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Water Quality in the Halawa, Haiku, and Kaneohe Drainage Basins Before, During, and After H-3 Highway Construction, Oahu, Hawaii, 1983–99

U.S. Department of the Interior
U.S. Geological Survey
Scientific Investigations Report 2004-5002

About the cover: This vertical aerial color photograph was taken on June 2, 1989, by Air Survey Hawaii. The photograph shows the North Halawa Valley during the early phases of the construction of the H-3 freeway. At the time of this photograph, only the 2-lane paved access road had been constructed in the valley. The Hawaiian Cement quarry and plant, the H-1 freeway, and the urbanized areas near the mouth of the valley are visible in the lower left.

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U.S. Geological Survey

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Datums

Altitude, as used in this report, refers to distance above the vertical datum.
Horizontal coordinate information is referenced to the Old Hawaiian Datum unless otherwise specified.

Water Quality in the Halawa, Haiku, and Kaneohe Drainage Basins Before, During, and After H-3 Highway Construction, Oahu, Hawaii, 1983–1999

By Michael F. Wong

Abstract

Selected water-quality data collected before, during, and after construction of the H-3 Highway at 13 water-quality stations were compared to the State of Hawaii Department of Health water-quality standards to determine the effects of highway construction on the water quality of the affected streams. Highway construction had no effect on the high concentrations of total nitrogen and nitrite plus nitrate nitrogen observed except for increased nitrite plus nitrate nitrogen concentrations at one station on Hooleinaiwa Stream. Exceedences of the 10- and 2-percent-of-the-time concentration standards for total phosphorus, total suspended solids, and turbidity, all constituents associated with sediment, occurred more commonly and at more stations during construction than either before or after. These exceedences may be, in part, due to land disturbance caused by highway construction. Highway construction had no effect on the physical water-quality properties of pH, dissolved oxygen, temperature, and specific conductance except at North Halawa and Kuou Streams, where specific-conductance values increased throughout the study period, most likely due to highway construction. No effects on selected trace metals and organic chemical compounds were observed due to highway construction. No effects due to highway construction were observed in the water quality of Waimaluhia Reservoir. Runoff from areas of urban land use in the Kaneohe drainage basin contributed more to the higher loads of selected water-quality constituents than did runoff from areas affected by highway construction.

Introduction

The H-3 Highway is a major highway across the Koolau Range on the eastern part of the island of Oahu, Hawaii (fig. 1). Potential effects of construction, such as soil erosion from land disturbance, runoff from construction staging areas, and stream sedimentation that might degrade the water quality of streams along the route, were an issue of public concern, and construction began only after a lengthy environmental evaluation (U.S. Department of Transportation and others, 1987). In 1983, the U.S. Geological Survey (USGS), in cooperation with the State of Hawaii Department of Transportation and in collaboration with the Federal Highway Administration, began a study to assess the effects of highway construction on the water quality in the affected streams; specifically to determine whether highway construction resulted in any exceedence of the State of Hawaii water-quality standards. The results of the study also will add information to what is generally known about the effects of highway construction in tropical environments.

Purpose and Scope

The purpose of this report is to describe whether water-quality standards were exceeded before, during, or after construction, and if so, whether the exceedence could be attributed to highway construction. To meet this objective, data collection was carried out before, during, and after construction during 1983–99 at a network of 13 water-quality stations. Twelve of the stations were on streams and one station was in the Waimaluhia Reservoir.

This report describes the Halawa, Haiku, and Kaneohe drainage basins, the methods used for water-quality data collection, and a statistical analysis of water-quality data collected during the 17-year (1983–99) study period. Data were analyzed at 2 stations in the Halawa, 1 in the Haiku, and 10 in the Kaneohe drainage basins (figs. 1 and 2). Additional data from the Waimaluhia Reservoir also were analyzed. Only those constituents that can be compared to the State of Hawaii water-quality standards (State of Hawaii Department of Health, 2000) are described in this report. These and other constituents were previously summarized in two published statistical summaries of data; one covering data collected during water years 1983–89 (Wong and Hill, 1992), and the other during water years 1983–99 (Wong and Young, 2001). A water year is a 12-month period that extends from October 1 to September 30 and is designated by the calendar year in which it ends.

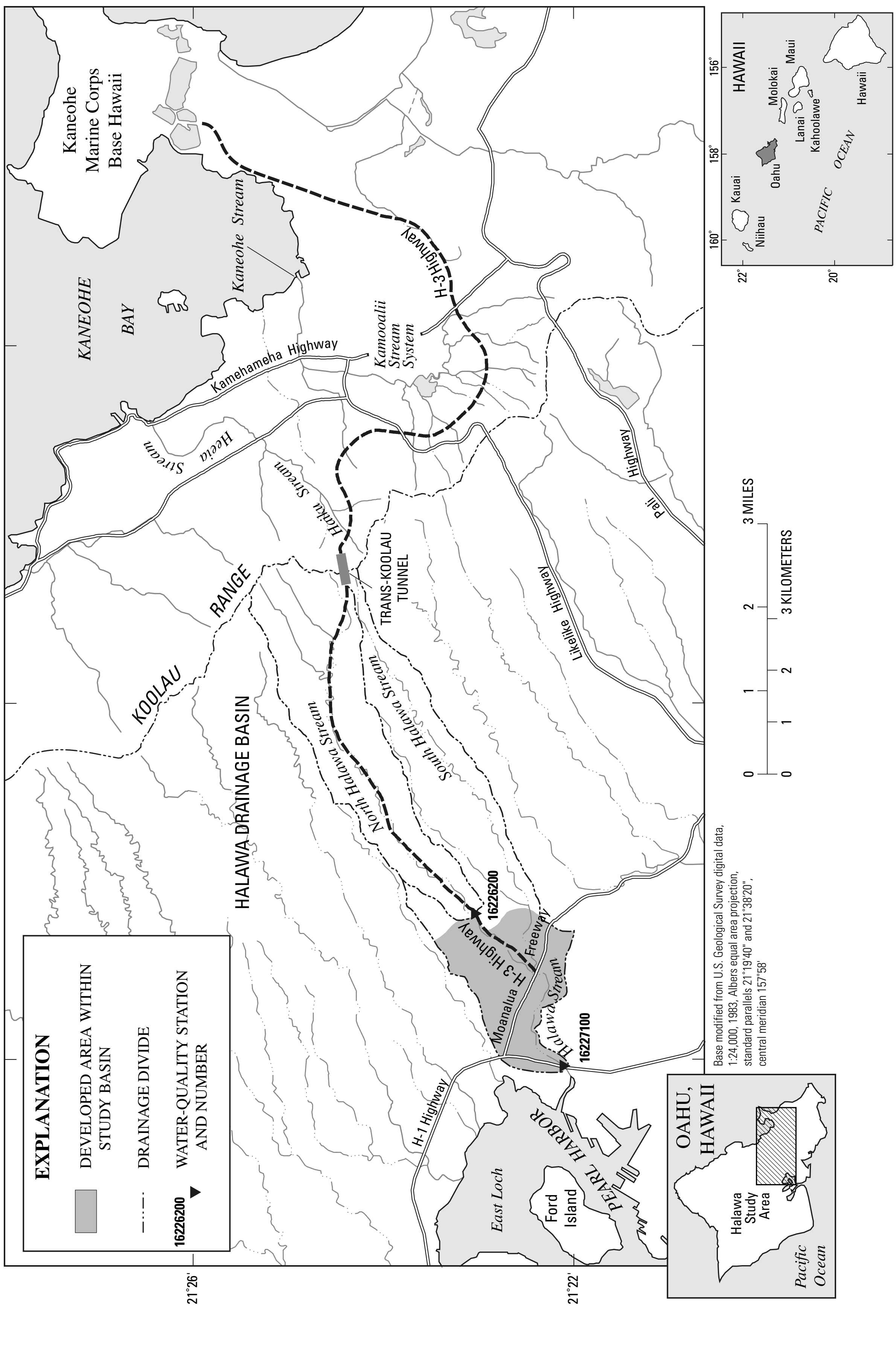

Figure 1. Selected water-quality stations and drainage basins in the H-3 Highway study area, Oahu, Hawaii.

Base modified from U.S. Geological Survey digital data, 1:24,000, 1983, Albers equal area projection, standard parallels 21°19'40" and 21°38'20", central meridian 157°58'

Figure 2. Water-quality stations in the Haiku and Kaneohe drainage basins, Oahu, Hawaii.

Instantaneous water-quality data used in the analyses in this report have been published in the U.S. Geological Survey's annual water-resources data reports for Hawaii, water years 1983 through 2000. See, for example, Hill and others (2000) for the water year 1999 report. These data also are available on the World Wide Web at NWISWeb (*http://waterdata.usgs.gov/nwis*).

H-3 Highway Construction

The H-3 Highway route traverses the drainage basins of Halawa and Haiku Streams and the tributaries of Kaneohe Stream (fig. 1). The H-3 segment that is the subject of this report extends from the H-1 Highway near the East Loch of Pearl Harbor on the leeward (southwestern) side of the Koolau Range to the Halekou Interchange on the windward (northeastern) side, where the H-3 connects to a previously constructed section of H-3 leading from Kamehameha Highway to Kaneohe Marine Corps Base–Hawaii. The completed H-3 Highway consists of part cut-and-fill and part viaduct sections in the lower North Halawa Valley, a viaduct through the upper North Halawa Valley, twin tunnels below the crest of the Koolau Range, a viaduct through the Haiku drainage basin, and a cut-and-fill section through the Kapunahala and Kamooalii drainage subbasins of the Kaneohe drainage basin (U.S. Department of Transportation and others, 1987). Highway construction affected from 3 to 15 percent of the drainage basin areas upstream from the water-quality stations discussed in this report.

Construction of the H-3 Highway proceeded in increments (table 1). Construction was, at times, halted by court actions, and the planned route was modified to avoid sites of cultural importance. The court actions also halted water-quality data collection before construction started. Access roads were built in the North Halawa and Haiku Valleys before construction of the highway. An exploratory tunnel was excavated below the crest of the Koolau Range before the larger traffic tunnels were excavated.

Study Area

The Koolau Range is the eroded remnant of the larger and younger of the two major shield volcanoes that formed the island of Oahu (Hunt, 1996). Much of the windward side of the original Koolau Volcano has been eroded, leaving a steep windward slope indented with short, broad, amphitheater-shaped valleys (Hinds, 1925). In contrast, the gentle leeward slope is deeply dissected by long, roughly linear valleys. Ridges on the leeward side approximate the original morphology of the Koolau volcanic dome (Wentworth, 1943).

Geology of the study area consists primarily of Koolau Basalt that was extruded in numerous gently dipping thin (less than 10 ft) flows of lava that are intruded by near-vertical, dense basaltic dikes near the crest of the present Koolau Range (Hunt, 1996). More recent volcanic rocks are exposed in small areas on the windward side of the study area (Takasaki and others, 1969). The gently sloping lower parts of the windward drainage basins and the valley floor of the North Halawa drainage basin are overlain by alluvium derived from erosion of the Koolau Range (Takasaki and others, 1969; Izuka, 1992).

The climate of Oahu is warm and humid. Average annual temperature near the study area is about 74°F and monthly averages range from 65°F to 84°F (Owenby and Ezell, 1992). Temperatures above 95°F and below 50°F are rare on Oahu (Blumenstock and Price, 1961). The distribution of rainfall is affected by the prevailing northeasterly trade winds and the topography of the island. Because of the Koolau Range, which has an altitude of 2,000 to 3,000 ft above mean sea level at the crest, there is orographic lifting and cooling of marine air masses moving with the trade winds. This lifting results in heavier and more frequent rainfall on the windward side and near the crest of the Koolau Range. The heaviest rain falls about 0.5 to 1 mi leeward of the crest (Wentworth, 1942; Mink, 1960). Rainfall varies seasonally, with most rain falling from November to April. Median annual rainfall ranges from 60 to 120 in. on the windward side of the study area and from 40 to more than 120 in. on the leeward side (Division of Water and Land Development, 1982). Average annual pan evaporation is between 50 to 70 in. on the windward side and between 30 to 80 in. on the leeward side of the study drainage basins (Ekern and Chang, 1985).

The temporal and spatial distribution of streamflow is determined almost exclusively by geology and climate. Streams on the windward side respond rapidly to direct runoff that takes place during periods of rainfall. Large quantities of rainfall and the presence of numerous low-permeability dikes result in storage of high-elevation ground water that maintains the base flow of streams on the windward side (Takasaki and others, 1969). As a result of the highly permeable bedrock and the orientation of dikes, ground water is known to flow between windward drainage basins. Rainfall infiltrating in one valley may emerge as streamflow in another (Hirashima, 1963, 1971; Takasaki and others, 1969). Streamflow in the Halawa Stream drainage basin is intermittent and is dependent primarily on direct runoff that occurs during rainfall. Most infiltrating rainfall in the North Halawa Valley percolates to the freshwater-lens aquifer and does not maintain base flows in the streams (Izuka, 1992). Streamflow is supplemented by the discharge of small quantities of ground water from alluvial aquifers that extend recession flows only to a minor extent (Izuka, 1992). The contrast between streamflow characteristics in the leeward and windward drainage basins of the study area is shown by using flow-duration curves (fig. 3). A flow-duration curve indicates the percentage of time that values of daily mean streamflow were equaled or exceeded (Searcy, 1959). The steep slope of the North Halawa Stream curve indicates the highly variable nature of streamflow in Halawa Valley, while the flat slope of the Haiku Stream curve indicates the large storage of ground water on the windward side (fig. 3).

Soils in the Halawa drainage basin are classified as low-permeability, very stony clays of the Kaena series with

Table 1. Chronology of highway construction activities within drainage basins of the H-3 Highway study area, 1983–98, Oahu, Hawaii.

[Locations of streamflow-gaging stations are shown in figures 1 and 2; do., ditto. Start and end dates provided by the State of Hawaii, Department of Transportation (written commun., 1999)]

Station	Drainage basin and highway construction activities	Start date	End date
16226200	**N. Halawa Stream and**		
16227100	**Halawa Stream**		
	N. Halawa access road	11/02/87	03/89
	Exploratory tunnel	02/27/89	03/90
	Drilled shaft test program	11/13/90	02/91
	Trans-Koolau Tunnel	03/19/91	02/07/98[1]
	N. Halawa viaduct	02/21/92	06/95
	N. Halawa Valley Highway Unit I Phase 1A	04/11/94	09/95
	N. Halawa Valley Highway Unit I Phase 1B	05/24/95	12/12/97
	N. Halawa Valley Highway Unit II	08/01/94	12/12/97
16265600	**Right Branch Kamooalii Stream and Waimaluhia Reservoir stations**		
212335157482603	Halekou Interchange[2]	02/22/83	12/01/83
212329157483102	do.	03/02/84	07/31/85
	do.	11/04/85	02/28/86
	do.	11/02/86	12/31/86
	do.	06/15/87	09/30/88
	Windward Highway	06/19/89	06/92
16265700	**Kamooalii Stream at altitude 200 feet and**		
16266500	**Hooleinaiwa Stream at altitude 220 feet and**		
16267500	**Hooleinaiwa Stream above confluence with Kamooalii Stream and**		
16269500	**Kuou Stream at altitude 220 feet**		
	Windward Highway	06/19/89	06/92
16270900	**Luluku Stream**		
	Windward Highway	06/19/89	06/92
	Kaneohe Interchange	01/19/93	12/22/95
16272200	**Kamooalii Stream**[3]		
16273950	**S. Fork Kapunahala Stream**		
	Hospital Rock Tunnel	03/06/89	05/92
	Kaneohe Interchange	01/19/93	12/22/95
16274100	**Kaneohe Stream**[4]		
16275000	**Haiku Stream**		
	Haiku access road	10/24/88	06/90
	Exploratory tunnel	02/27/89	03/90
	Haiku Valley bridges	08/07/89	03/91
	Windward viaduct	01/08/90	05/13/93
	Trans-Koolau Tunnel	10/01/90	02/07/98[1]

[1]This is the official completion date for all work on the tunnel; however, for the Haiku Valley part of the tunnel construction, all land-disturbance work was completed by November 1994, so for the purpose of determining the post-construction dates, November 1994 will be used. In North Halawa Valley, channel and earthwork by the tunnel continued until September 1997, so September 30, 1997 will be used for the purpose of determining the post-construction dates.

[2]Work on Halekou Interchange interrupted multiple times by court injunctions.

[3]Includes highway construction activities listed under stations 16265600 and 16270900, as these drainage basins drain into Kamooalii Stream.

[4]Includes highway construction activities listed under stations 16265600, 16270900, 16272200, and 16273950, as these drainage basins drain into Kaneohe Stream.

