GEOLOGY AND STREAM INFILTRATION OF NORTH HALAWA VALLEY, OAHU, HAWAII

By Scot K. Izuka

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CONVERSION FACTORS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
mile (mi)	1.609	kilometer
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square mile (mi^2)	2.590	square kilometer

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ABSTRACT

A geohydrologic investigation of North Halawa Valley, Oahu, Hawaii, and its stream was undertaken in response to concern that runoff from the H-3 highway draining into the stream might seep into the ground and seriously contaminate potable water pumped at a nearby skimming well.

North Halawa Stream flows over highly weathered alluvium or highly weathered basaltic basement for almost its entire course. Measurements of discharge at selected points along the stream indicate that infiltration occurs along some reaches. The infiltration of water from North Halawa Stream varies with season and stage. Water lost by the stream probably passes into and out of a perched aquifer in the alluvium of North Halawa Valley. Some of the water could pass from the alluvium to the basal aquifer from which the skimming well draws its water.

INTRODUCTION

North Halawa Valley overlies the Pearl Harbor aquifer (fig. 1), an important source of potable water for the island of Oahu. Freshwater in the Pearl Harbor aquifer is part of a large, lens-shaped body of ground water that is thickest in the central part of Oahu and thins toward the coastline. This lens of freshwater, known as the "basal lens," floats on saltwater that penetrates from the ocean into the basalt flows of which the island is composed. The basal lens is divided into multiple aquifers, including the Pearl Harbor aquifer, which are separated by structures of low permeability (Eyre and others, 1986). The Pearl Harbor aquifer is bounded on the northeast by the dike zone of the Koolau Range, on the southeast by valley-filling sediments, on the south by the sediments of the coastal plain, and on the west by the dike zone of the Waianae Range (Eyre, 1987). The nature of the aquifer's northern boundary is uncertain, but it separates the Pearl Harbor aquifer from the Schofield aquifer to the north (Dale and Takasaki, 1976).

A large part of the water developed from the Pearl Harbor aquifer is pumped from the Halawa shaft (plate 1), which is operated by the Honolulu Board of Water Supply. Approximately 8 to 12 Mgal/d are pumped from the shaft's development tunnels, which skim the top of the aquifer. The shaft is the only producing well in the study area (plate 1), but accounts for approximately 10 percent of Honolulu's water supply (Chester Lao, Board of Water Supply, City and County of Honolulu, oral commun., 1989).

This investigation, undertaken in cooperation with the State of Hawaii, Department of Transportation, stems from concern that runoff entering North Halawa Stream might seep into the ground and contaminate the ground water.

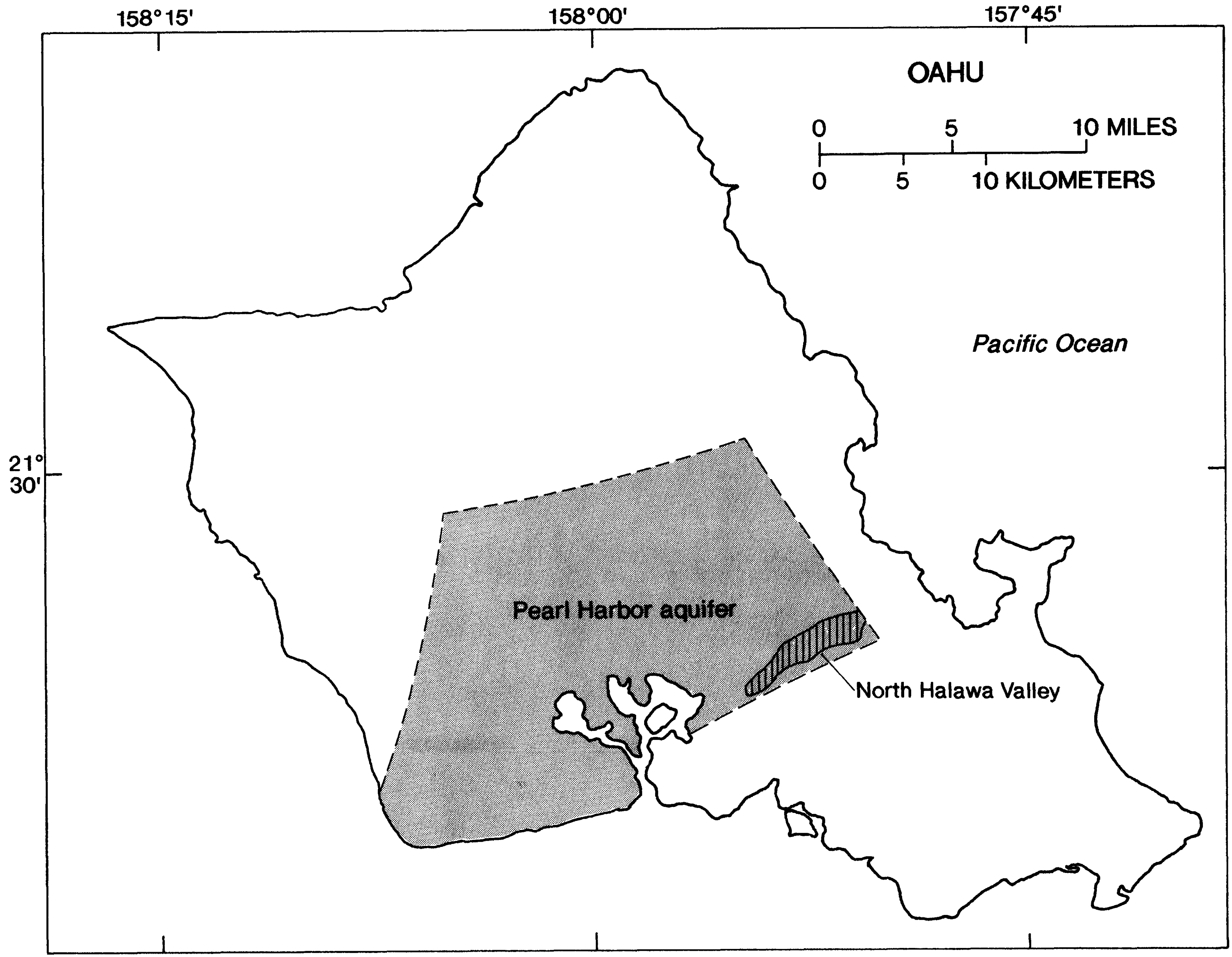


Figure 1. Location of North Halawa Valley and Pearl Harbor aquifer.

The objective of this investigation is to determine the general geohydrologic setting of North Halawa Valley through which a new interstate highway (H-3) will be constructed.

