# HYDROELECTRIC POWER IN HAWAII

## A RECONNAISSANCE SURVEY

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Department of Planning and Economic Development
State of Hawaii

by
W. A. Hirai & Associates, Inc.
Hilo, Hawaii

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# FOREWORD

Hawaii is firmly committed to expanding its use of indigenous, renewable energy resources to replace imported petroleum. Already we produce substantial quantities of electrical energy through the burning of biomass.

The year 1981 will see Hawaii become the second state in the Nation with on-line geothermal electricity.

In 1979, Hawaii pioneered in proving the principal and the efficiency of ocean thermal energy conversion.

We shall soon have many wind machines generating electricity.

All these developments, and more, give evidence of our determination to become more self-sufficient in energy.

One proven energy resource is flowing or falling water.

On the Mainland, enormous dams produce vast quantities of electricity by this means.

Here in Hawaii, run-of-the-river schemes best suit our terrain. Our State has needed new information about this potential in light of changing energy and economic conditions. Now, in this new report prepared for our State Department of Planning and Economic Development, we find this basic hydropower resource reassessed in terms of potential new sites for hydroelectric generation. Such studies are critical to moving in a well planned and systematic manner toward our goal.

I commend the careful assessment of this report to all who have Hawaii's future in mind. I hope it will spur increased attention to our energy needs as well as increased action toward achieving our energy objectives.

George R. Ariyoshi

George R. Ariyoshi

## PREFACE

In the past, Hawaii's sugar plantations produced hydroelectricity to pump water for cane irrigation and to power their mills because public utilities were either unavailable or unreliable. However, with the growth of extensive and reliable electric grids which provided low-cost power based on oil, hydropower generation by the sugar plantations became less and less profitable. As a result, equipment was poorly maintained or not repaired, penstock efficiency degraded and older power plants were abandoned, resulting in decreased hydro capacity and increased dependence upon oil-based utilities for electricity. This deterioration of hydro capacity coincided with the reduced fluming of cane, causing the loss of much of the extensive water transportation network developed over the years. In the last 15 years alone, nearly 1-1/2 megawatts of hydroelectric capacity were lost due to these events.

However, this trend has now been reversed, brought about in part by the steep increase in electricity prices due to oil price increases beginning in the mid 1970's, and partly by the attractive marketing environment for power sales and purchases enunciated in the Federal Public Utilities Regulatory Policies Act (PURPA) of 1978. These two factors necessitated a new look at the economics of hydropower in Hawaii. As a result, the consulting firm of W. A. Hirai & Associates, Inc., performed a statewide hydropower reconnaissance study for the State Department of Planning and Economic Development--a study partly funded by the U. S. Department of Energy. This report describes this study.

The study does not purport to be comprehensive in scope nor intensive for each site. But the study shows that more hydropower resources exist here than was previously thought, and that a number of sites on Kauai, Maui, and Hawaii appear economically feasible to develop now.

It is my belief and hope that this study will stimulate new interest in developing these resources by the private sector, which contributed greatly in making this study a valuable resource document.

Hideto Kono, Director
State Department of Planning
and Economic Development
State Energy Resources Coordinator

TABLE OF CONTENTS

## SUMMARY AND CONCLUSIONS

The major conclusion of this study is that hydropower resources in the State of Hawaii are substantial, and they offer the potential for major increases in hydropower generating capacity. Hydropower resources on all islands total about 50 megawatts of potential generating capacity. Combined with the 18 megawatts of existing hydropower capacity, hydropower resources potentially could generate about 307 million kilowatt-hours of electric energy annually. This represents about 28 percent of the present combined electricity needs of the Neighbor Islands--Kauai, Molokai, Maui, and the Big Island. Hydropower resources on Kauai equal 72 percent of that island's electricity needs; on Molokai, 40 percent; on the Big Island, 20 percent; and on Maui, 18 percent. The island of Oahu, however, has only small hydropower resources, and could only generate a negligible portion of its electricity needs from this energy source.

Table 1 is a summary of existing and future (potential) hydropower capacities and estimated annual outputs for each island. Future hydropower facilities are subdivided into two categories, which show how much of the potential capacity is being actively considered for development, and how much is only tentatively proposed at the time.

This study was intended only to provide a gross assessment of hydropower resources. Specific institutional barriers to development of the resource were not addressed and therefore the generating capacities quoted above are to be regarded as the resource potential.

TABLE 1. SUMMARY OF EXISTING AND POTENTIAL HYDROPOWER DEVELOPMENT IN HAWAII

| | EXISTING HYDROPOWER FACILITIES | | FUTURE (POTENTIAL) HYDROPOWER FACILITIES | | | |
|---|---|---|---|---|---|---|
| | | | ACTIVE INTEREST | | POTENTIAL | |
| ISLAND | CAPACITY (KW) | ANNUAL OUTPUT (MILLION KWH) | CAPACITY (KW) | ANNUAL OUTPUT (MILLION KWH) | CAPACITY (KW) | ANNUAL OUTPUT (MILLION KWH) |
| KAUAI | 7,900 | 48.60 | 2,900 | 13.8 | 22,150 | 76.4 |
| OAHU | -0- | -0- | -0- | -0- | 300 | 1.6 |
| MOLOKAI | -0- | -0- | 70 | 0.3 | 2,960 | 13.7 |
| MAUI | 5,300 | 21.75 | 500 | 2.5 | 9,540 | 44.0 |
| HAWAII | 4,150 | 21.25 | 500 | 4.1 | 11,660 | 59.4 |
| STATE | 17,350 | 91.6 | 3,970 | 20.7 | 46,610 | 195.1 |

Note:

"Active Interest" means either:

1. A prospective developer has announced plans to pursue development of the site; or
2. A feasibility study has been completed with positive results;
3. The plant is under construction or in an advanced planning stage.

"Potential" site means all other undeveloped sites considered in this study.

The economics of hydropower at specific sites were analyzed. The major conclusion of this analysis is that hydropower development costs vary widely among the different sites, but that generally the cost of hydroelectric power is either less than or comparable to the cost of oil-fired power.

The study combined the results of previous hydropower surveys with new map reconnaissance to identify a total of 28 potential sites around the State. The list of sites (Table 3.1) is not an exhaustive list of all possible sites. There are additional development opportunities in Hawaii, which may be identified with further study and the input of new data. However, contained within the list are the most promising sites for which feasibility studies are warranted.

Those sites with the potential of producing at least 5 million kilowatt-hours annually were selected for preliminary financial analysis. Project cost estimates for these sites were prepared, and the breakeven cost per kilowatt-hour of electric energy was computed using net-present-value techniques. The assumptions and procedures used in the engineering and financial analyses have been summarized in the Appendices. Two key variables in the analysis were the interest, or discount rate, and the rate of escalation of energy values. Calculations were performed using suitable ranges of values for these parameters, and the results were interpolated to produce price curves for each site.

The breakeven cost is simply the initial price which the site developer must receive in order to just recover all of his costs over the economic life of the project (20 years). The effect of energy value escalation is that the initial price will increase at some rate every year according to the prevailing market prices of electricity.

It is important to recognize the limitations of this reconnaissance-level analysis. Technical and financial analyses were done without the benefit of detailed site studies to accurately take into account all major factors. However, the advantage of the reconnaissance study is that it enables us to easily compare a number of prospective sites and select those which appear the most promising for further study. The breakeven cost analysis is only a rough-cut indicator of economic feasibility. Also, the major legal and environmental issues were not raised at this stage of hydropower site development. These issues, however, would be addressed in the feasibility study for each site, and during the project design phase.

The results show that hydropower breakeven costs range from $0.029 to $0.086 per kilowatt-hour, with most of the projects falling in the range of $0.03-0.06 per kilowatt-hour. Therefore, much of the developable hydropower in the State is cost-competitive with existing oil-fired generating units.

In addition to conventional run-of-the-river hydropower opportunities in Hawaii, pumped storage hydropower potential exists. Excerpts from a recent site reconnaissance survey report of prospective pumped storage sites are included in Appendix E. The report concluded that while numerous sites for pumped storage development exists, this technology is not yet cost-competitive with existing generating units. Pumped storage is a means of using water pumped uphill to store energy for use during peak power periods. The energy for pumping could either come from base-loaded generating plants or from variable energy sources, such as wind and solar. In either case, the pumped storage system allows these systems to be more efficiently utilized.

Hydropower resources offer the potential for significantly boosting the Neighbor Islands' programs for energy self-sufficiency. Therefore, the State of Hawaii should encourage and support the expeditious development of this renewable energy source.

1. Purpose

The purpose of this study was to develop a statewide list of promising hydropower sites, perform reconnaissance-level engineering and financial analyses, and make recommendations regarding the sites, which warrant feasibility studies.

2. Introduction

This report describes the results of a study to identify the most promising sites for hydropower plants in the State of Hawaii, which warrant detailed feasibility analysis.

Hydroelectric power has attracted a great deal of renewed interest within the past decade, as the developing world energy situation encourages us to seek domestic, renewable sources of power. Because most of the large hydropower sites in the United States have already been developed, attention is focused on small hydropower sites. In Hawaii, where the watersheds are relatively limited in area, all prospective hydropower projects will be in the "small hydro" category, which includes installations that have 30 megawatts or less capacity as defined by the Public Utility Regulatory Polices Act of 1978, as amended by the Energy Security Act of 1980.

Nationwide there is currently some 64,000 megawatts of hydropower capacity in about 1300 installations.[1] Of these, only 328 facilities

[1]U.S. Army Corps of Engineers. National Hydropower Study. Final Draft Report, January, 1981.

have installed capacities in excess of 25 megawatts. Of the remaining roughly 1000 plants, the average size is five megawatts, which means that most existing hydropower facilities fall into the category of "small hydropower" plants. In Hawaii, by comparison, hydropower plants range in size from 0.5 to 4.0 megawatts.

In general, the smaller hydropower installations tend to be older plants. In the past 15 years, about 385 megawatts of hydropower, mostly small plants, have been retired from service nationwide. During the same period, about 1.4 megawatts[1] in Hawaii have been phased out or abandoned. Most of these sites were abandoned in the consolidation of sugar mills, because the sugar companies did not find it economical to continue operation of the hydro plants. However, with the renewed interest in hydropower brought about by our State goal of energy self-sufficiency, this trend will surely reverse. A number of sugar companies have either begun or indicated a strong interest in developing new hydropower resources, or upgrading existing sites.

The current study represents part of the State of Hawaii's plan to aid and promote the further development of hydropower resources in Hawaii.

[1] Alternate Energy Sources for Hawaii. Report of the Committee on Alternate Energy Sources for Hawaii of the State Advisory Task Force on Energy Policy. Hawaii Natural Energy Institute, and Department of Planning and Economic Development, State of Hawaii. February, 1975.

## 3. Method and Scope of Study

Published studies of hydropower[1-23] in Hawaii were reviewed to obtain data on prospective sites. Additional sources of information and persons with expertise on small hydropower systems were also consulted. Those consulted included members of the sugar industry, the electric utilities, the U.S. Army Corps of Engineers (COE), and the Division of Water and Land Development (DOWALD) of the State Department of Land and Natural Resources. These interests in the State of Hawaii were represented on the Committee on Small Hydroelectric Power Systems. A list of those consulted, and the Committee on Small Hydroelectric Power Systems, are included in Appendix A.

The information collected was supplemented by map reconnaissance to develop a statewide list of prospective hydropower sites. This list is shown in Table 3-1. The list is not to be construed as an exhaustive list of all possible sites, because only a limited amount of time was devoted to map reconnaissance. With the exception of Wahiawa Reservoir on Oahu and Kualapuu Reservoir on Molokai, all sites involve the construction of low diversion dams (less than 10 feet high) on streams for run-of-the-river hydropower operations. With the exception of Kualapuu Reservoir, all sites involve the construction of a penstock for hydropower production. The present list does meet the objective of finding the best sites for which feasibility studies are warranted.

For each of the sites identified, a preliminary resources assessment was made, using flow duration analysis for those sites with sufficient streamflow gaging data. The principal source of flow duration data was the Water Resources Division of the U.S. Geological Survey. Adjustments of the data were made where required. For instance, if the assumed diversion point on a stream is far from a gage station, the station data were corrected for any significant difference in watershed area between

Table 3-1. Summary List of Prospective Hydropower Sites in the State of Hawaii.

| SITE | POTENTIAL CAPACITY (KW) | POTENTIAL ANNUAL ENERGY PRODUCTION (MILLION KWH) |
|---|---|---|
| KAUAI | | |
| 1. Wailua River | 11,700 | 25.2[1] |
| 2. Wainiha River | 3,700 | 17.4 |
| 3. Lumahai River | 2,800 | 14.1 |
| 4. Hanalei River | 2,550 | 11.5 |
| 5. Puu Lua-Kokee (Kitano Hydro) | 1,650 | 7.3 |
| 6. Hanalei Tunnel | 1,400 | 8.2 |
| OAHU | | |
| 1. Wahiawa Reservoir | 300 | 1.6 |
| MOLOKAI | | |
| 1. Halawa Stream | 2,100 | 9.9 |
| 2. Pelekunu Stream | 860 | 3.8 |
| 3. Kualapuu Reservoir | 70 | 0.3 |
| MAUI | | |
| 1. East and West Wailuaiki Str. | 2,750 | 15.1 |
| 2. Waihee River | 1,860 | 8.5 |
| 3. Hanawi Stream | 1,000 | 5.0 |
| 4. Kolea | 1,100 | 4.5 |
| 5. Hoopoi Chute | 2,000 | 5.5[2] |
| 6. Nailiilihaele Stream | 470 | 3.0 |
| 7. Kahakuloa Stream | 230 | 1.6 |
| 8. Honokohau (Honolua) Ditch | 130 | 0.8 |

Table 3-1. (Continued)

| SITE | INSTALLED CAPACITY (KW) | ESTIMATED ANNUAL ENERGY PRODUCTION (MILLION KWH) |
|---|---|---|
| HAWAII | | |
| 1. Honolii Stream | 3,900 | 17.6 |
| 2. Wailuku River | 1,970 | 11.1 |
| 3. Wailoa River | 1,850 | 10.3 |
| 4. Awini Falls | 1,500 | 7.7 |
| 5. Honokane Nui Stream | 1,100 | 6.2 |
| 6. Union Mill | 500 | 4.1[1] |
| 7. Pohakupuka Stream | 600 | 2.3 |
| 8. Keaiwa-Meyer Reservoirs | 280 | 1.7 |
| 9. Alia Stream | 330 | 1.5 |
| 10. Papaikou Mill | 130 | 1.0[1] |

Note: List does not include hydropower sites under construction: Kaumakani, Kauai (1250 kw); Hamakua Ditch, Maui (500 kw). See sections 3.4 and 5.0.

References:

[1]U.S. Army Corps of Engineers estimate.

[2]Estimate by Mr. Sachiyuki Masumoto, Alexander & Baldwin, Inc., Honolulu. Just prior to publication, the estimate was modified, to 1,000 kw capacity, and 3.0 million kwh/year.

the two points. The power and average energy potentials of the site were then computed using standard hydropower estimating techniques. A summary of the assumptions used and a sample calculation are included in Appendix B.

In order to avoid duplication of previous efforts, for those sites where previous studies had been performed, the original analyses were utilized. However, the previous results were updated where appropriate.

Environmental issues were not addressed in this reconnaissance-level survey. Any assessment of environmental concerns at a given site would require considerably more time and effort than was appropriate for this study. These environmental issues should be addressed specifically in the feasibility study for each proposed site.

Several potential environmental impacts are associated with the reduction of stream flow between the point of water diversion and the powerplant discharge. Presently, there are no minimum stream flow standards established for Hawaiian streams, and each stream would have to be considered on a case-by-case basis. Consequently, in determining the hydropower potential of streams, minimum flows for environmental protection were not considered, although in some cases minimum flows were dictated by mechanical limitations of the turbines.

The sites were ranked according to the magnitude of their potential average annual energy production. This ranking was done separately for each island. The sites with energy potential in excess of five million kwh per year were then selected for preliminary financial analysis.

The financial analysis consisted of determining the "breakeven" hydro energy cost, that is, the initial cost per kilowatt-hour of hydro electricity required so that the costs of the hydropower project equal the revenues received over the life of the project. The analysis utilized standard net present worth techniques. The assumptions used and a sample calculation are included in Appendix C. The key variables in the analysis were the discount, or interest rate, and the rate of increase of hydro energy value. The price charged for hydro energy is assumed to increase over the economic life of the project. Energy prices currently are linked with the price of petroleum, and because of the market instability of this commodity, no attempt was made to predict long-term energy prices. Similarly, interest rates are not fixed. Therefore, a range of interest and price escalation rates were used, so that the prospective hydropower developer using the results of this analysis can apply whatever projections he feels are the most realistic at the time. A sensitivity analysis was performed using different values for these parameters.

A summary of the financial analysis for selected sites, those with a potential for at least five million kilowatt-hours per year, is given in Table 3.2. The breakeven prices listed in Table 3.2 are those assuming an interest rate of 12 percent, and an energy value escalation of 6 percent per year. These values were selected because they are in the middle range of all the interest and energy escalation rates considered in the financial calculations. For breakeven prices assuming other combinations of these parameters, see Appendix D, where the breakeven prices for the selected sites are presented in graphical form, as functions of the interest and energy escalation rates.

Table 3.2. Results of Financial Analysis of Selected[1] Hydropower Sites.

| SITE | INSTALLED CAPACITY (KW) | ANNUAL ENERGY PRODUCTION (MILLION KWH) | FIRST COST (MILLION $) | BREAKEVEN ENERGY VALUE ($/KWH)[2] |
|---|---|---|---|---|
| Wailua River Basin | 11,700 | 25.2 | 14.0 | 0.062 |
| Wainiha River | 3,700 | 17.4 | 6.1 | 0.040 |
| Lumahai River | 2,800 | 14.1 | 6.2 | 0.049 |
| Hanalei River | 2,550 | 11.5 | 8.8 | 0.086 |
| Hanalei Tunnel | 1,400 | 8.2 | 3.7 | 0.050 |
| Puu Lua-Kokee (Kitano Hydro) | 1,650 | 7.3 | 3.2 | 0.048 |
| Halawa Stream | 2,100 | 9.9 | 3.5 | 0.040 |
| E. & W. Wailuaiki Streams | 2,750 | 15.1 | 4.3 | 0.032 |
| Waihee River | 1,860 | 8.5 | 3.9 | 0.052 |
| Hoopoi Chute[3] | 2,000 | 5.5 | 3.5 | 0.072 |
| Hanawi Stream | 1,000 | 5.0 | 2.4 | 0.054 |
| Honolii Stream | 3,900 | 17.6 | 4.5 | 0.029 |
| Wailuku River | 1,970 | 11.1 | 3.6 | 0.036 |
| Wailoa River | 1,850 | 10.3 | 5.8 | 0.063 |
| Awini Falls[4] | 1,500 | 7.7 | 4.0 | 0.059 |
| E. Br. Honokane Nui[4] | 1,100 | 6.2 | 4.4 | 0.080 |

[1]Sites identified which have at least 5 million kwh/year hydropower potential.

[2]At 12% interest rate, 6% annual hydro price escalation.

[3]Just prior to publication, the estimate of site potential by Alexander & Baldwin, Inc., was modified to 1,000 kw capacity, 3.0 million kwh/year. The breakeven cost estimate, however, is based on the original figures stated here.

[4]Awini Falls and Honokane Nui sites could be developed together, with a savings in project costs; combined project cost is $5.7 million, breakeven value is $0.045/kwh.

## 3.1 Kauai

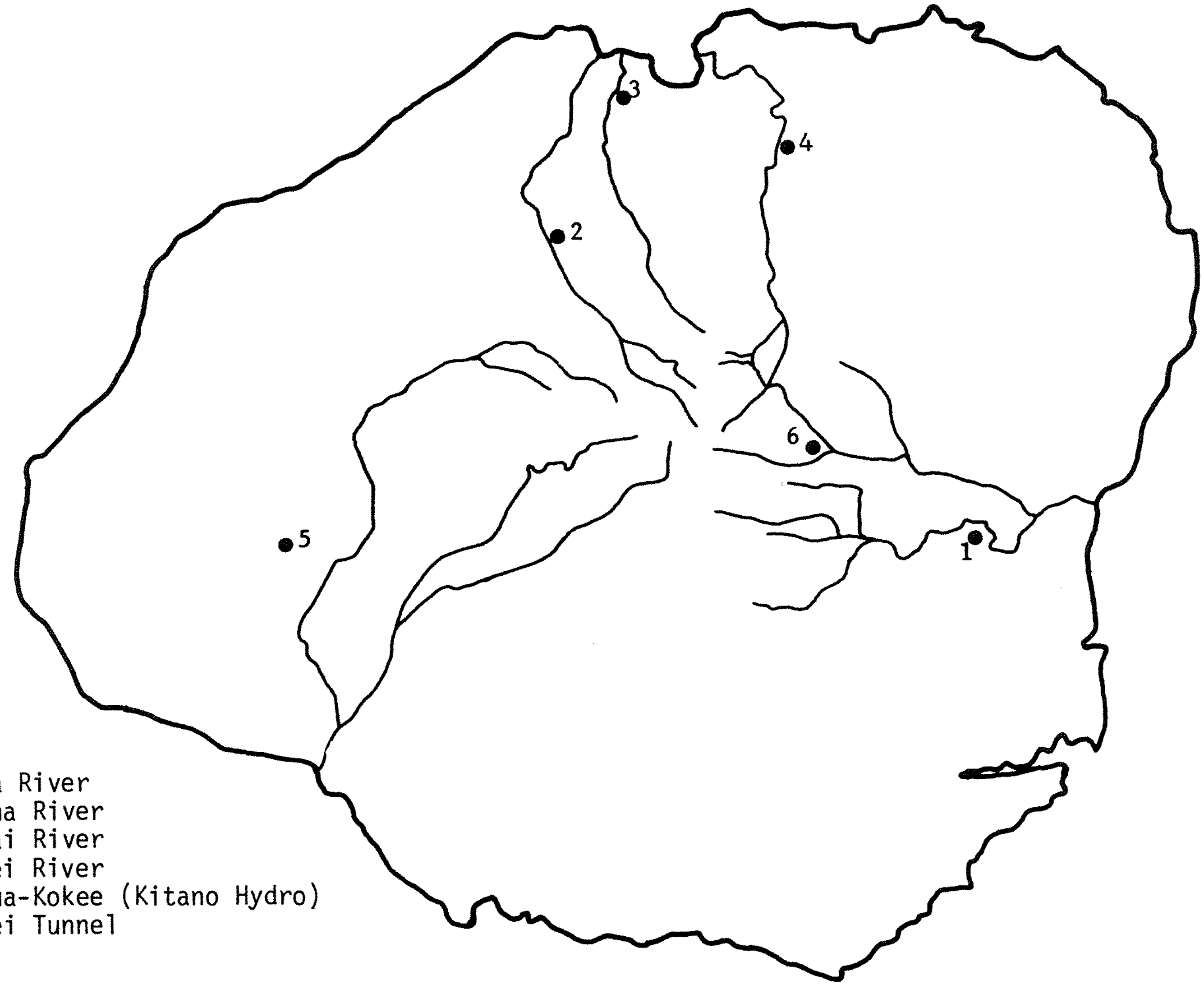
Kauai currently produces more hydroelectricity than all the other Hawaiian islands combined; about 50 million kilowatt-hours annually. Additional hydropower potential exists in the great river valleys of the northern and eastern portions of the island: Wainiha, Lumahai, Hanalei, and Wailua. As Table 3.1 shows, 21 megawatts of currently undeveloped hydropower is potentially available from these four river basins.