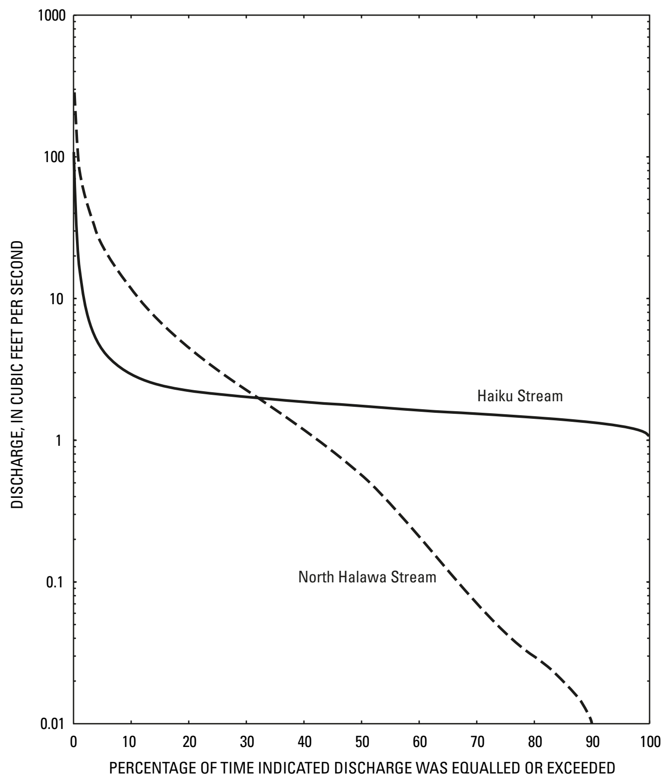

Figure 3. Flow-duration curves of daily flows for stations 16226200 North Halawa Stream and 16275000 Haiku Stream, 1983–99, Oahu, Hawaii.

Kawaihapai clay loam soils by the mouth of Halawa Stream (Foote and others, 1972). Soils in the Haiku and Kaneohe drainage basins are classified as Lokelaa with some Kaneohe and Hanalei series silty clays. These types of silty clays have moderate permeability and are highly erodible on steep slopes (Foote and others, 1972). Most of the mountainous areas within all the study drainage basins are classified as "rough mountainous land," "rock land," or "rock outcrop" (Foote and others, 1972), and little information is available on the soils of these areas.

Except where disturbed by development (figs. 1 and 2), all study basins are completely covered with some type of vegetation. Most of the native vegetation on the windward side of the study area has been replaced by cultivated crops such as bananas, other nonnative plants, and residential and commercial developments. Much of the Luluku subdrainage basin (fig. 2, station 16270900) has been converted to banana plantations. Vegetation in the North Halawa Valley is representative of undisturbed forest in the leeward Koolau Range and includes native and introduced species.

Eight-digit station numbers are used throughout the report to refer to locations of data collection and their corresponding drainage basins. Stations with 15 digit station numbers are referred to by their names. Table 2 lists station numbers and their corresponding station names, drainage areas, locations, and periods of water-quality data collection. Water-quality data collection continues (2004) at station 16226200, and data through July 2000 was used in this report.

Halawa Drainage Basin.—The Halawa drainage basin is on the leeward side of the crest of the Koolau Range and has a drainage area of 8.90 mi^2 upstream from station 16227100. Halawa Stream flows into the East Loch of Pearl Harbor and originates at the confluence of North and South Halawa Streams, downstream from Moanalua Freeway (fig. 1). Data collection in the Halawa drainage basin was concentrated in the North Halawa Stream valley. For this study, the water-quality data collected at station 16227100 on Halawa Stream (fig. 1) were the only data collected in the Halawa drainage basin outside of North Halawa Valley. Between stations 16227100 and 16226200, the land is developed and consists of a light industrial park near the mouths of both North and South Halawa Streams and residential areas near the Moanalua Freeway and H-1 Highway. The H-3 Highway composes about 3 percent of the drainage area upstream from station 16227100 and about 4 percent of the North Halawa 4.01-mi^2 drainage area upstream from station 16226200.

Before highway construction in the North Halawa Stream valley began in November 1987, this drainage basin was undeveloped, but the lower valley was used for agriculture from 1850 to 1947 (Spear, 1990). The stream is more than 100 ft above the freshwater-lens water table throughout the valley and flow in the main channel is intermittent in most

Table 2. Locations and period of water-quality data-collection activities in the H-3 Highway study area, Oahu, Hawaii.

[mi², square miles; ft, feet; Str, stream; P, data collection continues at present, 2004]

USGS station number	Station name	Drainage area (mi²)	Altitude of station (ft)	Location		Period of water-quality data	
				Latitude	Longitude	Start	End
Halawa drainage basin							
16227100	Halawa Str below H-1	8.90	20	21°22′17″	157°55′57″	Nov 1988	Nov 1998
N. Halawa subdrainage basin							
16226200	North Halawa Str near Honolulu	4.01	160	21°23′04″	157°54′22″	May 1983	P
Haiku drainage basin							
16275000	Haiku Str	0.97	272	21°24′46″	157°49′33″	Mar 1983	Apr 1998
Kaneohe drainage basin							
16274100	Kaneohe Str	5.22	40	21°24′54″	157°48′03″	Nov 1988	Aug 1999
South Fork Kapunahala subdrainage basin							
16273950	South Fork Kapunahala Str	0.40	111	21°24′21″	157°48′31″	Aug 1983	Apr 1998
Kamooalii subdrainage basin							
16265600	Right Branch Kamooalii Str	1.11	195	21°23′22″	157°47′44″	Feb 1983	Jan 1998
16265700	Kamooalii Str at altitude 200 ft	0.46	200	21°23′11″	157°47′56″	Feb 1983	Jan 1998
16266500	Hooleinaiwa Str at altitude 220 ft	0.41	220	21°23′06″	157°48′16″	Feb 1983	Feb 1997
16267500	Hooleinaiwa Str above confluence with Kamooalii Str	0.57	180	21°23′15″	157°48′19″	Feb 1983	Jan 1998
16269500	Kuou Str at altitude 220 ft	0.34	220	21°23′30″	157°48′45″	Feb 1983	Jan 1998
212335157482603	RES 1-3 (Waimaluhia Reservoir)	3.20	160	21°23′35″	157°48′26″	May 1983	Jan 1998
212329157483102	RES 3-2 (Waimaluhia Reservoir)	3.20	160	21°23′29″	157°48′31″	May 1983	Jan 1998
16270900	Luluku Str	0.44	220	21°23′42″	157°48′44″	Feb 1983	Apr 1998
16272200	Kamooalii Str	3.81	116	21°23′47″	157°48′23″	Oct 1980	Apr 1998

years (Izuka, 1992). About 20 percent of the stream channel was channelized during the highway construction.

Haiku Drainage Basin.—The Haiku drainage basin (fig. 2) is on the windward side of the Koolau Range and adjoins the Halawa drainage basin along the crest of the Koolau Range (fig. 2). At station 16275000, Haiku Stream flows perennially. Almost all of the 0.97-mi² drainage basin upstream from station 16275000 was undeveloped except for a road and large building that was part of a U.S. Coast Guard low-frequency radio navigational facility. This station was operated from 1944 to September 30, 1997. The main land-use impact of the station was an array of radio antenna wires suspended over the valley, anchored from the ridge crests. A municipal water-supply tunnel and well also are located in the valley. Highway construction in the Haiku drainage basin began in October 1988 (table 1). The part of the H-3 Highway located within the Haiku drainage basin was constructed entirely as a viaduct and covers about 3 percent of the drainage area upstream from station 16275000.

Kaneohe Drainage Basin.—The Kaneohe drainage basin (fig. 2) is on the windward side of the Koolau Range, south of the Haiku drainage basin, and has an area of 5.22 mi² upstream from station 16274100. Kaneohe Stream flows into Kaneohe Bay downstream from the confluence of Kapunahala and Kamooalii Streams, which join to form Kaneohe Stream near Kamehameha Highway (fig. 2). Data collection in the study basin was concentrated in the Kapunahala and Kamooalii subdrainage basins. The water-quality data collected at station 16274100 on Kaneohe Stream (fig. 2) were the only data collected in the Kaneohe drainage basin outside of these two subbasins. Land use upstream from station 16274100 and downstream from stations 16272200 and 16273950 consists entirely of residential and urban areas of Kaneohe town. H-3 Highway construction affected about 3 percent of the drainage area upstream from station 16274100.

In the Kapunahala subdrainage basin, only the South Fork of Kapunahala Stream was monitored during the study. The South Fork Kapunahala subdrainage basin lies to the southeast of the Haiku drainage basin and has a drainage area of 0.40 mi² upstream from station 16273950, located at an altitude of 111 ft (fig. 2). The subdrainage basin consists of residential and some agricultural lands in the lower parts of the basin. H-3 Highway construction in the basin began in March 1989 (table 1), with most construction activities occurring near the 400-ft altitude. The H-3 Highway covers about 15 percent of the drainage area upstream from station 16273950. Drainage patterns to station 16273950 from the existing Likelike Highway were altered during the H-3 Highway construction.

The Kamooalii sub-drainage basin upstream from station 16272200, at an altitude of 116 ft, has a drainage area of

3.81 mi^2 (fig. 2). Highway construction within the Kamooalii subdrainage basin began in 1983 (table 1) with the construction of the Halekou Interchange upstream from station 16265600 on the right branch of Kamooalii Stream (fig. 2). Numerous court injunctions delayed the construction at various times (table 1). Construction of the Windward Highway segment of the H-3 Highway (the section between the Halekou and Kaneohe Interchanges), which affects most of the basin, began in the summer of 1989 and ended in the summer of 1992 (table 1). Most of the highway segments in the Kamooalii subdrainage basin were constructed using cut-and-fill techniques. The H-3 Highway composes about 4 percent of the drainage area upstream from station 16272200.

In addition to station 16272200, water-quality data were collected in the Kamooalii subdrainage basin at stations 16265600 Right Branch Kamooalii Stream, 16265700 Kamooalii Stream at altitude 200 ft, 16266500 Hooleinaiwa Stream at altitude 220 ft, 16267500 Hooleinaiwa Stream above confluence with Kamooalii Stream, 16269500 Kuou Stream at altitude 220 ft, and at station 16270900 Luluku Stream (fig. 2). Streamflow at all stations except 16269500 is perennial. Kuou Stream at station 16296500 was observed to be dry numerous times during the study period. Streamflow at station 16272200 includes water that has flowed through Waimaluhia Reservoir, a flood-control reservoir completed in 1981 upstream from the confluence of Luluku and Kamooalii Streams. Water from Luluku Stream does not flow through the Waimaluhia Reservoir. The reservoir consists of a 26-acre permanent pool with a capacity of 209 acre-ft in 1998 (Wong, 2001). Mean depth is about 8 ft with depths up to 16 ft. The area affected by the H-3 Highway construction includes about 4 percent of the drainage area at station 16266500, about 5 percent of the drainage areas at stations 16265600, 16265700, 16269500, and 16270900; and about 6 percent of the drainage area at station 16265700.

Land use upstream from station 16272200 includes the Hoomaluhia Botanical Garden, a public park operated by the City and County of Honolulu (fig. 2), which includes the Waimaluhia Reservoir. Stations 16265700, 16266500, 16267500, 16269500, and 16270900 all are within the park boundaries. Downstream from the botanical garden, most of the drainage basin has been developed for residential use. Upstream from the botanical garden to the east and southeast is the Pali Golf Course, built in 1957; the Koolau Golf Course built between 1989 and 1991; and the Hawaii Loa campus of Hawaii Pacific University (fig. 2). Both the Pali Golf course and the Hawaii Loa campus are upstream from station 16265600. The Koolau Golf Course is upstream from stations 16265600, 16265700, 16266500, and 16267500. The remaining land area in the Kamooalii drainage basin is banana plantations, which covers about 40 percent of the area upstream from station 16270900, or undeveloped land. Parts of both Likelike and Pali Highways cross the drainage basin near the Koolau Range (fig. 2). More information on the land use and land cover in the Kamooalii drainage area can be found in Wong (2001).

Previous Studies

Except for studies of suspended sediment (Hill, 1996; Wong and Yeatts, 2002), no previous studies of water-quality effects of highway construction are known for Oahu or other similar central Pacific Islands. Investigations from the continental United States on the effects of highway construction on water quality (Parizek, 1971; Barrett and others, 1993) have detected increases in suspended solids and turbidity due to increased soil erosion caused by highway-construction activities. Once highway construction was completed, suspended-solids and turbidity values returned to ambient levels (Barrett and others, 1993). Other water-quality constituents such as nutrients, bacteria, oxygen demand, trace metals, and oil and grease monitored in these studies did not significantly change during highway construction (Barrett and others, 1993, 1995).

Previous studies on stream water quality in the H-3 Highway study area were done in the Kaneohe and Haiku Stream drainage area. The Kaneohe drainage area studies were done to determine the water-quality effects of urban Kaneohe town on Kaneohe Bay or the effects of constructing the Waimaluhia Reservoir, and included sampling at some stream sites that also were sampled as part of this study. Quan and others (1970) sampled for bacteria and nutrients in Kaneohe Stream, downstream from station 16274100, from February to April 1968. Cox and others (1973) collected samples for pH, nutrients, dissolved oxygen, and oxygen demand from September 1968 to April 1969 from Kamooalii Stream near currently discontinued station 16273900 (which was located on Kamooalii Stream about 50 ft upstream from the confluence with Kapunahala Stream) and from Haiku Stream at station 16275000. Cox and others (1973) concluded that total nitrogen concentrations in streams were greater than the State of Hawaii water-quality standards for coastal waters, and that sewage sources had the greatest effect on nutrient loading to Kaneohe Bay. As part of studies supporting the environmental impact statement for the Waimaluhia Reservoir, the U.S. Army Corps of Engineers (1975) collected biweekly samples for pH, dissolved oxygen, turbidity, nutrients, and fecal coliform at sites on Kamooalii Stream near station 16272200 and discontinued station 16273900 and on Kaneohe Stream downstream from station 16274100 from February 1972 to February 1973. Dugan (1977) collected monthly samples for nutrients from February 1974 to February 1975 at stations 16270900 and 16274100. Dugan (1977) also sampled for nutrients and turbidity of storm runoff at discontinued station 16273900 from November 1974 to March 1975. Dugan (1977) concluded that constituent concentrations were related to flow and not the time phase of the storm runoff, with increasing concentrations with increasing flow. Finally, AECOS, Inc. (1981), sampled for turbidity and nutrients upstream and downstream (near station 16272200) from the Waimaluhia Reservoir construction site during 1977–81.

Because of changes in land use in the upper Kaneohe drainage basin, especially the construction of the Hoomaluhia botanical garden and Waimaluhia Reservoir during 1976–81, direct comparison of water-quality data from this study with data collected prior to 1981 for Kamooalii and Kaneohe Streams to detect changes associated with construction of the H-3 Highway cannot be made. Comparisons with previous data from stations 16270900 and 16275000, however, can be made because the only land-use change of significance in these basins during the time interval between studies is the construction of the H-3 Highway. More recent water-quality data were collected at station 16274100 by Brasher and Anthony (2000), who sampled for organochlorine pesticides in fish tissue and bed sediments in 1998. In the Haiku drainage area, Izuka and others (1993) sampled for polychlorinated biphenyls (PCBs) in Haiku Stream as part of a study on PCB transport.

The USGS collected water-quality data at some study stations in the past. These data include measurements of physical properties such as pH, temperature, and specific conductance and samples for major ions, except at station 16275000, where additional samples for nitrite plus nitrate nitrogen (NO_2+NO_3) were collected (Matsuoka, 1983). Data from sites along Kamooalii Stream were collected during 1967–75 and 1967–77 at discontinued stations 16270500 (which was located downstream from Waimaluhia Reservoir but upstream from Luluku Stream) and 16273900, and during 1977–79 at station 16272200. Data also were collected at stations 16270900 and 16275000 during 1970–76 and 1970–77. Because of the occurrence of multiple land-use changes in most basins, only data from stations 16270900 and 16275000 can be used for comparison with current data to detect changes associated with construction of the H-3 Highway.

A statistical summary of hydrologic and water-quality data collected by the USGS in the H-3 Highway study area during water years 1983–89 was presented in Wong and Hill (1992). Wong and Young (2001) presented an updated statistical summary of hydrologic and water-quality data through water year 1999. These summary reports presented annual rainfall, streamflow, suspended-sediment loads, particle size, and concentrations, and water-quality data from streamflow and suspended-sediment gaging stations in the H-3 Highway study area.

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Data Collection and Statistical Analysis

To determine whether the State of Hawaii water-quality standards were exceeded before, during, or after construction of H-3 Highway, sample data from each time period were compared to the standards. In cases where the standards were exceeded during construction, sample data were compared between time periods by simple statistical tests. The results of these comparisons were used to determine if any exceedence of the standards could be attributed to highway construction. Additional comparisons were made between upstream and downstream locations and with previous water-quality data collected at selected stations.

The State of Hawaii water-quality standards specific to streams are presented in table 3 (State of Hawaii Department of Health, 2000). The standards use the geometric mean for selected constituents (table 3). The geometric mean is computed by taking the logarithms of the data set, determining the mean of the logarithms, and then back transforming the mean of the logarithms to the original units. Geometric means are used to reduce the effects of outliers on the mean value of a data set. The geometric mean is an estimate of the median when the logarithms of the data are symmetric. Additional properties of the geometric mean as used for water-quality standards can be found in Landwehr (1978). Natural (base e) logarithms were used throughout this report. Data from Waimaluhia Reservoir station RES 1-3, were compared to these stream standards (table 3), although they are not applicable to lakes and reservoirs. The State of Hawaii does not have similar standards for lakes and reservoirs.

The State of Hawaii water-quality standards also include concentration values that should not be exceeded more than 10- and 2-percent-of-the-time (table 3). Values to compare to these exceedence criteria were computed as the 90th and 98th percentiles, which are equivalent to the 10- and 2-percent exceedence. Percentiles were computed by assuming no statistical distribution and by using only the instantaneous water-quality data collected. Each sample was assumed to represent an equal period of time. Percentiles were computed by ranking the data from lowest to highest in value and then dividing the rank by the total number of samples (Iman and Conover, 1983). Values for the 90th and 98th percentiles were interpolated when necessary because of sample size between the given percentages assigned to each data point. Percentiles were only computed when sample size was greater than five values.