This report includes (1) a description of the geology of North Halawa Valley from the crest of the Koolau Range to the Halawa shaft, (2) a description of the Pearl Harbor aquifer in this region, including the depth of the aquifer below the stream channel and an estimate of the zone of capture of the Halawa shaft, (3) a survey of stream seepage by measurements of discharge at selected points along the stream, and (4) a study of stream discharge using records from two U.S. Geological Survey (USGS) stream-gaging stations (16226000 and 16226200) on North Halawa Stream (plate 1).

REGIONAL SETTING AND GEOMORPHIC FEATURES

North Halawa Valley is a narrow, V-shaped valley on the leeward, southwestern flank of the Koolau Range, the younger of two large shield volcanoes that make up the bulk of the island of Oahu. The axis of the valley trends roughly northeast-southwest and extends 5 mi from the crest of the Koolau Range at the 2,400 ft elevation, to where the Koolau Basalt dips under the sediments and volcaniclastic deposits of the coastal plain at about 50 ft elevation. Rainfall ranges from an annual average of 150 in. in the upper valley to 40 in. in the lower valley (Blumenstock and Price, 1967).

The main shield-building stage of the Koolau Range ended approximately 2 million years ago. The original form of the shield volcano has been carved by erosion (Macdonald and others, 1983). A thick sequence of thin lava flows constitute the basement rock in the study area. Material eroded from the shield has been deposited on the lower slopes and has partially filled the valley. The resulting topography consists of steep valley walls composed of basalt flows of the Koolau Range, a moderately sloping colluvial apron at the base of the valley walls, and nearly flat-lying sediments on the valley floor (plate 1).

Geology

Basalt Basement Rock

The oldest geologic unit exposed in North Halawa Valley is the Tertiary Koolau Basalt which includes the tholeiitic basalts of the Koolau Range (Stearns, 1939; Langenheim and Clague, 1987). Exposures of these rocks in Halawa Valley consist of many thin (1- to 10-ft) aa and pahoehoe flows of the Koolau Basalt. Outcrops of pahoehoe are characterized by smooth or rounded outlines and abundant spherical vesicles. Aa flows are recognized by their two-part (clinker and core) constitution. Aa clinker is so different in character from the core of the flow that alternate layers of clinker and cores in a succession of aa flows can be recognized from a distance of hundreds of feet, if not obscured by vegetation. Pyroclastic deposits in the Koolau

Basalt are uncommon, but do occur as small, discontinuous outcrops of tuff in North Halawa. The basalts and pyroclastics of the Koolau Basalt constitute the basement rock on which all the younger alluvium and colluvium were deposited. An erosional unconformity between the Koolau Basalt basement and the overlying sediments is exposed in many road cuts and in some parts of the channel of North Halawa Stream (plate 1).

Quaternary Volcanic Rock

The Quaternary Honolulu Volcanics include tuff cones less than 1 mi southwest of the Halawa shaft and pyroclastic deposits in Haiku Valley to the northeast (Stearns and Vaksvik, 1935; Langenheim and Clague, 1987). No volcanic rocks younger than the Tertiary Koolau Basalt were found in the study area, although tuff encountered during the excavation of the Halawa shaft may be of Pleistocene age. No other evidence of Honolulu Volcanics was found in the study area.

Sedimentary Deposits

Sedimentary deposits in North Halawa Valley are primarily gravels and conglomerates. These clastic deposits include Quaternary alluvium and colluvium, which are easily distinguished from each other in outcrop, but are difficult to distinguish if obscured by vegetation. The colluvial and alluvial deposits are thus mapped as a single unit (Qac in plate 1).

Alluvium

Alluvium includes the sediments deposited by North Halawa Stream, its tributaries, and their predecessors. These sediments, which consist of conglomerates and gravels, have varied weathering and diagenetic histories and different lithologic and hydrologic character. Previous investigators have subdivided the alluvium of Oahu into "older" and "younger" subunits on the basis of diagenetic and weathering criteria (Stearns and Vaksvik, 1935; Wentworth, 1951). In this report, the term "young alluvium" refers to the deposits of the active reaches of North Halawa Stream and its tributaries, and "old alluvium" refers to consolidated or highly weathered alluvium not deposited by the present stream, including deposits that are at such an elevation that they could not be considered part of the present stream system. Young alluvium consists of rounded, loose boulders, cobbles, pebbles, and sand in a clast-supported fabric. Silt and clay are only minor components of the alluvium. Old alluvium is similar to young alluvium but is commonly cemented and slightly to highly weathered. In some outcrops, the weathering is superficial and the clasts are hard, but in other outcrops the alluvium has been weathered to a soft or friable consistency. Weathering has given rise to secondary clays, but because they coat grains rather than fill interstices, the secondary clays are easily distinguished from the detrital clays. With the exception of secondary clays, old and young alluvium contain little clay.

Colluvium

Colluvium includes the veneer of sedimentary deposits on the steep slopes of the valley walls as well as thicker deposits from mass wasting. Colluvium has a greater proportion of silt and clay than alluvium has (Stearns and Vaksvik, 1935). The colluvial deposits contain clasts that are angular and poorly sorted, and the fabric of the deposits is matrix supported.

Distribution of sedimentary deposits

Young alluvium forms thin, patchy deposits that line the channels of the present North Halawa Stream, its tributaries, and many of the interstream areas. Test borings near the stream show that young alluvium is several feet thick in some places, but most of the sediment that fills the valley, particularly in the lower valley, is old alluvium. Old alluvial deposits occur along some banks of the stream at elevations above the present stream level in Halawa Valley.

The sediments of North Halawa Valley are thicker and more extensive in the lower valley (plate 1). Borings near the Halawa shaft indicate that the total thickness of the sediment at the axis of the valley is more than 100 ft (plate 1, section A-A'). Midway up the valley, as also indicated by borings, the sediments are only about 30 ft thick (plate 1, section D-D'), and in the upper valley the sediment is absent or only a few feet thick (plate 1, section F-F'). The sediments thin away from the axis, and are overlain by the colluvial apron fringing the steep valley walls.

Weathering

Rocks from the outcrops of the Koolau Basalt in North Halawa Valley show a range in the degree of weathering: from slightly weathered basalt in the lower valley to basalts that have been highly weathered to a soft, clay-like consistency. Some of the rocks exposed in the valley walls and in the channel of the lower reaches of North Halawa Stream have been weathered only slightly, whereas other rock exposures have been highly weathered to a soft, clay-like consistency. Exposures of heavily weathered basalt lava flows are typically red-brown or tan and their original mineralogy has been completely altered, but the weathered basalts still retain the original lava-flow structures. Despite extensive weathering, it is usually possible to distinguish basement rock from sedimentary cover, and aa from pahoehoe.

