UNDER THE WEATHER
GRADE 8

LESSON # 5 TITLE: RAINFALL

OVERVIEW:
Hawai'i is the most remote archipelago on earth. Hawai'i is the only one of the 50 United States surrounded completely by the ocean. It is also the only state within the tropics. Both of these facts contribute significantly to its climate, as also does its division into widely spaced islands and its topographic diversity.

STANDARDS:
Standard 8 Forces that Shape the Earth
Benchmark 8.8.3 Describe how the Earth's motions and tilt on its axis affect the seasons and weather patterns
Benchmark 8.8.4 Explain how the sun is the major source of energy influencing climate and weather on Earth.

MATERIALS NEEDED:

DURATION: 90 minutes or approximately 2 class periods

PROCEDURE:

Measuring Rainfall
Students can make a gauge to measure rainfall and see how much rain falls over several days.

What You Need
- glass or clear plastic container at least 10 inches high
- marbles or small pebbles
- permanent or waterproof marker
- 12-inch plastic ruler
- observation chart

Observations of Rainfall

Day	Height of Water	New Rainfall (today's height – yesterday's height)	Observations
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			

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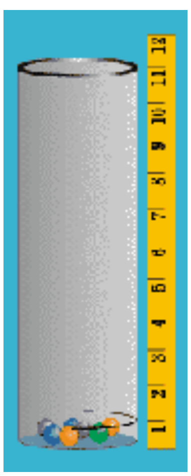
What to Do

1. Place several marbles or pebbles into the container and add water until it is about one inch deep. Draw a line on the container to show the water level. The marbles and the water will steady the container against wind. The water will also provide a base level for measurements.
2. Put the rain gauge outside on a level surface, away from any overhanging eaves or trees. Leave the gauge outside all week. Measure the rainfall every day at about the same time of day. Record readings and comments about the weather on an observation chart.

To Measure Rainfall

Have one student hold the ruler against the side of the container, with the ruler's bottom end even with the base line. Have another student read the height of the water column. To get an accurate reading, the student must be at eye level with the top of the water. Subtract the previous day's reading from the new reading to determine how much rain fell between readings. Always use the original mark as the base line.



ASSESSMENT:

Benchmark 8.8.3: Describe how the Earth’s motions and tilt on its axis affect the seasons and weather patterns.

- formative assessment – Lesson #5 understanding of rainfall patterns
- summative assessment -- Lesson #5 cumulative tracking of rainfall totals over time and formulation of forecast

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Benchmark 8.8.4: Explain how the sun is the major source of energy influencing climate and weather on earth.

BACKGROUND INFORMATION FOR TEACHER:

HUMIDITY AND CLOUDINESS – Because of the diversity of valleys, hills, and mountains, the moisture distribution within the air that moves across Hawaii is far from uniform, even at one level in that air. There are, however, a few major features of that distribution which are evidenced repeatedly, and which give coherence to the observed variations in humidity and cloudiness conditions.

Under trade-wind conditions, there is very often a pronounced moisture discontinuity at heights of between 4,000 and 8,000 feet. Below these heights, the air is moist; above it is dry. The break occurs in association with a temperature inversion that is typically embedded in the moving trade-wind air, and represents a large-scale feature of the Pacific Anticyclone. From the surface up to the inversion, the temperature decreases with increasing height in a uniform manner. The moisture is well distributed throughout this lower layer, and the moisture content of the air is relatively high. At the base of the inversion, the temperature increases by several degrees, sometimes quite suddenly. These higher temperatures may extend upward for several hundred feet before the temperature begins once more to decrease upward, in the manner that is most usual in the atmosphere. The significance of the inversion climatically is that it tends not only to produce a lower, more moist layer as against a higher, more dry layer, but it also tends to suppress the vertical movement of air and hence to restrict cloud development to the zone beneath the base of the inversion.

When the inversion is present, as it is 50 to 70 percent of the time, its height fluctuates from day to day, but it is usually between 5,000 and 7,000 feet. On trade-wind days when the inversion is well defined, the clouds develop most markedly below these heights with only an occasional cloud top breaking through the inversion. These towering clouds form chiefly along the mountains in particular local situations where the incoming trade-wind air converges as it moves up a valley way and is forced up over the mountains to heights of several thousand feet. The overall result is a complicated cloud patter, typically with scattered to broken clouds above the lowlands at a uniform height on the windward coasts and with more dense cloud masses along the mountains; these clouds are generally of uniform height, but with some smaller masses that bulge upwards.