The State of Hawaii water-quality standards for physical properties—pH, temperature, dissolved oxygen, and specific conductance—are given as numeric values or ranges not to be exceeded (table 3). The standard for specific conductance is listed in units of micromhos per centimeter. During this study, specific conductance was measured in units of microsiemens

Table 3. State of Hawaii water-quality standards specific for streams.

[mg/L, milligrams per liter; NTU, Nephelometric Turbidity Unit; standards listed in Hawaii Administrative Rules, Title 11, Chapter 54, Section 5.2, dated April 4, 2000; wet season is from November 1 to April 30 and dry season is from May 1 to October 31; ambient conditions are conditions that would occur in the receiving waters if these waters were not influenced by the proposed new human activity]

Property or constituent	Season	Geometric mean not to exceed the given value	Not to exceed the given value more than 10 percent of the time	Not to exceed the given value more than 2 percent of the time
Total nitrogen (mg/L as N)	wet	0.25	0.52	0.80
	dry	0.18	0.38	0.60
Nitrite plus nitrate nitrogen (mg/L as N)	wet	0.07	0.18	0.30
	dry	0.03	0.09	0.17
Total phosphorus (mg/L as P)	wet	0.05	0.10	0.15
	dry	0.03	0.06	0.08
Total suspended solids (mg/L)	wet	20	50	80
	dry	10	30	55
Turbidity (NTU)	wet	5.0	15.0	25.0
	dry	2.0	5.5	10.0
pH units	Shall not deviate more than 0.5 units from ambient conditions and shall not be lower than 5.5 nor higher than 8.0			
Dissolved oxygen	Not less than 80 percent saturation, determined as a function of ambient water temperature and barometric pressure			
Temperature	Shall not vary more than 1 degree Celsius from ambient conditions			
Specific conductance	Not more than 300 micromhos per centimeter			

per centimeter. Both of these units are numerically equivalent (Hem, 1985).

The final aspect of the State of Hawaii water-quality standards, called basic standards, are standards for trace metals and organic chemical compounds that are applicable to all surface waters, fresh and salt, in the State. These standards list numeric values for acute and chronic conditions that are not to be exceeded (State of Hawaii Department of Health, 2000). Table 4 lists the trace metals and organic compounds that were analyzed during this study. Only those constituents with State water-quality standards were further analyzed for this report.

Water-Quality Data Collection

Water-quality measurements and samples were collected at the following 12 stream- water-quality stations: 16226200, 16227100, 16265600, 16265700, 16266500, 16267500, 16269500, 16270900, 16272200, 16273950, 16274100, and 16275000 (table 2), and at various depths at 2 sites in Waimaluhia Reservoir (figs. 1 and 2). Measurements of physical properties such as streamflow, water temperature, specific conductance, pH, and dissolved oxygen were made in the field. In addition, samples were collected and subsequently analyzed for inorganic constituents such as turbidity, total suspended solids, major ions, nutrients, and trace metals; biological constituents such as fecal coliform bacteria; and organic constituents such as total organic carbon, oil and grease, pesticides, and polychlorinated compounds. All field measurements and samples for chemical constituent analyses were collected, processed, and treated according to guidelines in Ward and Harr (1990), Sylvester and others (1990), and Shelton (1994). Direct measurements of streamflow were made using standard practices for current-meter measurements (Rantz and others, 1982).

Stream-sample collection was done using an equal-width increment method when flow conditions (stream widths greater than 3 ft and depths greater than 0.5 ft) permitted. Otherwise, dip samples were collected at the centroid of streamflow. Inorganic samples were collected using a DH–81 sampler with 1-L polyethylene bottles when depths were greater than 0.5 ft. An open-mouth polyethylene bottle was used to collect samples from shallower depths. A churn splitter (Ward and Harr, 1990) was used to composite and split all inorganic samples. Samples for fecal coliform bacteria and organic constituents were collected directly into sterile (bacteria) or baked (organic) glass containers by dip sampling at the centroid of streamflow.

Samples from Waimaluhia Reservoir were collected using a modified vertical configuration Van Dorn sampler until 1995; after which, a standard horizontal configuration Van Dorn sampler was used (Ward and Harr, 1990). Reservoir measurements for physical properties and sampling for turbidity, total suspended solids, nutrients, and fecal coliform bacteria were done by depth at RES 1-3 and 3-2 (fig. 2). In addition, at RES 1-3, the primary reservoir sampling site, samples were collected at various depths and then composited for analysis of major ions, trace metal, and organic constituents. All other samples, except those for major ions and trace metals, were collected directly into sample bottles using the Van Dorn sampler. Major-ion and trace-metal

Table 4. Trace metals and organic compounds analyzed at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, February 1983 to August 1999.

[µg/L, microgram per liter; *, State of Hawaii water-quality standard exists for this constituent; diss., dissolved]

Trace metal constituent	Original minimum reporting level (µg/L)	Revised minimum reporting level, December 1997 (µg/L)	Organic constituent	Minimum reporting level (µg/L)
Aluminum, total and diss.*	28 total, 10 diss.	28 total, 10 diss.	Aldrin *	0.01
Arsenic, total and diss.*	1	1	Chlordane *	0.1
Barium, total and diss.	100 total, 2 diss.	1 total, 2 diss.	Chlorpyrifos *	0.01
Beryllium, total and diss.*	10 total, 0.5 diss.	5 total, 1 diss.	DDD	0.01
Cadmium, total and diss.*	1	1 total, 8 diss.	DDE *	0.01
Chromium, total and diss.*	1	1 total, 14 diss.	DDT *	0.01
Cobalt, total and diss.	1 total, 3 diss.	1 total, 12 diss.	DEF	0.01
Copper, total and diss.*	1	1 total, 10 diss.	Diazinon	0.01
Iron, total and diss.	10 total, 3 diss.	14 total, 10 diss.	Dieldrin *	0.01
Lead, total and diss.*	1	1 total, 100 diss.	Disulfoton	0.01
Lithium, total and diss.	10 total, 4 diss.	10 total, 4 diss.	Endosulfan-alpha *	0.01
Manganese, total and diss.	1	3 total, 4 diss.	Endrin *	0.01
Mercury, total and diss.*	0.1	0.1	Ethion	0.01
Molybdenum, total and diss.	1 total, 10 diss.	1 total, 60 diss.	Fonofos	0.01
Nickel, total and diss.*	1	1 total, 40 diss.	Heptachlor *	0.01
Selenium, total and diss.*	1	1	Heptachlor epoxide	0.01
Silver, total and diss.*	1	1 total, 4 diss.	Lindane *	0.01
Strontium, diss.	0.5	1	Malathion *	0.01
Vanadium, diss.	6	10	Methyl-Parathion	0.01
Zinc, total and diss.*	10 total, 3 diss.	40 total, 20 diss.	Methoxychlor *	0.01
			Mirex *	0.01
			Parathion *	0.01
			Perthane	0.1
			Phorate	0.01
			PCB *	0.1
			PCN	0.1
			Toxaphene *	1
			Trithion (carbophenothion)	0.01
			2,4-D *	0.01
			2,4-DP (dichlorprop)	0.01
			2,4,5-T	0.01
			Silvex (2,4,5-TP)	0.01

samples were composited in a churn splitter. The composite for organic constituents at RES 1-3 was done by filling part of each organic sample bottle from samples collected at the various depths in equal proportions based on the number of different depths sampled. Measurements for only physical properties (pH, dissolved oxygen, temperature, specific conductance) were done by depth at 10 other reservoir sites, although these data are not summarized in this report.

Water-quality samples at stream sites were collected, on average, 10 times per year. Sampling dates were equally divided between wet (October to April) and dry (May to September) seasons. Measurements of streamflow, water temperature, specific conductance, pH, and dissolved oxygen and samples for turbidity and total suspended solids were collected for all 10 of the sampling dates during a water year. Samples for nutrients and fecal coliform bacteria were collected during 4 of the 10 sampling dates, approximately quarterly, twice during the wet season and twice during the dry season. Samples for major ions, trace metals, and organic constituents were collected during 2 of the 10 sampling dates, approximately semiannually, once during the wet season and once during the dry season. At Waimaluhia Reservoir, measurements of water temperature, specific conductance, pH, and dissolved oxygen and samples for turbidity, nutrients, and fecal coliform bacteria were collected four times per year, approximately quarterly; and samples for major ions, trace metals, and organic constituents were collected during two of the four sampling dates, approximately semiannually. Sample dates were not always equally spaced in time.

Samples for major ions, nutrients, and trace metals that were required to be filtered prior to laboratory analysis were filtered at the field site using a 0.45-μm pore-size plate filter prior to water year 1995. Starting in water year 1995, a 0.45-μm pore-size capsule filter was used and sample filtering was done in the office following the filtering protocol in Horowitz and others (1994). Sample filtering for nutrient samples on sampling dates when only the nutrient samples required filtering continued to be filtered at the field site.

Starting in water year 1995, samples for inorganic constituents such as major ions, nutrients, and trace metals were collected and processed using the part per billion protocol in Horowitz and others (1994). This protocol uses cleaner techniques than previous methods and provides for accurate, quality-assured, inorganic data at lower concentration levels. Beginning in water year 1997, because of the use of the part per billion protocol, quality-assurance field-blank samples for trace metals were processed twice a year. Prior to water year 1997, no field quality-assurance samples were collected. All personnel responsible for field data collection participated annually in the USGS National Field Quality Assurance (NFQA) Program during the study period (Stanley and others, 1998). The NFQA Program checks the proficiency of personnel making pH and specific-conductance measurements.

Samples for trace-metal analysis were preserved with nonultrapure nitric acid until water year 1995, when the use of ultrapure nitric acid was started. Prior to October 1994, samples for nutrient analyses were preserved with mercuric chloride and then chilled to $4^{o}C$. After October 1994, nutrient samples were preserved only by chilling (U.S. Geological Survey, 1994). Starting in January 1999, nutrient samples for total ammonia and organic nitrogen and total phosphorus were preserved with sulfuric acid and then chilled (U.S. Geological Survey, 1998b). Only data collection at stations 16226200 and 16274100 were affected by this change because data collection ended at all the other stations prior to January 1999 (table 2).

The methods used for the analysis of all the water-quality properties and constituents followed those in Wershaw and others (1987), Britton and Greeson (1989), Fishman and Friedman (1989), Patton and Truitt (1992), and Fishman (1993). All laboratory analyses were conducted by the U.S. Geological Survey's National Water Quality Laboratory (NWQL) in Colorado. Quality-assurance practices at NWQL are documented in Friedman and Erdmann (1982) and Pritt and Rease (1992). In January 1993, laboratory analysis for unfiltered NO_2+NO_3 nitrogen was discontinued, and only filtered NO_2+NO_3 was analyzed after that date, because values for unfiltered and filtered NO_2+NO_3 nitrogen were statistically indistinguishable (U.S. Geological Survey, 1992).

Statistical Analysis

Water-quality constituents that are not detected in a sample are commonly reported to be below the minimum reporting level. The minimum reporting level is the smallest measured concentration of a constituent that can be reliably reported by using a given analytical method (Childress and others, 1999). This means that the actual concentration can be anywhere from zero to the minimum reporting level. A concentration less than the minimum reporting level does not mean that the constituents are not present in the sample. Minimum reporting levels can change over time because of improved laboratory techniques or as a result of refinements in the analytical methods used.

During this study, minimum reporting levels for several constituents changed. The minimum reporting level for (NO_2+NO_3) nitrogen changed from 0.10 to 0.05 mg/L in April 1991 due to changes in laboratory method. The minimum reporting level for ammonia and organic nitrogen decreased from 0.20 to 0.10 mg/L in November 1997, and values from 0.05 to 0.10 mg/L were reported as estimates starting in October 1998 because of changes in laboratory method and new reporting procedures (U.S. Geological Survey, 1997a, 1998a). Total nitrogen values used in this report were computed by adding the concentrations of NO_2+NO_3 nitrogen, ammonia, and organic nitrogen. The minimum reporting level for total phosphorus changed from 0.01 to 0.05 mg/L in October 1998, although values between 0.03 and 0.05 mg/L may be reported as estimates (U.S. Geological Survey, 1998a). The minimum reporting level for total suspended solids was raised from 1 to 10 mg/L in April 2000 (U.S. Geological Survey, 2000). This change only affected total suspended-solids data collected at station 16226200 because data collection ended earlier at all the other stations (table 1). The changes to the minimum reporting levels for total phosphorus and total suspended solids were due to new reporting procedures based on statistical and quality-assurance analyses (Childress and others, 1999). Constituents with variable minimum reporting levels were analyzed in this report using the minimum reporting level applicable at the time the samples were originally collected. Constituents reported as estimates were used at the reported value. The changes in minimum reporting levels mostly occurred during the after-construction data-collection period at all stations (table 1).

Methods for computing summary statistics such as the geometric mean when data are reported as less than the minimum reporting level, commonly called censored data, are summarized in Helsel (1990). The method recommended by Helsel (1990) for computing means is log-probability regression. This method requires at least three detected observations not having the same value and can be used on data sets with up to 80 percent censored data, but error and bias increase when more than 60 percent of the data set is censored data (Gilliom and Helsel, 1986). The log-probability method is robust, easy to compute with standard statistics software, can be used with multiple minimum reporting levels (Helsel and Cohn, 1988), and is ideal for computing geometric means (Travis and Land, 1990). In this study, log-probability regression was used when censored data did not constitute more than 60 percent of the data set for data sets greater than 10 values and more than 50 percent for data sets with 5 to 10 values. Where log-probability regression could not be used because of the above limitations, a simple substitution method of using one-half the minimum reporting level was used. Compared to other simple substitution methods (Helsel and Gilliom, 1986; Helsel, 1990), this substitution method provided the lowest error and bias in computing sample means and also provided a lower error than log-probability regression when samples sizes were small (less than 10 samples)(Clarke, 1998).

Although useful, the comparison of geometric means with water-quality standards cannot be used to infer the effects of highway construction at the study stations. It was assumed, however, that at stations where the geometric mean did not exceed the water-quality standards, the effects of highway construction were negligible. At stations where the geometric mean did exceed the water-quality standards, a rank-sum test was conducted to determine if there were any significant differences between the before-, during-, and after-construction data sets.

The rank-sum test, also known as the Wilcoxon-Mann-Whitney rank-sum test, is a nonparametric hypothesis test used to compare two independent sample sets for differences (Iman and Conover, 1983; Helsel and Hirsh, 1992). The rank-sum test was used to compare seasonal data sets between the time periods before and during, during and after, and before and after. The null hypothesis was no difference between time periods and was tested with a significance level of α=0.10. Because all rank-sum tests in this study were computed as two-sided, the actual test statistic was $\alpha/2$=0.05, so a *p*-value less than 0.05 is needed to reject the null hypothesis. The rank-sum test is valid for all sample sizes and distributions but does assume that both sample sets are random samples of their respective populations (Iman and Conover, 1983).

To compare data sets at one station over two different time periods requires the assumption that variations in rainfall and streamflow are similar for both time periods. The small data sets in this study prevented the use of more rigorous statistical methods such as analysis of covariance to account for this variation. Therefore, an assumption was made that if the stream discharges associated with the water-quality samples were similar, then any variation in rainfall between the two time periods tested would have a minimal effect on the rank-sum test results. Thus, stream discharge between time periods, but not by season, also were tested using the rank-sum test with a null hypothesis of no difference in stream discharge. Where discharges were found to be significantly different, no rank-sum test on the water-quality constituent was done.

Another problem that would affect the interpretation of the rank-sum test between time periods is the change in minimum reporting levels for certain constituents. Most of these changes occurred to the sample data in the after-construction time period. Differences were checked visually using time-series plots of the data and if there appeared to be a noticeable difference in the data due to the change in the minimum reporting level, then no rank-sum test was done. Such differences were more easily seen in data sets with large numbers of values below the minimum reporting levels.

In addition to comparing the data between time periods, total nitrogen, NO_2+NO_3 nitrogen, phosphorus, total suspended solids (TSS), and turbidity data between two pairs of stations also were compared using the rank-sum test. Stations 16227100 Halawa Stream and 16274100 Kaneohe Stream were established in 1988 at sites near the mouth of each stream downstream from the urban areas (figs. 1 and 2). The upstream sites, stations 16226200 on North Halawa Stream and 16272200 on Kamooalii Stream, are upstream from the urban areas and downstream from the area affected by highway construction. The purpose of comparisons at station 16226200 with 16227100 and station 16272200 with 16274100, using the during-construction data sets, was to determine if the water-quality effects from the H-3 Highway construction were any different from the existing urban effects.

Because of differences in streamflow between the two sampling locations, this comparison was done using instantaneous constituent loads and not concentration data, because concentration data may be affected by inflows and outflows between locations. Constituent loads were computed by multiplying the concentration data in milligrams per liter with its corresponding instantaneous discharge in cubic feet per second and by a conversion factor of 5.394 to convert all units into pounds per day. The rank-sum test was computed comparing the load data except for turbidity, because turbidity data are not reported in a concentration unit. The basic hypothesis was no difference between loads or turbidity at sampling locations and this was tested with a significance level of $\alpha/2$=0.05.

Data sets were tested first using all the data collected during the construction time period, and then by using wet- and dry-season data sets. Because this was a test between data at different locations during a similar time period, the rainfall variations and changes in minimum reporting levels were assumed to be the same at both locations and would have no effect on the interpretation of these rank-sum test results.