The topography of the valley partly reflects the extent of weathering. In the lower valley, the topography is characterized by small escarpments formed by the erosion-resistant cores of unweathered aa flows (fig. 2; Macdonald and others, 1983). In highly weathered areas in the humid upper

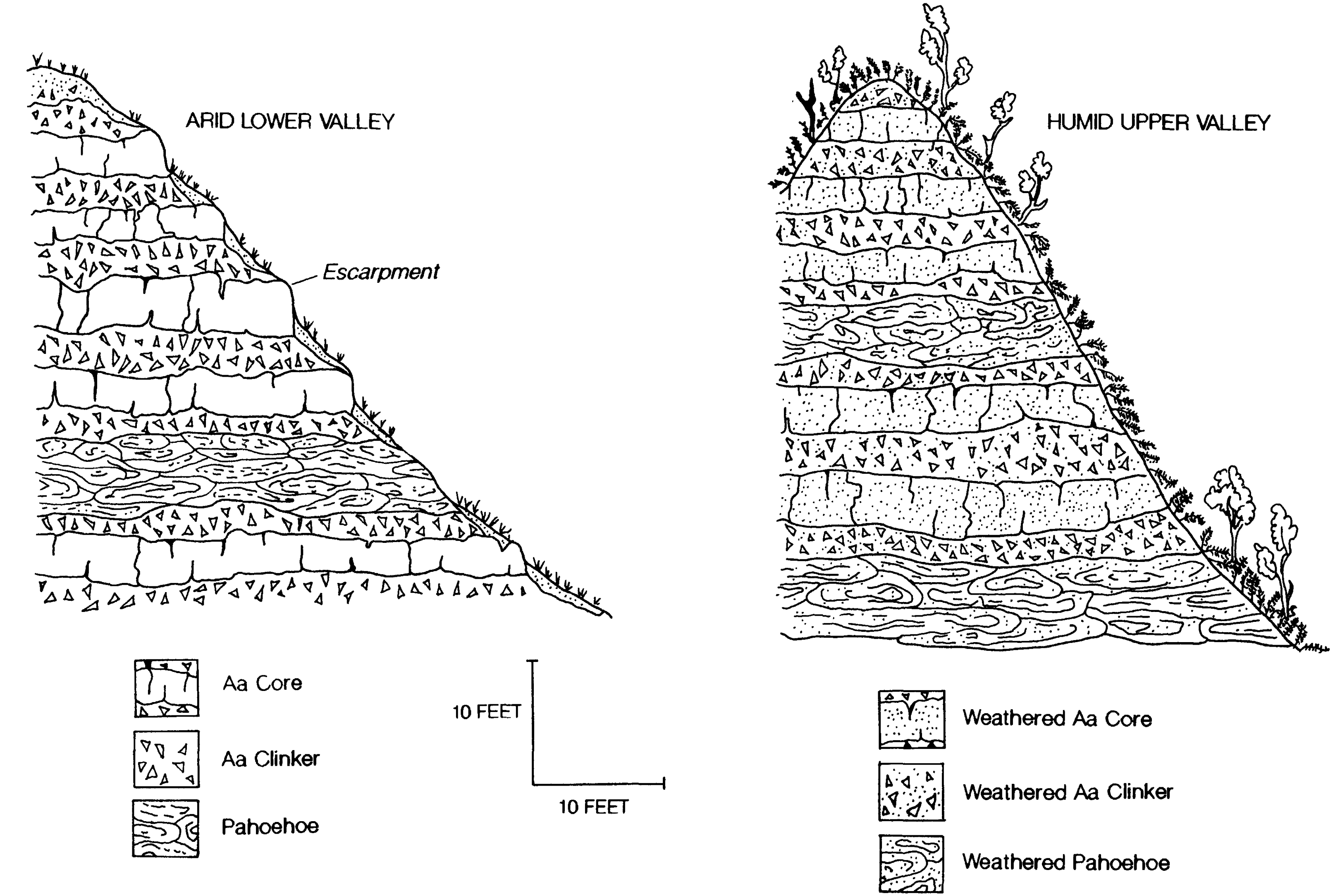


Figure 2. Diagrammatic geologic sections through valley walls in the arid lower valley and the humid upper valley. Differences in depth of weathering results in differences in slope, topography, and vegetation.

valley, slopes are smoother and the small escarpments are absent. Landslide scars show that when the highly weathered rock fails, the newly formed slope cuts smoothly across both aa and pahoehoe flows (fig. 2). Apparently, because the rock is so thoroughly weathered, aa flows lose their distinctive hardness and resistance to erosion. The differences in topography are helpful in estimating the areal extent of highly weathered rock.

Weathering of the bedrock is more extensive in the upper part of North Halawa Valley than in the lower part of the valley. In the upper valley, the basalt bedrock is deeply weathered over a wide area, even on steep slopes. Test borings indicate that the weathered layer in the upper valley is several tens of feet, but because of removal by mass-wasting, the thickness probably varies. In contrast, the bedrock in the walls of the lower valley is only slightly weathered. Resistant cores of aa flows form small escarpments in the valley walls. However, weathered rock is present in the lower valley. Midway up the valley axis at about the 440 ft elevation, test borings penetrated highly weathered rock below old alluvium. The occurrence of highly weathered basalt underlying old alluvium is common in alluvial valleys of Oahu (Mink and Lau, 1980). A layer of highly weathered old alluvium occurs under the floor of the lower valley, and a layer of highly weathered basalt probably underlies the old alluvium. Thus, although very little weathered rock is exposed on the slopes of the lower valley, it probably does occur under the floor of the valley. Deeply weathered rock also occurs on the ridges above the valley walls (Wentworth, 1942).

The widespread distributuion of highly-weathered rock in the upper valley results from the higher rainfall near the crest than on the leeward slopes of the Koolau Range (Macdonald and others, 1983; State of Hawaii Department of Land and Natural Resources, 1984; Giambelluca and others, 1984). In the lower valley, the occurrence of weathered rock is controlled by the rate of erosion, which is, in turn, governed by relief. Gentle slopes allow the development of thick weathered layers (Macdonald and others, 1983). Although rocks in the steep walls of the lower valley are only slightly weathered, deeply weathered rocks occur under the valley floor and on the ridge top where slopes are gentler (Wentworth, 1942).

Hydrologic Characteristics of the Rock Types

The rate at which stream water infiltrates to the basal aquifer depends on the permeability of the material forming the stream channel. Permeability was not measured in this study, but may be estimated from the results of previous work. A variety of methods to test the permeabilities of Hawaiian rocks and soils have been used by previous investigators. Results (table 1) show that permeability varies with rock type and degree of weathering. The rocks of North Halawa Valley are likely to show similar variations in permeability.