On days when there is no inversion, the vertical development of clouds is much greater. There may then be towering clouds at sea as well as over the land. There is still a tendency for the maximum cloud development to occur along the mountains with individual clouds likely to tower upward 15,000 feet or more. With a storm or other disturbance in or near the islands, the cloud pattern may become very complicated, often with very high cirrus clouds in different arrangements, with layered or cellular cloud decks beneath them at heights of 8,000 or 15,000 feet, and with masses of cumulus clouds rising from near the surface to 30,000 to 50,000 feet. At the other extremes, there are occasional days without an inversion when the sky is almost cloudless, and a few times a year it is possible to scan the entire sky without seeing a single cloud.

Under standard definitions of cloudiness, clear represents 3/10 or less of the entire sky dome covered with cloud, partly cloudy, 4/10 to 7/10, and cloudy 8/10 or more. With reference to these definitions, throughout the lowlands in windward areas in the islands the sky is cloudy about 40 to 60 percent of the time during the daylight hours and is clear 15 to 20 percent of the time. In downtown Honolulu, which is to the leeward of a low mountain range, these values are 27 percent cloudy and 25 percent clear during the daylight hours. In leeward locations well screened from the trade winds, as along the west coasts of Maui, Kauai, and Oahu, the percentage of clear daylight conditions ranges from 30 to 60 percent and cloudy conditions decrease to less than 20 percent. However, in these leeward areas as in those to the windward, the cloudiness increases rapidly as the mountains are approached.

In general, windward areas tend to be cloudier during the summer, when trade winds and trade wind clouds are more prevalent, while leeward areas – which are less affected by trade-wind cloudiness – tend to be cloudier during the winter, when general storms and frontal passages are more frequent. Leeward coasts and lowlands are actually sunnier than the foregoing percentages suggest, since a large part of the reported sky cover consists of clouds which lie over the mountains to windward, but may not obscure the sun or the sky directly overhear. The cloudiest zones of all are at and just below the summits of the mountains of Kauai, Oahu, Molokai, Lanai, and western Maui, and at elevations of 2,000 to 4,000 feet on the windward sides of Haleakala, Mauna Loa, and Mauna Kea. In these locations, the sky is cloudy more than 70 percent of the time.

In contrast, the areas of least cloudiness include the high mountains above about 8,000 feet. Here the skies are normally clear between late evening and forenoon, but tend to become cloudier during the middle part of the day. The description by Price and Pales of the usual regime at the Mauna Loa Observatory (11,150 feet) is representative of most high mountain locations:

"…a typical day at the Observatory may dawn bright and clear. Visibility is excellent. Peaks on other islands 80 miles distant and more are distinguishable without difficulty. The trade inversion lies several thousand feet below, and trapped beneath it are the clouds and the bulk of the water vapor, dust, and haze. In the clear atmosphere, insolation in intense…."

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"By early afternoon, moister air appears to be seeping upward along the mountain. The humidity increases and fractocumuli (broken cumulus clouds) advance up the slopes. In the next hours, the observatory may be briefly enveloped in fog or light rain; but by evening the clouds have dissipated and the conditions, which opened the day return. Nights are generally clear."

The usual clarity of the air in the high mountains is associated with the low moisture content of the air. Except for occasional periods of a few hours duration, which seem to accompany the arrival of more moist air from below, the relative humidity is generally below 40 percent, and it often falls to 10 or even five percent. Such low humidities are characteristic of the zone above the inversion that separates the lower and upper air.

Below the inversion, the lowlands and along the lower mountains, the relative humidity commonly averages 70 to 80 percent in windward areas and 60 to 70 percent in leeward ones. Winter relative humidities are somewhat higher than summer ones; and in terms of daily variations the maximum values occur with the minimum temperatures, during the late night and very maximum values occur with the minimum temperatures, during the late night and very early morning. Nighttime values in the cooler and rainier areas often exceed 90 percent, but are more frequently between 70 to 80 percent in the leeward lowlands and other drier localities. Afternoon values are commonly between 60 to 70 percent in the windward and uplands regions, not infrequently between 50 to 55 percent in the drier, warmer coastal zones, and seldom fall below 40 percent anywhere at elevations below the trade wind inversion. Thus, except on the high mountains, the general regime in Hawaii is one of high humidities as compared with conditions in most other states.