Extensive ditch systems in the western part of Kauai irrigate the dry land sugarcane fields. One of these, the Kokee Ditch, feeds the Puu Lua Reservoir at an elevation of about 3,300 feet, before continuing down to provide water for irrigation of the sugar fields of Kekaha. This area was the subject of a major study in the 1960's, the Kokee Water Project.[1] The plan was to construct a large reservoir on Kawaikoi Stream to back waters into the Alakai Swamp. The project was never implemented because of the unavailability of Federal funds for construction. Besides providing irrigation water for 1500 acres of new cane land, the project would have provided 10,000 kilowatts of hydroelectric power.

However, a significant hydropower potential exists with a run-of-the ditch system, utilizing Puu Lua Reservoir. The division of Water and Land Development (DOWALD) and Amfac, Inc., are interested in developing this capacity, and have initiated preliminary studies.

[1]Kokee Water Project. Report R22, Division of Water and Land Development, Department of Land and Natural Resources, State of Hawaii, 1964.

# KAUAI




Key:

1 Wailua River
2 Wainiha River
3 Lumahai River
4 Hanalei River
5 Puu Lua-Kokee (Kitano Hydro)
6 Hanalei Tunnel

Figure 3-1. Potential Hydropower Sites, Kauai.

The proposed Puu Lua-Kokee Project would consist of three stages. The first stage would involve the construction of a 1600-kilowatt hydroplant, utilizing Kitano Reservoir as an afterbay. Stage 2 would be a 950-kilowatt hydroplant with Puu Opae Reservoir as the afterbay. Finally, Stage 3 would involve the construction of a dam and reservoir on Kawaikoi Stream, which would be smaller than that contemplated in the original Kokee Water Project report. The hydropower potential of Stage 3 has not yet been determined.

The Wailua River Basin was the subject of a study for a storage-type hydropower project in 1978.[1] More recently, the U.S. Army Corps of Engineers has an ongoing reconnaissance study of the Wailua River Basin for run-of-the-river hydropower. The Stage 1 report is scheduled for completion in early 1981. The purpose of the Stage 1 effort is to determine whether detailed feasibility analysis is warranted. Preliminary results of the study are summarized in Tables 3.1 and 3.2. Because the Stage 1 results of the Corps study are expected shortly, their work on the Wailua River Basin has not been duplicated in this study. However, the results in Tables 3.1 and 3.2 are first-cut estimates only, and subject to change in the final analysis.

## 3.2 Oahu

While the greatest demand for electricity in Hawaii is on the island of Oahu, the hydroelectric potential on Oahu is small. The major

[1] Belt, Collins & Associates, Waialeale Hydropower Study. Division of Water and Land Development, Department of Land and Natural Resources. Honolulu, Hawaii, 1978.

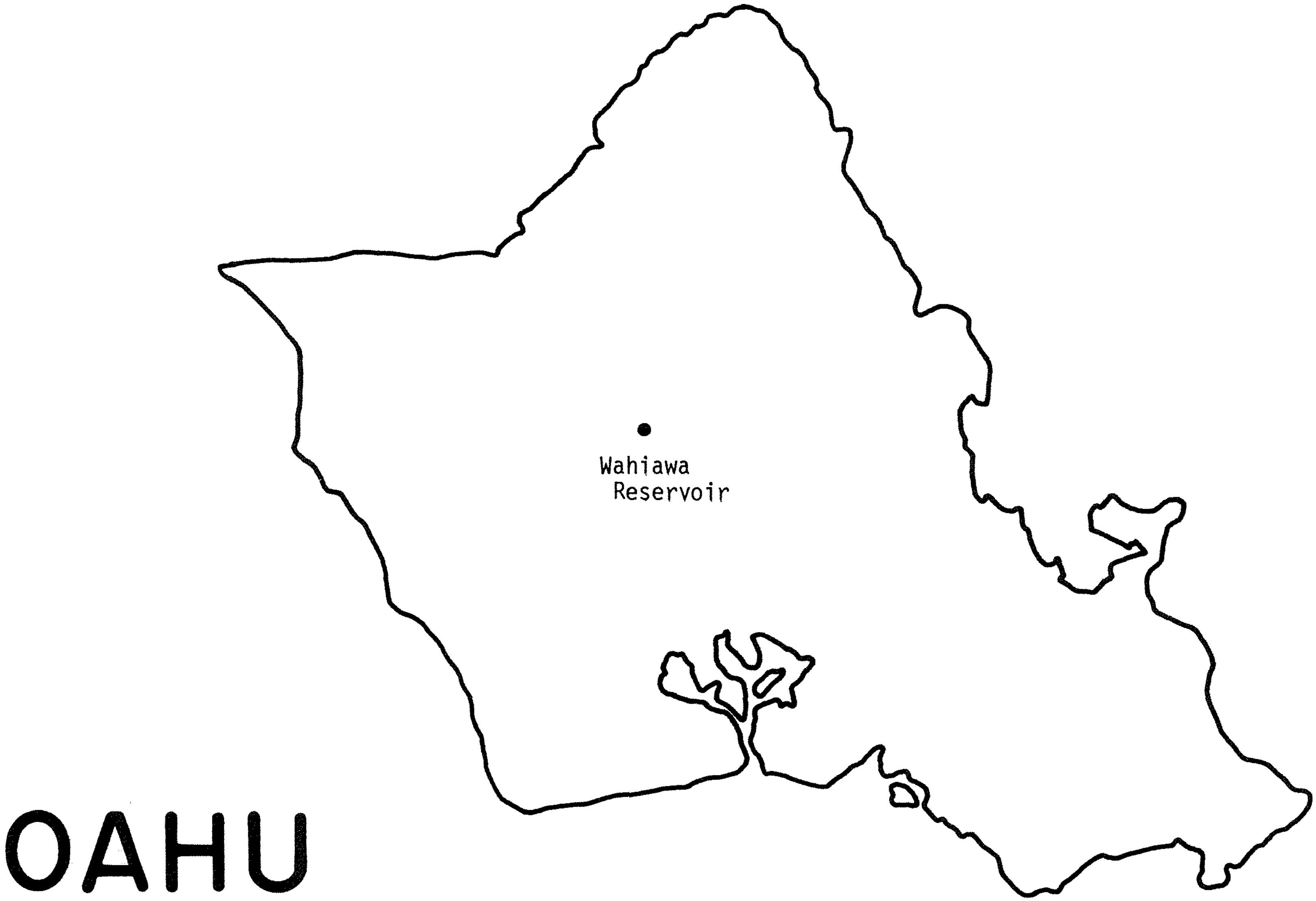



Figure 3-2. Potential HYdropower Site, Oahu

contributing factors are Oahu's small watershed areas, low available heads and the extensive diversion of waters for irrigation and domestic uses.

The small watershed areas do not allow the streams to gain sufficient flows before reaching the lower elevations. Headwaters are scattered among numerous stream branches in the steep, upper elevations, particularly on the windward side of the Koolau Range. Because the terrain's slope is relatively gentle in the lower elevation, the available heads are small. The extensive diversion of the existing water for irrigation and domestic uses further diminishes the flow available for hydropower.

A literature search and discussions with the U.S. Army Corps of Engineers and the Department of Water and Land Development (DOWALD) have singled out the Wahiawa Reservoir as the only prospective site, at this time, for the generation of hydroelectric power. Because of the limited amount of map reconnaissance time available it was not possible to seek additional prospective sites.

It is possible that small amounts of hydropower potential may be scattered throughout Oahu. Areas with the greatest possibilities for hydroelectric power generation are the streams of windward Oahu, particularly in the Koolauloa District (e.g., Kahana Stream), the upper Kaukonahua watershed in the Wahiawa District, and the irrigation systems of Waialua and Oahu Sugar Companies. It is recommended that further investigations be made in these areas.

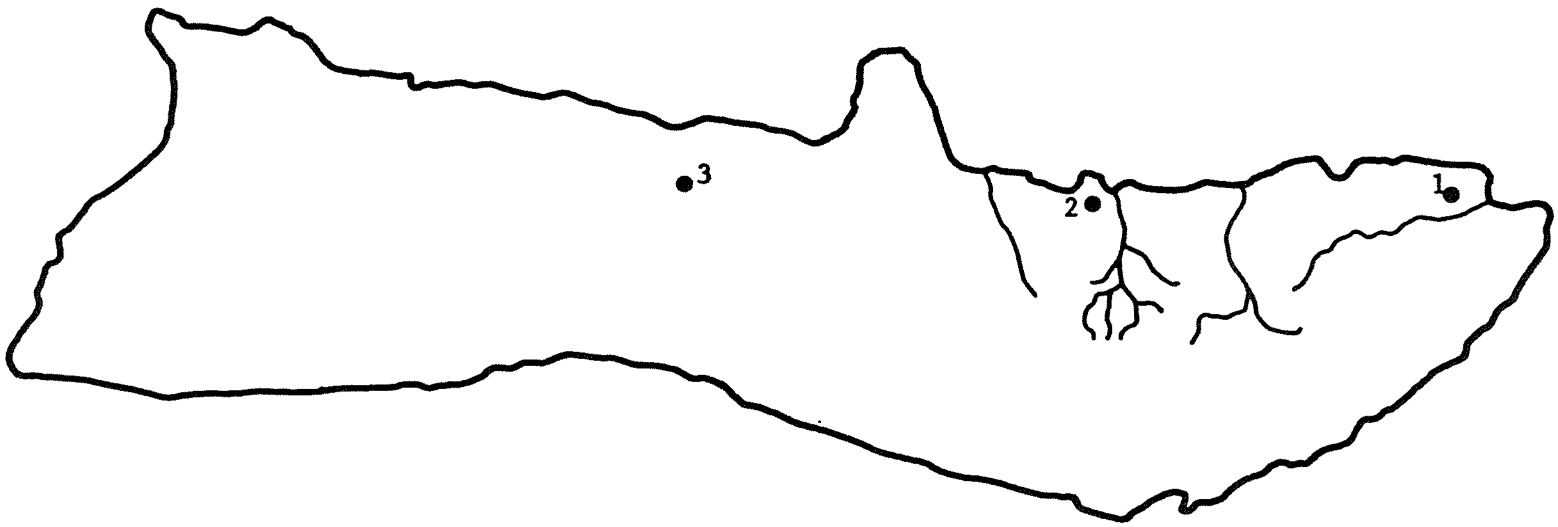
Despite the general lack of conventional hydropower resources, Oahu has significant potential for pumped storage hydropower. Although studies to date have been of only a preliminary nature, four sites on the island have been identified as prospective candidates for pumped storage. Appendix E is an excerpt from a recent study of pumped storage potential in Hawaii.

## 3.3 Molokai

The island of Molokai consists of two volcanic domes, East and West Molokai. Rainfall is abundant in the windward areas of East Molokai, but scarce on the plains of West Molokai. Consequently, almost all of the hydropower resources are in East Molokai, in the windward valleys of Waikolu, Pelekunu, Wailau, and Halawa.

Waikolu Valley waters are currently diverted at a number of points for irrigation and domestic water use. The Molokai Irrigation System diverts water at elevations of 700 and 1000 feet in the valley into the Molokai Tunnel, and then to Kualapuu Reservoir in West Molokai. Further down the valley, water is diverted to the Kalaupapa settlement for domestic use, leaving little water for hydropower use. However, the waters diverted by the Molokai Irrigation System to Kualapuu Reservoir contain a small amount of developable hydropower. A study done in 1980[1] showed that, given a reasonable set of assumptions about future water demand in West Molokai, about 10 million gallons per day will need to be

[1]C. Beck. Moloka'i Irrigation System Hydroelectric Feasibility Study. Report R60, Division of Water and Land Development, Department of Land and Natural Resources, State of Hawaii, Honolulu, 1980.




# MOLOKAI

Key:

1 Halawa Stream
2 Pelekunu Stream
3 Kualapuu Reservoir

Figure 3-3. Potential Hydropower Sites, Molokai diverted to Kualapuu Reservoir by the year 1985. With an available head of 124 feet at the Reservoir inlet, a 90 kilowatt hydropower plant could be installed. Currently, the input to Kualapuu Reservoir has a developable potential of 70 kilowatts, as shown in Table 3.1.

Wailau Valley was not considered a likely prospect for hydropower development because of its remote location. Although there is about 1,000 kilowatts of resource potential, the transmission line required would be 4 to 5 miles long, which would result in a high cost and significant power losses.

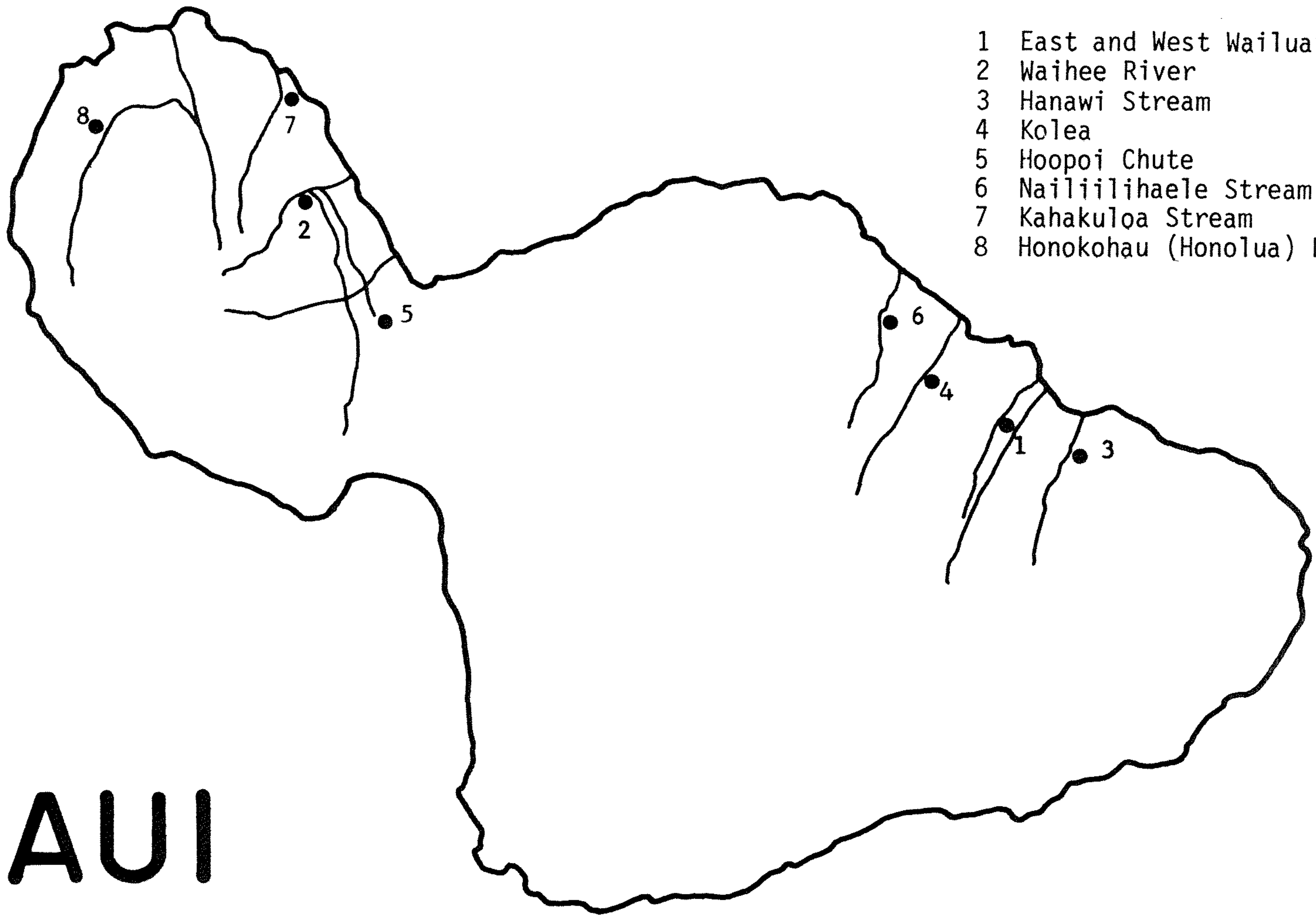
While Pelekunu and Halawa Valleys are also remote from electric demand centers, they are close enough to existing transmission lines to merit consideration. Together, the two sites could provide nearly 3,000 kilowatts of installed capacity, and 14 million kilowatt-hours annually, about 45% of the current electrical demand on Molokai. Construction costs are extremely high for these two sites, due to their remote locations, and the rough terrain. However, a continued rapid escalation of electricity rates would make the two projects economically feasible.

## 3.4 Maui

The island of Maui consists of two volcanic domes, East and West Maui. Rainfall and surface water are abundant in the windward areas of both. In west Maui, hydropower resource areas include the great stream valleys of Honokohau, Kahakuloa, and Waihee. Honokohau Valley is remote, making access for hydropower development difficult, but its waters are diverted via the Honokohau, or Honolua, Ditch system to the pineapple and

Key:

1 East and West Wailuaiki Streams
2 Waihee River
3 Hanawi Stream
4 Kolea
5 Hoopoi Chute
6 Nailiilihaele Stream
7 Kahakuloa Stream
8 Honokohau (Honolua) Ditch




MAUI

Figure 3-4. Potential Hydropower Sites, Maui.

sugarcane fields of West Maui. An old hydropower site exists at Honokahua Valley near the Kapalua Resort where the Honolua Ditch crosses the valley in a siphon. Before the water enters the siphon, about 45 feet of head is available. An old turbine and portions of a penstock remain at the site, but are unusable. The capacity of this site is about 127 kilowatts.

Kahakuloa Stream to the east of Honokohau Valley also has a small resource, about 230 kilowatts. Further to the east is Waihee River, whose waters are diverted via the Waihee Ditch system to sugarcane fields in the central portion of Maui. An estimated 1860 kilowatts of hydropower potential are available above the diversion point. Near the town of Wailuku, the Waihee Ditch feeds two reservoirs through the Hoopoi Chute. The drop is about 240 feet in elevation, and the hydropower potential of this site is 1000 kilowatts.

The streams of East Maui were the subject of a study by a State task force on hydropower in 1974.[1] Streams with good hydropower potential include the East and West Branches of Wailuaiki Stream, Hanawi Stream, Kolea Stream and Nailiilihaele Stream. Together these sites have a potential of over 3,200 kilowatts of capacity.

Also in East Maui is the Wailoa Ditch system which diverts waters from nearly every stream along the windward coast and transports it to Central Maui for sugarcane irrigation. The Wailoa Ditch is already the source of nearly 5,000 kilowatts of hydropower capacity at two sites, Paia and

[1] Report of Hydro Electric Subcommittee of Governor's Committee on Alternate Energy Sources for Hawaii. Robert T. Chuck, Chairman. September, 1974.

Kaheka. At Kolea Stream, there are actually two ditches, with an elevation difference of about 360 feet. There was a small hydropower plant at this site at one time. The waters of the upper ditch could be dropped to the lower ditch, to generate a maximum of 1,100 kilowatts of power.

The Wailoa Ditch empties into the Wailoa Forebay near Paia. The forebay supplies the two existing hydropower plants at Paia and Kaheka. The overflow from Wailoa Forebay goes down a chute ditch to the Hamakua Ditch. About 45 feet of head are available at this site, and the Hawaiian Commercial and Sugar Company, Ltd., is planning to install a 60-inch diameter penstock and 500-kilowatt hydropower plant. The estimated annual output of the plant is expected to be 2.5 million kilowatt-hours.

## 3.5 Hawaii

Although rainfall is abundant in many areas of the Big Island of Hawaii, geologic conditions do not favor abundant surface waters in some places. The rock strata of the relatively young volcanoes of Kilauea, Mauna Loa, and Hualalai, are very porous, and rainfall is absorbed rapidly into the ground. Most streams flow only during periods of heavy rainfall. The only perennial streams are found in Kohala, and along the Hamakua Coast, where the older soils are somewhat more impervious to water, and rainfall is abundant throughout the year.