Table 1.--*Permeability estimates for various rock types in Hawaii*

[ft/day, feet per day]

Rock type	Permeability (ft/day)	Method	Reference
Basalt[1]	1.82×10^3 to 3.52×10^3	Pump test	Wentworth (1938)
	2.38×10^2 to 1.52×10^3	Pump test	Williams and Soroos (1973)
Basalt[2]	1.28×10^{-1}	Lab test, constant head	Wentworth (1938)
	2.83×10^{-3} to 2.83×10^2	Marshall water retention	Miller (1987)
	1.96 to 7.08	Borehole, constant head	Geolabs-Hawaii (1988)
Alluvium	1.80 to 3.86×10^2	Lab test, constant head	Wentworth (1938)
Old Alluvium	1.08	Lab test, constant head	Wentworth (1938)
Saprolite and unweathered pahoehoe, mixed	8.50×10^{-1}	Borehole, constant head	Geolabs-Hawaii (1988)

[1] includes units described as "unweathered," "slightly weathered," "moderately weathered," or "basalt aquifer."
[2] includes units described as "soil," "saprolite," and "weathered."

In general, unweathered basalt has permeabilities several orders of magnitude greater than weathered basalt (Mink and Lau, 1980). The permeability of young alluvium can also be high (Wentworth, 1938). The permeability of weathered old alluvium may be as low as that of weathered basalt (table 1). Therefore, it appears that the permeability of Hawaiian rocks depends more on the degree of weathering than on whether the rocks are sedimentary or basaltic basement. Of the rock types present in Halawa Valley, the weathered basalts and old alluvium (Wentworth, 1942; Mink and Lau, 1980) are most likely to impede infiltration. The data in table 1 indicate that the greatest infiltration will take place where the stream flows over unweathered basalt flows, and the least infiltration will occur where the stream flows over highly weathered basalt or highly weathered alluvium.

Relation of Stream Channel to Underlying Geology

In the lower valley below the 600-ft elevation, the stream flows mainly over thick alluvial deposits. However, because the valley is narrow and the stream meanders across the valley floor, the stream comes in contact with unweathered basalt bedrock in many places as it flows against the valley wall (plate 1, section B-B'). The thickness of the alluvium directly beneath the stream channel thus varies as the stream meanders from one wall of the valley

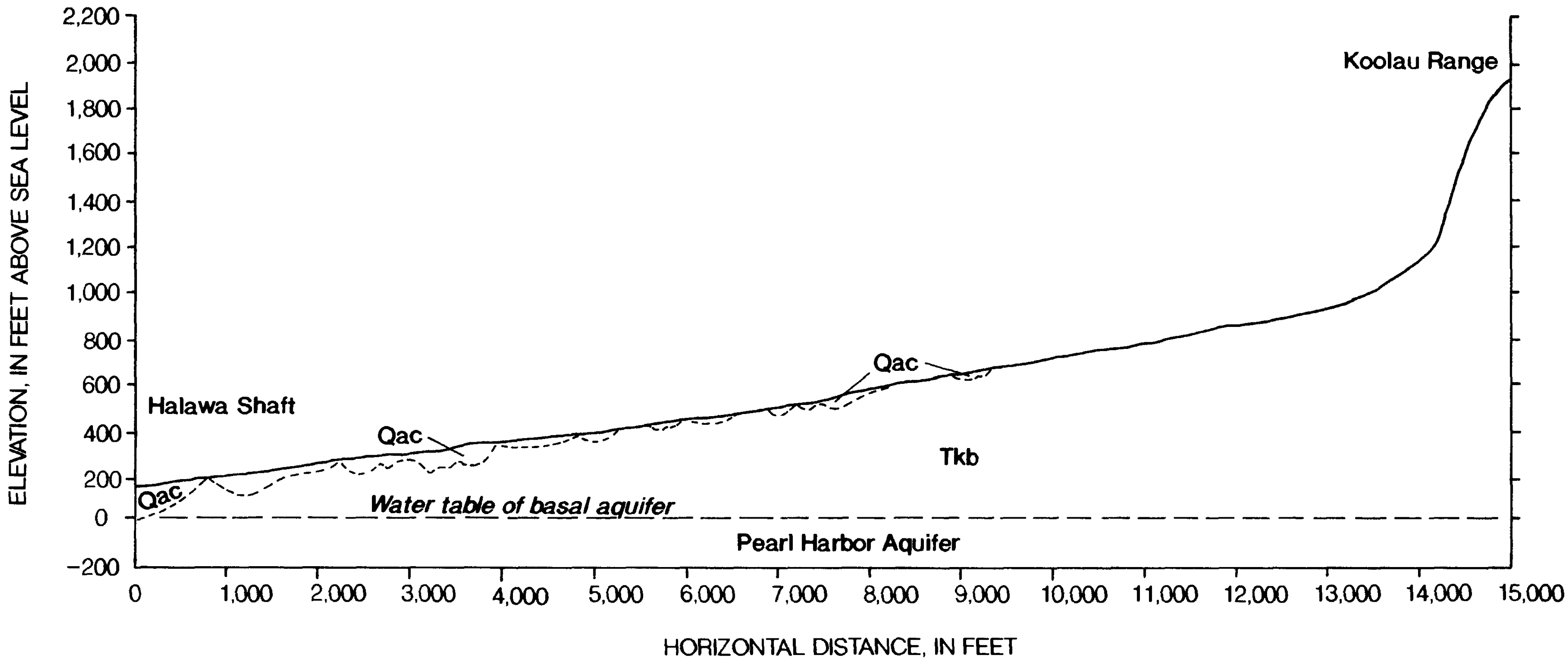


Figure 3. Stream profile and subsurface geology along the channel of North Halawa Valley. The gradient of North Halawa Stream is greatest at the head of the valley but decreases abruptly below the 900-foot elevation.

to the other (fig. 3). In the upper valley, above the 600 ft elevation where the alluvium is thin and discontinuous, the stream flows over weathered basalt for much of its course.

The stream channel cuts down into older alluvium and bedrock along many segments. The alluvium and bedrock cut by the stream are generally highly weathered. In the upper valley, the stream cuts into highly weathered basalt; in the lower valley, the stream cuts mainly into the highly weathered old alluvium of the valley floor. Only in a few isolated reaches in the lower valley does the stream flow directly over unweathered basalt. In these areas, the stream meanders against the unweathered basalt exposed in the valley wall (plate 1, section B-B').

The Basal Aquifer and Effects of Pumping From the Halawa Shaft

The water table of the Pearl Harbor aquifer lies near sea level and gently slopes from the boundary of the Koolau dike complex toward the mouth of the valley (Visher and Mink, 1964). Ambient ground-water flow direction approximately parallels the axis of North Halawa Valley and is directed seaward from the crest of the Koolau Range. The zone of capture of a well in a unidirectional field such as this is bounded by a curve described by the equation (Todd, 1964):

$$y/x = \pm \tan\left(\frac{2\pi q_o\, b(y)}{Q_w}\right), \qquad (1)$$

where: Q_w = discharge at well,
b = thickness of the aquifer contributing to the well,
x = direction parallel to ambient flow,
y = direction perpendicular to ambient flow, and
q_o = specific discharge of the aquifer.

Stream lines within the zone of capture converge at the well. If water infiltrates from the surface to the water table within the zone of capture, the water flows toward the well and will eventually be pumped there.