Water Quality Before, During, and After Highway Construction

Nitrogen.—Geometric mean values for total nitrogen ranged from 0.14 mg/L at station 16267500 after construction, wet season, to 0.89 mg/L at station 16265600 during construction, dry season. This dry-season maximum value is almost five times higher than the State of Hawaii standard of 0.18 mg/L (table 3). The State of Hawaii standards for total nitrogen geometric means were exceeded at almost all stations both before and during construction (table 5). The only exception was at station 16267500 where the wet-season, during-construction geometric mean value was below standards. After construction, the total nitrogen geometric means exceeded the standards at most stations except the wet-season geometric means at stations 16226200, 16267500, 16273950, and 16275000. Dry-season after-construction geometric means also were below standards at stations 16266500 and 16267500. At the majority of sites where the geometric mean standards were exceeded, the 10- and 2-percent-of-the-time exceedence values also were exceeded (table 5).

Table 5. Total nitrogen at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.

[--, no data; mg/L, milligrams per liter; e, value estimated by log-probability regression; h, value estimated by one-half minimum reporting limit substitution; minimum reporting limits for total nitrogen were determined by the addition of minimum reporting limits for nitrite plus nitrate nitrogen, ammonia, and organic nitrogen and changed from 0.30 to 0.25 mg/L in 1992 and to 0.15 mg/L in 1997; shaded values exceeded the State of Hawaii water-quality standards in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than minimum reporting level	Geometric mean (mg/L)	Concentration (mg/L) exceeded: 10 percent of the time	Concentration (mg/L) exceeded: 2 percent of the time
16226200	before	wet	1	0	--	--	--
		dry	6	0	h0.46	h0.85	h0.85
	during	wet	18	2	h0.26	h0.87	h2.6
		dry	15	2	h0.27	h1.0	h1.7
	after	wet	8	4	e0.21	0.94	0.99
		dry	1	0	--	--	--
16227100	during	wet	17	6	h0.32	0.63	0.69
		dry	13	5	h0.51	1.0	3.4
16265600	during	wet	18	10	e0.80	1.2	1.8
		dry	20	16	e0.89	1.3	3.6
	after	wet	12	1	h0.59	h0.69	h0.90
		dry	7	0	h0.49	h0.59	h0.60
16265700	before	wet	5	5	0.80	1.2	1.3
		dry	6	5	e0.56	0.70	0.70
	during	wet	7	2	h0.43	0.94	1.2
		dry	7	4	e0.52	0.83	0.89
	after	wet	10	0	h0.40	h0.48	h0.62
		dry	5	0	h0.48	h0.68	h0.69
16266500	before	wet	5	1	h0.26	h0.52	h0.66
		dry	5	0	h0.20	h0.30	h0.34
	during	wet	7	1	h0.28	h0.49	h0.66
		dry	7	3	h0.29	0.66	0.77
	after	wet	7	1	h0.26	h0.39	h0.58
		dry	6	0	h0.17	h0.21	h0.22
16267500	before	wet	5	0	h0.33	h0.55	h0.55
		dry	6	1	h0.26	h0.57	h0.71
	during	wet	7	2	h0.24	0.53	0.59
		dry	7	0	h0.22	h0.44	h0.61
	after	wet	10	0	h0.14	h0.19	h0.20
		dry	6	0	h0.17	h0.24	h0.33

Table 5. Total nitrogen at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.—Continued

[--, no data; mg/L, milligrams per liter; e, value estimated by log-probability regression; h, value estimated by one-half minimum reporting limit substitution; minimum reporting limits for total nitrogen were determined by the addition of minimum reporting limits for nitrite and nitrate nitrogen and ammonia and organic nitrogen and changed from 0.30 to 0.25 mg/L in 1992 and to 0.15 mg/L in 1997; shaded values exceeded the State of Hawaii water-quality standards listed in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than minimum reporting level	Geometric mean (mg/L)	Concentration (mg/L) exceeded 10 percent of the time	Concentration (mg/L) exceeded 2 percent of the time
16269500	before	wet	5	4	e0.68	1.2	1.5
		dry	5	1	h0.52	h2.6	h4.5
	during	wet	7	2	h0.50	0.70	0.70
		dry	7	3	h0.47	0.83	1.3
	after	wet	10	2	h0.41	h0.53	h0.59
		dry	5	0	h0.37	h0.45	h0.51
16270900	before	wet	10	6	e0.71	1.1	1.9
		dry	9	1	h0.35	h0.58	h1.64
	during	wet	12	3	h0.36	0.50	0.58
		dry	12	4	h0.28	0.40	0.55
	after	wet	7	0	h0.26	0.31	0.33
		dry	2	0	--	--	--
16272200	during	wet	20	11	e0.56	0.80	1.1
		dry	25	16	e0.53	0.80	1.3
	after	wet	7	3	h0.47	0.53	0.55
		dry	2	1	--	--	--
16273950	before	wet	1	1	--	--	--
		dry	8	0	h0.35	h0.68	h0.82
	during	wet	12	2	h0.37	h0.78	3.65
		dry	12	2	h0.24	h0.62	0.78
	after	wet	7	0	h0.17	h0.20	h0.22
		dry	2	0	--	--	--
16274100	during	wet	13	5	h0.62	0.87	0.98
		dry	12	9	e0.54	0.77	0.88
	after	wet	7	4	e0.48	0.54	0.60
		dry	3	3	0.54	--	--
16275000	before	wet	3	0	h0.33	--	--
		dry	8	0	h0.27	h0.57	h0.63
	during	wet	11	3	h0.27	0.40	0.48
		dry	10	0	h0.22	h0.27	h0.57
	after	wet	8	0	h0.18	h0.22	h0.23
		dry	4	0	h0.19	--	--
RES 1-3	during	wet	30	23	e0.74	1.1	1.3
		dry	45	44	e0.71	1.2	1.4
	after	wet	13	0	h0.51	h0.57	h0.59
		dry	6	2	h0.56	0.84	0.85

Rank-sum test *p*-value results comparing geometric means between construction time periods for total nitrogen are shown in table 6. Rank-sum tests could not be computed because of small sample size, n<5, in one of the construction or seasonal time periods at stations 16226200, 16270900, 16272200, 16273950, 16274100, and 16275000. The changes in the minimum reporting level for total nitrogen were most obvious at station 16267500 as shown in figure 4, so no rank-sum test was done comparing the after-construction data with the other two time periods at this station. Rank-sum tests could not be computed because streamflow values associated with the total nitrogen samples were significantly different between some of the construction time periods at stations 16269500, 16270900, and 16275000. At station 16275000, for example, the difference in the before- and during-construction discharges was significant with a *p*-value of 0.01. Before-construction discharges were lower (fig. 5*C*). Results were similar at stations 16269500 and 16270900 except that at station 16269500, the after-construction discharges were significantly lower than the before-construction discharges. Also, because no before-construction data were collected at stations 16227100, 16265600, 16272200, and 16274100, comparisons with before-construction data could obviously not be made. Where the rank-sum test was computed, only stations 16265600, 16265700, 16270900, 16273950, and 16275000 had statistically significant differences between comparisons with the after-construction time period (table 6).

At all five stations where statistically significant differences in total nitrogen were found, the geometric means were lower after construction than either before or during construction (tables 5 and 6). This may be, in part, due to the lower minimum reporting levels for total nitrogen (0.25 mg/L starting in April 1991 and 0.15 mg/L in November 1997) that affected the after-construction data at most sites (table 1). However, time-series plots of the total nitrogen data show that the effect of lower minimum reporting levels is minimal (fig. 5). In figure 5, total nitrogen concentrations are mostly above the minimum reporting level at stations 16265700 and 16270900, while at station 16275000, concentrations are mostly below the minimum reporting level; yet in both cases, the after-construction concentrations are significantly lower than the before- or during-construction concentrations. The lower after-construction concentrations may be due to a decrease in land disturbance after highway construction or land-use change because land-use prior to construction upstream from these stations was not pristine.

Of the two major components of total nitrogen, standards exist only for NO_2+NO_3 nitrogen (table 3). The lowest NO_2+NO_3 nitrogen geometric mean was at station 16267500 after construction, dry season, with a value of 0.04 mg/L; the highest geometric mean was at station 16265600 during construction, dry season, with a value of 0.50 mg/L (table 7). The geometric mean standards at all sites and during all time periods were exceeded except for before construction, wet season, at stations 16266500, 16267500, and 16275000 and after construction, wet season, at stations 16226200 and 16267500 (table 7). The 10- and 2-percent-of-the-time exceedence values were not exceeded as often for total nitrogen (table 5). Stations 16267500 and 16275000 had no exceedence of the 2-percent-of-the-time exceedence value. Stations 16226200, 16266500, 16267500, and 16275000 had the least amount of developed land prior to highway construction.

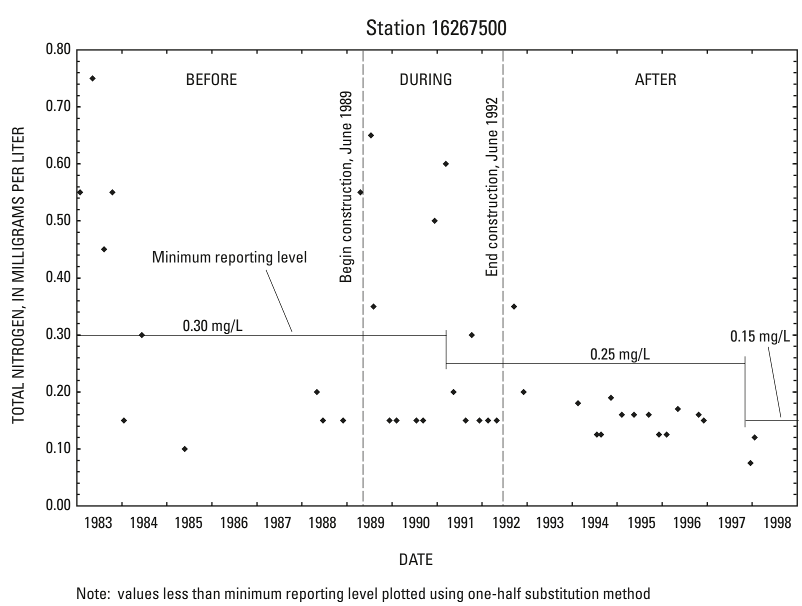

Figure 4. Total nitrogen concentrations at station 16267500, February 1983 to January 1998, Oahu, Hawaii.

Table 6. Rank-sum test *p*-value results comparing selected water-quality constituents and turbidity between highway construction time periods in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.

[Shaded values represent significant results with *p*-values less than 0.05; wet season is from November 1 to April 30 and dry season is from May 1 to October 31; --, no test done]

Station	Construction periods	Season	Total nitrogen	Nitrite plus nitrate nitrogen	Total phosphorus	Turbidity
16226200	before and during	dry	0.19	1	--	--
	during and after	wet	0.89	0.23	--	0.25
16265600	during and after	wet	0.06	0.93	--	--
		dry	0.00	0.03	--	--
16265700	before and during	wet	0.12	0.86	--	0.02
		dry	0.56	0.55	0.94	0.05
	during and after	wet	0.59	0.24	--	--
		dry	1	0.62	0.59	--
	before and after	wet	0.02	0.11	--	--
		dry	0.52	0.29	0.38	--
16266500	before and during	wet	0.68	0.05	--	--
		dry	0.31	0.03	--	--
	during and after	wet	0.80	0.52	--	--
		dry	0.17	0.17	--	--
	before and after	wet	0.68	0.01	--	--
		dry	0.64	0.39	--	--
16267500	before and during	wet	0.48	0.13	--	0.01
		dry	0.66	0.49	--	0.02
16269500	before and during	wet	0.25	0.57	--	--
		dry	1	0.80	--	--
	during and after	wet	0.20	0.10	--	--
		dry	0.41	0.68	--	--
16270900	during and after	wet	0.04	0.13	--	--
	before and after	wet	0.00	0.03	--	--
16272200	during and after	wet	0.40	0.05	--	--
16273950	before and during	dry	0.45	0.14	--	0.97
	during and after	wet	0.02	0.15	--	--
		dry	--	--	--	0.75
	before and after	dry	--	--	--	0.88
16274100	during and after	wet	0.07	0.02	--	--
16275000	during and after	wet	0.01	0.06	--	--

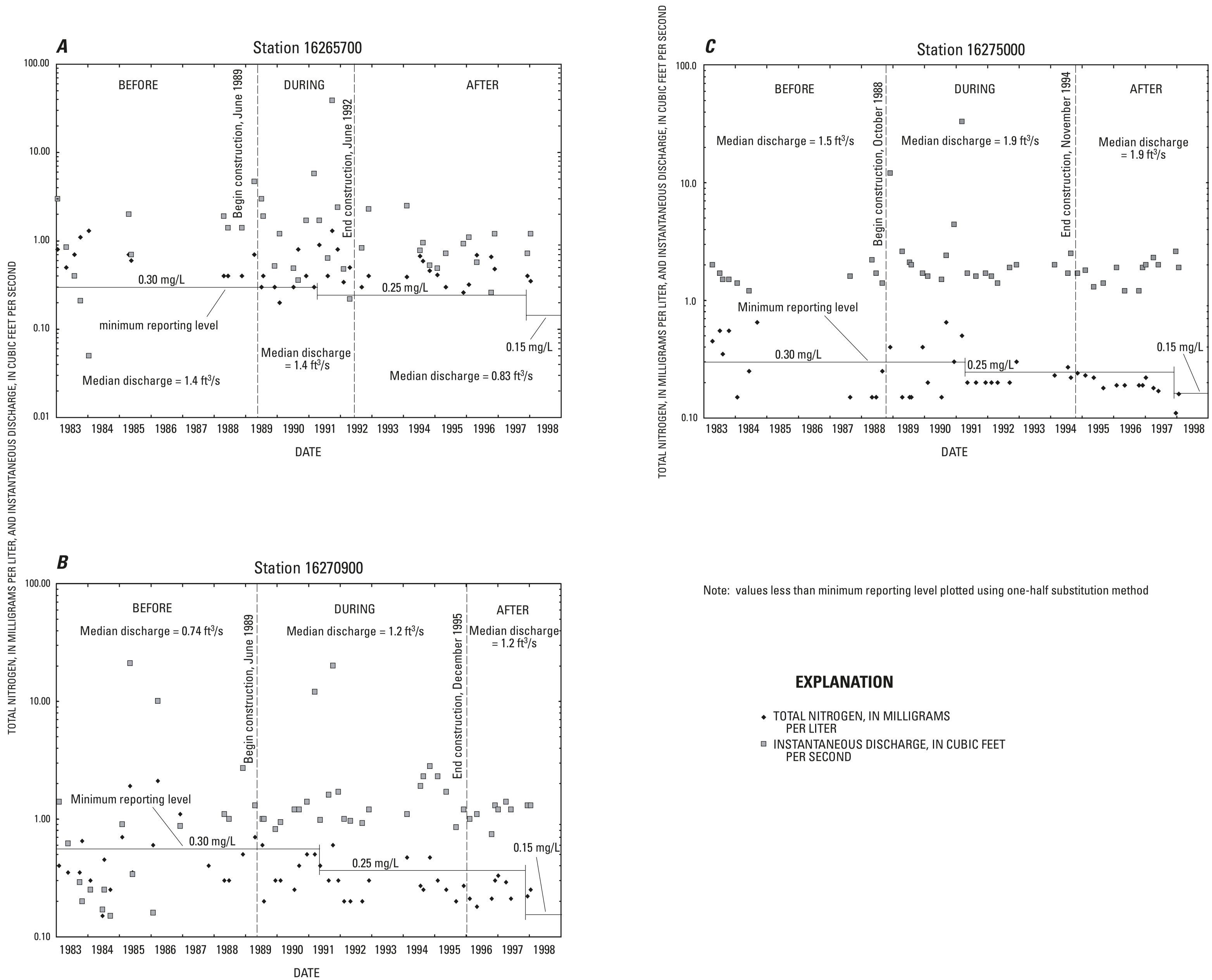

Figure 5. Total nitrogen concentrations and instantaneous discharges at (*A*) station 16265700, February 1983 to January 1998; and (*B*) station 16270900, February 1983 to January 1998; and (*C*) station 16275000, April 1983 to February 1998, Oahu, Hawaii.

Table 7. Total nitrite plus nitrate nitrogen at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.