A small amount of hydropower potential is found in the Ka'u District, on the leeward flank of Mauna Loa. Numerous water development tunnels have been constructed to tap water perched at high elevations for irrigation

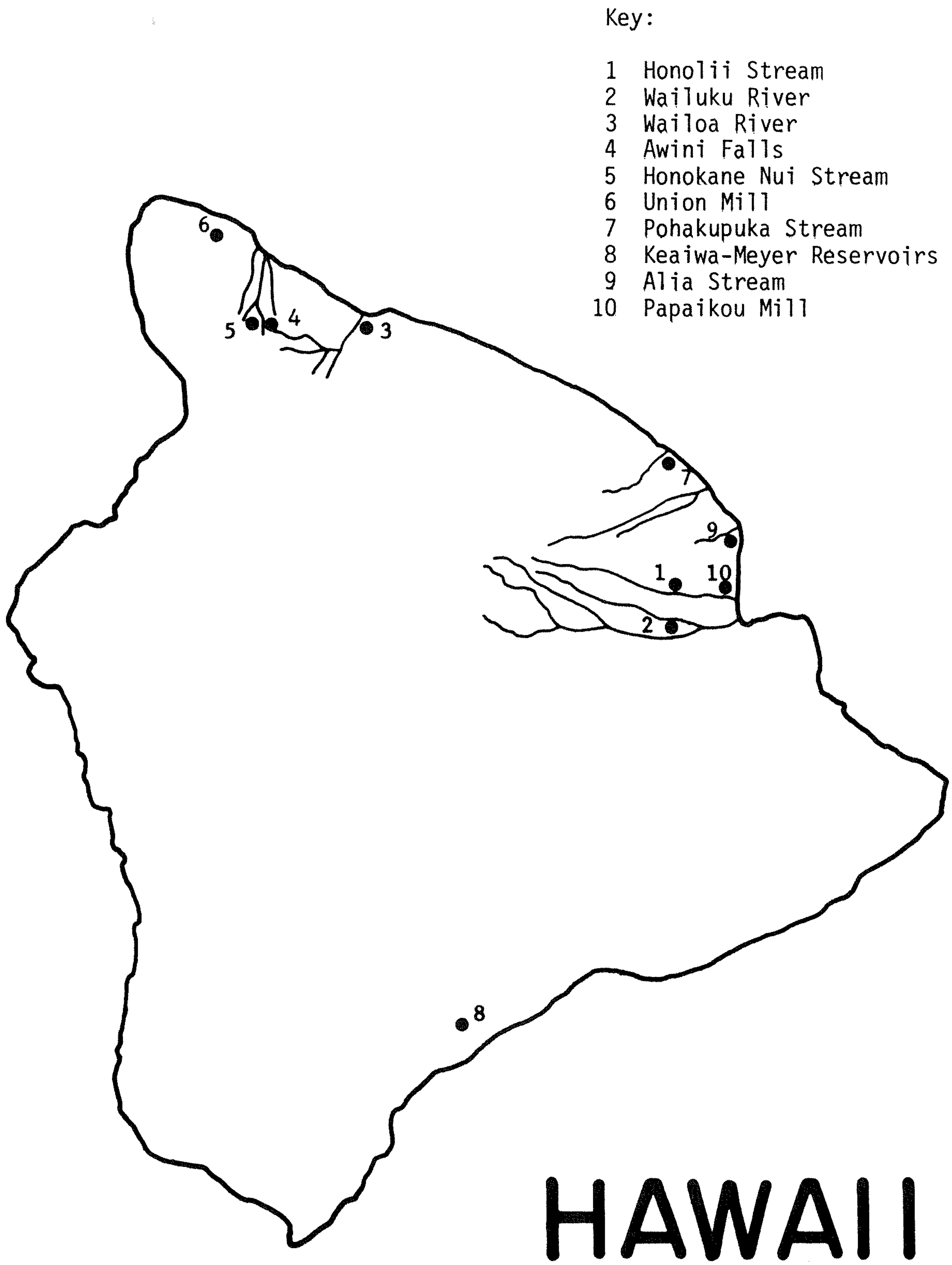



Figure 3-5. Potential Hydropower Sites, Big Island (Hawaii).

and domestic use. The available heads are tremendous, partially offsetting the relatively low flows. At Ka'u Sugar Company, a hydropower capacity of 280 kilowatts is possible from waters which drop a total of 1870 feet in elevation from Keaiwa Reservoir to the sugar factory.

The Kohala area has been the subject of a study by the State task force on hydropower, mentioned in the previous section on Maui. Wailoa River, Awini Falls, and Honokane Nui Stream have a combined hydropower potential of nearly 4,500 kilowatts. The Kohala Ditch system once fed two hydropower plants with a combined capacity of 800 kilowatts near Hawi. The prospect of restarting these two plants has been investigated by the Hawaii Electric Light Company and the Army Corps of Engineers. Since the cessation of sugar operations in 1975, there is only limited irrigation of truck farms in the area. The Kohala Ditch has deteriorated significantly so that major repairs would be needed to restore flow to the Union Mill hydro. Continued maintenance of the Kohala Ditch would be feasible only if the Ditch water were sold for irrigation use as well as for hydropower use. The current owner is unwilling to commit water for hydropower development without concurrent irrigation demand.

The Hamakua Ditch System also has been suggested as a source of water for hydropower. Water is collected from the headwaters of Waipio Valley, and is transported via two ditches, the Upper and Lower Hamakua Ditches, to the Honokaa area, a distance of about ten miles. It is the chief source of water for the Davies-Hamakua Sugar Company factory in Haina. Theo H. Davies & Company, Ltd., is considering ways to utilize Hamakua Ditch water to increase the hydropower capacity at the Haina mill, which is currently 800 kilowatts.

Similarly, the old Laupahoehoe Sugar Company (now Davies-Hamakua Sugar) ditch system, once used for cane fluming operations, represents an opportunity for hydropower development. The current owner has expressed an interest in assessing its hydropower potential.

The Hamakua Coast on the Big Island of Hawaii stretches from Hilo to Honokaa, a distance of about 40 miles. The 20-mile stretch from Hilo to Laupahoehoe is the wettest region of the Big Island, with rainfall averaging 300 inches annually at the 3000-foot elevation. Rainfall drops off rapidly between Laupahoehoe and Honokaa, but is still as great as 75 inches annually on the slopes above Honokaa. Except for the Kohala Mountains, the Hamakua Cost is the only area on the Big Island where perennial streams reach the sea. Springs fed by perched groundwater proliferate along the coast between sea level and 2000 feet elevation, as shown in Figure 3-6. Most of the land up to 2000 feet elevation is planted in sugarcane.

Because of the abundant rainfall, numerous springs, and relatively easy access, the Hamkua Coast is a good prospect for hydropower development. The Wailuku River currently is the only Hamakua Coast stream with operating hydropower plants. However, at least four other hydropower plants , which ranged from 60-150 KW, have been in operation over the years, at the Wainaku, Papaikou, Pepeekeo, and Hakalau sugar mills. These plants utilized excess water from cane fluming operations. Trucking has replaced fluming as a means of transporting cane, and all but the Pepeekeo mill are now closed, although the water collection system for the Papaikou hydropower plant is still partially intact.

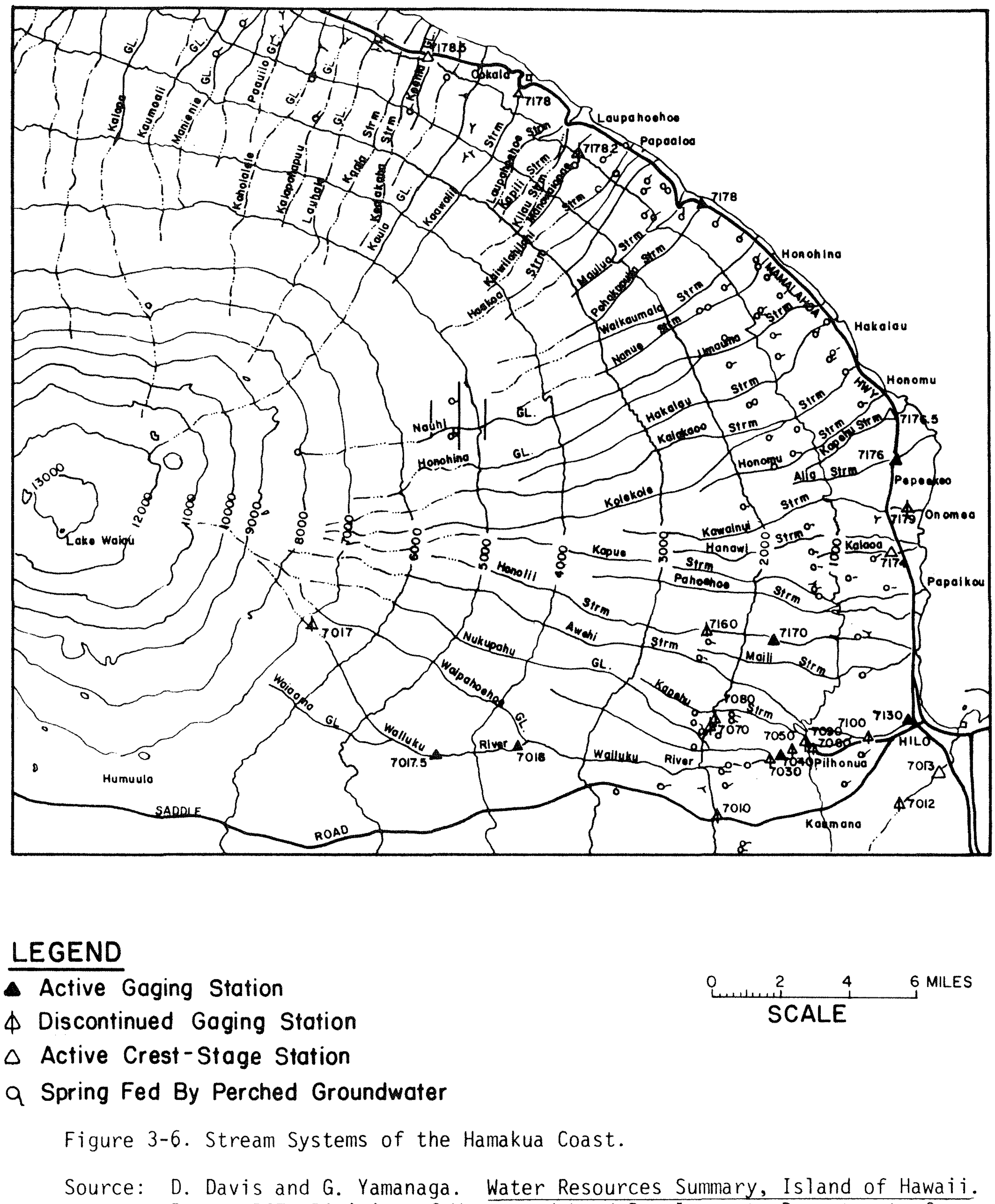



Figure 3-6. Stream Systems of the Hamakua Coast.

Source: D. Davis and G. Yamanaga. Water Resources Summary, Island of Hawaii. Report R47, Division of Water and Land Develcpment, Department of Planning and Economic Development, State of Hawaii, Honolulu, 1973.

Additional hydropower potential exists on the Wailuku River. There is about 260 feet of head available at, and downstream of Pukamaui Falls. With the diversion of Hookelekele Stream to the top of the Falls, about 2,000 kilowatts of hydropower is potentially obtainable.

### 3.6 Stream Gaging Requirements

The major source of streamflow data for hydropower assessment is the United States Geological Survey (USGS). The USGS annually publishes records of the 111 continuous-record gaging stations it now maintains around the State. Records are also available for about 420 other USGS stations, now discontinued, with data extending as far back as 1900. Between the years 1900 and 1920, the USGS maintained an extensive network of staitons in Hawaii recording daily or monthly flow data. Extensive use was made in this study of these old records for some sites, as they were the only data available. However, this old data may not be accurate, and should be checked by re-measuring the stream during the feasibility study phase.

USGS water records are supplemented by the records of sugar and pineapple companies, ranches, and domestic water supply agencies. Despite the great accumulation of data, gaps exist in the knowledge of streamflow behavior for some areas in Hawaii. These data gaps prevent reliable estimates of hydropower potential for several important streams.

The USGS performed an internal evaluation of its streamflow-data program in Hawaii eight years ago,[1] and pointed out areas where new gaging

[1] G. Yamanaga. Evaluation of the Streamflow-Data Program in Hawaii. Open-File Report. United States Department of Interior, Geological Survey, Water Resources Division, Honolulu, Hawaii, 1972.

Table 3.3 Stream Gaging Requirements For Hydropower Assessment.

| ISLAND | GENERAL COMMENTS | CANDIDATE STREAMS FOR GAGE STATIONS |
|---|---|---|
| Kauai | In general, data were adequate for reconnaissance level hydropower assessment; | Lumahai River - site of previous USGS station;<br>Kalihiwai River<br>Makaweli River (higher elevations)<br>Olokele River (higher elevations) |
| Oahu | Unfavorable terrain for hydropower, and extensive stream diversions, but some additional data-gathering is warranted; | Punaluu Stream (higher elevations)<br>Kahana Stream (higher elevations) |
| Molokai | Data appear adequate at this time for reconnaissance-level hydropower assessment. | |
| Maui | In general, although sufficient data were found for reconnaissance-level hydropower assessment, much data are old (1910-1920) and may be inaccurate; | Keanae Valley - either Piinaau Stream or Waiokamilo Stream;<br>Iao Stream<br>Waihee Stream |
| Hawaii | Hamakua Coast near Hilo appears to have good hydropower potential, but there is a general lack of data for most streams in the area; | Kolekole Stream<br>Kawainui Stream<br>Umauma Stream<br>Kapue Stream<br>Waiau Stream<br>Waikaumalo Stream<br>Nanue Stream<br>Hakalau Stream<br>Pukihae Stream |

stations are needed. However, in order for USGS to properly respond to changing State needs for streamflow-data for hydropower assessment, they should be provided with additional input from those interested in hydropower development.

Limitations of time and scope of this study did not allow a systematic assessment of statewide stream gaging needs. However, in certain areas there were obvious needs for additional data for hydropower resource assessment. Our general observations relating to stream gaging needs are summarized in Table 3.3. It is further recommended that more study, including field work, be initiated to provide additional input on stream gaging needs.

## References


[1]Belt, Collins and Associates, Waialeale Hydropower Study, Belt, Collins and Associates, Honolulu, 1978.

[2]Bowles, S.P., Kohala Water Resources Management and Development Plan, Phase I, State of Hawaii, Honolulu, May 1973.

[3]Bowles, Stephen, et. al., Kohala Water Resources Management and Development Plan, Phase II, State of Hawaii, Honolulu, May 1974.

[4]Davis, Dan A. and George Yamanaga, Water Resources Summary: Island of Hawaii, U.S.G.S., Honolulu, April 1973.

[5]Davis, Dan A. and George Yamanaga, Preliminary Report on the Water Resources of the Ka'u District, Hawaii, U.S.G.S., Honolulu, October 1966.

[6]Davis, Dan A. and George Yamanaga, Preliminary Report on the Water Resources of Kohala Mountain and Mauna Kea Hawaii, U.S.G.S., Honolulu, January 1963.

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[10]Department of Land and Natural Resources, Kokee Water Project, State of Hawaii, Honolulu, 1964.

[11]Department of Land and Natural Resources, A Water Development Plan for South Kohala-Hamakua, State of Hawaii, Honolulu, January 1965.

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[17]Sullivan, Patrick K., Preliminary Report on Hydroelectric Power in Hawaii, Hawaii Natural Energy Institute, Honolulu, May 1980.

[18]U. S. Army Corps of Engineers, National Hydropower Study, Hawaii Region, Final Draft Report, U.S. Army Corps of Engineers, Honolulu, January, 1981.

[19]U. S. Army Corps of Engineers, Reconnaissance Report for Small Hydropower, Union Mill, Hawi, Hawaii, U. S. Army Engineers District, Honolulu, October 1979.

[20]U. S. Army Corps of Engineers, Summary Report for Hydroelectric Power, U. S. Army Engineer District, Honolulu, October 1978.

[21]U. S. Geological Survey, Flow Characteristics of Selected Steams in Hawaii, U.S.G.S., Honolulu, September 1964.

[22]U. S. Geological Survey, Water Resources Data for Hawaii and Other Pacific Areas, U.S.G.S., Honolulu. Various volumes, 1965-1980.

[23]W. A. Hirai and Associates, Inc., Moloka'i Irrigation System Hydroelectric Feasibility Study, W. A. Hirai and Associates, Inc., Hilo, 1980.

## 4. Previous Hydropower Surveys

There have been two previous major surveys of hydropower potential in Hawaii, both of which were conducted by the U.S. Army Corps of Engineers. In January 1981, the COE completed a final draft report of the Hawaii Region portion of the National Hydropower Study. Prior to this, the COE had published, in October, 1978, its Summary Report on "Hydroelectric Power, State of Hawaii."

The 1978 study was undertaken under authority of the River and Harbor and Flood Control Act of 1962, and in compliance with the Water Resources Development Act of 1976. Its purpose was to establish the feasibility, and determine the extent of Federal participation in the development of hydroelectric power in the State of Hawaii. The study involved a reconnaissance level evaluation of hydroelectric facilities and resulted in the identification of seven projects. Six were run-of-the-river projects and one involved a storage reservoir. (Table 4.1)

The initial screening of possible sites was done on generalized technical, economic and environmental factors. Those passing the initial test were then subjected to site-specific reconnaissance studies.

The initial screening was based on general assumptions and criteria. It was assumed that production of hydroelectric power would be the only use of the site. Other uses such as recreation, irrigation, flood control, and water supply were not considered during this screening process but existing water uses were assumed to be continued.

Table 4.1. Army Corps of Engineers Hydropower Study, 1978.

| Site | Net Head (feet) | Plant Capacity (kw) | Annual Energy Generation (kwh) | First Cost | Cost per Unit Energy mills/kwh | Benefit/ Cost Ratio |
|---|---|---|---|---|---|---|
| Storage<br>Hanalei, Kauai | 261 | 1,400 | 12,300,000 | $35,000,000 | 201 | .2 |
| Run-of-the-River<br>Wainiha, Kauai | 189 | 430 | 3,770,000 | 6,000,000 | 116 | .4 |
| Lumahai, Kauai | 263 | 170 | 5,170,000 | 5,600,000 | 202 | .4 |
| Hanalei, Kauai | 312 | 590 | 1,490,000 | 7,200,000 | 275 | .2 |
| Pelekunu, Molokai | 194 | 30 | 263,000 | 1,800,000 | 513 | .1 |
| Waihee, Maui | 241 | 350 | 3,070,000 | 4,000,000 | 98 | .4 |
| Wailoa, Hawaii (Waipio Valley) | 253 | 550 | 4,820,000 | 7,600,000 | 117 | .4 |

Source: U.S. Army Engineer District, Honolulu, Hawaii
Summary Report for Hydroelectric Power, October 1978.

Only those streams with a base flow of at least ten cubic feet per second were considered further. Areas with significant environmental sensitivity were identified and eliminated from further consideration.

It was also assumed that the projects would be designed and constructed by the U.S. Army Corps of Engineers (COE) so COE criteria were used in the engineering and financial determinations. Because of this, facilities that would have primarily benefited private interests were not considered. It was also necessary that the financial benefits outweigh the costs.

The seven sites listed in Table 4.1 passed the initial screening and were then evaluated according to another set of criteria and assumptions. To evaluate the potential for each waterway, a plant factor of 100 percent was assumed. According to this assumption, the plant would operate at the minimum, firm (dependable) stream flow level. Maintenance of a minimum stream flow of three cubic feet per second would be required at all times for the preservation of fish and wildlife.

The cost estimates used to evaluate the power plants were based on preliminary planning curves developed by the North Pacific Division of the COE, updated to July 1977 price levels.

In the financial analysis it was assumed that the engineering and administrative costs would run at twelve per cent of construction costs and that contingencies would be one fourth of the construction costs. Operating, maintenance and replacement costs were set at 0.5 percent of the first cost, excluding engineering and design, for run-of-the-river facilities and 0.2 per cent for storage systems. Financing of projects was assumed to correspond to federal financing of major water resource projects at the then-current rate of 6-5/8 per cent over 100 years.

The hydroelectric power benefits were assumed to equal the preliminary values established by the Federal Energy Regulatory Commission (FERC) including the credits for dependable capacity as well as kilowatt-hour production. No escalation of energy values was assumed.

A final draft report completed by the COE in January, 1981, is part of the ongoing National Hydropower Study. The objective was to determine the potential for increasing hydroelectric generation capacity by developing new sites, and by the addition of generating capacity to existing water resources projects. Also considered in the study were the possibilities of reactivating hydroelectric plants that had been deactivated or abandoned.

An inventory of existing dams, hydroelectric facilities and undeveloped sites were evaluated. To be included for further study, dams had to have heads exceeding forty feet and 800 acre-feet of storage. Existing hydroelectric power facilities were retained if they had planned incremental capacity expansion. All sites had to have dependable capacity of at least 100 kilowatts. General environmental and socio-economic impacts of the hydroelectric power plant development were also included in the assessment. Sites with overriding economic, environmental, social or institutional problems were screened out.

Although detailed engineering and technical studies were not performed, cost estimates were developed by the COE based on standard, preliminary planning, cost estimating techniques. In the financial evaluation, the financing was assumed to be at the FY-1980 Federal discount rate of 7-1/8 per cent for fifty years.

Thirteen sites and fifteen projects met the valuation criteria and were ranked. (Table 4.2). These sites were ranked according to the magnitude of the unit energy costs and environmental considerations. The ranking was further broken into "short term" and "long range" categories based on energy marketing considerations.

Table 4.2. National Hydropower Study Plan for the Hawaii Region

| Name of Project | Island | Owner | Rank | Incremental Capacity (mw) | Incremental Energy (million kwh) | Type of Project |
|---|---|---|---|---|---|---|
| | | | Short Term | | | |
| Hydro Kaumakani | Kauai | Olokele Sugar Co. | 1 | 0.75 | 8.3 | Existing Plant |
| Union | Hawaii | Kohala Corp. | 2 | 0.5 | 4.1 | Rehabilitation |
| Hamakua Ditch | Maui | Hawaiian Commercial and Sugar Co. | 3 | 0.5 | 2.5 | New site (run of river) |
| Hoopoi Chute | Maui | Hawaiian Commercial and Sugar Co. | 4 | 2.0 | 5.5 | New site (run of (river) |
| Kualapuu Reservoir | Molokai | State of Hawaii | 5 | 0.09 | 0.6 | Existing reservoir |
| Wailua | Kauai | ----- | 6 | 11.70 | 25.2 | New site (run of river) |
| | | | Long Range | | | |
| Wahiawa Reservoir | Oahu | Waialua Sugar Co. | 1 | 2.8 | 7.5 | Existing reservoir |
| Puulua Reservoir | Kauai | Kekaha Sugar Co. | 2 | 1.7 | 3.0 | Existing reservoir |
| Wailoa | Hawaii | ----- | 3 | 2.9 | 12.3 | New site (run of river) |
| Waimea | Kauai | Kekaha Sugar Co. | 4 | 2.9 | 3.9 | Existing plant |
| Waihee | Maui | ----- | 5 | 0.73 | 2.0 | New site (run of river) |
| Kapaia Reservoir | Kauai | Lihue Plantation Co., Ltd. | 6 | 0.12 | 0.2 | Existing reservoir |
| Waialeale[1] | Kauai | ----- | 7 | 7.8 | 42.7 | New site (storage) |
| Hanalei | Kauai | ----- | 8 | 4.5 | 16.5 | New site (run of river) |
| Kokee | Kauai | ----- | 9 | 10.0 | 29.2 | New site (storage) |

Source: U.S. Army Corps of Engineers, Pacific Ocean Division, National Hydropower Study, Hawaii Region, Final Draft Report, January, 1981.

[1]Deleted in final tabulation (Wailua was selected for development in the coincident drainage area).

## 5. Existing Hydropower Systems

Numerous surveys of existing hydropower plants in Hawaii have been made.[1,2,3,4] A data summary of these plants is given in Table 5.1.[5] A number of hydropower plant owners are investigating or implementing plans to upgrade existing sites.

Upgrading of existing sites is possible in the following ways:

1) Efficiency increases by the replacement of older turbine/generators with modern equipment.
2) Replacement of the existing penstock with a larger penstock, to reduce friction losses, or addition of another penstock.
3) Diversion of additional flow from a stream, and installation of additional generating capacity to utilize the flow.
4) Repair of tunnel and ditch systems to remove silt, gravel, and obstructions, and to reduce leaks.
5) Relocation of turbine/generator or penstock to increase the available head.

Not all of these are applicable to any given site. The improvements possible in the energy outputs of the sites also will vary considerably depending on the specific site circumstances.