The specific discharge (q_o) in equation 1 is a property of the aquifer and is given by:

$$q_o = -K(dh/dx), \qquad (2)$$

where: K = hydraulic conductivity, and
dh/dx = slope of the potentiometric surface of the aquifer.

Darcy's law gives the flow of water through a specified cross-sectional area of an aquifer:

$$Q_a = -KA(dh/dx), \qquad (3)$$

where: Q_a = flow through the cross-sectional area in the aquifer, and
A = cross-sectional area perpendicular to flow direction.

Combining equations 2 and 3 gives the specific discharge in terms of flow through the aquifer and cross-sectional area perpendicular to stream lines:

$$q_o = Q_a/A. \tag{4}$$

Flow in the Pearl Harbor aquifer has been extensively studied, but the estimated flow rates are not yet published. In general, however, approximately 20 Mgal/d will pass across a 1-mi line drawn anywhere perpendicular to the stream lines on the water table of the Pearl Harbor aquifer (P.R. Eyre, USGS, oral commun., 1989). In other words, 20 Mgal/d will flow through an area with dimensions A = B X 1 mi, where B is the total thickness of the aquifer. Substituting these values into equation 4 gives:

$$q_o = [(20 \text{ Mgal/d})/\text{mi}]/B. \tag{5}$$

An estimate of the part of the aquifer thickness drawn into the well is approximately one-half, or b/B = 0.5. Thus, the quantity $q_o b$ for the Pearl Harbor aquifer is approximately:

$$q_o b = 0.5\ [(20 \text{ Mgal/d})/\text{mi}]. \tag{6}$$

Substituting this quantity and a pumping rate of 12 Mgal/d for the Halawa shaft (maximum pumping rate from records) into equation 1 gives the boundary of the zone of capture of the Halawa shaft shown in plate 1. The zone of capture includes nearly all of North Halawa Valley. Water infiltrating to the basal aquifer from anywhere in North Halawa Valley could be drawn into the Halawa shaft.

GROUND-WATER AND SURFACE-WATER RELATIONS ALONG NORTH HALAWA STREAM

From its headwaters to the Halawa shaft, North Halawa Stream drains an area of approximately 4 mi^2 (plate 2). The drainage basin is a V-shaped, amphitheater-headed valley with steep walls. The gradient of the stream is steepest above the 1,200-ft elevation where it flows down the head of the valley (plate 2). Similarly, the gradients of tributaries are steep because they descend the walls of the valley.

The stream forks into a northern branch and southern branch at an elevation of 750 ft. Both branches drain small, steep basins of approximately equal area. The stream is fed by many small tributaries above the fork but by only a few tributaries below the fork. A small water tunnel, constructed in the early 1900's by the Honolulu Plantation Company, probably contributes small amounts of water to the stream. The tunnel is located in the upper the early 1900's by the Honolulu Plantation Company, probably contributes small amounts of water to the stream. The tunnel is located in the upper valley at an elevation of 680 ft, and in 1932 had a discharge of only about 0.05 ft^3/s (Stearns and Vaksvik, 1935).

Gain and Loss Estimates From Long-Term Stream-Discharge Records

Two stream-gaging stations (16226000 and 16226200) on North Halawa Stream are operated by the U.S. Geological Survey. Differences in discharge between these stations were used to estimate stream gains and losses. A flow-duration curve for each station (fig. 4) was plotted from daily discharge values for the period from October 1983 to September 1987.

Flow was absent on North Halawa Stream approximately 30 percent of the time during the 4-year period of the gaging-station records (fig. 4). Approximately 70 percent of the time, flow ranged from 0.03 ft^3/s to about 100 ft^3/s at the lower station and from 0.02 ft^3/s to about 100 ft^3/s at the upper station. Comparison of the flow-duration curves (table 2) shows that over the period of record, the stream gained water between stations.

Table 2.--*Estimates of stream gain from flow-duration curves for period between 1983 to 1987 of gaging stations on North Halawa Stream*

[ft^3/s, cubic feet per second; $(ft^3/s)/ft$, cubic feet per second per foot of channel]

Percentage of time discharge equaled or exceeded	Discharge (ft^3/s)			
	Upstream station 16226000	Downstream station 16226200	Difference	Gain per unit channel length (X 10^{-6} $(ft^3/s)/ft$)
70	0.02	0.03	+ 0.01	+ 1.46
60	0.07	0.10	+ 0.03	+ 4.37
50	0.33	0.41	+ 0.08	+ 11.65
40	0.74	0.88	+ 0.14	+ 20.39
30	1.5	1.7	+ 0.2	+ 29.13
20	2.9	3.2	+ 0.3	+ 43.70
10	7.5	7.5	0.0	0.00

The accuracy of the continuous flow record is rated good (within 5 percent of true discharge) at the upper gaging station. At the lower gaging station the accuracy is rated poor (greater than 8 percent of true discharge) at discharges of less than about 4 ft^3/s, the average discharge of North Halawa Stream at the lower station. Thus for lower flows, the estimate of gains may not be accurate. For higher flows, however, ratings of records for both the upper and lower stations are within 5 percent.

Stream Gain and Loss Estimates From Discharge Measurements

Gains and losses in flow (seepage) along reaches of stream above and below the two gaging stations were estimated from current-meter measurements