[--, no data; mg/L, milligrams per liter; e, value estimated by log-probability regression; h, value estimated by one-half minimum reporting limit substitution; minimum reporting levels for nitrite plus nitrate nitrogen were changed from 0.10 to 0.05 mg/L in 1992; <, actual value is less than value shown; shaded values represent total nitrite plus nitrate nitrogen values that have exceeded the State of Hawaii water-quality standards listed in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than minimum reporting level	Geometric mean (mg/L)	Concentration (mg/L) exceeded: 10 percent of the time	Concentration (mg/L) exceeded: 2 percent of the time
16226200	before	wet	1	0	--	--	--
		dry	6	0	h0.05	<0.10	<0.10
	during	wet	18	11	e0.08	0.18	0.19
		dry	15	5	h0.06	0.10	0.74
	after	wet	8	4	e0.05	0.12	0.13
		dry	1	0	--	--	--
16227100	during	wet	17	7	e0.13	0.29	0.30
		dry	13	5	h0.08	0.39	2.2
16265600	during	wet	18	18	0.44	0.60	0.67
		dry	20	20	e0.50	0.60	1.8
	after	wet	12	12	0.48	0.54	0.59
		dry	7	7	0.39	0.49	0.50
16265700	before	wet	5	5	0.24	0.30	0.30
		dry	6	6	0.24	0.30	0.30
	during	wet	7	7	0.26	0.44	0.73
		dry	7	7	0.28	0.53	0.59
	after	wet	9	9	0.30	0.38	0.52
		dry	5	5	0.37	0.58	0.59
16266500	before	wet	5	2	h0.06	0.10	0.10
		dry	5	0	h0.05	<0.10	<0.10
	during	wet	7	6	e0.16	0.30	0.30
		dry	7	5	e0.12	0.26	0.37
	after	wet	8	8	0.13	0.18	0.20
		dry	6	4	e0.08	0.11	0.12
16267500	before	wet	5	0	h0.05	<0.10	<0.10
		dry	6	2	h0.06	0.10	0.10
	during	wet	7	3	h0.10	0.23	0.29
		dry	7	1	h0.06	h0.06	h0.09
	after	wet	10	7	e0.06	0.09	0.10
		dry	6	3	h0.04	0.06	0.07
16269500	before	wet	5	4	e0.21	0.80	1.0
		dry	5	3	h0.24	2.2	3.7
	during	wet	7	7	0.34	0.50	0.50
		dry	7	7	0.24	0.41	0.64
	after	wet	10	10	0.26	0.36	0.47
		dry	5	5	0.27	0.35	0.41

Table 7. Total nitrite plus nitrate nitrogen at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99—Continued

[--, no data; mg/L, milligrams per liter; e, value estimated by log-probability regression; h, value estimated by minimum reporting limit substitution; minimum reporting levels for nitrite and nitrate nitrogen were changed from 0.10 to 0.05 mg/L in 1992; <, actual value is less than reported value; shaded values represent total nitrite and nitrate nitrogen values that have exceeded the State of Hawaii water-quality standards listed in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than the minimum reporting level	Geometric mean (mg/L)	Concentration (mg/L) exceeded	
						10 percent of the time	2 percent of the time
16270900	before	wet	10	9	e0.31	0.60	1.2
		dry	9	4	h0.11	0.35	0.79
	during	wet	12	12	0.21	0.35	0.39
		dry	12	11	e0.12	0.16	0.19
	after	wet	7	7	0.17	0.21	0.23
		dry	2	2	--	--	--
16272200	during	wet	20	19	e0.29	0.40	0.40
		dry	25	23	e0.24	0.36	0.56
	after	wet	7	7	0.35	0.38	0.40
		dry	2	2	--	--	--
16273950	before	wet	1	1	--	--	--
		dry	8	0	h0.05	<0.10	<0.10
	during	wet	12	9	e0.14	0.58	3.4
		dry	12	6	e0.05	0.11	0.48
	after	wet	7	6	e0.09	0.12	0.13
		dry	2	2	--	--	--
16274100	during	wet	13	13	0.43	0.60	0.75
		dry	12	12	0.20	0.30	0.34
	after	wet	7	7	0.29	0.40	0.40
		dry	3	3	0.16	--	--
16275000	before	wet	3	0	h0.05	--	--
		dry	8	0	h0.05	<0.10	<0.10
	during	wet	11	10	e0.13	0.20	0.20
		dry	10	6	e0.09	0.12	0.16
	after	wet	8	8	0.09	0.12	0.13
		dry	4	4	0.09	--	--
RES 1-3	during	wet	30	28	e0.33	0.40	0.50
		dry	45	45	0.27	0.40	0.50
	after	wet	13	13	0.41	0.47	0.49
		dry	6	6	0.41	0.54	0.55

Rank-sum test comparisons between construction time periods were done for the same stations and seasons as with total nitrogen because both constituents were sampled with the same conditions. Rank-sum results were statistically significant at stations 16265600, 16266500, 16270900, and 16274100 (table 6). At three of the stations, NO_2+NO_3 nitrogen geometric means were lower after construction (table 7). At station 16266500, NO_2+NO_3 nitrogen geometric means were lower before construction than during and after construction (table 7). The change in the minimum reporting level from 0.10 to 0.05 mg/L in April 1991 did not evidently affect the lower after-construction geometric means. At station 16266500, all the before-construction concentrations were less than the minimum reporting level (fig. 6*A*) and at station 16274100, all sample concentrations were greater than the higher minimum reporting level (fig. 6*B*).

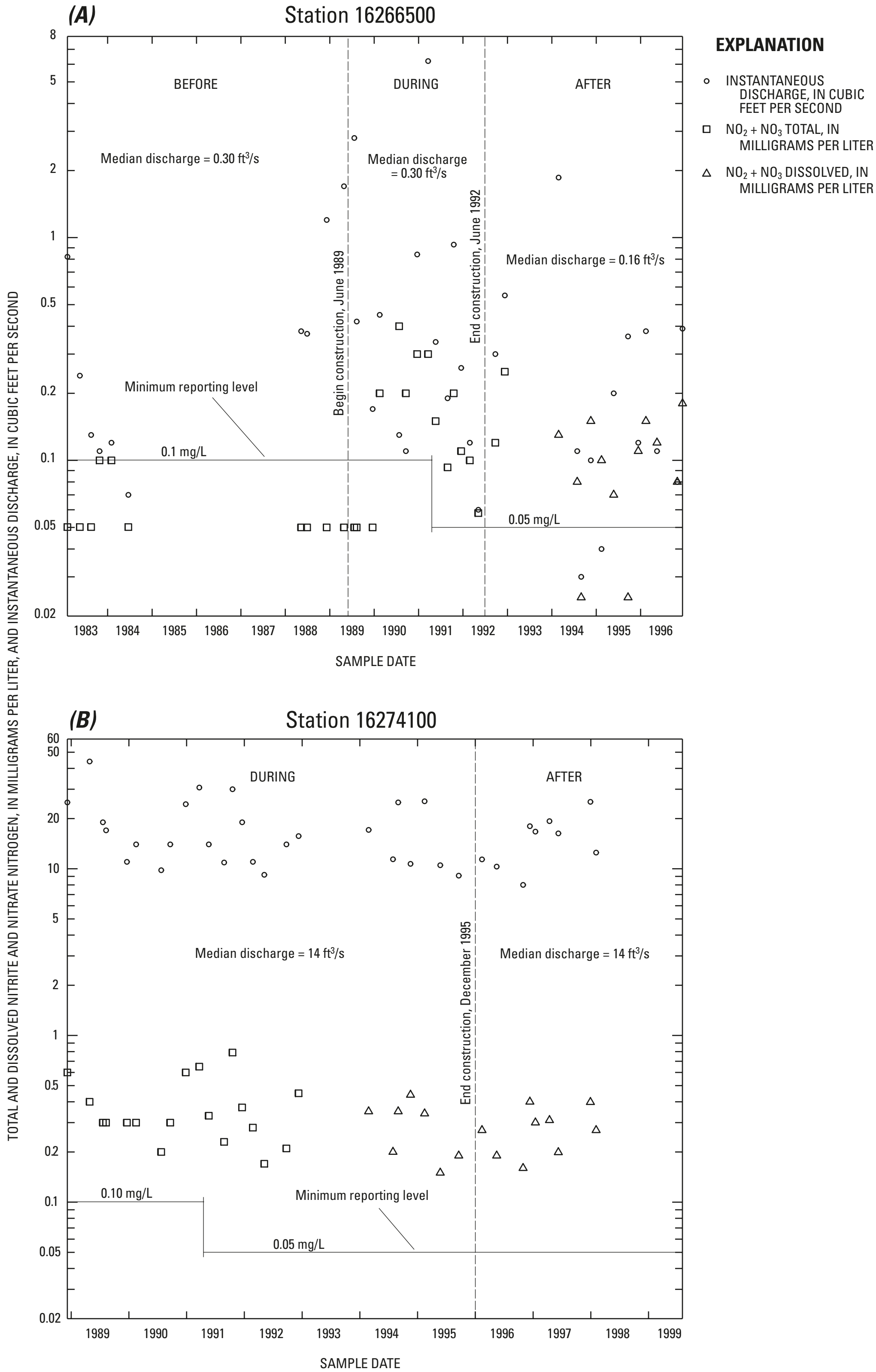

Figure 6. Nitrite and nitrate nitrogen concentrations and instantaneous discharges at (A) station 16266500, February 1983 to December 1996, and (B) station 16274100, December 1988 to February 1998, Oahu, Hawaii

Because the minimum reporting limits for total and NO_2+NO_3 nitrogen were greater than the State of Hawaii geometric mean standards for most of the study period, it is difficult to determine the effects of highway construction on these two constituents. However, because before-construction data for both total and NO_2+NO_3 nitrogen were not statistically different from during-construction data at all stations where the tests could be conducted (table 6), no highway construction effects on total or NO_2+NO_3 nitrogen can be attributed to any station except at station 16266500.

Nitrogen component data collected during 1991–92 at all stations showed that, on average, total nitrogen was made up of 45 percent nitrate (NO_3), 45 percent organic N, 5 percent nitrite (NO_2), and 5 percent ammonia (NH_4) (unpublished data on file at Hawaii District, U.S. Geological Survey). Looking at the geometric mean values of NO_2+NO_3 nitrogen in relation to total nitrogen, a distribution change can be seen at stations 16265700, 16275000, and RES 1-3 (tables 5 and 7). At these sites, after-construction geometric means for total nitrogen show a greater NO_2+NO_3 nitrogen component than either before or during construction. Increasing NO_2+NO_3 nitrogen can be attributed to increased anthropogenic effects from the increase in urban land use (Mueller and others, 1995; Thom and others, 2001).

Phosphorus.—Geometric mean values for total phosphorus ranged from 0.01 mg/L at many stations to 0.05 mg/L at station 16275000 before construction, wet season (table 8). Geometric mean values for total phosphorus exceeded the standards only during construction, dry season, at stations 16265600 and 16265700 (table 8). Rank-sum tests could be done only at station 16265700 because of significantly different phosphorus sample discharges, *p*-value of 0.02, between during- and after-construction time periods at station 16265600. Rank-sum results (table 6) indicate no significant differences between the before-, during-, and after-construction geometric means for phosphorus at station 16265700. Total phosphorus concentrations exceeded water-quality standards more commonly for the 10- and 2-percent standards than for the geometric mean, in contrast to the opposite pattern for nitrogen (tables 5 and 7). The 10- and(or) 2-percent-of-the-time exceedence values for total phosphorus were exceeded before construction at stations 16269500 and 16270900; during construction at stations 16226200, 16227100, 16265600, 16265700, 16270900, 16272200, and 16273950; and after construction only at stations 16226200 and 16265600 (table 8). Except for station 16226200, all the other stations with high phosphorus values have upstream land-use activities, such as golf courses or banana plantations, where fertilizers would be used. Because phosphorus tends to adsorb to sediment particles, increased land disturbance due to highway construction also may have caused the higher observed phosphorus values.

Total suspended solids and turbidity.—Total suspended solids (TSS) geometric means ranged from 1 to 17 mg/L and only exceeded the standard at stations 16227100 and 16274100, both during construction, dry season (table 9). The high TSS geometric means at stations 16227100 and 16274100 may be a result of other urban land-use activities upstream from these stations. No rank-sum test could be computed for either station, because no or insufficient before- or after-construction data were collected. The 10- and (or) 2-percent-of-the-time exceedence standards (table 3) were exceeded, for the most part, only during construction at most stations and after construction only at stations 16226200 and 16267500 (table 9). The high TSS values are probably the result of land disturbance caused by highway construction and also by golf-course construction upstream from stations 16265600 and 16265700. A larger number of samples for the concentration of suspended sediment were collected during this study, especially during periods of storm runoff. Suspended-sediment data were summarized in Wong and Young (2001) and suspended-sediment loads were analyzed by Wong and Yeatts (2002). Results in Wong and Yeatts (2002) show that suspended-sediment loads increased at most stations during construction, even though that increase is not reflected in the TSS data.

Turbidity geometric mean values ranged from 0.3 to 14 NTU and exceeded the standard before construction at stations 16226200, 16267500, 16269500, and 16273950; during the construction period at stations 16226200, 16227100, 16265600, 16265700, 16267500, 16273950, and 16274100; and after construction at stations 16267500, 16273950, and 16274100 (table 10). During highway construction the 10-percent-of-the-time exceedence standards were exceeded at all stations except 16273950, 16275000, and RES 1-3; after construction, only at stations 16226200 and 16267500. The 2-percent-of-the-time exceedence standards were exceeded at all stations during highway construction and after construction at stations 16226200, 16265600, 16267500, 16270900, and 16275000.

Rank-sum tests could not be computed because of small sample size (less than five samples) in one of the construction or seasonal time periods at stations 16226200, 16273950, and 16274100 (table 10). Rank-sum tests also could not be computed because of discharges associated with the turbidity samples being significantly different between some of the construction time periods at stations 16226200, 16265600, 16265700, and 16267500. Figure 7 shows this difference at station 16265600, where the after-construction discharges were significantly lower (*p*-value of 0.001) than the during-construction discharges. Stations 16265700 and 16267500 had significant differences between the during- and after-construction discharges (*p*-values of 0.02 and 0.01, respectively), while station 16226200 had significant difference (*p*-value of 0.03) between the before- and after-construction discharges. Rank-sum test results (table 6) indicate that the differences in the before and during turbidity geometric means at stations 16265700 and 16267500 are statistically significant, with the during-construction geometric means being higher (table 10).

Because turbidity values represent not only suspended particulate matter that can be caused by land disturbance, but

Table 8. Total phosphorus at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.

[--, no data; mg/L, milligrams per liter; e, value estimated by log-probability regression; h, value estimated by one-half minimum reporting level substitution; minimum reporting level changed from 0.01 to 0.05 mg/L in 1998; <, actual value is less than value shown; shaded values represent total phosphorus values that have exceeded the State of Hawaii water-quality standards listed in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than the minimum reporting level	Geometric mean (mg/L)	Concentration (mg/L) exceeded: 10 percent of the time	Concentration (mg/L) exceeded: 2 percent of the time
16226200	before	wet	2	2	--	--	--
		dry	6	4	e0.02	0.05	0.06
	during	wet	20	13	e0.02	0.13	0.22
		dry	17	9	e0.02	0.05	0.10
	after	wet	8	3	h0.03	0.12	0.14
		dry	1	0	--	--	--
16227100	during	wet	19	13	e0.02	0.07	0.14
		dry	15	13	e0.03	0.08	0.10
16265600	during	wet	18	18	0.03	0.10	0.35
		dry	20	16	e0.04	0.10	0.39
	after	wet	14	8	e0.01	0.02	0.16
		dry	9	7	e0.02	0.07	0.24
16265700	before	wet	5	5	0.02	0.04	0.04
		dry	6	6	0.03	0.05	0.07
	during	wet	7	5	e0.04	0.28	0.33
		dry	7	5	e0.04	0.25	0.34
	after	wet	11	9	e0.02	0.04	0.06
		dry	8	7	e0.02	0.04	0.06
16266500	before	wet	5	3	h0.01	0.04	0.06
		dry	4	2	h0.01	--	--
	during	wet	7	2	h0.01	0.03	0.06
		dry	7	4	e0.02	0.04	0.06
	after	wet	10	1	h0.01	h0.01	h0.10
		dry	8	2	h0.01	0.02	0.02
16267500	before	wet	5	4	h0.02	0.03	0.03
		dry	6	4	h0.01	0.03	0.03
	during	wet	7	4	e0.02	0.07	0.11
		dry	7	4	e0.01	0.03	0.04
	after	wet	12	5	h0.01	0.02	0.02
		dry	8	5	h0.01	0.03	0.08
16269500	before	wet	5	3	h0.01	0.02	0.02
		dry	5	4	e0.02	0.12	0.18
	during	wet	7	5	e0.02	0.03	0.04
		dry	7	4	h0.01	0.02	0.02
	after	wet	12	5	e0.01	0.06	0.08
		dry	6	4	h0.01	0.02	0.03

Table 8. Total phosphorus at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99—Continued

[--, no data; mg/L, milligrams per liter; e, value estimated by log-probability regression; minimum reporting limit changed from 0.01 to 0.05 mg/L in 1998; <, actual value is less than value shown; shaded values represent total phosphorus values that have exceeded the State of Hawaii water-quality standards listed in table 3]

						Concentration (mg/L) exceeded	
Station	Construction period	Season	Number of samples	Number of samples greater than minimum reporting level	Geometric mean (mg/L)	10 percent of the time	2 percent of the time
16270900	before	wet	10	9	e0.03	0.14	0.26
		dry	9	9	0.02	0.04	0.13
	during	wet	14	13	e0.04	0.19	0.77
		dry	14	12	h0.02	0.03	0.03
	after	wet	7	5	e0.01	0.02	0.03
		dry	2	2	--	--	--
16272200	during	wet	23	20	e0.03	0.18	0.26
		dry	27	24	e0.02	0.02	0.16
	after	wet	7	6	e0.01	0.02	0.02
		dry	2	2	--	--	--
16273950	before	wet	1	1	--	--	--
		dry	8	8	0.02	0.03	0.04
	during	wet	15	14	e0.04	0.06	0.22
		dry	14	12	e0.02	0.04	0.04
	after	wet	7	7	0.02	0.03	0.03
		dry	2	2	--	--	--
16274100	during	wet	15	15	0.04	0.08	0.09
		dry	14	12	e0.03	0.04	0.05
	after	wet	7	4	e0.02	0.04	0.04
		dry	3	3	0.03	--	--
16275000	before	wet	3	3	0.05	--	--
		dry	8	7	e0.02	0.06	0.07
	during	wet	13	10	e0.02	0.04	0.13
		dry	12	11	e0.02	0.03	0.08
	after	wet	8	5	e0.01	0.02	0.02
		dry	4	4	0.02	--	--
RES 1-3	during	wet	30	26	e0.02	0.03	0.05
		dry	45	40	e0.02	0.04	0.08
	after	wet	16	7	e0.01	0.01	0.03
		dry	9	7	e0.02	0.03	0.03

Table 9. Total suspended solids at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.