[1] Alternate Energy Sources for Hawaii. Report of the Committee on Alternate Energy Sources For Hawaii of the State Advisory Task Force on Energy Policy. Hawaii Natural Energy Institute, and Department of Planning and Economic Development, State of Hawaii, February, 1975.

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[5] Communications with hydropower plant owners, 1980.

Table 5.1. Summary of Existing Hydroelectric Plants - December 1980.

| Island & Location | No of Units | Stream | Owner | Installed Capacity (kw) | Avg. Annual Energy (gwh) | Up-Grade Plans |
|---|---|---|---|---|---|---|
| HAWAII: | | | | | | |
| - Puueo | 2 | Wailuku | HELCO | 1,500; 750 | 14.0 | Under study. |
| - Waiau | 2 | Wailuku | HELCO | 750; 350 | 6.5 | Under study. |
| - Haina | 1 | Lower Hamakua Ditch | DHSC | 800 | 0.75 | Under study. |
| SUBTOTAL, HAWAII | 5 | | | 4,150 | 21.25 | |
| MAUI: | | | | | | |
| - Kauaula | 1 | Kauaula | PMC | 500 | 0.75 | Under study. |
| - Paia | 1 | Wailoa Ditch | HCSC | 800 | 3.0 | In planning. |
| - Kaheka | 3 | Wailoa Ditch | HCSC | 3 x 1,333 | 18.0 | 500 kw addition on Hamakua Ditch, 1981. |
| SUBTOTAL, MAUI | 5 | | | 5,300 | 21.75 | |
| KAUAI: | | | | | | |
| - Waiawa | 1 | Kekaha Ditch | KSC | 500 | 1.9 | Under study. |
| - Waimea | 1 | Waimea | KSC | 1,000 | 5.0 | Under study. |
| - Wainiha | 2 | Wainiha | MSC | 1,800; 1,800 | 26.0 | Under study. |
| - Kaumakani | 1 | Makaweli | OSC | 500 | 3.1 | Replace with 1,250 kw, generate 6.5 gwh, 1981. |
| - Alexander Res. | 1 | -- | MSC | 1,000 | 4.5 | Under study. |
| - Lower Lihue | 1 | N. Wailua and Iliiliula Ditch | LPC | 800 | 5.0 | Under study. |
| - Upper Lihue | 1 | N. Wailua and Iliiliula Ditch | LPC | 500 | 3.1 | Under study. |
| SUBTOTAL, KAUAI | 8 | | | 7,900 | 48.6 | |
| TOTAL, STATE | 18 | | | 17,350 | 91.6 | |

[1]Source of Data: Communications with hydropower plant owners, 1980.

Key:
- HELCO - Hawaii Electric Light Company, Inc.
- DHSC - Davies Hamakua Sugar Company
- PMC - Pioneer Mill Company, Ltd.
- HCSC - Hawaiian Commercial & Sugar Company
- KSC - Ka'u Sugar Company, Intd.
- MSC - McBryde Sugar Company, Ltd.
- OSC - Olokele Sugar Company, Ltd.
- LPC - Lihue Plantation Company, Ltd.

On the Big Island of Hawaii, Hawaii Electric Light Company (HELCO) is studying the possible addition of capacity at their existing plants at Waiau and Puueo. The presently installed penstocks are capable of handling additional flows, enough to more than double the present installed capacities of 1,100 and 2,250 kilowatts, respectively. The existing diversion works would need to be upgraded, and additional study is needed to determine the effect of additional removal of water from the Wailuku river at these diversion points.

HELCO has also looked into the prospect of restarting the old Union Mill hydroelectric plant (500 kilowatts), but so far has not been able to get a commitment for a firm water supply from Kohala Corporation, which owns the Kohala Ditch system.

Davies Hamakua Sugar Company is interested in utilizing the effluent water from their sugar factory at Haina for hydropower generation. The effluent, amounting to about eight million gallons per day, is currently dumped to a gulch below the factory. The available head is about 300 feet, giving a hydropower potential of about 250 kilowatts.

C. Brewer and Company has looked into the possibility of restarting or relocating its hydroplant at the old Papaikou Mill. However, the equipment is in poor condition, the water system is no longer intact, and the present location is subject to flooding. C. Brewer therefore has no plans at the present time to reactivate it. A new diversion system on Honolii, Pahoehoe, and Kapue Streams could increase the capacity of the site. Additional field work would be required to determine the water available.

On Maui, both Pioneer Mill and Hawaiian Commercial & Sugar (H C & S) are looking into replacement of their old turbines (pre-1920) with newer, more efficient units, and possibly additional capacity. H C & S is proceeding with plans to add 500 kilowatts of additional capacity on the Hamakua Ditch in 1981. They are also studying the old Kolea hydropower site for possible redevelopment.

On Kauai, most of the existing hydropower plants are under study for upgrading. The two Lihue plants could gain additional energy output from repair of existing tunnel and ditch systems, which are believed to have lost some capacity over the years from the accumulation of silt and gravel, and increased leakage. The Waiawa turbine at Kekaha Sugar Co. is very old, and needs replacement by a more efficient unit. Estimates by Amfac are that the output of these three plants could be increased by about 50%, although further field investigations of tunnel-ditch systems are needed to establish this. A small efficiency increase may also be possible at the Waimea Canyon plant, which is under study at this time.

The hydropower plant in Wainiha Valley currently generates 3,600 kilowatts. Alexander and Baldwin, Inc., the parent company of the McBryde Sugar Company which operates the plant, is studying the feasibility of upgrading the diversions and tunnel-ditch system which feed the plant in order to increase output.

Olokele Sugar Company is proceeding with plans to replace its 500 kilowatt Kaumakani turbine with a 1,250 kilowatt unit that will double the present annual energy output of the site. The old 500 kilowatt unit will be retained as a spare, to generate additional electricity during high flows.

## 6. Small Hydropower Project Implementation Schedules

The typical timetable between the decision to develop a small hydro project and its operation is about forty (40) months. This includes the time for studies, obtaining permits, securing funding, negotiating with purchasers, and construction and testing of the plant. (Figure 6-1).

Before any decision can be made to develop a hydro plant, the feasibility of such a project must be determined. The first step would be the reconnaissance study of the project. This would be done to justify a detailed feasibility study of the project. The reconnaissance study, requiring two to four weeks and about one-half of one percent of the total project cost, should be a cursory evaluation of the proposed project to determine the attractiveness of pursuing the project and to delineate some of the problems to be encountered in such a pursuit. The present study serves as a reconnaissance-level investigation for sites of prime interest, those with a potential of at least five million kilowatt-hours per year.

A favorable determination in the reconnaissance study would require an in-depth feasibility study of the project. Consulting engineers would be retained at this time as well as financial and legal consultants. A detailed feasibility study would require three to six months for completion. Cost of such a study would be about two to five per cent of the total project cost.

Only after the completion of the feasibility study would there be a decision to implement the plans for the development of the project. This decision would be more than six months after the first move on

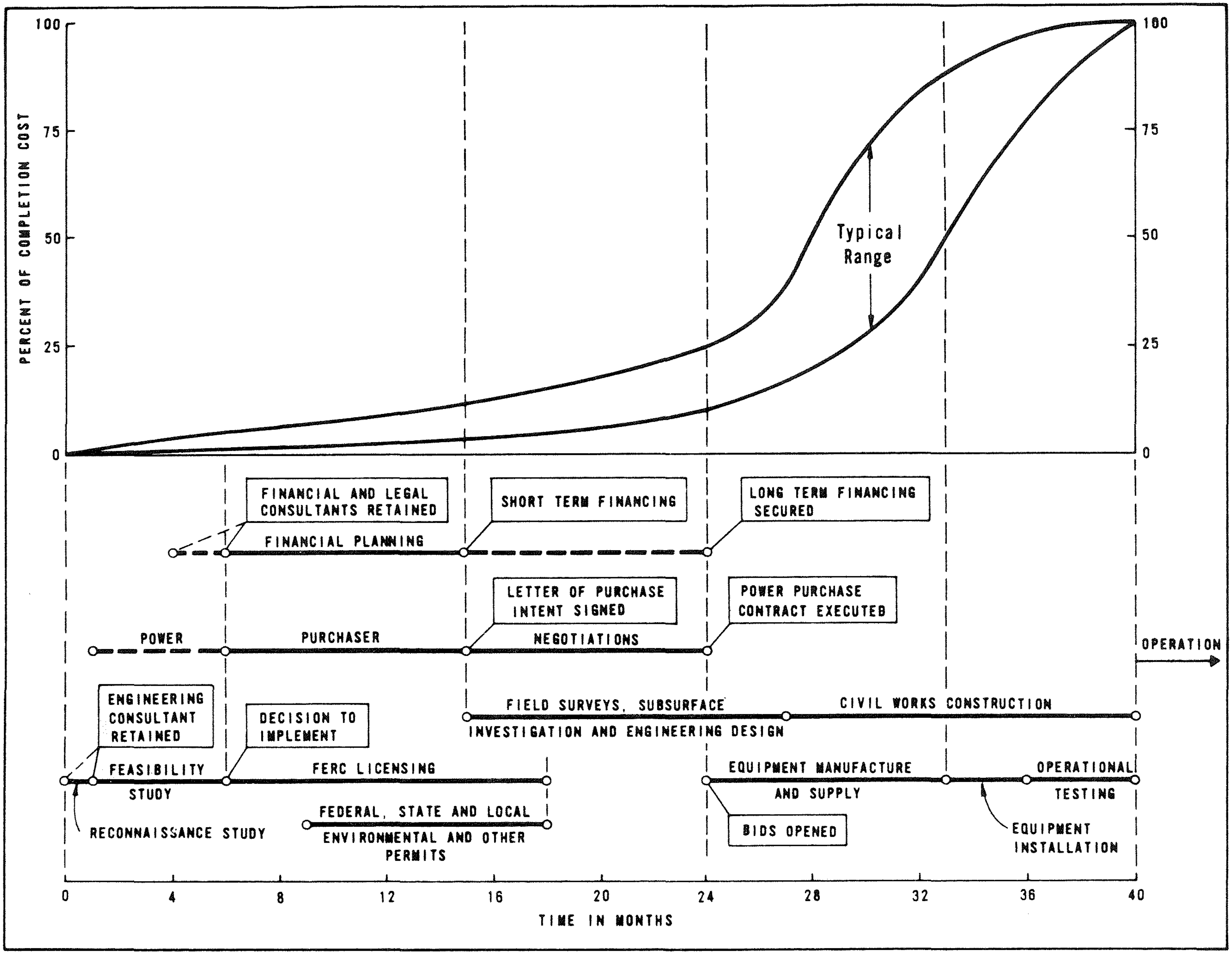


Figure 6-1. Typical Project Implementation Schedule and Expenditure Pattern

Source: <u>Feasibility Studies for Small Scale Hydropower Additions</u>, U. S. Army Corps of Engineers.

the project is made. With the decision to implement the project, financial and legal advice becomes imperative. The advice is important not only to the financial planning that must be done but also to aid in obtaining the required licenses, permits and approvals from the various agencies in the federal, state and local governments.

The development of financial plans requires about nine months. Until these plans are made financing for the project cannot be obtained. The financial plans include the amount and timing of capital required. Short term financing would be required for the pre-construction phase and long-term financing arrangements must be made for the construction and start-up phases.

Implementation of plans to develop hydro power requires approval from all levels of government in the forms of licenses and permits. Completing the Federal Energy Regulatory Commission's (FERC) requirements alone would take about one year. The Energy Security Act of 1980, however, provides for exemptions from FERC licensing of small hydropower projects with an installed capacity of five megawatts or less. With the exception of the Wailua River Basin, all of the hydropower projects identified in Hawaii meet this criterion for exemption. The FERC rules further provide for an automatic granting of a licensing exemption if FERC fails to act within 120 days of receiving an exemption application.

If funding is to be through public equity, the Securities Exchange Commission (SEC) may become involved and time should be allowed for the development and registration of the prospectus and review by the SEC.

Federal, state and local governments have each developed their body of requirements that must be met. Environmental consideration is required at all levels. Local utility regulations must be met as must local requirements such as zoning, shoreline management, etc. associated with the project.

Purchasers for the power must be sought. "Letters of Intent" to purchase the power generated should be signed at about the time that the short term financing arrangements are being made. Negotiations for the power purchase agreements should be conducted while long-term financing is being secured.

Once the short-term financing and the "Letter of Intent" are secured, at about the fifteenth month into the project, field surveys, subsurface investigations and engineering design can be started. About a year should be allotted for this phase. Three quarters of the way through this phase, once the long-term financing is secured and the power purchase contract is executed, bids for the equipment can be opened.

Actual construction of civil works, installation of equipment, and testing would take about 12 to 14 months. Actual operation would begin a little more than three years after the initial studies are implemented.

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## Appendix B. Engineering Analysis and Sample Calculations

The purpose of the engineering analysis is to select a configuration for the hydropower project, calculate the power potential of the site, size the major equipment components and site factors for the subsequent cost analysis, and determine the average annual energy production of the plant.

Topographic map reconnaissance was used to determine the locations of diversion and intake works, penstock path, powerplant site, and transmission line route. Streamflow data were obtained from water resource reports of the U.S. Geological Survey. The local Honolulu office of the Water Resources Division of the USGS provided preliminary flow duration curve parameters for many of the sites. For some sites, particularly those for which flow data extend back only a few years, no statistics were available, and flow duration parameters were calculated using a limited amount of daily flow data. The flow duration curves were adjusted where necessary from the gaging station site to the intake site.

Turbines were sized using the assumed flow duration curves. The low flow was established, usually at the 85-percentile point of the flow duration curve. Mainly, this point is determined by the mechanical limitations of the turbines, which operate efficiently only over a limited range of flows. The low flow used is not intended to represent an environmental limitation on water diversion. Environmental considerations would be addressed in the feasibility study and during the permit process.

The operating flow range of a turbine was assumed to be 40% to 100% of design (maximum) flow. A second turbine was added whose minimum flow is eoual to the design flow of the first turbine if this flow is equaled or exceeded at least 40% of the year. For some sites, it was possible to add a third turbine in this way. Other configurations are possible, as different types of turbines have different operating ranges. Several alternatives for a site would be evaluated and compared in the feasibility study to find the one that is the most economical.

The power capacities of the turbines were then computed using the following equation:

(1) $$P = 0.085 \times Q_{max} \times H_{eff} \times e$$

Where $P$ = power in kilowatts (kw)

$Q_{max}$ = design (maximum) flow through the turbine

$H_{eff}$ = the effective head at a flow of $Q_{max}$

$e$ = the efficiency of the turbine/generator

The efficiency e was assumed to be 85% in the calculations.

The procedure is illustrated in Figure B-1, for the example case of Honolii Stream. In this case, two turbines with the assumed operating range are used. A third turbine might be added to utilize the extreme high flows, but it can be seen from the curve that it would have a very low capacity factor. Further, during very high flows the stream is turbulent and full of debris, and the plant may not be able to operate.

To obtain the average annual energy production, the curve was numerically integrated between the limits of $Q_{MIN}$ and $Q_{MAX}$, using the following equation:

(2)
$$E = \sum_i P_i \times \frac{\Delta P_i}{100} \times 8766$$

Where E = average annual electricity production, kwh

$\Delta P_i$ = increments along the percentile scale; normally, $\Delta P_i$ was taken as 5% increments, or about 438 hours.

$P_i$ = the average power output in the percent increment $\Delta P_i$, as determined by an equation similar to (1).

8766 is the number of hours in an average year (includes 24 extra hours in leap years.)

In determining the power outputs in each increment, the head loss due to friction was determined as a function of penstock flow using the Hazen-Williams equation, assuming a C-factor of 120. The C-factor is a parameter which indicates the relative smoothness of a pipe, that is, its frictional resistance to fluid flow.

A certain amount of downtime is expected, both scheduled and unscheduled. Scheduled downtime is for routine maintenance and might require from 10 to 15 days per year. It is assumed that routine maintenance can be scheduled during low flow periods when the plant is shut down or at minimum output. Unscheduled outages are not taken into account in the calculations, however.

The energy calculations were facilitated by the use of a computer program. A sample output for the case of Honolii Stream follows.

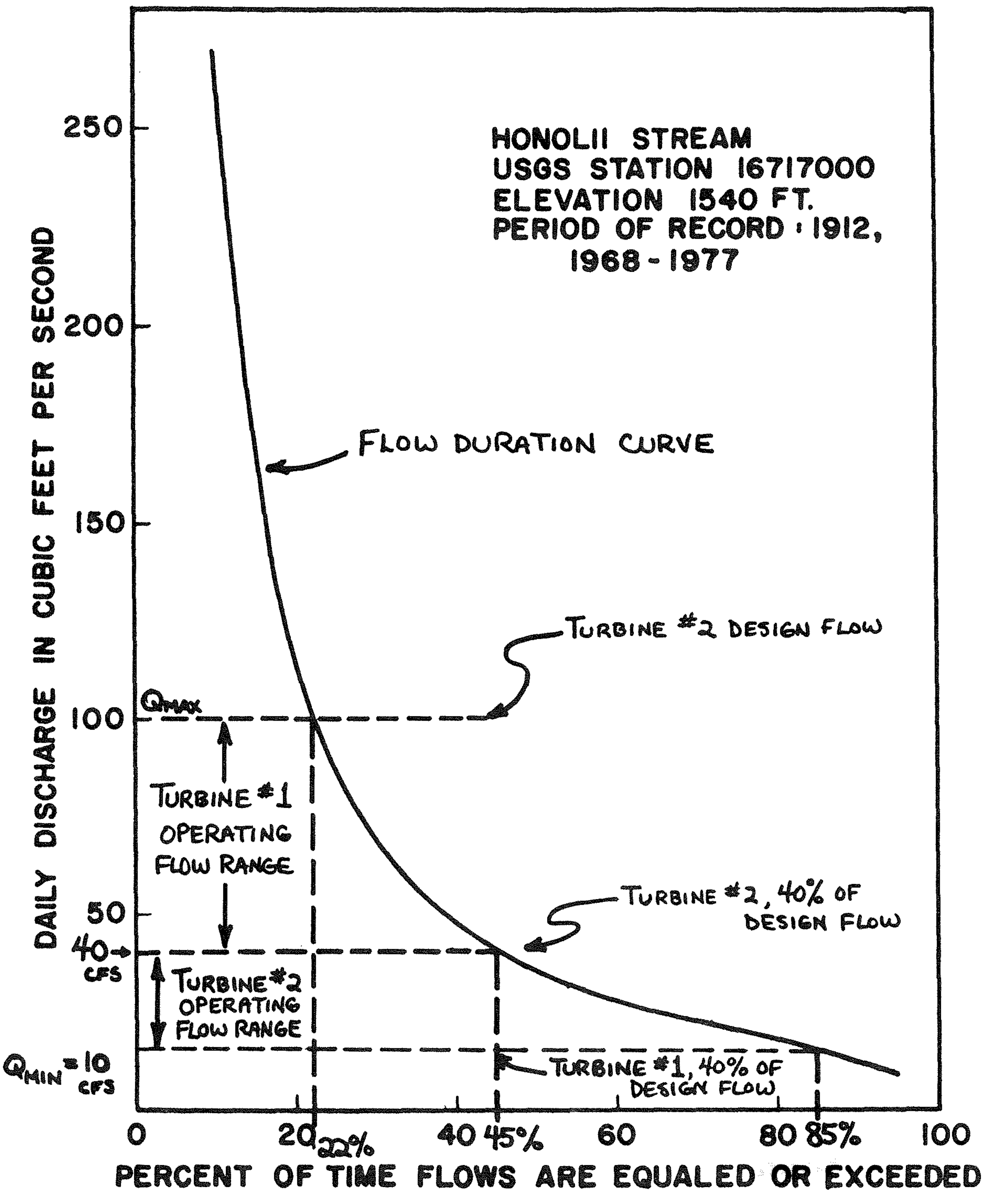



Figure B-1. Sizing of Turbines, Sample Calculation.

Table B-1. Sample Program Output of Annual Energy Calculation.

HYDRO SITE HONOLII STREAM

36-INCH PENSTOCK 8300 FEET LONG

| BIN # | FLOW (CFS) | FRACT. OCCUR. | HRS/YR | FRICTION LOSS(FT) | NET HEAD (FT) | POWER (KW) | ENERGY (KWH/YR) |
|---|---|---|---|---|---|---|---|
| 1 | 100.0 | 0.220 | 1928.5 | 133.3 | 546.7 | 3931 | 7581398 |
| 2 | 94.0 | 0.030 | 263.0 | 118.9 | 561.1 | 3793 | 997430 |
| 3 | 77.0 | 0.050 | 438.3 | 82.2 | 597.8 | 3310 | 1450790 |
| 4 | 63.0 | 0.050 | 438.3 | 56.7 | 623.3 | 2824 | 1237631 |
| 5 | 52.0 | 0.050 | 438.3 | 39.8 | 640.2 | 2394 | 1049311 |
| 6 | 43.0 | 0.050 | 438.3 | 28.0 | 652.0 | 2016 | 883674 |
| 7 | 38.0 | 0.050 | 438.3 | 22.3 | 657.7 | 1797 | 787771 |
| 8 | 34.0 | 0.050 | 438.3 | 18.1 | 661.9 | 1618 | 709284 |
| 9 | 30.0 | 0.050 | 438.3 | 14.4 | 665.6 | 1436 | 629380 |
| 10 | 27.0 | 0.050 | 438.3 | 11.8 | 668.2 | 1297 | 568608 |
| 11 | 24.0 | 0.050 | 438.3 | 9.5 | 670.5 | 1157 | 507181 |
| 12 | 22.0 | 0.050 | 438.3 | 8.1 | 671.9 | 1063 | 465897 |
| 13 | 19.0 | 0.050 | 438.3 | 6.2 | 673.8 | 921 | 403517 |
| 14 | 17.0 | 0.050 | 438.3 | 5.0 | 675.0 | 825 | 361657 |
| TOTALS | | | 7451.1 | | | | 17633528 |

## Appendix C. Hydropower Project Financial Analysis

A project cost estimate was made for each selected hydropower site. The capital cost items were divided into two categories, electromechanical features and civil construction work. Included in the electromechanical features category were the turbine/generators, station electrical equipment, miscellaneous power plant equipment, and transmission lines.

The civil construction costs included site preparation work, powerhouse construction, valves and miscellaneous piping, penstock, and access roads. The site preparation work was further divided into drainage systems, erosion control, final grading, and environmental controls. Included in the powerhouse construction costs were structural work excavations, foundation, and switchyard civil construction costs. The cost of the diversion works and intake screens were not delineated in separate categories, but included as miscellaneous equipment.

Except for the penstock, access roads, structural work, and excavation, all costs were estimated using standardized planning and cost estimating curves of the U.S. Army Corps of Engineers (COE).[1] The cost estimates for the turbine/generators were based on the installation of horizontal Francis-type turbines. The COE cost estimating curves are based on July 1978 cost levels. These costs were escalated by a factor of 1.18 according to the increase in the ENR construction cost index to October 1980. Civil construction costs only were further escalated by a factor of 1.3, to reflect increased construction costs over mainland-based estimates.