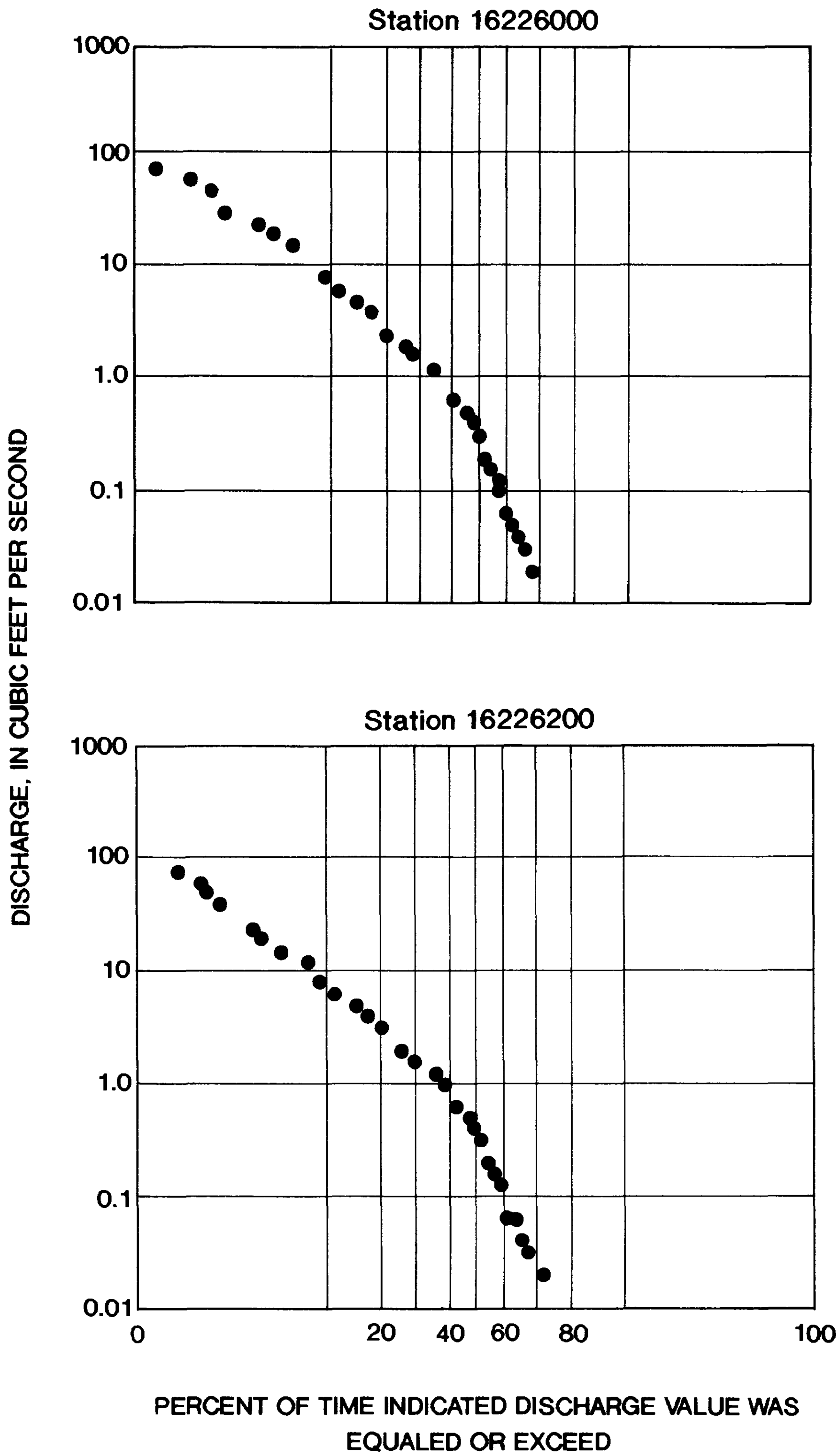


Figure 4. Flow-duration curves of discharge measurements between October 1983 and September 1987 for stream-gaging stations on North Halawa Stream.

of discharge at selected points along the stream channel. To study the relation between channel rock type and seepage, sites were selected to isolate parts of the stream flowing over fresh bedrock, weathered bedrock, or thick sedimentary deposits. Each seepage run consisted of the near-simultaneous (within one day) measurement of discharge at each site. Differences between discharge measured at two sites along the stream indicate the gain or loss of water along that reach of the stream.

Ten sites along North Halawa Stream were selected for streamflow measurements (plate 2). Discharge was measured on four separate occasions (fig. 5). Site 6 was abandoned because of uneven flow caused by boulders upstream from the site. The site was replaced on August 7, 1989 by site 6A 1,000 ft downstream. Site 3 was located at gaging station 16226000 and site 1 was located at gaging station 16226200 (plate 2). Because the accuracy of the stage-discharge relation at the upper gaging station is good, gage heights

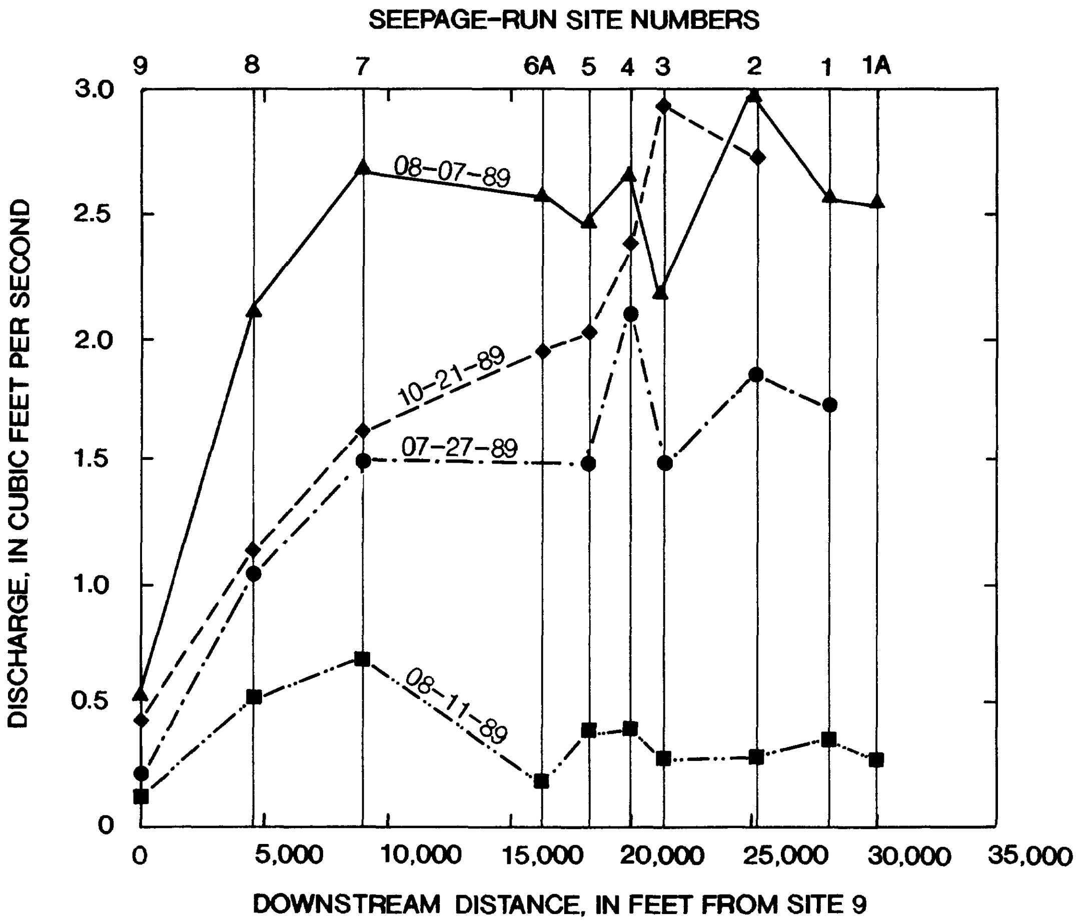


Figure 5. Plot of discharge with distance downstream from measuring site 9 on North Halawa Stream.

were used to determine discharge at this site during the seepage runs. Discharge at site 1 was measured with a current meter because the stage-discharge relation is poor at low flows.