RAINFALL – If the islands of the State of Hawaii did not exist, the average annual rainfall upon the water where the islands actually lie would be about 25 inches. Instead, the actual average is about 70 inches. Thus the islands extract from the air that passes across them about 45 inches of rainfall that otherwise would not fall. That the mountains are dominantly responsible for this added water bonus is evident from annual rainfall maps, which show the tremendous amounts of rainfall deposited in mountainous areas in the average year. In many mountainous areas of the State, these depths exceed 240 inches, or 20 feet. At Mt. Waialeale, on Kauai, the annual average reaches the extraordinary total of 486 inches – over 40 feet. This is the highest recorded annual average in the world.

An average of 70 inches of rainfall over Hawaii is equivalent to not quite 8,000 billion gallons of water per year. This is more than 10 times the annual water use of something over 700 billion gallons. According to the 1965 figures, irrigation accounted for 74 percent of this total use industrial uses (chiefly for cooling) accounted for 19 percent, while the remaining seven percent was used for domestic and miscellaneous purposes.

With actual water requirements running less than 10 percent of the water supplied annually by rainfall, it may seem strange that there are major problems of water supply in many parts of Hawaii. However, not only are there very substantial water losses due to evaporation, transpiration, and runoff, and by percolation into the porous lavas, but the rainfall distribution is exceedingly uneven. There are very few areas elsewhere in the World and none elsewhere in the United States where rainfall gradients are as steep as they are in Hawaii. In a great many places in Hawaii, the annual rainfall gradient exceeds 25 inches per mile; that is the rainfall increases 25 inches for each mile transversed along a straight line. In an extreme instance, the gradient is 118 inches per mile along the 2-1/2 mile line from Hanalei Tunnel to My Waialeale on Kauai. These steep rainfall gradients and the presence of very dry areas as well as very wet ones result in there being abundant water overall, but with great surpluses in some areas and great deficiencies in others. The major problem of water supply is therefore one of distribution rather than one of a general water shortage.

ANNUAL RAINFALL PATTERNS – The zones of highest rainfall on the flanks of the large, high mountains of Haleakala, Mauna Loa, and Mauna Kea lie at elevations of 2,000 to 4,000 feet. In contrast, on the remainder of the mountains, all of which are less than 6,000 feet in maximum elevations, the highest rainfall is along or near the crest line. The difference lies in the fact that the incoming ocean air that is the source of rain usually flows across the lower mountains, whereas it largely flows around the higher mountains. It is significant in this regard that the trade-wind inversion, which tends to suppress vertical lifting of the air, is usually above the level of the crests of the low mountains and is never above the level of the crests of the high mountains.

The driest areas are on the upper slopes of the high mountains, on leeward coasts, or in leeward locations in the interior of the islands as in central Maui. In the driest of these areas the average annual rainfall is less than 10 inches; and one area, around Kawaihae Bay near the northern end of the west coast of Hawaii, the rainfall is less than seven inches.

In many areas of intermediate rainfall, the natural landscape indicates great aridity. Thus xerophytic (drought-resistant) plants, widely scattered across otherwise barren ground, are sometimes found in areas in which the annual rainfall is 100 inches or more. This seeming anomaly is the result of very high infiltration rates in the volcanic rocks and soils so that the water that falls as rain moves rapidly downward to great depths in the regolith (loose material overlaying solid rock of earth) and is available to the plant only to a sharply limited extent.

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Areas of this kind are most commonly found on the relatively young island of Hawaii.

SEASONAL VARIATIONS IN RAINFALL – Except for the Kona coast of Hawaii, at elevations below 2,000 feet throughout the State winter is the season of highest average rainfall. The contrast is rainfall between the pronounced at low elevations in the areas with low annual rainfall. The contrast is least in areas of higher annual rainfall, as at Hilo. Further, within the extremely rainy areas above 2,000 feet, the winter rainfall maximum disappears in many localities and instead there is fairly uniform, superabundant rainfall all months of the year. Thus at Kukui, Maui, at an elevation of 5,788 feet, the average monthly rainfall is 32.81 inches in winter and 33.49 in summer, with April the wettest month (40.78) and October the driest (23.33). The average annual rainfall at Kukui is slightly over 399 inches. Finally, in the very high mountains where conditions are dry, winter is again the rainier of the two seasons, although only slightly so. This is indicated by the observations at Mauna Loa Observatory (11,150 feet), where with an annual precipitation of about 21 inches, winter precipitation averages 1.8 inches per month, and summer precipitation averages 1.6.