[1] Feasibility Studies For Small Scale Hydropower Additions, A Guide Manual. Hydrologic Engineering Center, and Institute For Water Resources. U.S. Army Corps of Engineers, July, 1979.

Other costs were estimated as follows:

1. Penstock costs were estimated assuming the use of cement-mortar lined and coated steel pipe (or "concrete cylinder pipe"). Penstock is assumed to be buried because of the potential for vandalism. However, this may not be a problem in some cases, and significant cost savings are possible with surface installation.
2. Access roads are assumed to be 12 feet wide, with crushed rock or coral surface course, at a cost of $30 per linear foot. In some areas, it may be sufficient to construct a lower quality road at least part of the way, or to utilize existing dirt roads, with consequent cost savings.
3. Structural work - $100 per square foot of plant area.
4. Excavations - $30 per cubic yard, assuming that a significant portion of the excavations will be in rock or rocky soils.
5. Diversion works, intake screen - lump sum, $150,000.
6. Contingencies - 20% of the total equipment and construction costs. Contingencies include an allowance of 10% for interest during construction, assuming a construction period of about one year.
7. Indirect Costs - 20% of the total equipment and construction costs and contingencies. Approximate breakdown of indirect costs includes:
    - Feasibility study - 2%
    - License and/or permit applications - 2%
    - Engineering and design - 10%
    - Construction management - 5%
    - Administration - 1%

The total project cost was input to a computer program to find the breakeven price of the hydropower. The breakeven price was determined to be the price per kilowatt-hour at which the present value of the sale of electricity, over the economic life of the plant, would be equal to the present value of the cost of constructing and maintaining the plant over the same period. The analysis used standard net present value techniques. The major assumptions used were the following:

- Economic life of project - 20 years. This is merely the period assumed in order to recover the initial capital investment. Additional time will be required to gain a return-on-investment. However, for this study, no ROI was assumed. The physical life of the plant will be much longer, typically 50 years or more.
- Annual operating and maintenance costs - 1.2% of the total project cost, the first year of operation; for each subsequent year, O & M costs are assumed to escalate 6% per year.

There were two variable parameters in the analysis, the interest rate and the rate of escalation of the value of the electricity produced by the hydroplant.

The following values for these parameters were used:

- Interest rate - 8%, 12%, 16%
- Energy value escalation rate - 0%, 10%, 20% (per year)

The results were interpolated to produce continuous graphs showing the breakeven cost versus energy value escalation for the three different interest rates. These graphs are included in Appendix D.

A sample computer output follows for the case of Honolii Stream, project cost $4.5 million, interest rate of 12%, and 6% energy value escalation. The breakeven point was determined to be $0.029 per kilowatt-hour.

The breakeven price for hydropower is the initial price for the power. In order to recover all project costs, the initial price must escalate at the assumed rate over the life of the project, in this case 20 years. Thus, for the Honolii example, the initial price of $0.029 per kwh would increase at 6% per year, reaching $0.093 after 20 years. The average price over 20 years would be $0.055 per kwh. This analysis does not address the energy price after 20 years. The hydropower plant is likely to last well beyond its economic life, given proper maintenance. Many installations have been operating for more than 60 years.

This breakeven analysis also does not address the profits to be required by hydropower developers. Return-on-investment (ROI) targets will differ among companies, and this parameter must be included in financial calculations in the feasibility study, when the developer is identified.

As an indicator of whether the computed costs justify proceeding with a project to the feasibility study stage, these can be compaed to current avoided costs of utility electricity. These were estimated to be:[1]

- Kauai - $0.045/kwh
- Molokai - $0.065/kwh
- Maui - $0.065/kwh
- Hawaii - $0.060/kwh

The State Public Utilities Commission is to determine the rate structure for small power producers under the Federal PURPA regulations. These rates, expected to be established early in 1981, are to reflect the avoided costs of utilities.

[1]Estimates by the Committee on Small Hydroelectric Power Systems. Oahu not included since no sites were identified for the financial analysis.

Table C-1. Sample Program Output, Net Present Worth Analysis.

HONOLII STREAM HYDRO

INTEREST RATE 12.0%
O&M COSTS ESCALATION 6.0%
ENERGY VALUE ESCALATION 6.0%

| K | NPW | BCR |
|---|---|---|
| 0.028 | -0.0491 | 0.9882 |
| 0.029 | 0.0979 | 1.0235 |
| 0.030 | 0.2450 | 1.0588 |

| YR | PWF | CAPITAL COSTS | PRESENT WORTH | RECURR COSTS | PRESENT WORTH | RECURR BENEFITS | PRESENT WORTH | TOTAL PRES WORTH |
|---|---|---|---|---|---|---|---|---|
| 0 | 1.000 | 0.4470 | 0.4470 | | | | | -0.4470 |
| 1 | 0.893 | 0.6705 | 0.5987 | | | | | -0.5987 |
| 2 | 0.797 | 3.3525 | 2.6726 | | | | | -2.6726 |
| 3 | 0.712 | | | 0.0536 | 0.0382 | 0.5104 | 0.3633 | 0.3251 |
| 4 | 0.636 | | | 0.0569 | 0.0361 | 0.5410 | 0.3438 | 0.3077 |
| 5 | 0.567 | | | 0.0603 | 0.0342 | 0.5735 | 0.3254 | 0.2912 |
| 6 | 0.507 | | | 0.0639 | 0.0324 | 0.6079 | 0.3080 | 0.2756 |
| 7 | 0.452 | | | 0.0677 | 0.0306 | 0.6444 | 0.2915 | 0.2608 |
| 8 | 0.404 | | | 0.0718 | 0.0290 | 0.6830 | 0.2759 | 0.2469 |
| 9 | 0.361 | | | 0.0761 | 0.0274 | 0.7240 | 0.2611 | 0.2336 |
| 10 | 0.322 | | | 0.0807 | 0.0260 | 0.7675 | 0.2471 | 0.2211 |
| 11 | 0.287 | | | 0.0855 | 0.0246 | 0.8135 | 0.2339 | 0.2093 |
| 12 | 0.257 | | | 0.0906 | 0.0233 | 0.8623 | 0.2213 | 0.1981 |
| 13 | 0.229 | | | 0.0961 | 0.0220 | 0.9140 | 0.2095 | 0.1875 |
| 14 | 0.205 | | | 0.1018 | 0.0208 | 0.9689 | 0.1983 | 0.1774 |
| 15 | 0.183 | | | 0.1079 | 0.0197 | 1.0270 | 0.1876 | 0.1679 |
| 16 | 0.163 | | | 0.1144 | 0.0187 | 1.0886 | 0.1776 | 0.1589 |
| 17 | 0.146 | | | 0.1213 | 0.0177 | 1.1540 | 0.1681 | 0.1504 |
| 18 | 0.130 | | | 0.1286 | 0.0167 | 1.2232 | 0.1591 | 0.1423 |
| 19 | 0.116 | | | 0.1363 | 0.0158 | 1.2966 | 0.1505 | 0.1347 |
| 20 | 0.104 | | | 0.1444 | 0.0150 | 1.3744 | 0.1425 | 0.1275 |
| TOTALS | | | | | 4.1664 | | 4.2643 | 0.0979 |

BENEFIT/COST RATIO = 1.02

APPENDIX D
TABLE OF CONTENTS

Table D-1. TECHNICAL DATA SUMMARY

PROJECT SITE Wailua River Basin, Kauai

| | | | |
|---|---|---|---|
| Plant Capacity | | 11,700 | kw |
| Static Head | | 360 | ft |
| Penstock Length | | 20,000 | ft |
| Average Gradient | | 0.015 | ft/ft |
| Stream Gage of Record | | USGS # 16060000 | |
| Streamflow Parameters | Average Flow | 116 | cfs |
| | $Q_{15}$ | N/A | cfs[1] |
| | $Q_{50}$ | N/A | cfs[1] |
| | $Q_{95}$ | N/A | cfs[1] |
| Turbine/Generator Capacities | 1. 3200 kw<br>2. 8500 kw | | |
| Average Annual Energy Production | | 25,200,000 | kwh |
| Overall Plant Factor | | 25 | % |

Miscellaneous: Ongoing study is being performed by the U.S. Army Corps of Engineers. A preliminary report is expected in early 1981, and additional data will be available.

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

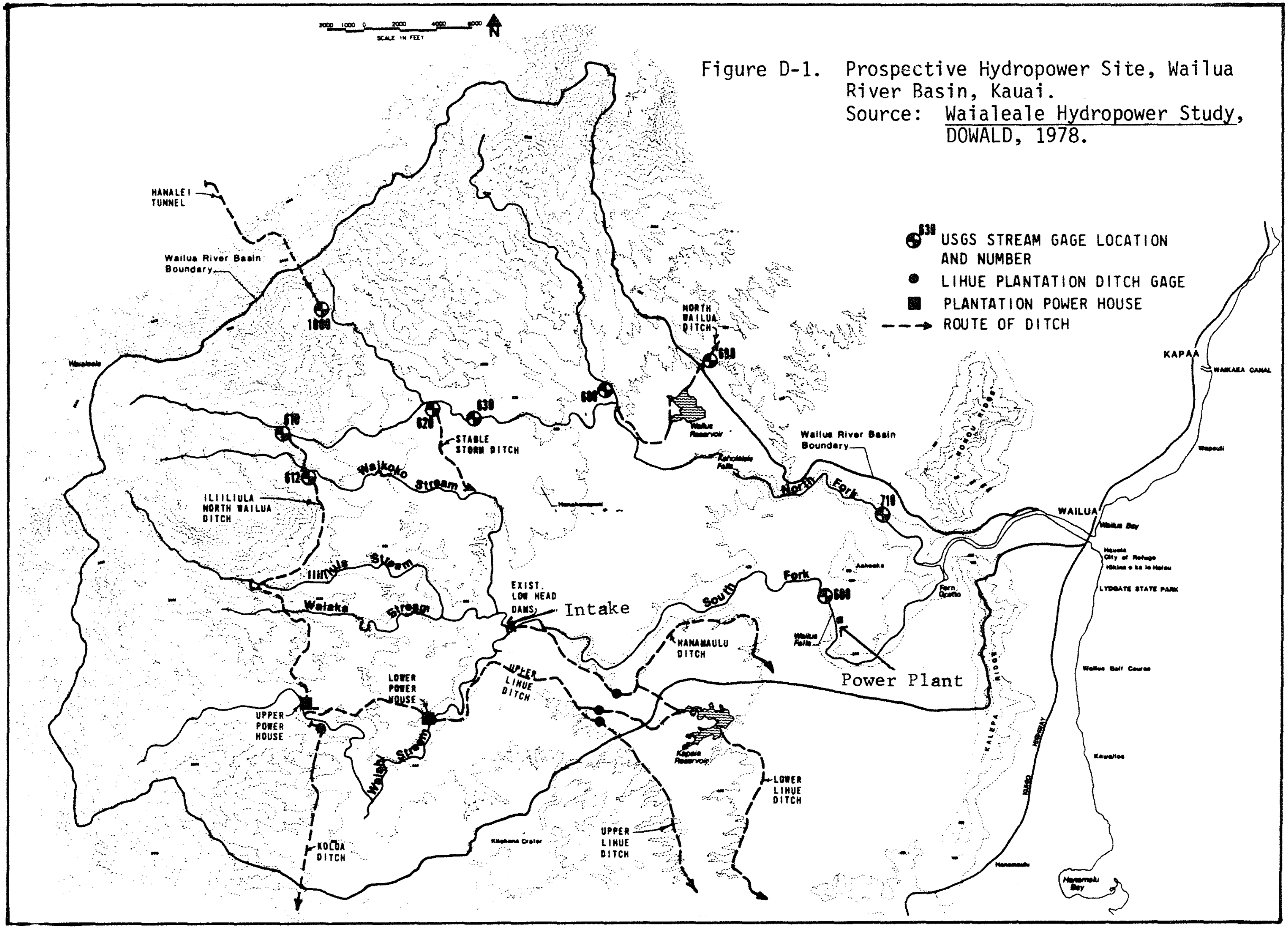



Figure D-1. Prospective Hydropower Site, Wailua River Basin, Kauai.
Source: Waialeale Hydropower Study, DOWALD, 1978.

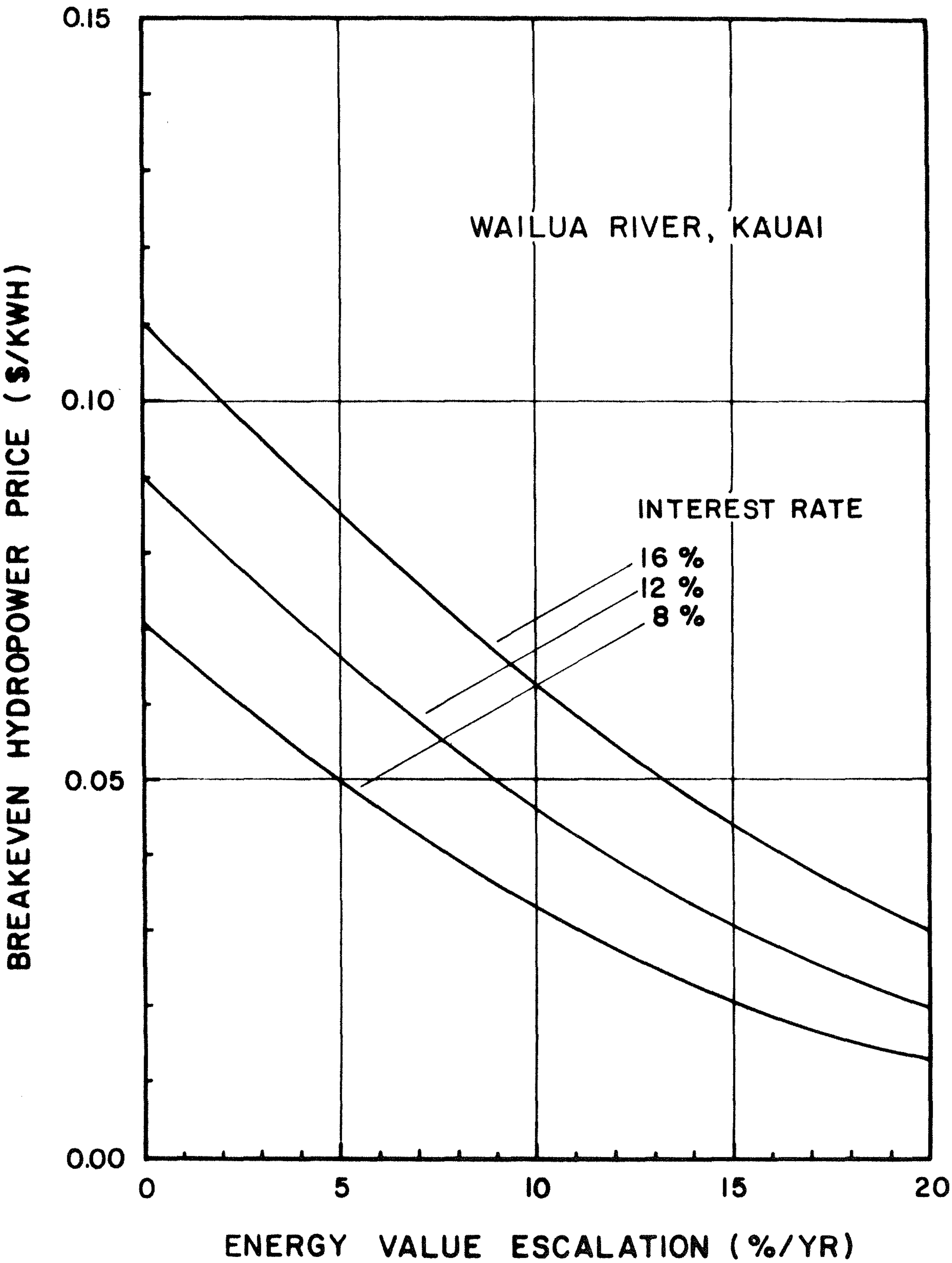



Figure D-2. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Wailua River, Kauai.

Table D-2. TECHNICAL DATA SUMMARY

PROJECT SITE Wainiha Stream, Kauai

| | | | |
|---|---|---|---|
| Plant Capacity | | 3700 | kw |
| Static Head | | 290 | ft |
| Penstock Length | | 7000 | ft |
| Average Gradient | | 0.041 | ft/ft |
| Stream Gage of Record | | USGS # 16108000 | |
| Streamflow Parameters | Average Flow | 139 | cfs |
| | $Q_{15}$ | 204 | cfs[1] |
| | $Q_{50}$ | 79 | cfs[1] |
| | $Q_{95}$ | 55 | cfs[1] |
| Turbine/Generator Capacities | 1. 1600 kw | | |
| | 2. 2100 kw | | |
| Average Annual Energy Production | | 17,400,000 | kwh |
| Overall Plant Factor | | 54 | % |

Miscellaneous:

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

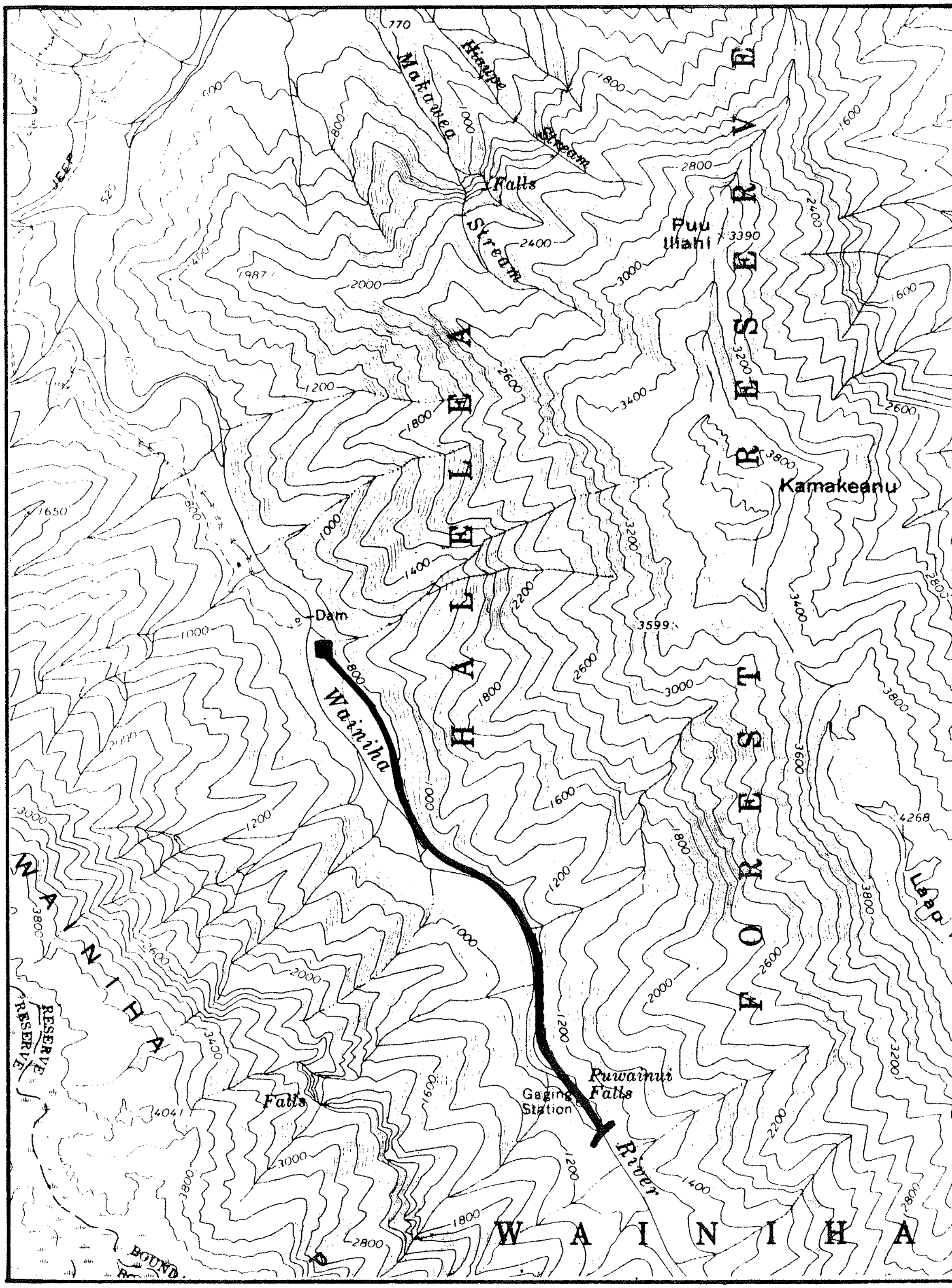



Figure D-3. Prospective Hydropower Site, Wainiha River, Kauai

Scale: 1 in. = 2000 ft.