To ensure that measured gains were not the result of tributary flow, tributaries to North Halawa Stream were checked before each seepage run. Tributaries in the lower valley below site 7 were not flowing during any of the seepage runs. Tributaries above site 7 are inaccessible and were not checked. Because tributary flow above site 7 cannot be quantified, stream gains cannot be interpreted as ground-water discharge.

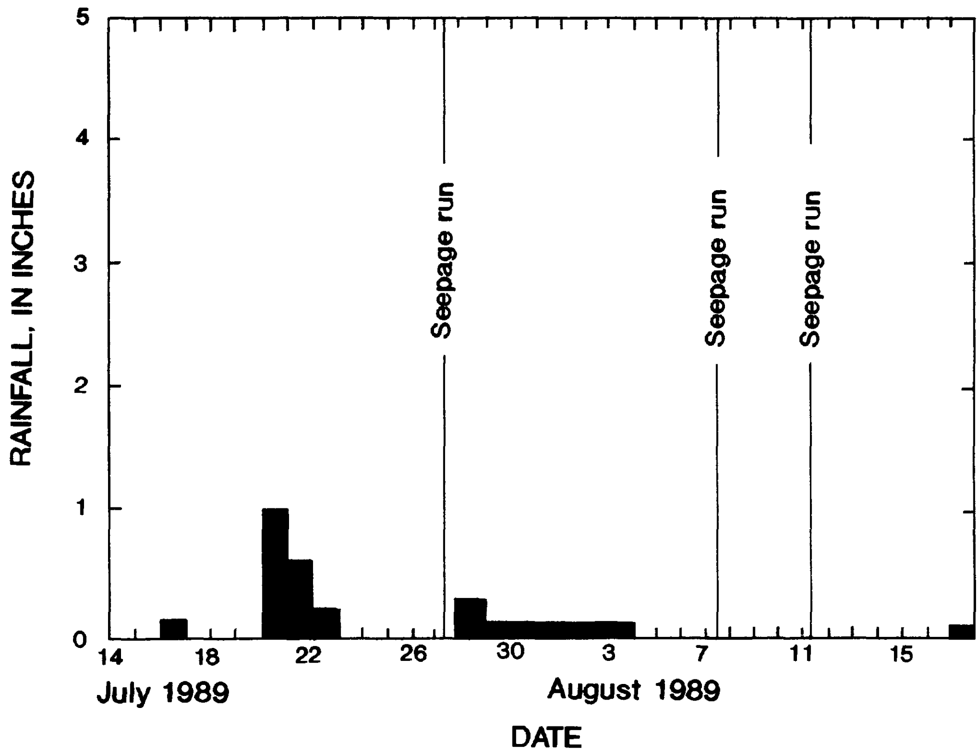
Hawaii's annual climatic cycle has two seasons. Rainfall is relatively higher in the wet season from October through April, and lower in the dry season from May through September (Blumenstock and Price, 1967). The character of the dry-season seepage runs in July and August are distinct from the wet-season seepage run in October (fig. 5).

Stream Gains and Losses During the Dry Season

Discharge measured after long periods without rain is instructive because seepage is not masked by runoff. Analysis of seepage runs made in the dry season shows that the pattern of gains and losses changes with stages of the stream (fig. 5). Some segments gained water during one seepage run, yet lost water during other seepage runs. Segments that showed consistent gains at all three stages measured in the dry season are those above site 7 and between sites 4 and 5. The only segments that showed a consistent loss during the dry season were between sites 3 and 4 and between sites 6 and 7.

The seepage run of August 11, 1989 shows the infiltration characteristics of the stream after a period of dry weather (fig. 5). No rainfall was recorded at station 16226200 for 7 days prior to August 11 (fig. 6). Despite the dry weather, the stream gained water between stations 4 and 5. Discharge dropped significantly between sites 6A and 7, and showed small gains between sites 1A and 6A. In the absence of rainfall, and therefore runoff, the gain must be attributed to ground water discharging into the stream, and losses must be attributed to infiltration.

The seepage run of August 11 can be used to quantify seepage along reaches of North Halawa Stream. The volume of water lost or gained by a reach is related to its length. By dividing the losses and gains by the length of the reach between measuring sites, seepage can be compared for reaches of varying length. The loss or gain per unit length of stream channel can be estimated from the slope of the lines in figure 5. Steeper slopes indicate greater loss or gain per foot of channel length. The reach between sites 6A and 7 lost the greatest volume of water (0.51 ft^3/s) on August 11, but the reach between sites 3 and 4 showed the greatest loss per foot of channel (1.1 X 10 ft^3/s per foot of channel). The slopes of the lines in figure 5 show greater losses at higher stages for some reaches of the stream.



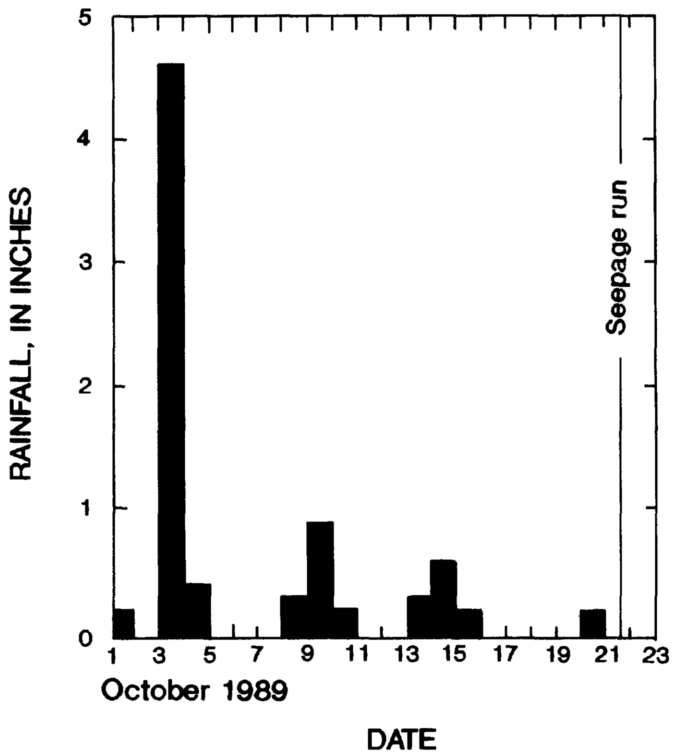


Figure 6. Rainfall recorded at stream-gaging station 16226200, during period of seepage runs.

Stream and Ground-Water Exchange

Gains and losses shown by the seepage runs, even on days when tributaries are dry, indicate that some exchange of water between the ground and the stream is occurring. Water is discharged into the stream along some reaches and seeps from the stream into the ground along others. Reaches between sites 6 and 7 and between 3 and 4 showed consistent losses during the dry season. The stream flows over both alluvium and unweathered bedrock along these reaches. The only reach that showed consistent gains throughout all the dry weather seepage runs was between sites 4 and 5, where the stream is incised into slightly weathered basalt lava flows. Despite the contrasting permeabilities of alluvium, basalt, and the weathered products of these materials shown in table 1, the pattern of gains and losses appears to be unrelated to the channel rock type.