The Kona coast of Hawaii has a unique seasonal rainfall regime. The summers are wetter than the winters. At Napoopoo, for example, the average monthly rainfall in winter is 2.80 inches, while the average in summer is 3.70. November is the driest month, with an average of 2.06 inches. September is wettest, with an average of 3.90 inches. Napoopoo is at an elevation of 400 feet and has an average annual rainfall of 38.05 inches. The summer maximum on the Kona coast is associated with the fact that the well-protected Kona coast is associated with the facts that in the well-protected Kona area, which lies to the leeward of Mauna Loa and Mauna Kea, there is a distinctive local circulation. Daytime onshore breezes yield fairly regular and sometimes in summer than winter. The winter storms that contribute the bulk of the average annual rainfall in other lowland regions of the State contribute less rain to the Kona coast.

DIURNAL VARIATIONS IN RAINFALL – In the lowlands at all times of the year, rainfall is most likely to occur during the nighttime or in the morning hours and least likely to occur during midafternoon. Correspondingly, not only is rainfall more frequent at night, but also the total nighttime fall averages more than the total daytime fall when the two 12-hour periods are compared. The values for Honolulu are representative. They show that 59 percent of the annual rainfall total falls, on the average, between 8 p.m. and 8 a.m. In general, this diurnal variation is far more pronounced in summer than in winter, especially with respect to rainfall frequency. Thus in summer, rainfall during the early morning hours (3 to 8 a.m.) is about twice as frequent as during the late morning and early or middle afternoon (11 a.m. to 4 p.m.)

The more pronounced diurnal variations in summer is associated with the fact that most summer rainfall consists of trade-winds showers and these showers are most apt to occur at night. On winter most of the rainfall is the lowlands occurs in general storm situations, and these are as likely to take place during the daytime as at night.

It seems reasonable to suppose that at elevations of a few thousand feet, where trade-wind showers contribute very substantially to the total rainfall in winter as well as summer, the nighttime rainfall maximum is better marked in winter than it is in the lowlands. However, on the very high mountains above the trade-wind inversions, the diurnal cycle appears to be reversed since, judging from the Mauna Loa Observatory observations, the late afternoons are the time when light rains are most apt to occur as accompaniment to the arrival of moist air carried upward by the upslope wind from below.

RAINFALL VARIABILITY AND DROUGHT – In most parts of the tropics rainfall is highly variable from one year to another and Hawaii is no exception. Even in areas where the rainfall is very high and the monthly averages are above 10 inches, the rainfall of particular months may vary by 200 to 300 percent from one year to another and there may be occasional months with only one or two inches of rain.

The great variability in annual rainfall is evident from the extreme values at several different stations during their periods of record. IN downtown Hilo, in 79 years of record, the highest annual total was 207 inches the lowest 72. At Honolulu, in 62 years, the extreme values were 46 inches and 10 inches at Mana, Kauai, in 61 years, 48, and five inches. During a period of only 23 years at Kukui, Maui, the extremes were 578 and 250 inches.

Rainfall variability is far greater during the winter, when occasional storms contribute appreciably to rainfall totals, than during summer, when trade-wind showers provide most of the rain. In January, Hilo has received less than 0.2 inches of rain, but also more than 50 inches. Honolulu has received as little as 0.12 and as much as 18 inches. The highest January total in 23 years at Kukui was 58 inches. The extreme August rainfall totals have a much smaller range. At Hilo, the range was from two to 38 inches. At Honolulu, it was from 0.2 inches to four inches. At Kukui during 23 years, it was from 10 to 88 inches.

With such wide swings in rainfall, it is inevitable that there are occasional doubts, sometimes with severe economic losses. The real drought years are the ones where the winter rains fail, in which there are only one or two or even no rainstorms whatsoever on real magnitude. Although such a deficit of winter storms can affect any portion of the State, it hits hardest in the normally dry areas that depends chiefly on winter rains and receive little rain from the trade wind showers. In these localities, the small amount of rainfall that occurs during the usual dry summer season is insufficient to prevent severe drought. Severe droughts are usually limited to an area of 50 square miles or so, but even so, they may be very costly because of the increased water costs. Where irrigations is not practiced they may destroy r severely damage the crops and range grasses.