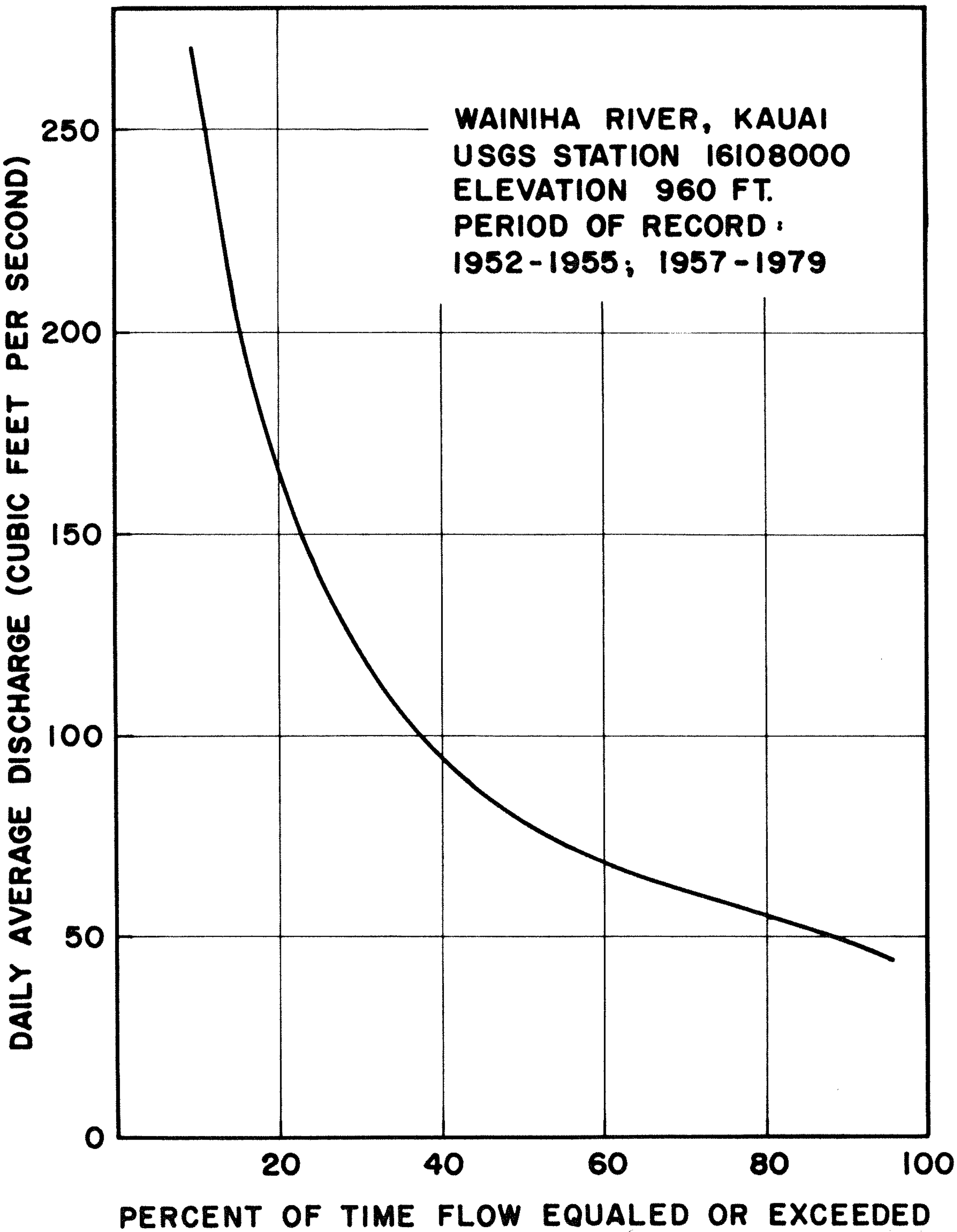



Figure D-4. Flow Duration Curve, Wainiha River, Kauai.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-3. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Wainiha River, Kauai

| | | |
|---|---|---|
| Turbine/Generators | 770,000 | |
| Station Electrical Equipment | 570,000 | |
| Penstock | 1,400,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 235,000 | |
| Access Road | 720,000 | |
| Transmission Line | 270,000 | |
| Miscellaneous Equipment | 250,000 | |
| SUBTOTAL | | 4,245,000 |
| Contingencies[2] | 850,000 | |
| Indirect Costs[3] | 1,020,000 | |
| TOTAL | | 6,115,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance for interest during construction.(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

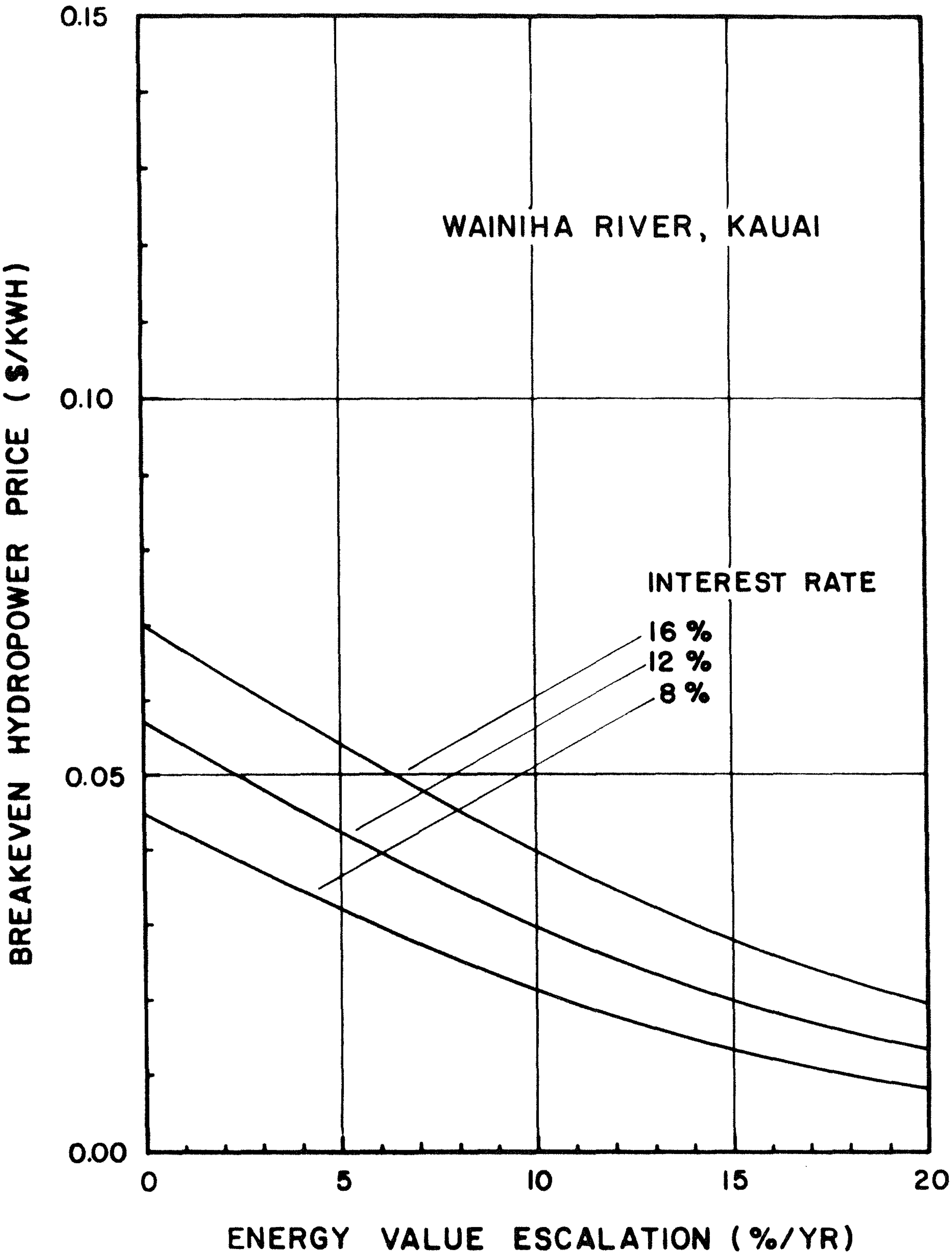



Figure D-5. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Wainiha River, Kauai.

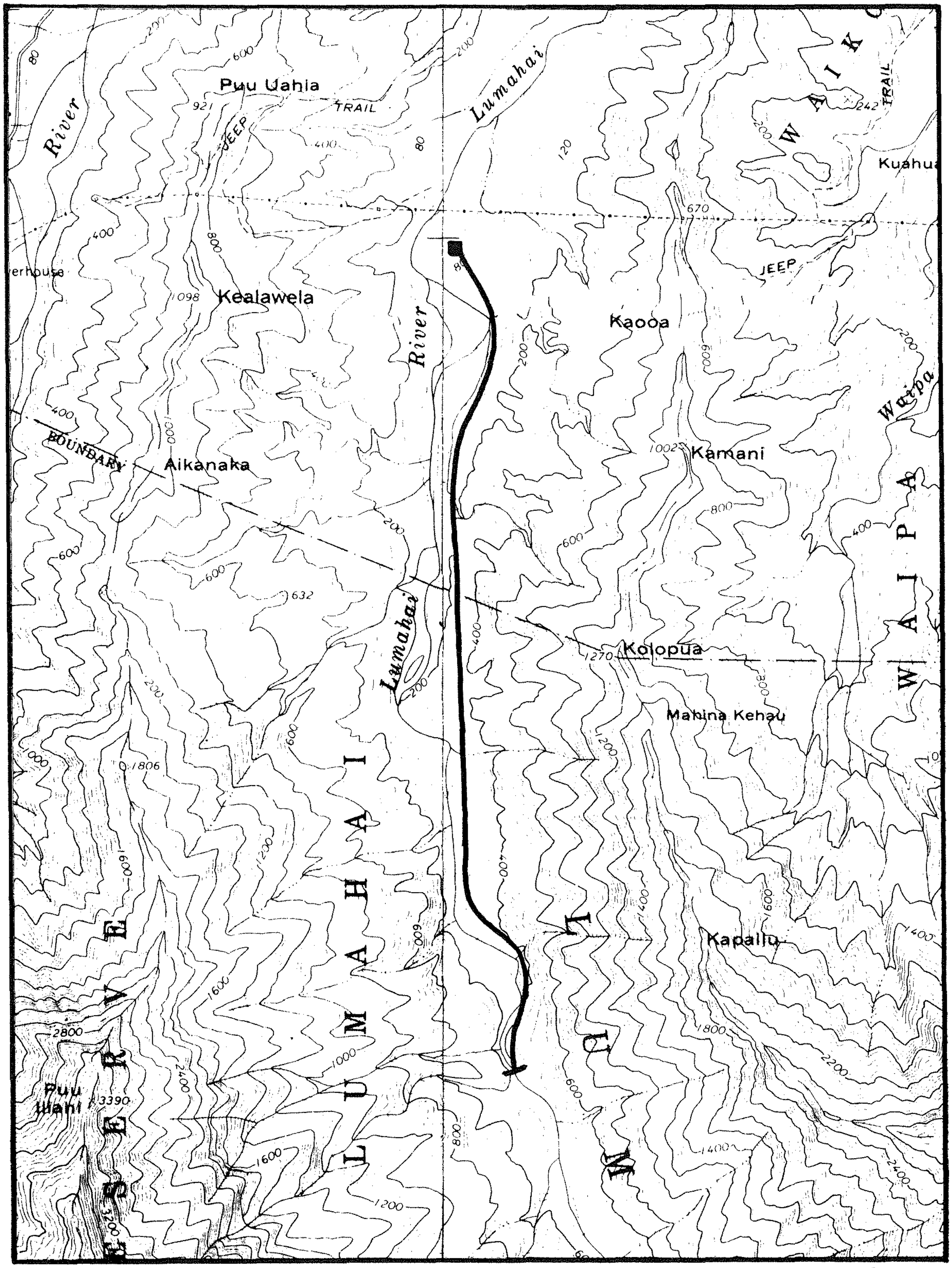
Table D-4. TECHNICAL DATA SUMMARY

PROJECT SITE Lumahai River, Kauai

| | | | |
|---|---|---|---|
| Plant Capacity | | 2,800 | kw |
| Static Head | | 312 | ft |
| Penstock Length | | 11,400 | ft |
| Average Gradient | | 0.027 | ft/ft |
| Stream Gage of Record | | USGS # | 16106000 |
| Streamflow Parameters | Average Flow | 120 | cfs |
| | $Q_{15}$ | 154 | cfs[1] |
| | $Q_{50}$ | 63.5 | cfs[1] |
| | $Q_{95}$ | 31 | cfs[1] |
| Turbine/Generator Capacities | 1. 1500 kw | | |
| | 2. 1300 kw | | |
| Average Annual Energy Production | | 14,100,000 | kwh |
| Overall Plant Factor | | 57 | % |

Miscellaneous:

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-6. Prospective Hydropower Site, Lumahai River, Kauai.

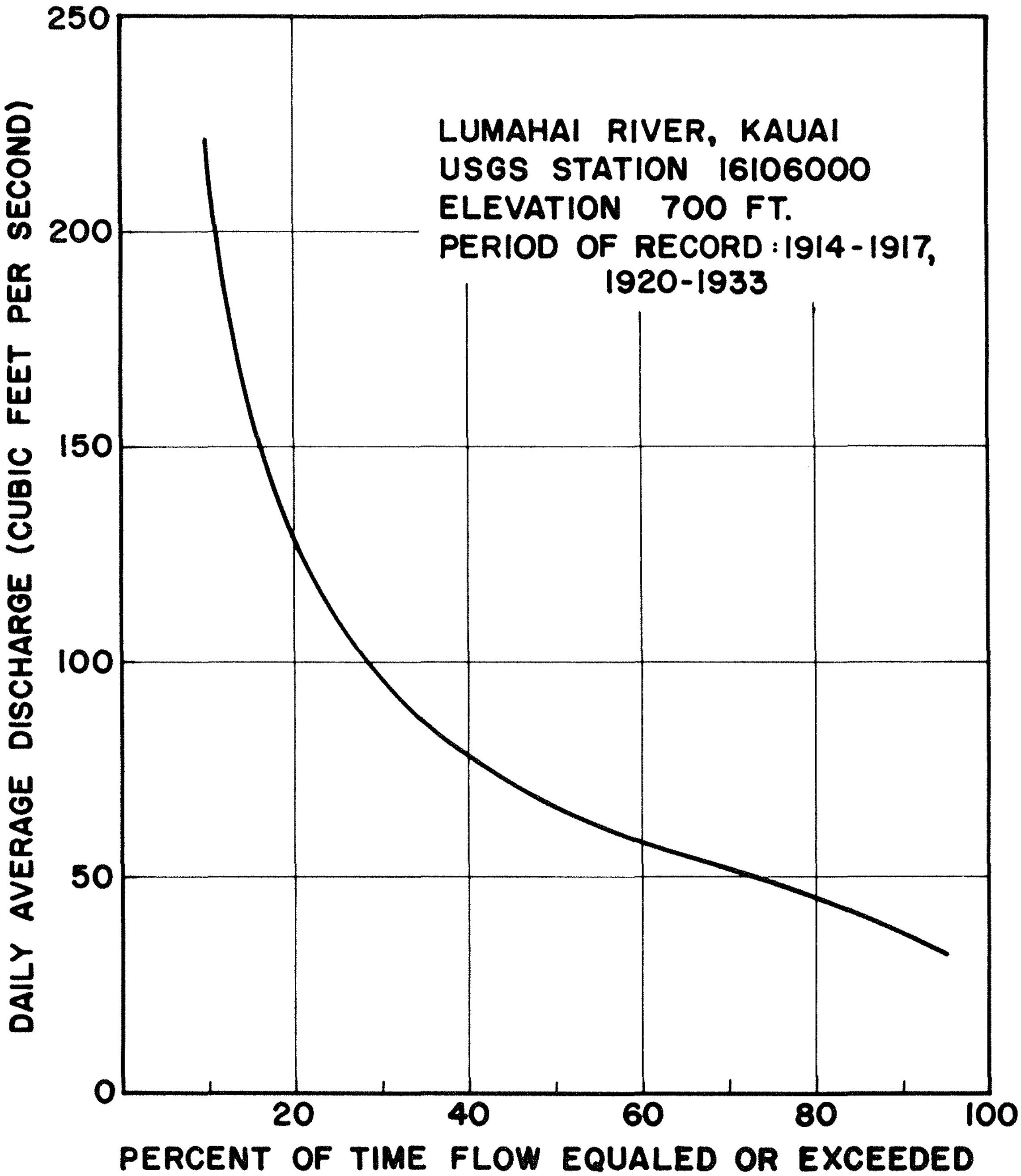



Figure D-7. Flow Duration Curve, Lumahai River, Kauai.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-5. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Lumahai River, Kauai

| | | |
|---|---|---|
| Turbine/Generators | 600,000 | |
| Station Electrical Equipment | 510,000 | |
| Penstock | 2,280,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 225,000 | |
| Access Road | 450,000 | |
| Transmission Line | 0 | |
| Miscellaneous Equipment | 235,000 | |
| SUBTOTAL | | 4,330,000 |
| Contingencies[2] | 865,000 | |
| Indirect Costs[3] | 1,040,000 | |
| TOTAL | | 6,235,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction (1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

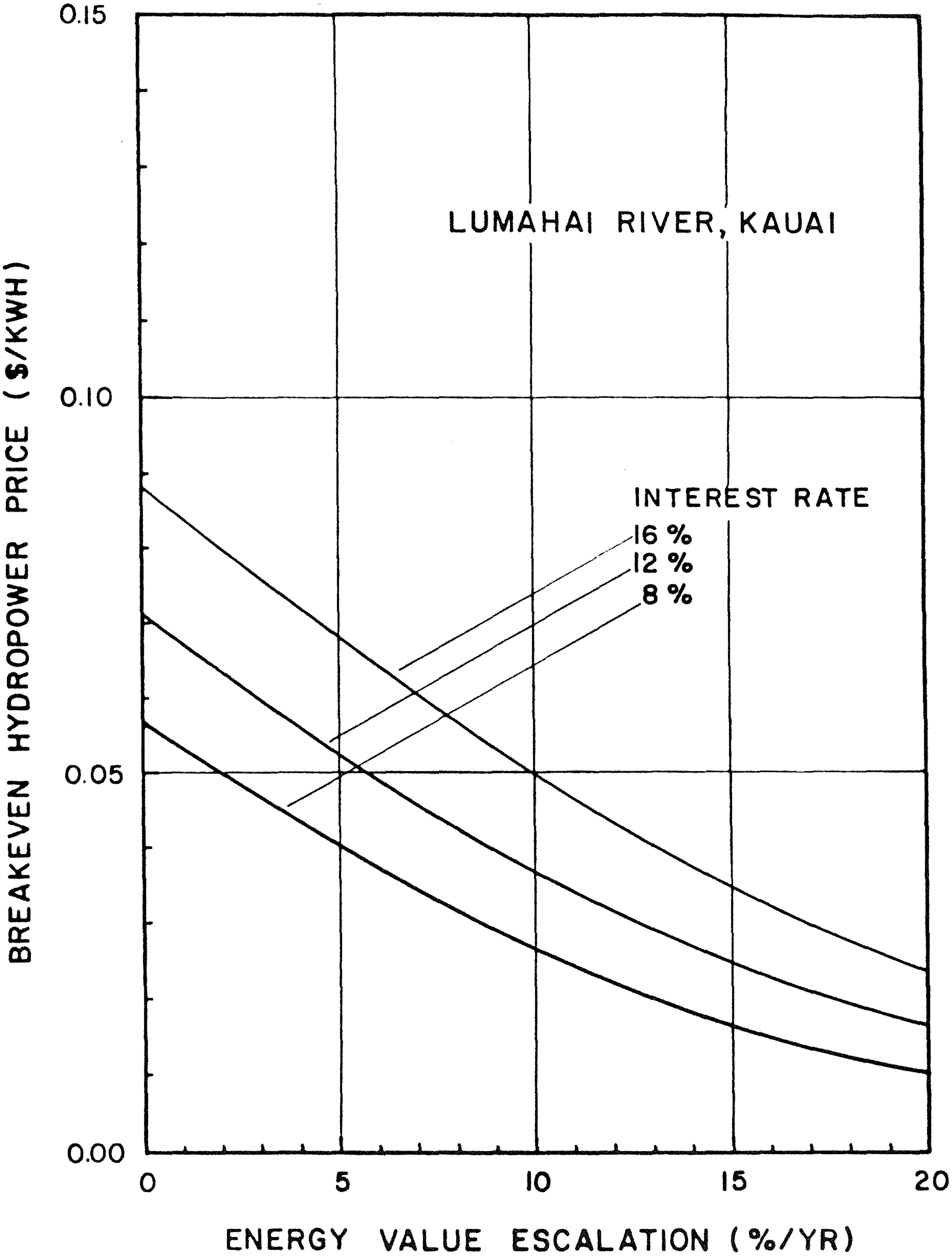



Figure D-8. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Lumahai River, Kauai.

Table D-6. TECHNICAL DATA SUMMARY

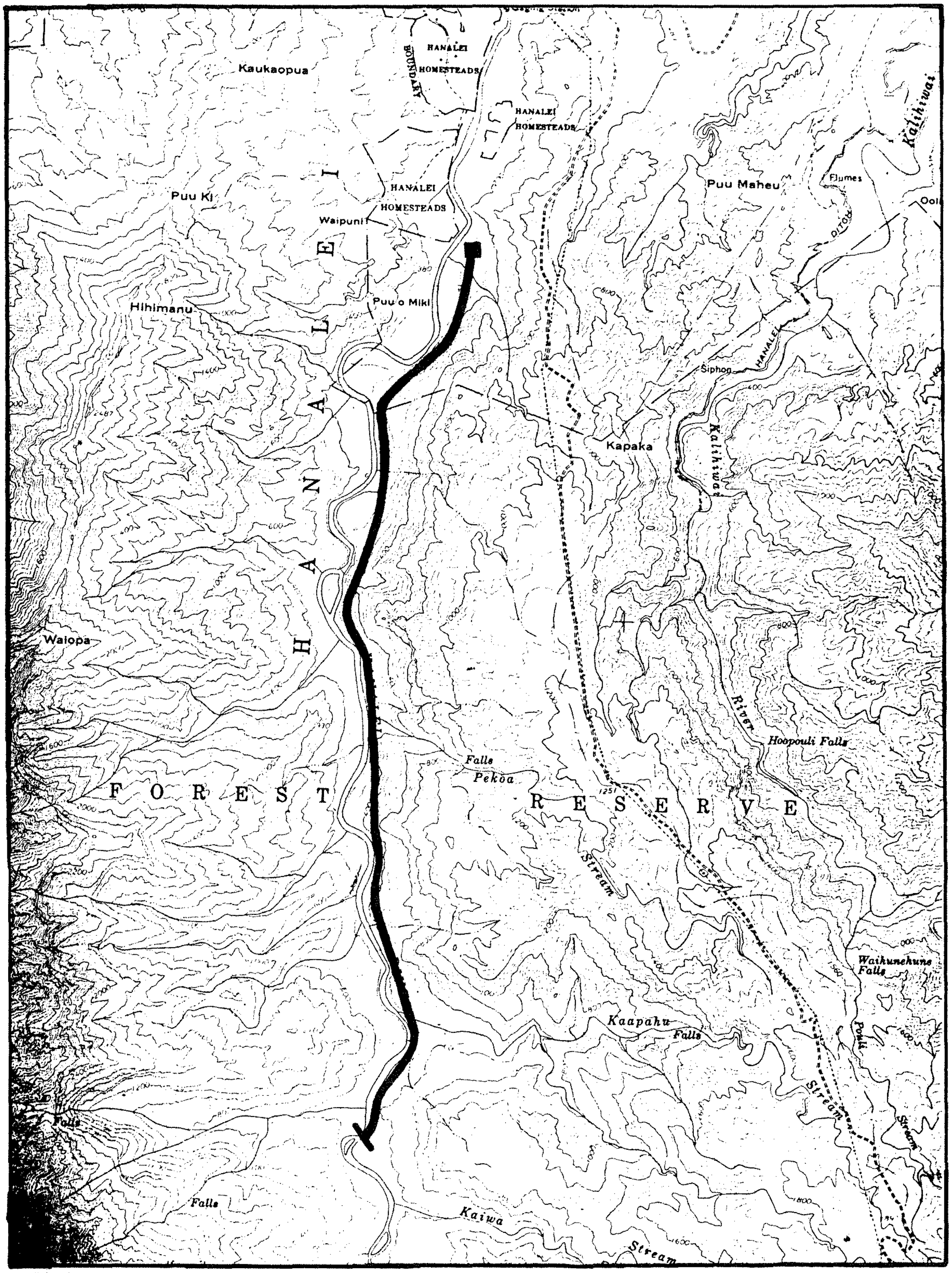
PROJECT SITE Hanalei River, Kauai

| | | | |
|---|---|---|---|
| Plant Capacity | | 2,550 | kw |
| Static Head | | 360 | ft |
| Penstock Length | | 20,000 | ft |
| Average Gradient | | 0.018 | ft/ft |
| Stream Gage of Record | | USGS # | 16101000 |
| Streamflow Parameters | Average Flow | 87 | cfs |
| | $Q_{15}$ | 117 | cfs[1] |
| | $Q_{50}$ | 49 | cfs[1] |
| | $Q_{95}$ | 16 | cfs[1] |
| Turbine/Generator Capacities | 1. 1200 kw | | |
| | 2. 1350 kw | | |
| Average Annual Energy Production | | 11,460,000 | kwh |
| Overall Plant Factor | | 51 | % |

Miscellaneous:

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in = 3100 ft.