The exchange does not necessarily occur between the basal aquifer and stream, but could occur between the stream and alluvium (Hirashima, 1971). The fact that the basal aquifer lies well below the stream bed eliminates the possibility that stream gains are the result of discharge from the basal aquifer. Instead, water is probably discharging from and infiltrating into a perched aquifer in the alluvium. A perched aquifer is one that is maintained above another aquifer by a layer of rock or soil with low permeability (Bear, 1979). Two lines of evidence indicate the presence of a perched aquifer: (1) test borings in the alluvium show water levels that are well above the basal water table, and (2) North Halawa Stream gains from ground-water discharge despite its elevation far above the basal water table. The occurrence of this perched water supports the conclusion that the alluvium is an aquifer itself, which can exchange water with the stream (fig. 5).

Whether water from the perched alluvial aquifer seeps into the bedrock and eventually into the basal aquifer cannot be documented from the data in this study. Gravity may draw water from the alluvium to the basal aquifer because the basal water table lies below the alluvial aquifer. The layer of highly weathered basalt below the alluvium could, however, restrict this exchange to small rates.

Seasonality in Seepage

Losses along reaches of the stream below site 7 are more pronounced in the dry season than in the wet season (fig. 5). The wet-season seepage run in October indicated gains along most of the stream, even though the stage was lower than during the summer seepage runs and tributaries were not flowing. The difference between dry-season and wet-season seepage runs reflects the uneven and seasonally variable pattern of rainfall distribution that is characteristic of the Hawaiian Islands (Mink, 1960). The difference in rainfall between drier and wetter areas is greater in the dry season than in the wet season (State of Hawaii, Department of Land and Natural Resources, 1984). In the dry season, rainfall frequently occurs in the upper valley while the lower valley remains dry. During the dry season, the stream gains water from the tributaries in the upper valley, but little surface water enters the stream through tributaries in the lower valley. During the wet season, when rain is more evenly distributed in upper and lower parts of the valley, discharge increases along the entire length of the stream.

Part of the difference between dry- and wet-season gains and losses may be linked to the effect of seasonal rainfall on soil moisture, which in turn affects infiltration rate (Musgrave and Holtan, 1964). During tropical storm Dalilia (July 20, 1989), the rain gage at station 16226200 indicated that heavy rain fell in the lower valley. Despite the widespread rainfall, the seepage run completed 5 days after the end of the storm does not show consistent gains in the lower valley as seen in the fall seepage run (fig. 5). Rainfall was infrequent in late July and early August, 1989, when the dry-season seepage runs were made (fig. 6). Long periods of no rainfall allow the soil and alluvium to dry. After a dry-season rain, tributaries stop flowing quickly because the undersaturated soil retains a greater percentage of the rainfall than in the wet season. Discharge in the main channel of the stream may remain high because of contribution from the wet upper valley, but little water is gained from tributaries in the lower valley. If the alluvium becomes saturated by persistent rain in the wet season, infiltration is minimized (Hirashima, 1971). Thus, the infiltration of water from North Halawa Stream is likely to vary by season, with a greater proportion of water infiltrating during the dry season and a lower proportion infiltrating during the wet season.

FATE OF CONTAMINANTS IN HIGHWAY RUNOFF

Runoff from the proposed H-3 freeway could carry contaminants. If water from the freeway drains into North Halawa Stream, the water-borne contaminants could enter the ground-water systems. Evidence from the present study indicates that water from North Halawa Stream seeps into the ground along some reaches of the stream. Most of the exchange appears to occur to and from a perched alluvial aquifer. Some water from the alluvial aquifer could continue downward to the basal aquifer.

Whether contaminants carried by the stream could contaminate the water in the basal aquifer depends on several conditions, including (1) the chemical behavior of the contaminants, (2) the concentration of the contaminants in the highway runoff, (3) the rate at which the water passes from the alluvial aquifer to the basal aquifer, and (4) dilution effects as the highway runoff mixes with water in the stream and in the ground. The assessment of the effects of these factors is beyond the scope of the present study. Further study, directed particularly at (1) the movement of water within the alluvium, (2) the quantity of water passing from the alluvium to the basal aquifer, and (3) the chemical behavior of possible water-borne contaminants as they pass through the ground-water systems, would be required to assess the effect of highway runoff on the water supply from the basal aquifer. Such a study would require determination of how much water is entering the perched alluvial aquifer and how much water leaves the aquifer.

CONCLUSIONS

The geologic units present in North Halawa Valley include basaltic lava flows and alluvial and colluvial sediments. Differential weathering has given rise to a variety of rocks that have different hydrologic properties. Weathering tends to decrease the permeability of both sedimentary rock and basalt flows. The degree of weathering is an important consideration in an infiltration study.

North Halawa Stream flows over alluvium for most of its course. Parts of the stream flow over basalt bedrock, particularly in the upper valley, but the bedrock in the upper valley is deeply weathered. In the lower valley, the stream flows mostly over a thick sequence of alluvium. Most of the alluvium is deeply weathered. The upper part of the basalt basement directly underlying the weathered old alluvium is deeply weathered also. North Halawa Stream thus flows over deeply weathered rock for almost its entire course.

The data from this study show that North Halawa Stream loses water by infiltration into the ground along some reaches, and gains from ground-water discharge along other reaches. Water infiltrating along the stream passes into and out of a perched aquifer formed by alluvium in the valley. Water could pass from the perched alluvial aquifer to the basal aquifer.

Differences between the results of the summer and fall seepage runs reflect the uneven and seasonally variable pattern of rainfall distribution characteristic of the Hawaiian Islands and the effect of seasonal rainfall on soil moisture, which in turn affects infiltration rate. Thus, the infiltration of water from North Halawa Stream is likely to vary by season, with a greater proportion of water infiltrating during dry periods than in the wet seasons.

The Halawa shaft draws its water from an area that includes nearly all of North Halawa Valley, its stream, and alluvium. Any water reaching the basal water table in the valley would eventually be pumped at the Halawa shaft.

If runoff from the future H-3 freeway is allowed to enter North Halawa Stream, water-borne contaminants could enter the ground-water systems. Whether contaminants carried by the stream could contaminate the water in the aquifer depends on several factors that are beyond the scope of this study. The present study has shown that the water is exchanged between ground-water systems and the stream in North Halawa Valley, but further study would be required to assess the effect of highway runoff on the basal water supply. To minimize the infiltration of roadway contaminants in North Halawa Valley, the State of Hawaii, Department of Transportation, modified the design of the highway drainage (E.Y. Hirata, Department of Transportation, State of Hawaii, written commun., 1991).

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