[Minimum reporting level is 1 mg/L; --, no data; mg/L, milligrams per liter; e, value estimated by log-probability regression; h, value estimated by one-half detection limit substitution; shaded values represent total suspended-solids values that have exceeded the State of Hawaii water-quality standards listed in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than the minimum reporting level	Geometric mean (mg/L)	Concentration (mg/L) exceeded: 10 percent of the time	Concentration (mg/L) exceeded: 2 percent of the time
16226200	before	wet	3	1	--	--	--
		dry	7	5	e2	5	25
	during	wet	20	19	17	210	530
		dry	16	12	e3	54	480
	after	wet	8	8	10	53	74
		dry	1	0	--	--	--
16227100	during	wet	18	15	e7	39	280
		dry	15	13	e12	72	320
16265600	during	wet	20	15	e5	113	424
		dry	21	17	e7	54	214
	after	wet	14	9	e2	15	42
		dry	9	6	e2	8	9
16265700	before	wet	6	6	5	9	11
		dry	8	7	e4	12	17
	during	wet	7	6	e10	44	47
		dry	7	5	e6	227	369
	after	wet	11	7	e1	4	7
		dry	8	6	e2	5	7
16266500	before	wet	6	4	e3	18	28
		dry	7	5	e4	12	14
	during	wet	7	3	h2	14	32
		dry	7	4	e2	18	33
	after	wet	10	3	h1	2	69
		dry	8	6	e2	5	7
16267500	before	wet	6	4	h3	11	12
		dry	8	7	e4	10	12
	during	wet	7	7	12	99	154
		dry	7	5	h5	18	27
	after	wet	12	9	e3	21	28
		dry	8	7	e5	36	146
16269500	before	wet	6	3	h2	11	12
		dry	7	5	e5	10	12
	during	wet	7	7	5	18	20
		dry	7	3	h1	6	10
	after	wet	12	9	e3	13	38
		dry	6	4	e2	9	9

Table 9. Total suspended solids at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99—Continued

[Minimum reporting level is 1 mg/L; --, no data; mg/L, milligrams per liter; e, value estimated by log-probability regression; h, value estimated by one-half detection limit substitution; shaded values represent total suspended-solids values that have exceeded the State of Hawaii water-quality standards listed in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than minimum reporting level	Geometric mean (mg/L)	Concentration (mg/L) exceeded	
						10 percent of the time	2 percent of the time
16270900	before	wet	13	9	e5	23	28
		dry	9	6	e5	24	64
	during	wet	14	10	e2	109	770
		dry	14	7	e2	7	12
	after	wet	7	5	h1	3	3
		dry	2	2	--	--	--
16272200	during	wet	26	24	e8	106	149
		dry	27	24	e4	11	68
	after	wet	7	3	h1	5	7
		dry	2	2	--	--	--
16273950	before	wet	2	2	--	--	--
		dry	7	6	e6	9	11
	during	wet	15	13	e8	19	109
		dry	14	13	e6	14	14
	after	wet	7	6	e4	6	9
		dry	2	2	--	--	--
16274100	during	wet	15	15	8	22	26
		dry	14	13	e11	25	32
	after	wet	7	6	e5	10	18
		dry	2	2	--	--	--
16275000	before	wet	5	3	e3	8	9
		dry	8	5	e5	10	11
	during	wet	13	11	e5	34	162
		dry	12	7	e2	10	27
	after	wet	8	4	e1	2	4
		dry	4	2	h1	--	--
RES 1-3	during	wet	33	30	e4	13	18
		dry	45	30	e2	12	17
	after	wet	22	17	e3	8	11
		dry	10	10	4	8	10

Table 10. Turbidity at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.

[Minimum reporting level is 0.1 NTU; --, no data; NTU, Nephelometric Turbidity Unit; shaded values represent turbidity values that have exceeded the State of Hawaii water-quality standards for turbidity listed in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than the minimum reporting level	Geometric mean (NTU)	Concentration (NTU) exceeded	
						10 percent of the time	2 percent of the time
16226200	before	wet	3	3	5.6	--	--
		dry	8	8	1.5	5.4	6.7
	during	wet	52	52	9.0	190	520
		dry	37	37	2.2	85	400
	after	wet	8	8	3.8	20	31
		dry	3	3	0.4	--	--
16227100	during	wet	52	52	3.2	38	390
		dry	35	35	2.5	34	270
16265600	during	wet	30	30	5.4	60	300
		dry	34	34	4.0	31	79
	after	wet	35	35	1.8	9.0	29
		dry	21	21	1.1	2.0	8.6
16265700	before	wet	9	9	1.4	5.3	5.8
		dry	9	9	0.9	1.8	7.6
	during	wet	19	19	11	116	2,660
		dry	17	17	7.4	199	8,800
	after	wet	30	30	0.7	1.7	2.3
		dry	17	17	0.4	1.0	1.2
16266500	before	wet	8	8	0.8	1.5	2.2
		dry	7	7	0.5	0.9	1.2
	during	wet	17	17	1.8	23	3,140
		dry	17	17	0.8	1.6	22
	after	wet	29	29	0.5	1.4	13
		dry	17	17	0.5	1.1	2.8
16267500	before	wet	8	8	3.5	6.2	11
		dry	9	9	3.0	3.5	7.5
	during	wet	16	16	14	120	447
		dry	17	17	4.0	8.9	22
	after	wet	31	31	3.1	8.2	17
		dry	17	17	4.1	16	51
16269500	before	wet	8	8	3.8	12	37
		dry	7	7	3.2	4.8	6.3
	during	wet	16	16	2.2	5.2	13
		dry	17	17	2.0	6.0	13
	after	wet	31	31	0.8	2.8	25
		dry	14	14	1.0	3.5	3.9

Table 10. Turbidity at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99—Continued

[Minimum reporting level is 0.1 NTU; --, no data; NTU, Nephelometric Turbidity Unit; shaded values represent turbidity values that have exceeded the State of Hawaii water-quality standards for turbidity listed in table 3]

Station	Construction period	Season	Number of samples	Number of samples greater than minimum reporting level	Geometric mean (NTU)	Concentration (NTU) exceeded	
						10 percent of the time	2 percent of the time
16270900	before	wet	15	15	3.1	44	115
		dry	10	10	1.1	1.2	27
	during	wet	37	37	2.2	24	300
		dry	32	32	0.9	3.5	7.9
	after	wet	15	15	1.0	9.6	29
		dry	5	5	0.3	0.3	0.4
16272200	during	wet	52	52	3.7	31	120
		dry	46	46	1.7	2.8	5.0
	after	wet	15	15	1.6	2.6	5.1
		dry	5	5	0.7	1.2	1.4
16273950	before	wet	3	3	13	--	--
		dry	8	8	2.8	3.5	3.7
	during	wet	39	39	3.8	6.5	37
		dry	34	34	3.0	4.4	17
	after	wet	15	15	2.7	4.0	4.7
		dry	5	5	3.1	4.1	4.7
16274100	during	wet	40	40	4.4	18	25
		dry	34	34	3.5	6.3	11
	after	wet	15	15	2.7	5.2	6.7
		dry	4	4	4.5	--	--
16275000	before	wet	5	5	0.7	1.0	1.0
		dry	10	10	0.7	0.8	1.4
	during	wet	32	32	1.0	2.6	190
		dry	30	30	0.8	5.1	19
	after	wet	22	22	0.4	0.8	41
		dry	9	9	0.4	0.6	0.8
RES 1-3	during	wet	40	40	2.3	5.0	9.2
		dry	73	73	1.6	3.4	13
	after	wet	35	35	2.6	8.8	16
		dry	24	24	1.4	2.5	7.9

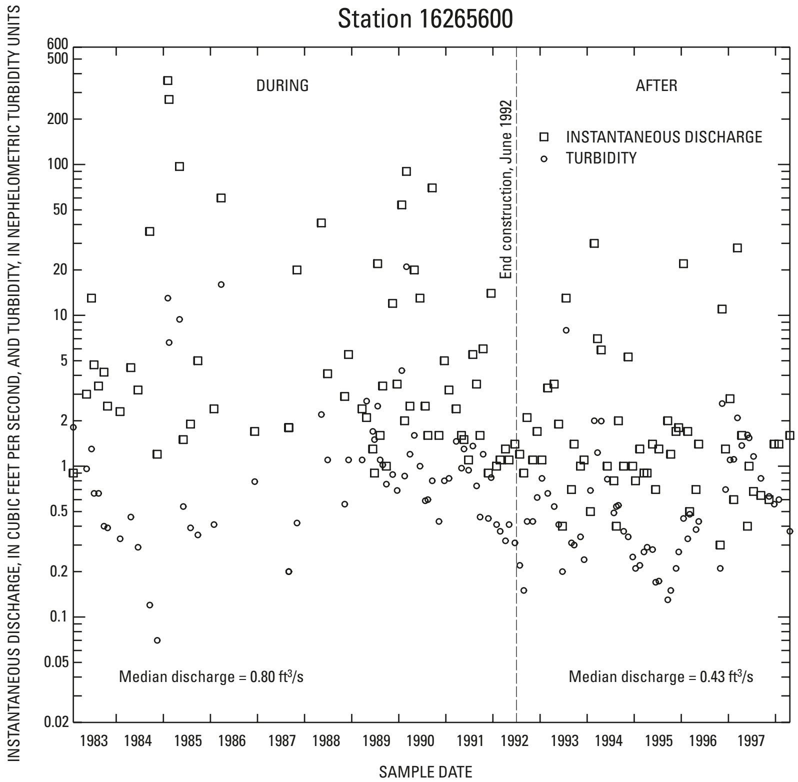

Figure 7. Turbidity concentrations and instantaneous discharges at station 16265600, February 1983 to April 1998, Oahu, Hawaii.

also organic matter, high values at these sites may be, in part, due to algae growth observed during low-flow conditions at all stations that exceeded the geometric mean standards and to the waterfowl habitat observed upstream from stations 16267500 and 16273950. The high turbidity values computed for station 16265700 during construction also may be due to the upstream golf-course construction, which occurred during the same time as the highway construction (table 10). Because of these circumstances, none of the geometric mean exceedences during the construction time period can be attributed solely to highway construction. However, the 10- and(or) 2-percent-of-the-time exceedences during construction at all stations may be, in part, due to land disturbance caused by highway construction.

pH.—Median pH values at all stations ranged from 6.6 to 9.0 pH units (table 11). Lowest and highest pH values measured were 4.5 at station 16265700 and 10.1 pH at station 16227100. Normal pH values range from 6.5 to 8.5 for uncontaminated natural waters (Hem, 1985, p. 64). Except for a few high values of pH at most stations, pH values exceeded the standard, both during and after construction, only at the two urban stations, 16227100 and 16274100 (table 11). The interquartile ranges, the difference between values of the 75- and 25-percentile concentrations, were all less than or equal to 0.5 pH units except before construction at station 16275000; during construction at stations 16226200, 16227100, and 16272200; and after construction at station 16274100 (table 11). The median and 75-percentile pH values increased by more than 0.5 pH units from before to during construction at stations 16226200 and 16272200 (table 11). These increases may be construed as a violation of the pH standard (table 3).

Dissolved oxygen.—Median dissolved-oxygen values ranged from 61 to 132 percent saturation (table 12). Dissolved-oxygen values tended to be low in 25 percent of the measurements during all time periods only in the Kamooalii drainage basin at stations 16265600, 16265700, 16266500, 16267500, and 16269500, and in the reservoir itself (table 12). Station 16265600 was the only site with constantly low dissolved-oxygen values after construction. Low median dissolved-oxygen values in the reservoir were due to the low dissolved oxygen at deeper depths.

Temperature.—Whether any water-temperature values exceeded the standard is difficult to determine, because no day and night measurements were made to determine the ambient water temperatures. However, the majority of daytime water-temperature measurements tended not to vary more than 1°C from the median (table 13). Highest median water temperatures were measured at the urban sites, stations 16227100 and 16274100.

Specific conductance.—Specific-conductance values exceeded the standards most often at the intermittent stream sites, stations 16226200, 16227100, and 16269500 (table 14). At stations 16226200 and 16269500, the highest values occurred after highway construction. Specific-conductance

Table 11. pH at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.

[Resolution is 0.1 pH unit; --, no data; shaded values represent pH values that have exceeded the State of Hawaii water-quality standards for pH listed in table 3]

Station	Construction period	Number of measurements	Minimum	Concentration percentile 25	(median) 50	75	Maximum
16226200	before	23	6.5	6.9	6.9	7.3	7.5
	during	91	6.2	7.4	7.7	8.0	8.3
	after	11	6.7	7.3	7.6	7.7	7.9
16227100	during	89	6.7	8.6	9.0	9.3	10.1
	after	4	8.7	--	9.0	--	9.1
16265600	before	1	--	--	--	--	5.9
	during	74	5.7	6.5	6.6	6.8	7.9
	after	57	6.0	6.6	6.6	6.8	7.9
16265700	before	19	6.0	6.5	6.8	7.0	8.6
	during	35	6.4	6.9	7.0	7.4	8.1
	after	48	4.5	6.6	6.8	7.1	7.6
16266500	before	16	6.1	6.4	6.7	6.8	7.0
	during	33	6.2	6.8	7.0	7.2	7.5
	after	46	6.0	6.6	6.8	6.9	7.4
16267500	before	17	6.3	6.8	6.9	7.1	7.4
	during	33	6.8	7.0	7.3	7.4	7.8
	after	48	6.3	7.0	7.2	7.4	7.6
16269500	before	17	6.0	6.8	6.9	7.0	7.4
	during	32	6.6	7.0	7.0	7.4	8.7
	after	45	6.5	6.8	7.1	7.3	7.5
16270900	before	43	6.3	6.9	7.1	7.4	8.3
	during	70	6.0	7.2	7.5	7.7	8.1
	after	21	7.0	7.4	7.6	7.7	7.9
16272200	before	11	6.8	7.1	7.2	7.4	7.7
	during	113	6.4	7.3	7.8	8.0	8.5
	after	20	6.5	7.6	7.8	8.0	8.1
16273950	before	11	7.1	7.4	7.6	7.8	7.9
	during	73	6.8	7.6	7.8	7.9	8.1
	after	20	6.8	7.7	7.8	8.0	8.1
16274100	during	73	6.7	8.3	8.6	8.8	9.3
	after	20	7.9	8.4	8.6	9.0	9.3
16275000	before	28	6.3	7.0	7.3	7.7	7.9
	during	62	6.5	7.6	7.8	7.9	8.2
	after	31	7.3	7.6	7.7	7.8	8.0
RES 1-3	during	271	6.4	7.2	7.4	7.6	8.7
	after	109	6.9	7.2	7.4	7.6	7.8

Table 12. Dissolved oxygen saturation at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.
[Resolution is 1-percent saturation; --, no data; shaded values represent dissolved-oxygen percentages that have exceeded the State of Hawaii water-quality standards for dissolved oxygen listed in table 3]

Station	Construction period	Number of measurements	Minimum	Concentration percentile 25	(median) 50	75	Maximum
16226200	before	11	82	87	88	91	97
	during	89	65	88	95	98	108
	after	10	73	81	88	97	101
16227100	during	87	65	119	131	149	186
	after	4	114	--	132	--	137
16265600	before	1	--	--	--	--	79
	during	64	48	64	76	86	103
	after	57	37	56	61	68	102
16265700	before	18	74	83	90	95	106
	during	32	68	85	89	93	100
	after	47	50	74	85	92	101
16266500	before	15	78	82	85	97	107
	during	33	63	82	89	96	103
	after	45	47	74	79	84	99
16267500	before	17	74	78	81	92	97
	during	33	73	87	91	95	100
	after	47	63	81	84	90	107
16269500	before	15	60	64	82	92	105
	during	32	67	77	84	93	98
	after	45	30	81	86	91	133
16270900	before	25	79	86	94	102	113
	during	68	77	92	95	98	105
	after	20	78	95	98	100	101
16272200	before	1	--	--	--	--	96
	during	98	68	97	102	107	134
	after	19	90	102	104	109	113
16273950	before	9	89	92	93	94	97
	during	73	89	95	96	98	103
	after	19	93	95	98	99	101
16274100	during	74	67	106	112	116	122
	after	21	103	108	114	120	136
16275000	before	15	62	91	94	97	98
	during	61	93	96	97	98	101
	after	31	93	97	98	100	103
RES 1-3	during	265	31	72	84	92	111
	after	102	26	71	79	86	101

Table 13. Water temperature at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.
[Resolution is 0.5 degrees Celsius; --, no data]