Figure D-9. Prospective Hydropower Site, Hanalei River, Kauai.

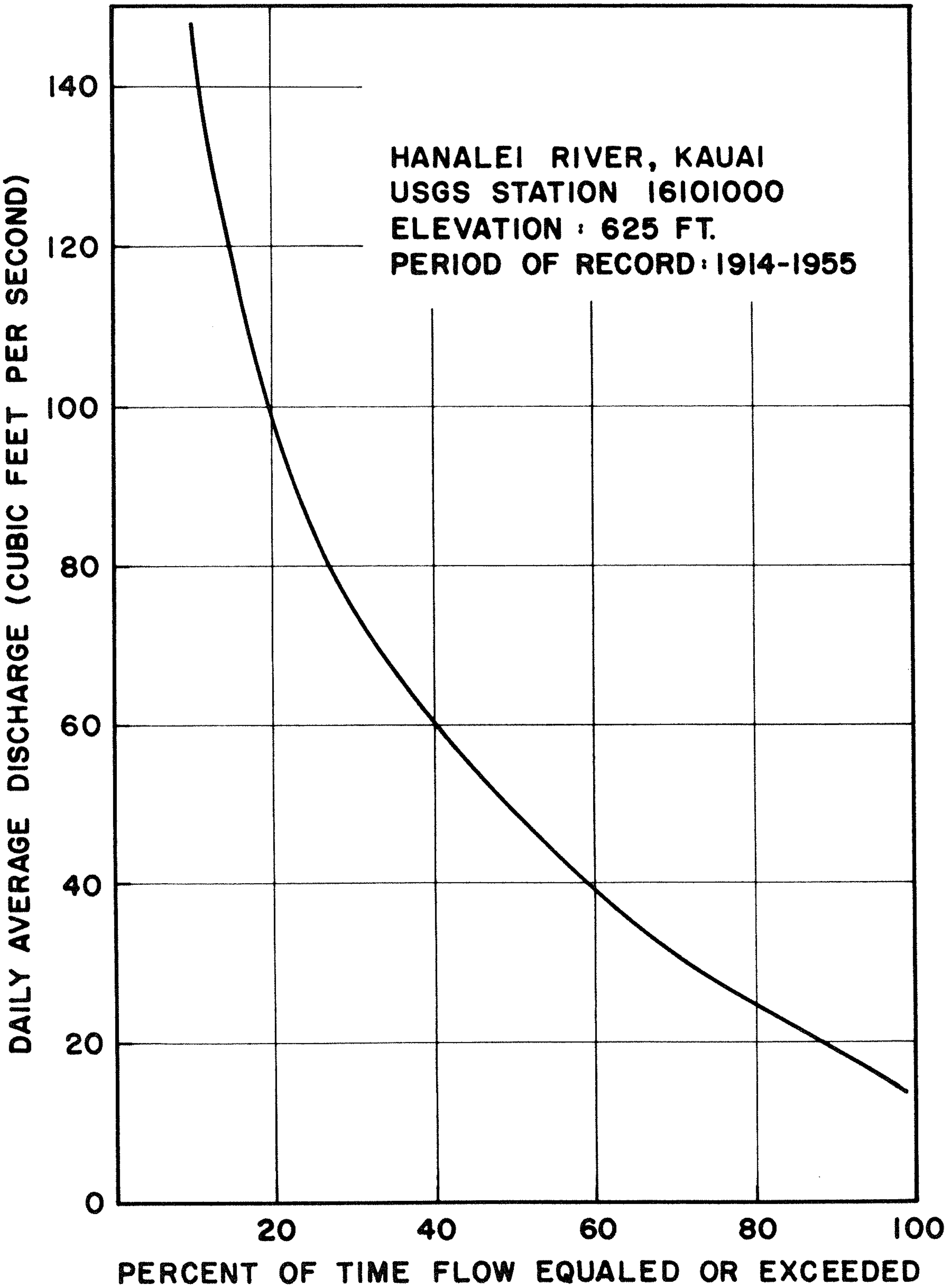



Figure D-10. Flow Duration Curve, Hanalei River, Kauai
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-7. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Hanalei River, Kauai

| | | |
|---|---|---|
| Turbine/Generators | 525,000 | |
| Station Electrical Equipment | 495,000 | |
| Penstock | 4,000,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 225,000 | |
| Access Road | 600,000 | |
| Transmission Line | 30,000 | |
| Miscellaneous Equipment | 230,000 | |
| SUBTOTAL | | 6,135,000 |
| Contingencies[2] | 1,220,000 | |
| Indirect Costs[3] | 1,470,000 | |
| TOTAL | | 8,825,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction (1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

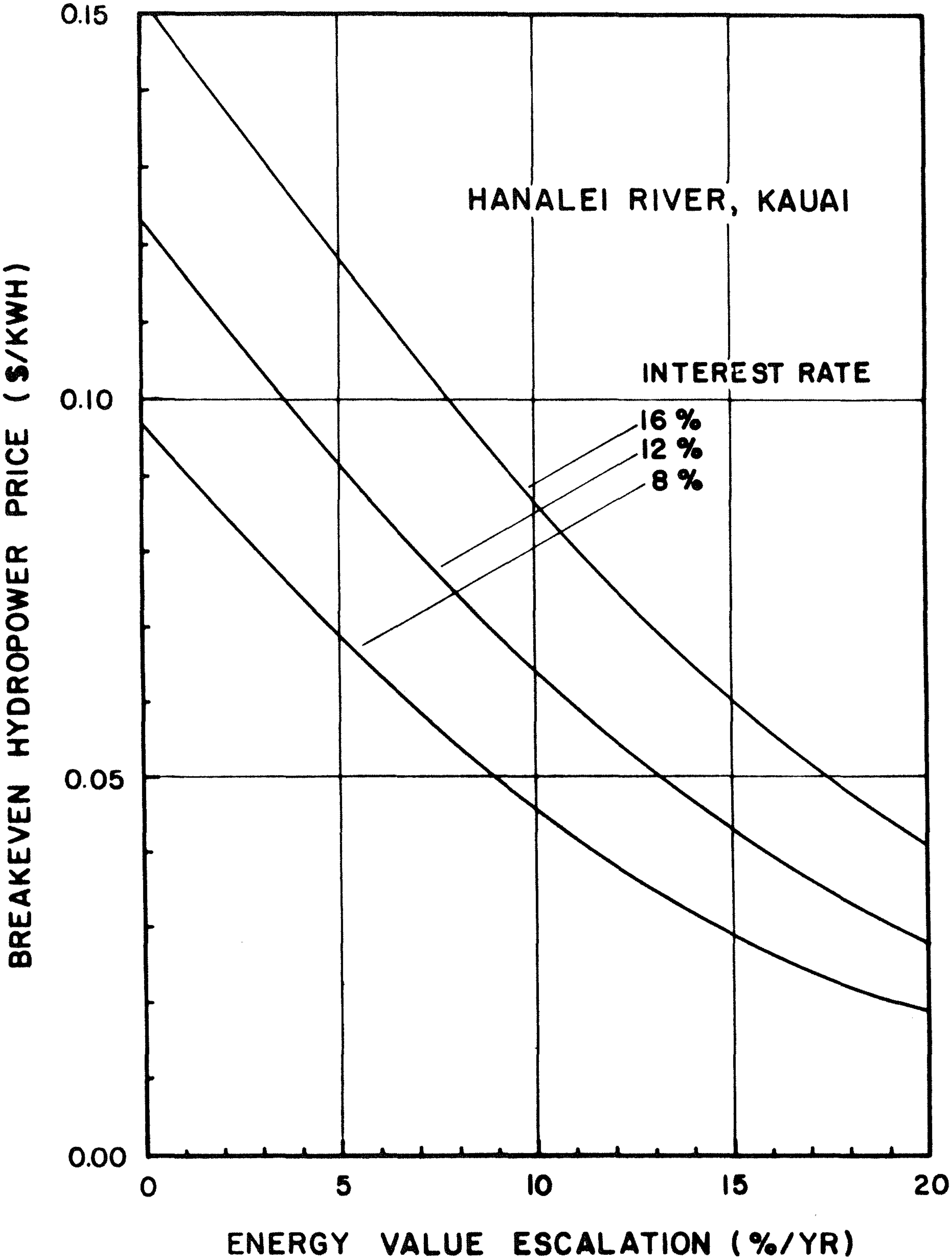



Figure D-11. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Hanalei River, Kauai.

Table D-8. TECHNICAL DATA SUMMARY

PROJECT SITE Puu Lua-Kokee, Phase 1 (Kitano Hydro), Kauai

| | | | |
|---|---|---|---|
| Plant Capacity | | 1,650 | kw |
| Static Head | | 800 | ft |
| Penstock Length | | 9,000 | ft |
| Average Gradient | | 0.089 | ft/ft |
| Stream Gage of Record | | USGS # | 16014000 |
| Streamflow Parameters | Average Flow | 16.9 | cfs |
| | $Q_{15}$ | 31.2 | cfs[1] |
| | $Q_{50}$ | 14.0 | cfs[1] |
| | $Q_{95}$ | 3.4 | cfs[1] |
| Turbine/Generator Capacities | 1. 700 kw | | |
| | 2. 950 kw | | |
| Average Annual Energy Production | | 7,350,000 | kwh |
| Overall Plant Factor | | 51 | % |

Miscellaneous: The project name is the same one given to this site by Amfac and DOWALD, who are jointly investigating hydropower development opportunities in Kokee. The Amfac/DOWALD approach and the approach used in this study are similar and obtain similar results. However, in the Amfac/DOWALD version, a single 1600-kilowatt Pelton turbine is assumed, with an estimated 7.0 million kwh production per year.

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[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

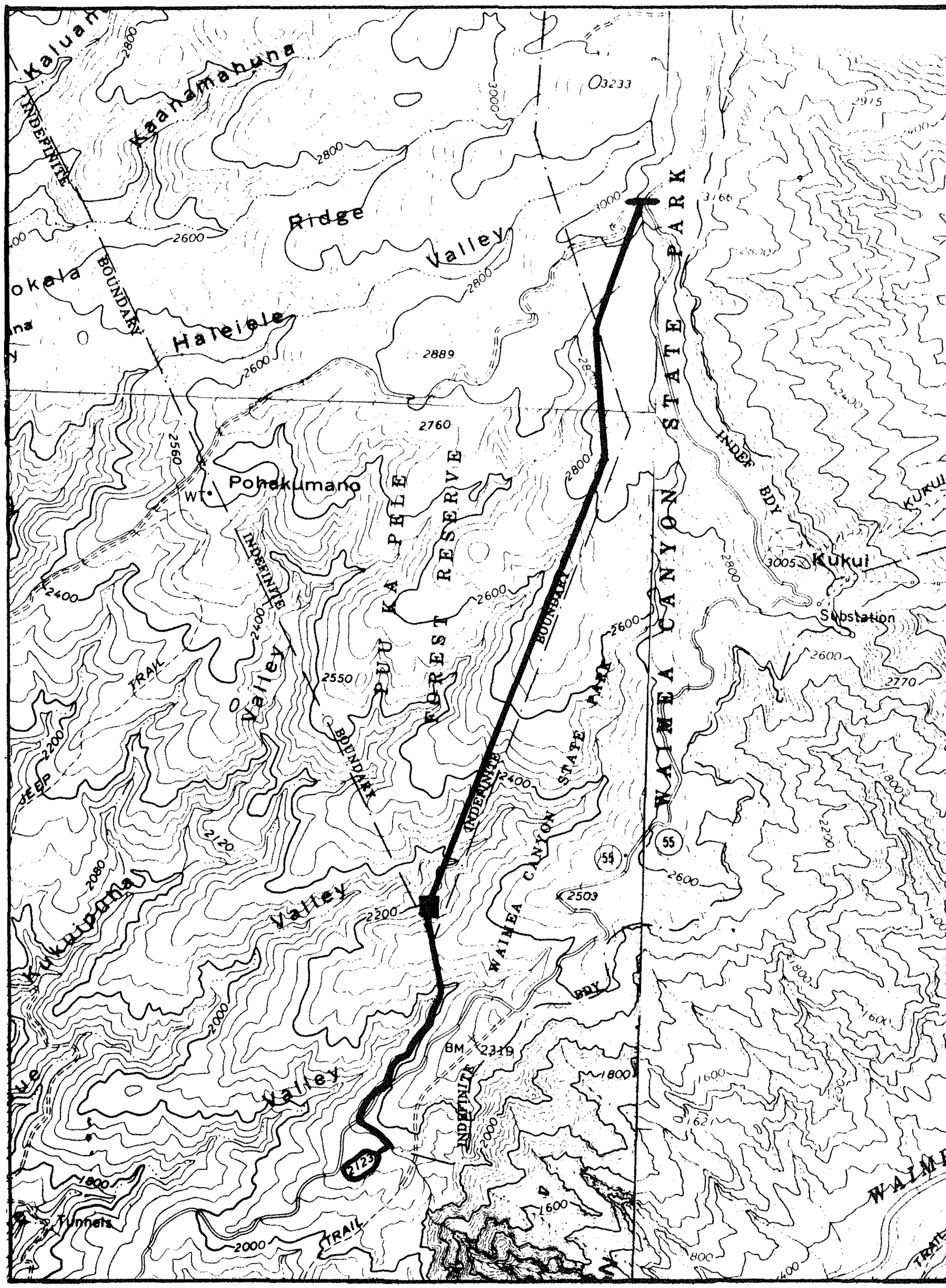



Figure D-12. Prospective Hydropower Site, Puu Lua-Kokee, Phase 1 (Kitano Hydro).

Scale: 1 in. = 2000 ft.

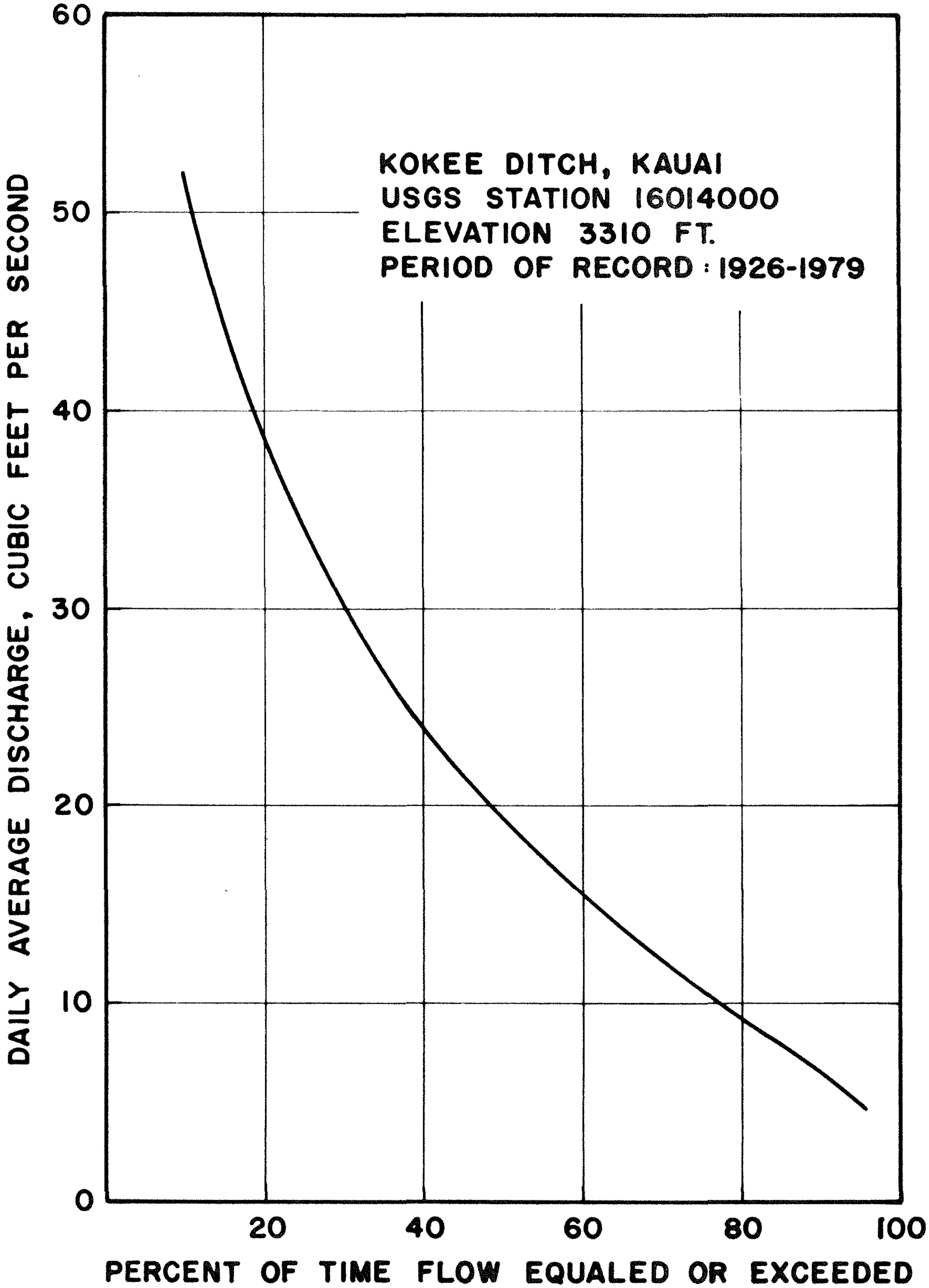



Figure D-13. Flow Duration Curve, Puu Lua-Kokee, Kitano Hydro (Kokee Ditch). (Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-9. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Puu Lua/Kokee, Kauai
(Phase I - Kitano Hydro)

| | | |
|---|---|---|
| Turbine/Generators | 320,000 | |
| Station Electrical Equipment | 295,000 | |
| Penstock | 900,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 145,000 | |
| Access Road | 270,000 | |
| Transmission Line | 30,000 | |
| Miscellaneous Equipment | 215,000 | |
| SUBTOTAL | | 2,205,000 |
| Contingencies[2] | 440,000 | |
| Indirect Costs[3] | 530,000 | |
| TOTAL | | 3,175.000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction (1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

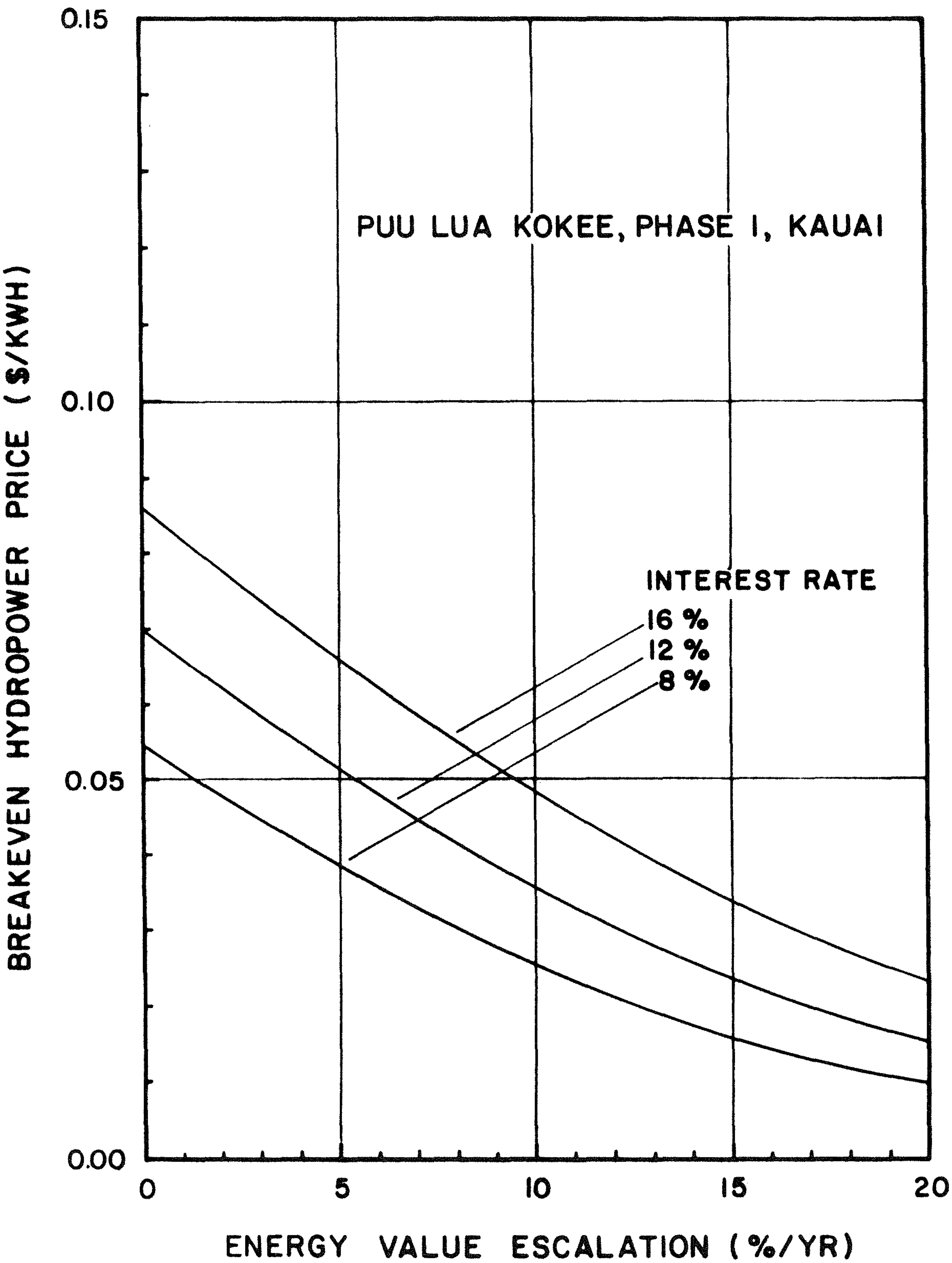



Figure D-14. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Puu Lua-Kokee, Phase 1 (Kitano Hydro), Kauai.