Among the winters of record when the rainfall was decidedly below, average throughout most of Hawaii was that of 1925-26. At Honolulu during this period, every month from November through April experienced below average rainfall and the total rainfall for the five-month period from January through May was less than three inches. For 100 consecutive days during the drought, there was not as much as 0.3 inch of rainfall on any one day at Honolulu and only on two days was there as much as 0.2 inch. Daily rainfall amounts of this magnitude are insignificantly small as far as any real benefit to crops is concerned, especially in a tropical area where water losses through evaporation and transpiration are high. During this drought period, there were severe water shortages in many areas on Hawaii, even though some areas received appreciably more rain than Honolulu. Drought damage was greatest on rangeland and in truck crop and pineapple areas, where irrigation was not being practiced.

RAINFALL INTENSITIES – Torrential rainfall is common in all parts of Hawaii except the very high mountains, although it has been known to occur even there. Yet it is also true that in Hawaii very light showers are extremely frequent in most localities. On windward coasts, for example, it is usual to have six, eight, or even 10 brief showers in a single day, not one of which is heavy enough to produce 0.01 inch of rain. This seeming contradiction is explained by the fact that the usual run of trade-wind weather yields many light showers in the lowlands, whereas the torrential rains are associated with other weather regimes: with a sudden surge in the trade-winds or with a major storm.

Extreme rainfall intensities are high in Hawaii. To take the most extreme instance of record, during the storm of January 24025, 1956, over 38 inches of rain fell at the Plantation Office, Kilauea Sugar Plantation, Kauai, within a 24-hour period, out of a storm total of 43.5 inches. During the same storm, six inches of rain fell during a single 30-minute period and about 12 inches fell in one hour. The 38-inch value for 24- hours is conservatively low, because the gage was already overflowing when it was emptied for the first time. The six-inch value is correct within one or two tenths of an inch; the 12-inch value for one hour is an estimate only – again because of overflow – and may be in error by as much as an inch.

Rainfall intensities and totals as high as the extraordinary values just cited appear to have occurred when a current or moist, unstable air, converges as it moves up a narrowing valley, and at the same time is forced to rise abruptly over steep mountains. Such special topographic circumstances are not essential to the occurrences of torrential rains. In November 1931 Moanalua, O'ahu received 15.2 inches of rain within three hours; Hana, Maui has had as much as 28 inches of rain in 24 hours; Opaeula, O'ahu, 26 inches; and Hilo 19 inches, even though none of these are favorably situated with references to topographic surroundings conducive to the occurrence of very high rainfall intensities. In fact, the most copious rains in Hawaii frequently do not occur in localities having the greatest average rainfall; nor is it uncommon during such storms for relatively dry areas to receive within a single day, or even a few hours, totals approaching their mean annual rainfall.

At Honolulu the greatest 24-hour fall in 55 years of record was that of March 5-6, 1958, when 17.41 inches of rain was recorded at the Federal Building in the downtown area. The gage where this total was recorded is situated well away from local topographic influences that might cause excessive rainfall, a fact that was evident from the distribution of maximum storm amounts. The second greatest fall of record in downtown Honolulu is 13.52 inches in 24-hours; the third, 8.07 inches. In general, all stations in Hawaii that have 50 years of record have experienced daily rainfalls of at least eight inches, and the majority have experienced falls of 12 inches or more. These values are comparable to or greater than those for the great majority of stations in the Gulf of Mexico area, which is the principal area in the Mainland United States in which extreme rainfalls are of the same magnitude as those in Hawaii, especially for periods of a few hours or more.

Torrential rains, falling on Hawaii's steep slopes and small drainage basin, often generate flash floods that erode fields and cause landslides and damage to homes. The last of these is an increasingly important problem, as residential development encroaches on flood plains.

FOG DRIP – Mountain slopes and crests within the cloud belt are frequently exposed to contact with fog or cloud mists. Although no measurable precipitation may be recorded by rain gages, experiments atop Lanai Hale, highest point on the island of lanai, suggest that this "fog drip" may contribute two-thirds as much water to vegetation and soil in that area as does rainfall itself – and proportionately more when rainfall is light.

WEB RESOURCES

Seasons and Months: Stories of an Ancient Island: Traditions of O'ahu: Asia-Pacific Digital Library - http://apdl.kcc.hawaii.edu/~oahu/stories/months.htm

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Education Center Activity: Tracking Rainfall -
http://www.eduplace.com/rdg/gen_act/weather/rain.html

PRINT RESOURCES
Holt Science and Technology, Earth Science, Teacher Edition, Chapter 15 – The Atmosphere, Chapter 16 – The Atmosphere, Section 1 *Understanding Weather.*