Station	Construction period	Number of measurements	Minimum	Concentration percentile 25	(median) 50	75	Maximum
16226200	before	23	19.0	21.0	22.0	23.0	24.5
	during	91	17.5	21.5	22.5	24.0	26.5
	after	11	18.0	20.0	21.5	23.0	25.5
16227100	during	89	19.5	24.0	27.5	30.0	37.0
	after	4	22.5	--	24.0	--	27.5
16265600	before	1	--	--	--	--	22.5
	during	76	20.0	23.0	24.0	25.0	27.5
	after	57	21.0	23.0	23.5	24.0	25.5
16265700	before	19	20.0	21.5	22.5	22.5	26.0
	during	35	20.0	21.0	22.0	23.0	24.0
	after	48	20.0	21.5	22.0	22.5	24.5
16266500	before	16	21.0	22.5	22.5	23.5	25.0
	during	33	20.0	22.0	22.5	23.0	24.5
	after	45	20.0	22.0	22.5	23.0	24.5
16267500	before	17	21.5	23.0	24.5	25.0	30.0
	during	33	20.0	22.0	23.5	24.0	26.0
	after	47	20.0	22.0	23.0	24.0	26.5
16269500	before	17	20.5	22.0	22.5	23.0	24.5
	during	33	20.5	22.0	22.5	23.0	25.0
	after	45	20.5	21.5	22.5	23.0	27.0
16270900	before	43	19.5	20.1	21.5	22.5	26.0
	during	69	19.5	20.0	21.0	21.5	26.0
	after	21	18.5	20.0	21.0	21.5	22.0
16272200	before	11	20.5	22.0	24.0	25.0	28.0
	during	113	20.5	23.0	25.0	26.5	31.0
	after	20	19.5	22.5	24.0	25.5	27.0
16273950	before	11	22.5	23.0	23.5	23.5	25.0
	during	73	20.0	21.5	22.0	23.0	25.5
	after	20	20.0	21.5	22.0	23.0	24.5
16274100	during	74	20.0	23.0	25.0	26.5	31.0
	after	21	21.0	22.0	24.5	26.5	29.0
16275000	before	35	19.5	20.5	21.0	21.5	23.0
	during	64	18.5	20.0	20.5	21.0	22.5
	after	32	18.0	20.0	20.0	20.5	22.5
RES 1-3	during	274	20.5	23.0	25.0	26.0	29.0
	after	109	20.5	21.5	23.5	26.0	28.0

values at stations 16226200 and 16269500 increased throughout the construction period (fig. 8) most likely due to construction. Increased municipal ground-water withdrawals began during the construction period in 1990 upstream from station 16269500. Because station 16269500 was not a continuous streamflow site, the effect of the increased pumpage on streamflow and specific conductance cannot be determined. No trend at station 16227100 due to construction is apparent (fig. 8). Values were high during and after construction (table 14). High values at station 16227100 are most likely due to the urban effects associated with the light industrial park and concrete-lined channel. The pattern of increasing conductance during and after construction also is present at stations 16266500 and 16267500 as well, although the values did not exceed the standard (table 14).

***Trace elements and organic compounds.*—**Ten constituents were detected at concentration levels in excess of the State of Hawaii water-quality standards for trace metals and organic compounds in freshwater (table 15). The detections in excess of standards were predominantly during construction and at a total of nine stations (table 16). In most cases, a constituent in excess of standards was detected only once at any station. Chlordane, copper, dieldrin, and zinc were the only constituents to be detected in excess of standards more than once at any station. At the urban station 16227100, four constituents were detected in excess of standards, and three constituents in excess of standards were detected at three stations: 16272200, 16273950, and 16274100.

Chlordane concentrations in excess of the chronic water-quality standard were detected in 3 out of 18 samples at station 16274100. Dieldrin concentrations in excess of the chronic water-quality standard were detected in nearly all samples from station 16274100 and in more than 15 percent of samples from the two stations immediately upstream, 16272200 and 16273950 (table 16). Stations 16272200, 16273950, and 16274100 all receive some runoff from urban areas (fig. 2). Chlordane and dieldrin, both insecticides used to control termites, were not detected in any samples from stations affected by highway construction without other urban influence. Bed-sediment data from station 16274100 also were high in dieldrin in a study by Brasher and Anthony (2000).

Acute water-quality standards were exceeded a few times by concentrations of the common metals aluminum, copper, and zinc and once by silver (table 16). Aluminum, copper, and zinc were detected in a majority of the samples collected during the study (table 15). Late in the study period, the NWQL raised the minimum reporting levels for a number of metals determined by inductively coupled plasma-atomic emission spectrometry method (ICP-AES) because of an excessive rate of false positive results (U.S. Geological Survey, 1997b, 1998a). These values are presented as the revised minimum reporting levels in table 4. Concentrations between the original and revised minimum reporting levels have a 1- to 50-percent chance, depending on the constituent, of being a false positive (U.S. Geological Survey, 1998a). The ICP-AES method was used to determine dissolved metal concentrations during the entire study period. During 1997 and 1998, the project also submitted 10 samples of blank water for analysis by inductively coupled plasma-mass spectrometry method (ICP-MS), which has lower minimum reporting levels than ICP-AES. These blank samples were processed through all the same steps as routine environmental samples and were intended to detect potential sources of the metals throughout the term of the study. When the study was initially planned 15 years earlier, such targeted quality-assurance samples had not been commonly recognized as necessary.

The distribution of copper and zinc contamination caused by sample handling and processing can be estimated from the analysis of blank water. The highest measured concentration among 10 blanks would be expected to be exceeded randomly in about 7 percent of all environmental samples (Jim Eychaner, U.S. Geological Survey, written commun., December 30, 2003). Thus, if the blank samples represent the full study period, more than 3-µg/L copper and 5-µg/L zinc could be found in 7 percent of the samples, even if none were present in the environment (table 17). In fact, 13 percent of the environmental samples exceeded 3-µg/L copper and 35 percent exceeded 5-µg/L zinc, which indicates that environmental sources of copper and zinc were measured in some cases. Copper usually has concentrations of less than 10 µg/L and zinc has a median value of 20 µg/L in streams (Hem, 1985). The high values of copper (detected at station 16226200) and zinc (detected at stations 16265600 and 16273950)(table 16) may indicate sources other than natural inputs, even though Hawaiian soils also are high in copper and zinc because of the volcanic parent material (De Carlo and Anthony, 2002; Halbig and others, 1985). Median copper and zinc concentrations from unfiltered samples, (total recoverable samples) were, on average, only twice as great as dissolved copper and zinc median values (Wong and Young, 2000). Both stations 16265600 and 16273950 are near heavily used highways, Kamehameha and Likelike, respectively (fig. 2), as well as residential areas, so potential anthropogenic sources exist. The high copper concentrations at station 16226200 may be due to highway construction because no other anthropogenic sources exist prior to highway construction upstream from this site.

High aluminum values are not surprising because Hawaiian soils are naturally high in aluminum (Moir and others, 1936), but aluminum usually does not exist in the dissolved fraction (Hem, 1985). Median aluminum concentrations from total recoverable samples are about 10 times higher than the median values for dissolved aluminum based on samples collected in the study area (Wong and Young, 2000). Aluminum contamination from sample handling and processing of the samples was very minimal (table 17).

Because silver is rare in Hawaiian soils and no readily apparent anthropogenic source exists anywhere in the study area, it was a surprise that silver was detected at station 16272200 (table 16). The detection of silver, however, may be false. The revised minimum reporting levels (table 4)

Table 14. Specific conductance at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, water years 1983–99.

[Resolution is 1 µS/cm at 25ºC; --, no data; µS/cm at 25ºC, microsiemens per centimeter at 25 degrees Celsius; shaded values represent specific-conductance values that have exceeded the State of Hawaii water-quality standards for specific conductance listed in table 3]

Station	Construction period	Number of measurements	Minimum	Concentration percentile 25	(median) 50	75	Maximum
16226200	before	23	69	120	135	145	180
	during	91	48	170	215	268	660
	after	11	107	144	310	351	386
16227100	during	89	90	328	570	770	1,500
	after	4	173	--	640	--	912
16265600	before	1	--	--	--	--	196
	during	74	87	200	220	237	360
	after	57	80	208	220	234	295
16265700	before	19	159	193	200	207	212
	during	35	148	205	225	235	380
	after	48	23	215	223	232	267
16266500	before	16	99	113	121	125	133
	during	33	110	132	152	160	190
	after	46	140	155	161	170	250
16267500	before	17	115	147	166	174	188
	during	33	65	155	180	195	204
	after	48	142	186	192	197	200
16269500	before	16	200	212	248	290	320
	during	33	225	260	280	300	325
	after	45	215	304	318	350	400
16270900	before	43	126	158	162	177	195
	during	70	108	150	160	170	218
	after	21	120	156	158	172	187
16272200	before	11	170	180	200	220	250
	during	113	80	175	182	190	220
	after	20	138	181	190	197	215
16273950	before	11	147	188	190	196	210
	during	73	160	190	198	205	376
	after	20	170	194	200	208	301
16274100	during	74	120	190	198	202	225
	after	21	194	198	202	208	213
16275000	before	28	140	145	148	159	185
	during	62	92	145	150	154	185
	after	31	114	146	150	153	165
RES 1-3	during	274	147	182	186	191	210
	after	109	152	186	192	196	214

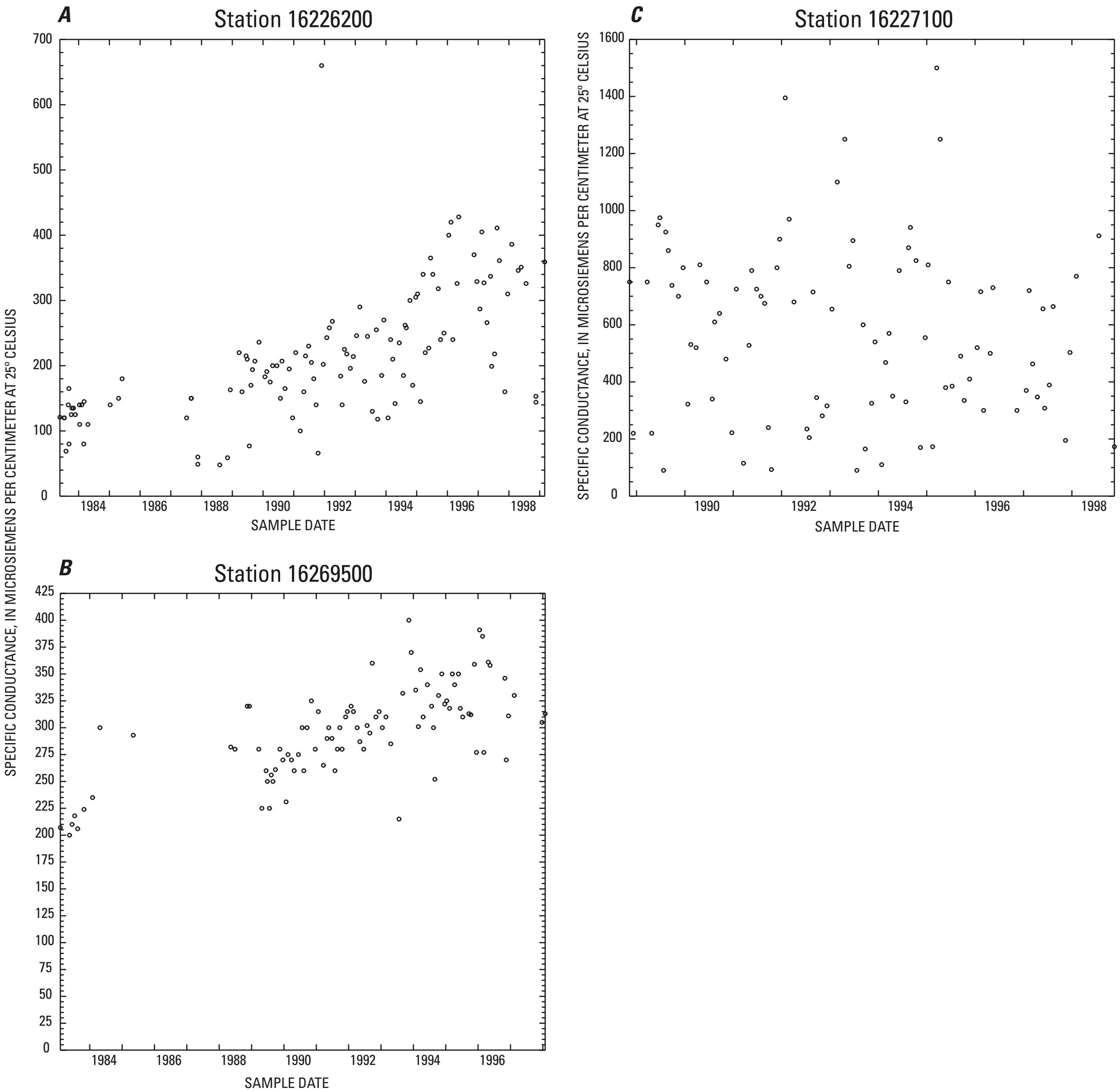

Figure 8. Specific conductance at (A) station 16226200, May 1983 to March 1999, (B) station 16269500, February 1983 to January 1998, and (C) station 16227100, November 1988 to November 1998, Oahu, Hawaii

Table 15. State of Hawaii water-quality standards for trace metals, insecticides, herbicides, and polychlorinated compounds, and the number of samples exceeding standards at water-quality stations in the H-3 Highway study area, Oahu, Hawaii, February 1983 to August 1999.

[µg/L, micrograms per liter; ns, no standard; +, value is minimum standard, higher standard may apply depending on the receiving water hardness value]

Constituent	State of Hawaii freshwater water-quality standard		Total number of samples at all study sites	Total number of samples exceeding original minimum reporting limit (table 4)	Total number of samples exceeding State of Hawaii standard acute/chronic
	acute (µg/L)	chronic (µg/L)			
Aldrin	3.0	ns	240	2	0
Aluminum, dissolved	750	260	235	144	1/2
Arsenic, dissolved	360	190	124	32	0
Beryllium, dissolved	43	ns	124	9	0
Cadmium, dissolved	3+	3+	124	6	0
Chlordane	2.4	0.0043	240	5	0/5
Chlorpyrifos	0.083	0.041	134	14	1/1
Chromium, dissolved	16	11	127	21	0
Copper, dissolved	6+	6+	127	102	2/2
DDE	0.03	ns	240	0	0
DDT	1.1	0.001	240	2	0/2
2,4-D	670	ns	222	18	0
Dieldrin	2.5	0.0019	240	28	0/28
Endosulfan-alpha	0.22	0.056	240	0	0
Endrin	0.18	0.0023	240	0	0
Heptachlor	0.52	0.0038	240	0	0
Lead, dissolved	29+	29+	127	32	0
Lindane	2.0	0.08	240	1	0
Malathion	ns	0.1	226	8	0/1
Mercury, dissolved	2.4	0.55	123	23	0
Methoxychlor	ns	0.03	240	0	0
Mirex	ns	0.001	240	0	0
Nickel, dissolved	5+	5+	238	83	0
Parathion	0.065	0.013	226	0	0
PCB	2.0	0.014	240	1	0/1
Selenium, dissolved	20	5	235	2	0
Silver, dissolved	1+	1+	235	4	1/1
Toxaphene	0.73	0.0002	240	0	0
Zinc, dissolved	22+	22+	127	85	3/3

Table 16. Summary of dissolved trace metals, insecticides, and polychlorinated compounds at water-quality stations that exceeded State of Hawaii water-quality standards in the H-3 Highway study area, Oahu, Hawaii, February 1983 to August 1999.

[µg/L, micrograms per liter; b, before-construction period; d, during-construction period; a, after-construction period; State of Hawaii standards listed in table 15]

Constituent	Station number	Station name	Total number of samples	Total number of samples exceeding State of Hawaii standard	Highest concentration measured (µg/L)	Time period when highest concentration occurred
Aluminum, dissolved	16226200	North Halawa Stream near Honolulu	25	1	340	d
	16227100	Halawa Stream below H-1	17	1	300	d
	16272200	Kamooalii Stream below Luluku Stream	31	1	1,200	d
Chlordane	16227100	Halawa Stream below H-1	16	1	0.1	d
	16273950	South Fork Kapunahala Stream	24	1	0.1	d
	16274100	Kaneohe Stream	18	3	0.1	d
Chlorpyrifos	16265600	Right Branch Kamooalii Stream	15	1	0.9	d
Copper, dissolved	16226200	North Halawa Stream near Honolulu	15	2	14	d
DDT	16227100	Halawa Stream below H-1	16	1	0.01	d
	16275000	Haiku Stream	32	1	0.08	d
Dieldrin	16227100	Halawa Stream below H-1	16	1	0.01	d
	16272200	Kamooalii Stream below Luluku Stream	33	5	0.01	d, a
	16273950	South Fork Kapunahala Stream	24	4	0.02	d
	16274100	Kaneohe Stream	18	17	0.05	d, a
	212335157482603	RES 1-3	22	1	0.01	d
Malathion	16265700	Kamooalii Stream at altitude 220 ft	3	1	0.28	b
PCB	16274100	Kaneohe Stream	18	1	0.2	d
Silver, dissolved	16272200	Kamooalii Stream below Luluku Stream	31	1	2.0	d
Zinc, dissolved	16265600	Right Branch Kamooalii Stream	15	2	160	d
	16273950	South Fork Kapunahala Stream	11	1	100	d

Table 17. Summary of dissolved trace metals quality-assurance blank samples collected during 1997 and 1998 as part of the water-quality monitoring study of the H-3 Highway, Oahu, Hawaii.

