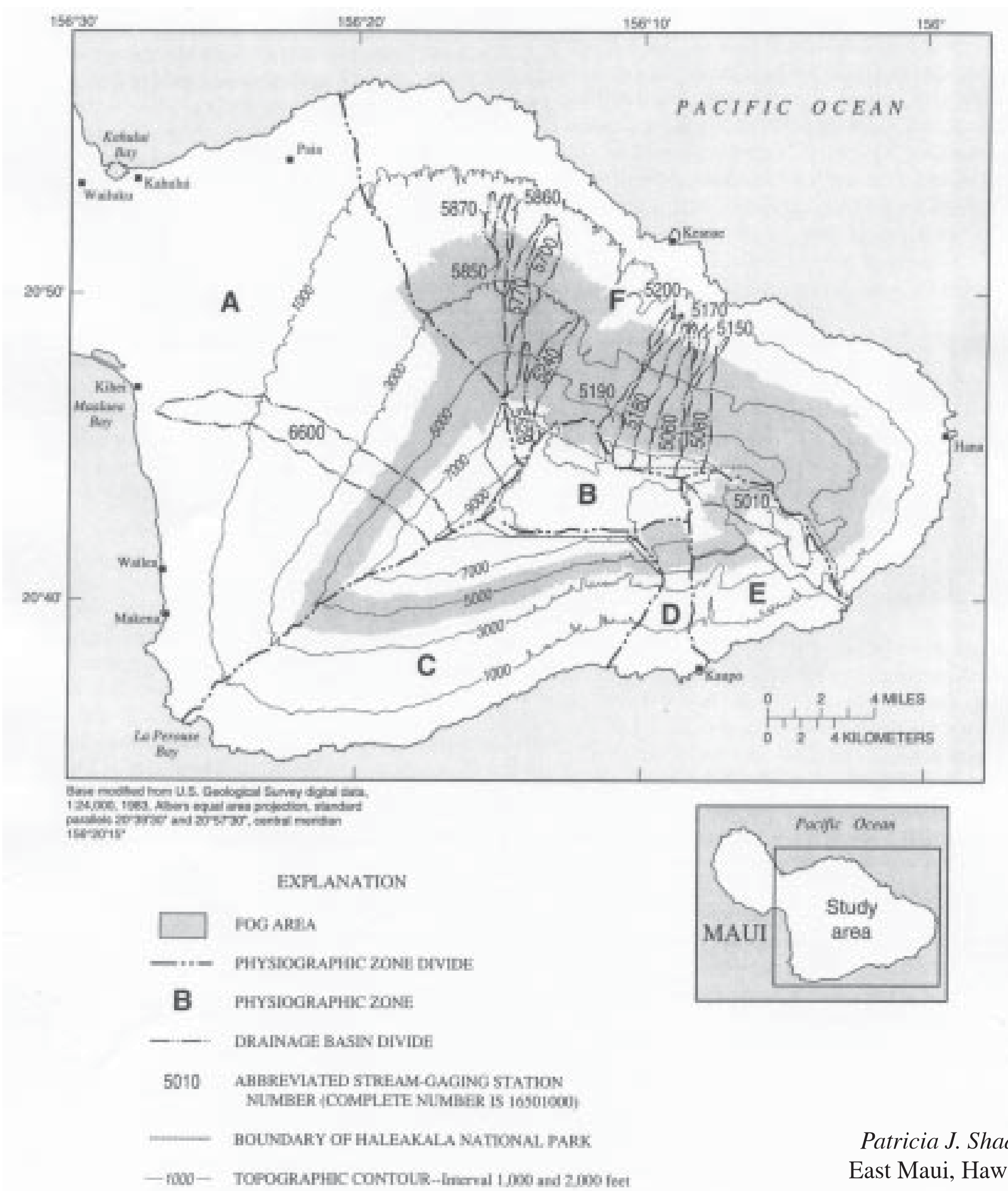



Title:
Axis Label:
Axis Label:
Legend
2000
1500
1000
500
0
-500
-1000
-1500
-2000
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.

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.**
<u>Windward Haleakalā</u>												
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
<u>Leeward Haleakalā</u>												
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.

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Ka Wai a Kāne (The Waters of Kāne)

He ui, he ni nau,	A question, a query
E ui aku ana au iā ʻoe:	I put to you:
Aia i hea ka wai a Kāne?	Where is the water of Kāne?
Aia i ka hikina a ka lā,	At the eastern gate
Puka i Haʻehaʻe	Where the sun comes in at Haʻehaʻe
Aia i laila ka wai a Kāne.	There is the water of Kāne.
E ui aku ana au iā ʻoe,	A question, a query I put to you:
Aia i hea ka wai a Kāne?	Where is the water of Kāne?
Aia i Kaulanakalā	Out there with the floating sun
I ka pae ʻōpua i ke kai,	Where cloud-forms rest of the ocean
Ea mai ana ma Nihoa	Uplifting their forms at Nihoa
Ma ka mole mai o Lehua,	This side the base of Lehua
Aia i laila ka wai a Kāne.	There is the water of Kāne.
E ui aku ana au iā ʻoe:	A question, a query I put to you:
Aia i hea ka wai a Kāne?	Where is the water of Kāne?
Aia i ke kuahiwi, i ke kualono,	There on the mountain peak, on the ridges steep,
I ke awāwa, i ke kahawai,	In the valleys deep, where the rivers sweep,
Aia i laila ka wai a Kāne.	There is the water of Kāne.
E ui aku ana au iā ʻoe:	A question, a query I put to you:
Aia i hea ka wai a Kāne?	Where is the water of Kāne?
Aia i kai, i ka moana,	There at sea, on the ocean
I ke Kaulau, i ke anuenue,	In the driving rain, in the rainbow arch,
I ka pūnohu, i ka uakoko	In the misty spray, in the blood-red rainbow
I ka ʻālewalewa	In the ghost-pale cloud form,
Aia i laila ka wai a Kāne.	There is the water of Kāne.
E ui aku ana au iā ʻoe:	A question, a query I put to you:
Aia i hea ka wai a Kāne?	Where is the water of Kāne?
Aia i luna ka wai a Kāne,	High up is the water of Kāne,
I ke ʻōuli, i ke ao ʻeleʻele,	In the heavenly blue, in the black-piled cloud,
I ke ao panopano,	In the thick dark cloud,
I ke ao popolohua mea a Kāne la e!	In the dark sacred cloud of the gods, indeed!
Aia i laila ka wai a Kāne.	There is the water of Kāne.
E ui aku ana au iā ʻoe:	A question, a query I put to you:
Aia i hea ka wai a Kāne?	Where is the water of Kāne?
Aia i lala, i ka honua, i ka wai hu,	Deep in the ground, in the gushing spring
I ka wai kau a Kāne me Kanaloa	In the place of Kāne and Kanaloa,
He waipuna, he wai e inu,	A wellspring of water, water to drink
He wai e mana, he wai e ola,	A water of power, the water of life!
E ola nō, ʻeā!	Life indeed!