[µg/L, micrograms per liter; --, not applicable]

Trace metal constituent, dissolved fraction	Minimum reporting limit (µg/L)	Method detection limit (µg/L)	Total number of samples	Total number of detections exceeding method detection limit	Highest concentration detected (µg/L)	Mean value of detected concentrations (µg/L)
Aluminum	10	0.3	10	1	1.1	--
Barium	2	0.2	10	0	--	--
Beryllium	0.5	0.2	10	0	--	--
Cadmium	1	0.3	10	0	--	--
Chromium	1	0.2	10	0	--	--
Cobalt	3	0.2	10	0	--	--
Copper	1	0.2	10	5	2.9	1.2
Iron	3	3	10	0	--	--
Lead	1	0.3	10	0	--	--
Manganese	1	0.1	10	1	1.7	--
Molybdenum	10	0.2	10	0	--	--
Nickel	1	0.5	10	0	--	--
Silver	1	0.2	10	0	--	--
Strontium	0.5	0.1	10	2	0.3	0.2
Zinc	3	0.5	10	6	4.9	1.9

calls into question the presence of silver at station 16272200, because the highest concentration of 2 µg/L is below the newer 4 µg/L minimum reporting level.

Waimaluhia Reservoir.—The water-quality data collected from Waimaluhia Reservoir at the primary reservoir site (RES 1-3) were compared to the State of Hawaii water-quality standards specific to streams, although these standards do not apply to reservoirs. This was done for comparative purposes with the tributaries and downstream stream sites of the reservoir. Geometric mean values in the reservoir exceeded the State standards for total and NO_2+NO_3 nitrogen (tables 5 and 7). Total nitrogen geometric means were higher during construction than after, and NO_2+NO_3 nitrogen geometric means increased after construction. This change was similar to the effect observed at stations on two tributaries to the reservoir (stations 16265700 and 16269500) (tables 5 and 7). Geometric mean values of total and NO_2+NO_3 nitrogen were lower downstream from the reservoir at station 16272200 than in the reservoir (tables 5 and 7). The remaining constituents had geometric mean values that were similar in and downstream from the reservoir. Geometric mean values of all constituents at station 16270900, which contributes flow to 16272200 downstream from the reservoir outlet, were all lower than at 16272200. There may be some dilution effect, but only very small, because the contribution of streamflow from station 16270900 to 16272200 is only about 12 percent, on average, computed from daily mean streamflow data collected in water years 1985–97 (Wong, 2001). Upstream from the reservoir, geometric mean values for total and NO_2+NO_3 nitrogen at all tributaries (stations 16265600, 16265700, 16266500, 16267500, and 16269500) were high, about equal to those at RES 1-3, and exceeded the standards during all time periods (before, during, and after construction) at all stations except 16266500 and 16267500 (tables 5 and 7). Therefore, much of the nutrient input to the reservoir exists as natural or anthropogenic sources not related to highway construction, and the reservoir may serve as a nutrient sink because nitrogen values are lower downstream. Nutrient values and other limnological data collected in Waimaluhia Reservoir (Matsuoka and others, 1991) indicate that the reservoir is eutrophic.

Temperature, pH, and specific-conductance data from all depths at RES 1-3 fell below or within the ranges listed in the water-quality standards (tables 3, 11, 13, and 14). Only dissolved oxygen fell below the standard level of 80 percent saturation (tables 3 and 12). This was due to the low dissolved oxygen at the deeper reservoir depths (table 18). Nutrient, pH, and specific-conductance data collected by reservoir depth (table 18) showed no differences with depth or by time period. The only changes by depth both during and after construction were with temperature and dissolved oxygen, which was expected because deeper waters tend to be cooler and have less oxygen (table 18). Turbidity and TSS were, on average, 1 NTU or 1 mg/L higher at the deepest depths compared to the shallower depths (table 18). This may be, in part, due to interference by the Van Dorn sampler close to the reservoir bottom or by possible turbidity currents.

Additional comparisons.—Results of the upstream/downstream comparisons between stations 16226200 and 16227100 and between stations

Table 18. Median values of selected water-quality properties and constituents by depth at Waimaluhia Reservoir, stations 212335157482603 (RES 1-3) and 212329157483102 (RES 3-2) during and after H-3 Highway construction, Oahu, Hawaii, May 1983 to January 1998.

[--, no data; mg/L, milligrams per liter; ^oC, degrees Celsius; µS/cm at 25^oC, microsiemens per centimeter at 25 degrees Celsius; NTU, Nephelometric Turbidity Unit; e, median estimated by log-probability regression due to values below the detection limit; <, less than]

Depth (feet)	pH (pH units)	Dissolved-oxygen saturation (percent)	Dissolved-oxygen concentration (mg/L)	Water temperature (^oC)	Specific conductance (µS/cm at 25^oC)	Total nitrate plus nitrite nitrogen (mg/L)	Ammonia and organic nitrogen (mg/L)	Phosphorus (mg/L)	Total suspended solids (mg/L)	Turbidity (NTU)
Station 212335157482603 (RES 1-3), during highway construction, May 1983 to June 1992										
Number of measurements or samples varied by depth, property, and constituent, and ranged from 9 to 38										
1	7.6	94	7.6	25.5	184	0.30	e0.40	e0.02	e2	1.2
3	7.6	94	7.5	25.5	184	--	--	--	--	--
5	7.6	88	7.2	25.5	185	--	--	--	--	--
7	7.4	84	7.0	25.0	186	0.30	e0.40	e0.02	e3	1.3
9	7.3	76	6.1	25.0	188	--	--	--	--	--
11	7.2	68	5.6	24.0	189	0.40	0.30	e0.02	e6	2.2
12	7.2	63	5.2	24.0	188	e0.30	e0.40	0.02	e6	2.3
Station 212335157482603 (RES 1-3), after highway construction, August 1992 to January 1998										
Number of measurements or samples varied by depth, property, and constituent, and ranged from 5 to 17										
1	7.4	84	7.0	23.0	188	0.41	<0.20	<0.01	e2	1.4
3	7.4	84	6.8	24.0	188	--	--	--	--	--
5	7.4	82	6.8	24.0	188	--	--	--	--	--
7	7.4	80	6.6	23.5	190	0.40	<0.20	<0.01	e4	1.3
9	7.3	70	6.2	23.5	192	--	--	--	--	--
11	7.3	66	5.6	23.0	196	0.44	<0.20	e0.02	e6	2.5
Station 212329157483102 (RES 3-2), during highway construction, May 1983 to June 1992										
Number of measurements or samples varied by depth, property, and constituent, and ranged from 6 to 23										
1	7.6	96	7.6	26.5	184	e0.30	e0.30	e0.01	e3	1.0
2	7.6	97	7.9	25.5	180	--	--	--	--	--
3	7.6	95	7.6	26.5	185	--	--	--	--	--
5	7.6	90	7.2	26.0	184	--	--	--	--	1.6
6	7.5	92	7.6	26.0	184	e0.30	e0.40	e0.01	e2	1.2
7	7.5	87	7.2	25.5	185	--	--	--	--	--
9	7.4	84	6.9	25.0	186	--	--	--	--	--
10	7.4	78	6.6	25.0	186	e0.30	0.30	e0.01	e4	2.4
11	7.3	68	5.6	24.0	182	--	--	--	--	--
Station 212329157483102 (RES 3-2), after highway construction, August 1992 to April 1998										
Number of measurements or samples varied by depth, property, and constituent, and ranged from 4 to 15										
1	7.6	87	7.3	23.0	186	0.37	<0.20	<0.01	e2	1.3
3	7.6	87	7.0	22.5	188	--	--	--	--	--
5	7.6	86	7.3	22.5	188	0.39	<0.20	<0.01	e2	1.3
7	7.6	85	7.0	22.5	188	--	--	--	--	--
9	7.6	83	7.0	22.5	186	--	--	--	--	--
10	7.6	81	6.8	23.0	188	0.38	<0.20	0.02	e4	2.8

16272200 and 16274100 are shown in table 19. Significant differences (*p*-values less than 0.05) between stations 16226200 and 16227100 were detected only among wet-season turbidity data (table 19). Wet-season turbidity values were significantly higher upstream at station 16226200, which could be a construction-related effect. The differences due to urban Kaneohe were more pronounced as shown by the data from stations 16272200 and 16274100. Combined (wet- and dry-season) data and dry-season data for all constituents tested were significantly higher downstream at station 16274100 because of urban effects (table 19). The only significant wet-season difference was with total and NO_2+NO_3 nitrogen loads, both being higher at station 16274100.

Because land-use changes upstream from stations 16270900 and 16275000 were minimal prior to highway construction, a comparison was made between data collected prior to 1983 (table 20) and data that was collected during this study. Cox and others (1973) determined a total nitrogen average of 0.26 mg/L at station 16275000. Compared to the geometric means, which would be lower than average

Table 19. Rank-sum test *p*-value results of selected water-quality constituent instantaneous loads and values between upstream and downstream stations during H-3 Highway construction in the Halawa and Kaneohe drainage basins, Oahu, Hawaii, 1983–1997

[Shaded values represent significant results with *p*-values less than 0.05; wet season is from November 1 to April 30 and dry season is from May 1 to October 31; lbs/day, pounds per day; NTU, Nephelometric Turbidity Unit]

Constituent	All data	Wet-season data	Dry-season data	Remarks
	Stations 16226200 (upstream) and 16227100 (downstream), Halawa drainage area, during highway construction, water years 1988-97			
Total nitrogen (lbs/day)	0.48	0.87	0.18	
Nitrite plus nitrate nitrogen(lbs/day)	0.93	0.59	0.46	
Total phosphorus (lbs/day)	0.36	0.82	0.13	
Total suspended solids (lbs/day)	0.83	0.38	0.15	
Turbidity (NTU)	0.35	0.02	0.16	Values at 16226200 higher.
	Stations 16272200 (upstream) and 16274100 (downstream), Kaneohe drainage area, during highway construction, water years 1983-96			
Total nitrogen (lbs/day)	0.00	0.04	0.02	Loads at 16274100 higher.
Nitrite plus nitrate nitrogen (lbs/day)	0.00	0.00	0.02	Loads at 16274100 higher.
Total phosphorus (lbs/day)	0.00	0.05	0.00	Loads at 16274100 higher.
Total suspended solids (lbs/day)	0.00	0.10	0.00	Loads at 16274100 higher.
Turbidity (NTU)	0.00	0.08	0.00	Values at 16274100 higher.

Table 20. Previously collected water-quality data at stations 16270900 Luluku Stream and 16275000 Haiku Stream in the H-3 Highway study area, Oahu, Hawaii

[--, no data; mg/L, milligrams per liter; °C, degrees Celsius; µs/cm, microsiemens per centimeter; >, greater than; JTU, Jackson turbidity units]

Constituent or property	Station 16270900				Station 16275000				Data source
	Number of observations or samples	Minimum	Median	Maximum	Number of observations or samples	Minimum	Median	Maximum	
pH (units)	6	6.0	7.2	7.5	28	6.0	7.1	8.5	Matsuoka, 1983
Temperature (°C)	5	18.0	20.0	21.0	26	19.0	20.5	22.0	Matsuoka, 1983
Specific conductance (µs/cm)	6	130	142	150	28	134	160	206	Matsuoka, 1983
Nitrite plus nitrate nitrogen (mg/L)	138	0.005	0.16	>1.4	8	0.01	0.04	0.21	Dugan, 1977, Matsuoka, 1983
Turbidity (JTU)	5	0	1	4	12	0	1	2	Matsuoka, 1983

(table 5), the earlier data were similar and slightly lower than the before- and during-construction data at station 16275000. The median NO_2+NO_3 nitrogen at station 16270900 computed by Dugan (1977) was similar to the study data geometric means (table 7). At station 16275000, median NO_2+NO_3 nitrogen also was lower than, but similar to, the before-construction study data and lower than the during-construction data (tables 7 and 20). The older Jackson Turbidity Unit (JTU) was similar to the NTU but not exactly equivalent (Fishman and Friedman, 1989), and geometric mean values (table 10) were similar to the older data median values at both stations. The pH and water temperature data collected by Cox and others (1973) were similar to that in Matsuoka (1983), so are not presented in table 20. For pH, temperature, and specific conductance, the older data were similar to the current data (tables 11, 13, and 14). The past pH data at station 16275000 have a lower median pH (table 20), and median temperature and specific conductance at station 16270900 also are lower in the previous data but, in all cases, not greatly so. Therefore, for these two stations, any effect the highway construction had on the above-discussed properties and constituents was temporary, and no long-term change in water-quality trends is apparent based on this simple comparison.

Summary and Conclusions

Selected water-quality data collected before, during, and after construction of the H-3 Highway at 13 water-quality stations were compared to the State of Hawaii Department of Health water-quality standards to determine the effects of highway construction on the water quality of the affected streams. The geometric mean and concentrations not to be exceeded 10- and 2-percent-of-the-time were used as numeric standards for five water-quality constituents: total nitrogen, nitrite plus nitrate (NO_2+NO_3) nitrogen, total phosphorus, total suspended solids, and turbidity. The remaining standards consist of a single numeric criteria not to be exceeded, except for water temperature and pH, which depend on deviations from ambient conditions. Numeric standards for total nitrogen, NO_2+NO_3 nitrogen, total suspended solids, and turbidity are dependent on wet or dry seasons, with wet-season standards being higher. For constituents with data determined to be below the minimum reporting levels, log-probability regression or one-half minimum reporting level substitution methods were used to determine the numeric values for comparison to the water-quality standards.

Highway construction had no significant effect on the geometric means of total nitrogen concentrations. The geometric means of total nitrogen exceeded the standards at all 12 streams and the primary reservoir site both before and during construction. At almost all stations where the total nitrogen geometric means exceeded the standards, the standards for the 10- and 2-percent-of-the-time concentrations also were exceeded.

The NO_2+NO_3 nitrogen geometric mean standards were exceeded before, during, and after construction at all sites except during the wet season before construction at stations 16266500, 16267500, and 16275000 and after construction at stations 16226200 and 16267500. At these sites, land-use effects prior to highway construction were minimal. Also, at almost all stations where the NO_2+NO_3 nitrogen geometric means exceeded the standards, the standards for the 10- and 2-percent-of-the-time concentrations also were exceeded. Highway construction had a significant effect on increasing NO_2+NO_3 nitrogen concentrations only at station 16266500.

Highway construction did not have an effect on total phosphorus values except at station 16226200. Geometric means for total phosphorus at all stations did not exceed the standards except at stations 16265600 and 16265700 during construction, dry season. Golf courses exist or were built upstream from both these stations, and fertilizer use may be the cause of high phosphorus values. No before-construction data were collected at station 16265600, but at station 16265700, there were no significant differences in phosphorus concentrations before, during, or after highway construction. Phosphorus standards for the 10- and 2-percent-of-the-time concentrations were exceeded at 7 of the 13 sites. Exceedences of these standards, except at station 16226200, may be, in part, due to existing upstream agricultural and urban land use. The land disturbances caused by highway construction most likely contributed to the high values at station 16226200.

Highway construction did have an effect on total suspended-solids concentrations. Geometric means for total suspended solids exceeded the standards only at stations 16227100 and 16274100, both urban sites, during construction during the dry season. The 10- and 2-percent-of-the-time concentrations were exceeded at most stations only during construction. High values for the 10- and 2-percent-of-the-time concentrations most likely are due to land disturbances caused by highway construction. After construction, total suspended-solids values were still high enough to exceed the 10- and 2-percent-of-the-time concentrations at stations 16226200 and 16267500.

High turbidity values during highway construction were, in part, due to land disturbance caused by the highway construction. Turbidity geometric means were high enough to exceed the standards during construction at stations 16226200, 16227100, 16265600, 16265700, 16267500, 16273950, and 16274100. These exceedences, however, cannot be directly attributed to highway construction because of before-construction exceedences and existing land-use activities upstream from these sites. The 2-percent-of-the-time standard was exceeded at all stations during construction while the 10-percent-of-the-time standard was exceeded at all stations except 16273950, 16275000, and RES 1-3.

The effects of highway construction on total suspended solids and turbidity can be considered temporary due to land disturbances, because after-construction values do not exceed the standards except at a few stations of which only total suspended solids at stations 16226200 and 16267500 and turbidity at station 16226200 can be directly attributed to after-construction effects. This effect is similar to those observed in other studies.

Highway construction had no effect on the physical water-quality properties of pH, dissolved oxygen, and temperature. No effects were observed on specific conductance except at stations 16226200 and 16269500. At these two sites, specific-conductance values increased throughout the study period, most likely due to changing land use caused by highway construction. Median values of specific conductance also increased during the study period at stations 16266500 and 16267500, although not in excess of standards. No effects were observed on selected trace metals and organic chemical compounds because of highway construction. High dieldrin concentrations detected at station 16274100 were likely caused by the urban use of this chemical. No effects due to highway construction were observed in the water quality of Waimaluhia Reservoir. The reservoir is naturally eutrophic and acts as a nutrient sink.

In comparing selected water-quality data collected downstream from highway construction but upstream from urban areas with that collected downstream from urban areas during highway construction, no significant differences were observed in Halawa Stream. Turbidity values were higher upstream at station 16226200 during the wet season than downstream because of the highway construction. Urban land use contributed to higher loads or values of total nitrogen, NO_2+NO_3 nitrogen, phosphorus, total suspended solids, and turbidity at station 16274100, than at station 16272200, which was affected only by highway construction or agriculture. Data at stations 16270900 and 16275000 collected prior to 1983 were similar to data collected during this study. Land-use changes prior to highway construction were minimal in these basins and for the properties and constituents compared; therefore, little long-term change due to highway construction was observed.

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