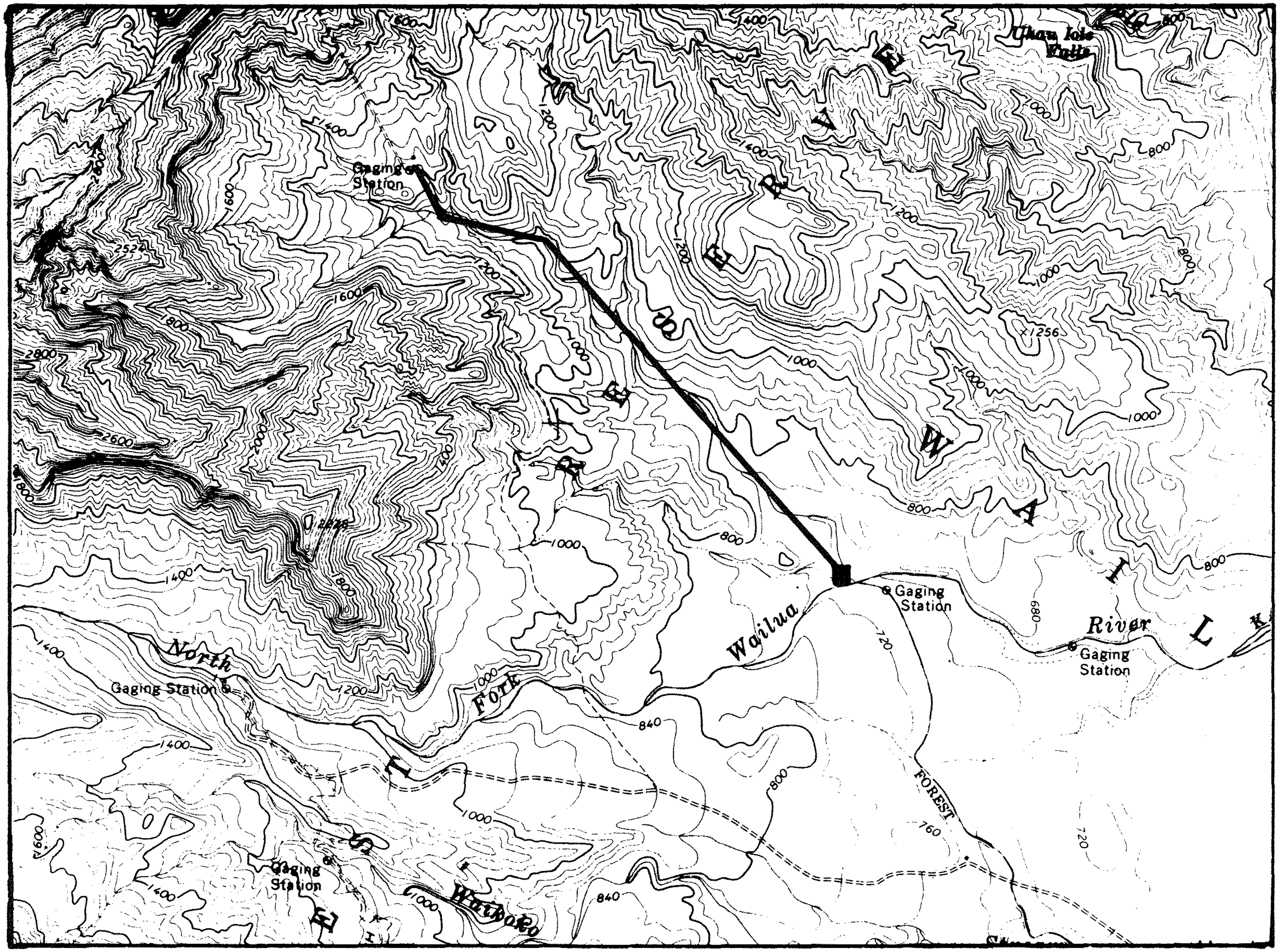
Table D-10. TECHNICAL DATA SUMMARY

PROJECT SITE Hanalei Tunnel, Kauai

| | | | |
|---|---|---|---|
| Plant Capacity | | 1,400 | kw |
| Static Head | | 510 | ft |
| Penstock Length | | 8,000 | ft |
| Average Gradient | | 0.064 | ft/ft |
| Stream Gage of Record | | USGS # 16100000 | |
| Streamflow Parameters | Average Flow | 27.3 | cfs |
| | $Q_{15}$ | 33.1 | cfs[1] |
| | $Q_{50}$ | 28.5 | cfs[1] |
| | $Q_{95}$ | 12.3 | cfs[1] |
| Turbine/Generator Capacities | 1400 kw | | |
| Average Annual Energy Production | | 8,200,000 | kwh |
| Overall Plant Factor | | 67 | % |

Miscellaneous:

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-15. Prospective Hydropower Site, Hanalei Tunnel, Kauai.

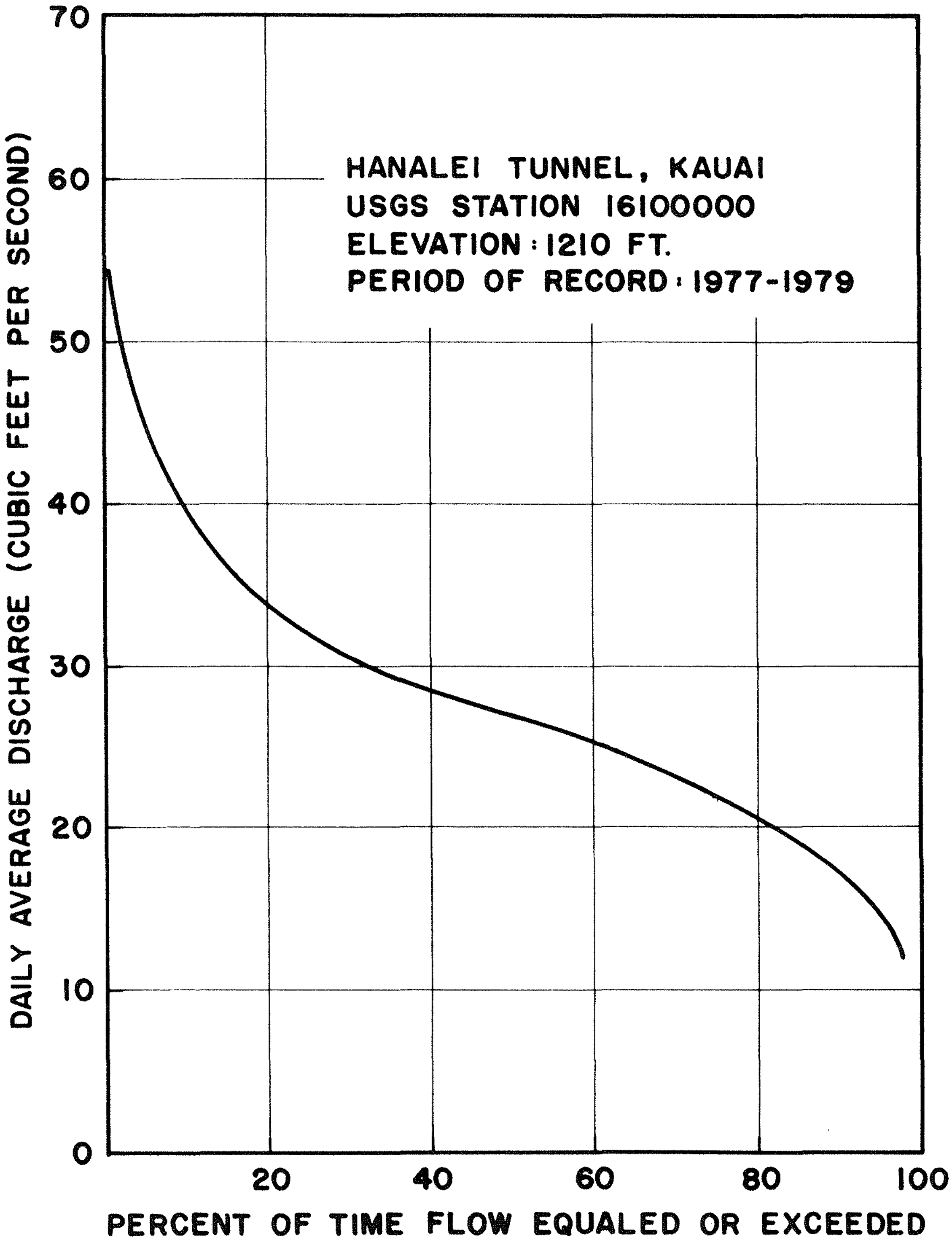



Figure D-16. Flow Duration Curve, Hanalei Tunnel, Kauai.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-11. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Hanalei Tunnel, Kauai

| | | |
|---|---|---|
| Turbine/Generators | 255,000 | |
| Station Electrical Equipment | 285,000 | |
| Penstock | 1,000,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 175,000 | |
| Access Road | 480,000 | |
| Transmission Line | 120,000 | |
| Miscellaneous Equipment | 215,000 | |
| SUBTOTAL | | 2,560,000 |
| Contingencies[2] | 510,000 | |
| Indirect Costs[3] | 620,000 | |
| TOTAL | | 3,690,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

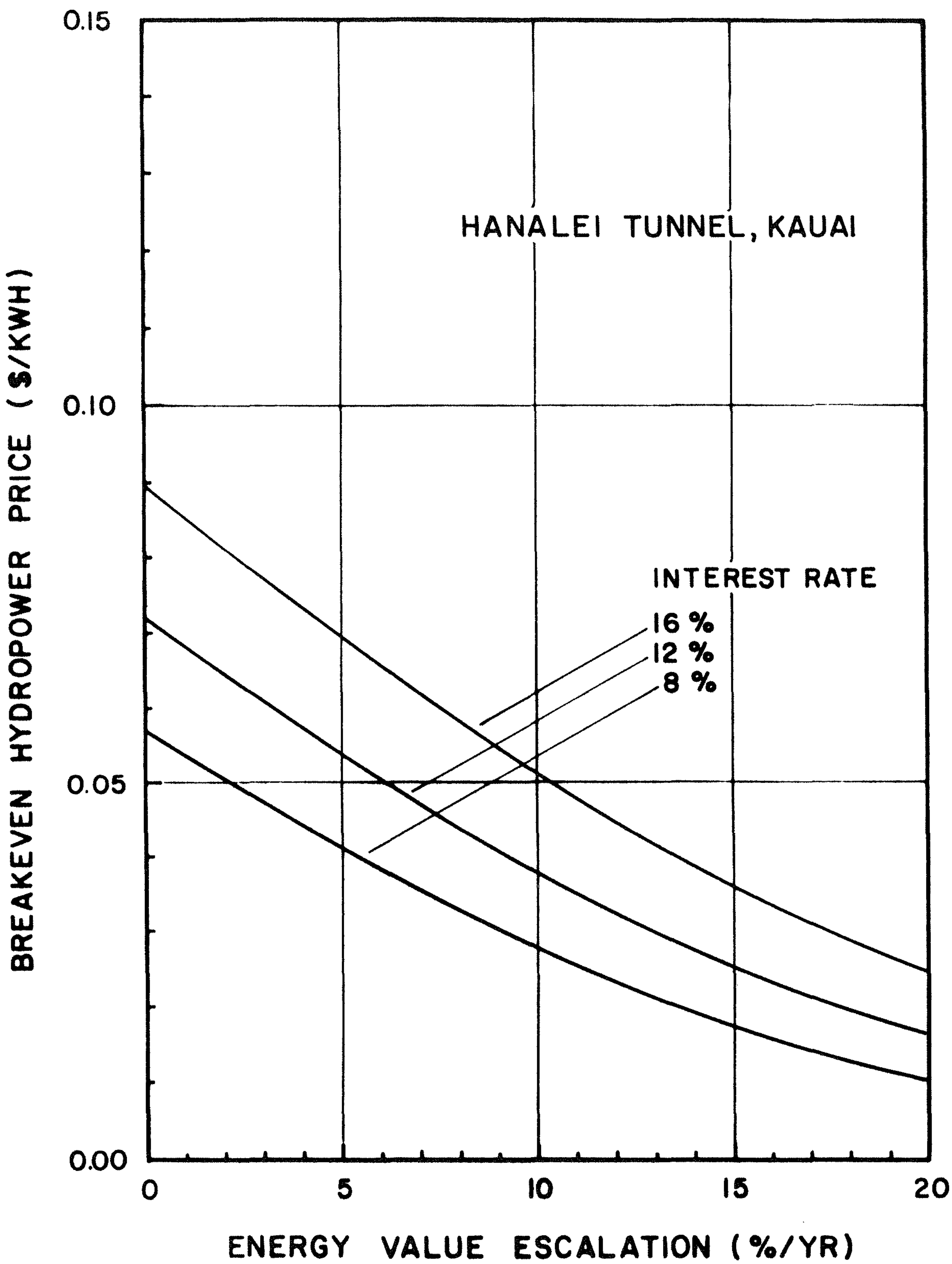



Figure D-17. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Hanalei Tunnel, Kauai.

Table D-12. TECHNICAL DATA SUMMARY

PROJECT SITE Wahiawa Reservoir, Oahu

| | | | |
|---|---|---|---|
| Plant Capacity | | 300 | kw |
| Static Head | | 40 | ft |
| Penstock Length | | 1,400 | ft |
| Average Gradient | | 0.029 | ft/ft |
| Stream Gage of Record | | USGS # | N/A |
| Streamflow Parameters | Average Flow | N/A | cfs |
| | $Q_{15}$ | 120 | cfs[1] |
| | $Q_{50}$ | 75 | cfs[1] |
| | $Q_{95}$ | 20 | cfs[1] |
| Turbine/Generator Capacities | 1. 150 kw | | |
| | 2. 150 kw | | |
| Average Annual Energy Production | | 1,650,000 | kwh |
| Overall Plant Factor | | 63 | % |

Miscellaneous:

Streamflow parameters in this case represent the outflow from Wahiawa Reservoir. There is no USGS station; the flow parameters are estimated from data provided by Waialua Sugar Company.

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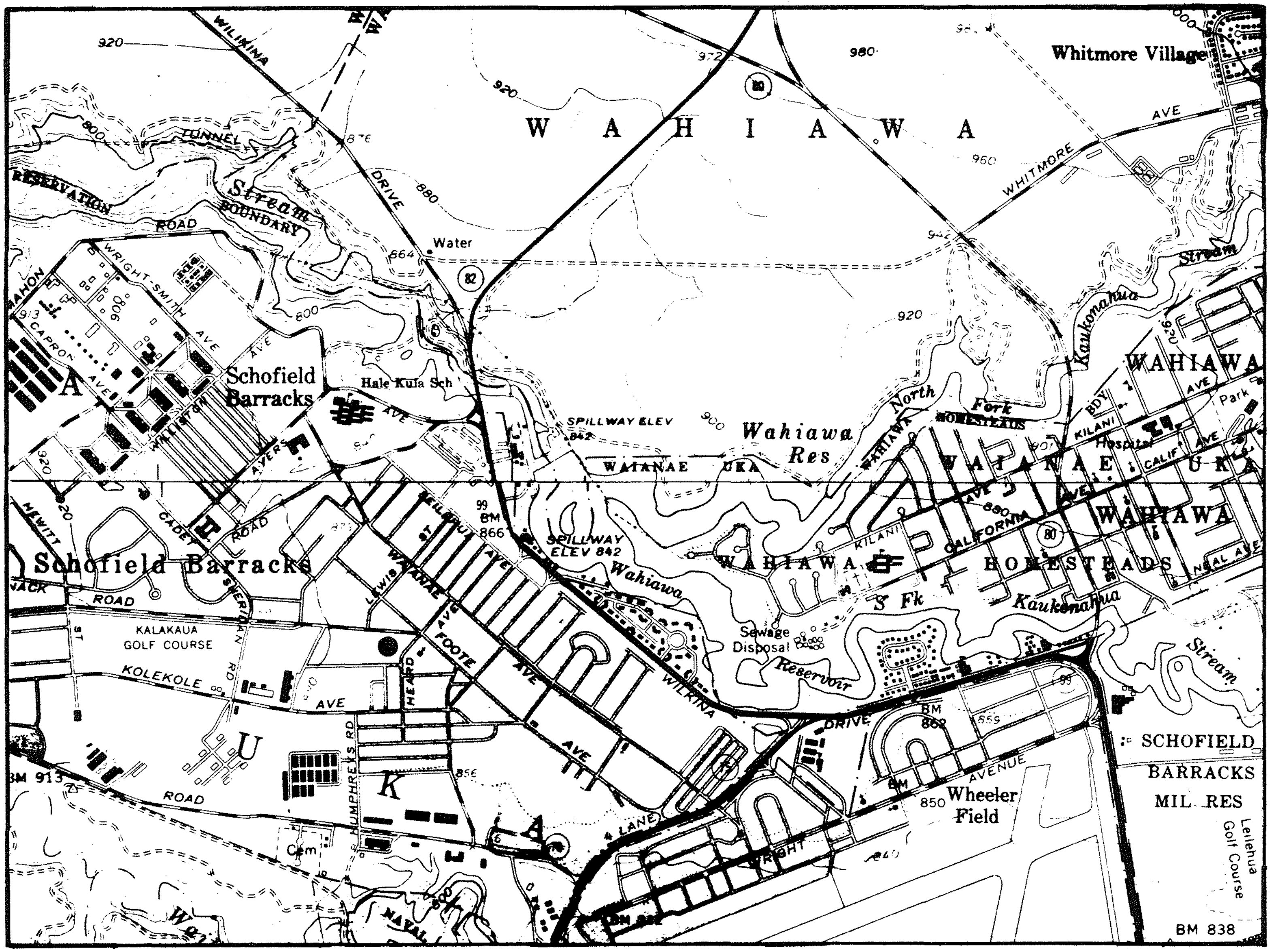
[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-18. Prospective Hydropower Site, Wahiawa Reservoir, Oahu.

Table D-13. TECHNICAL DATA SUMMARY

PROJECT SITE Halawa Stream, Molokai

| | | | |
|---|---|---|---|
| Plant Capacity | | 2100 | kw |
| Static Head | | 1000 | ft |
| Penstock Length | | 3000 | ft |
| Average Gradient | | .333 | ft/ft |
| Stream Gage of Record | | USGS # 16400000 | |
| Streamflow Parameters | Average Flow | 29.0 | cfs |
| | $Q_{15}$ | 45 | cfs[1] |
| | $Q_{50}$ | 14 | cfs[1] |
| | $Q_{95}$ | 4 | cfs[1] |
| Turbine/Generator Capacities | 1. 990 kw | | |
| | 2. 1110 kw | | |
| Average Annual Energy Production | | 9,917,000 | kwh |
| Overall Plant Factor | | 54 | % |

Miscellaneous:

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

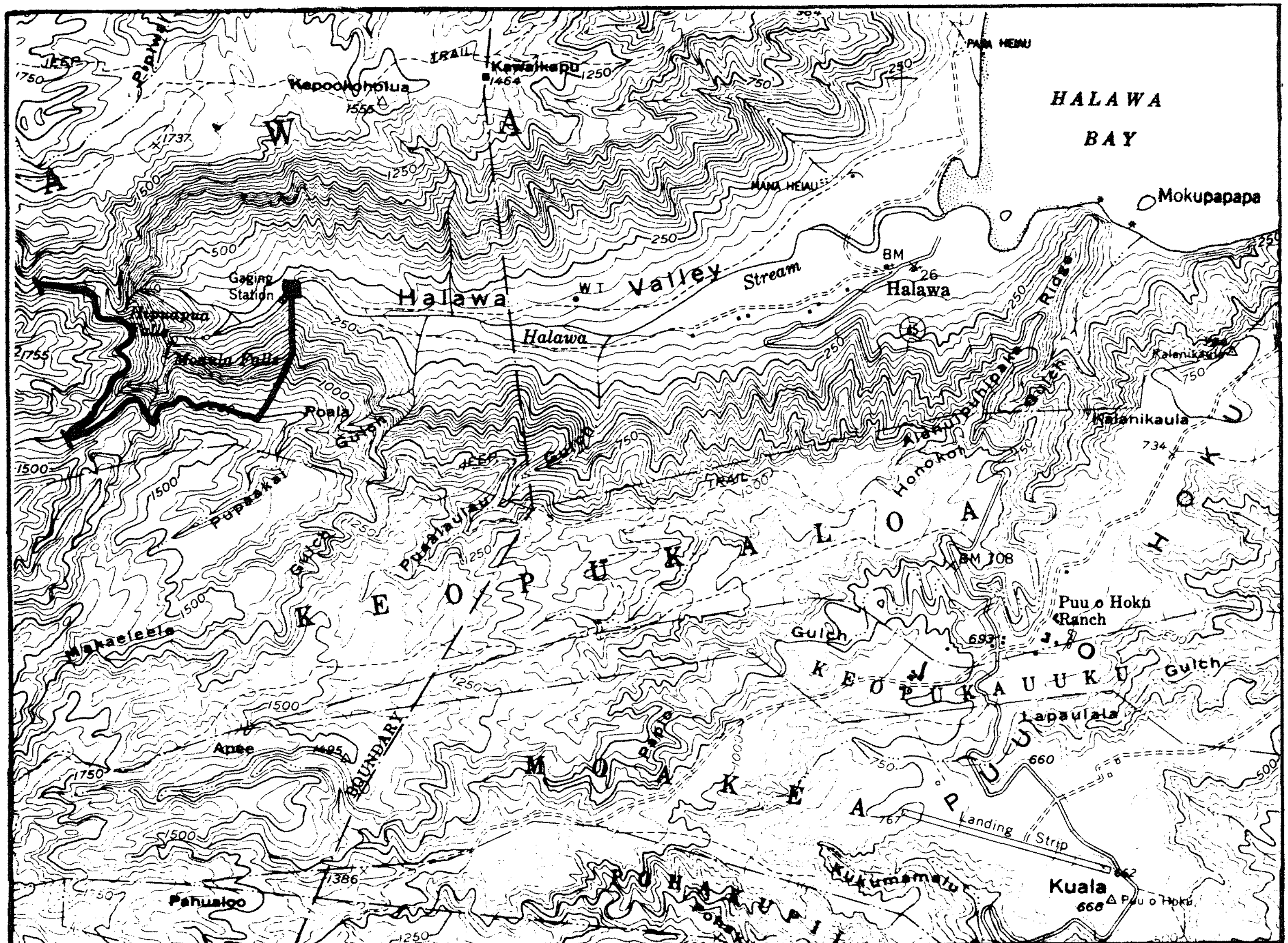



Figure D-19. Prospective Hydropower Site, Halawa Stream, Molokai.

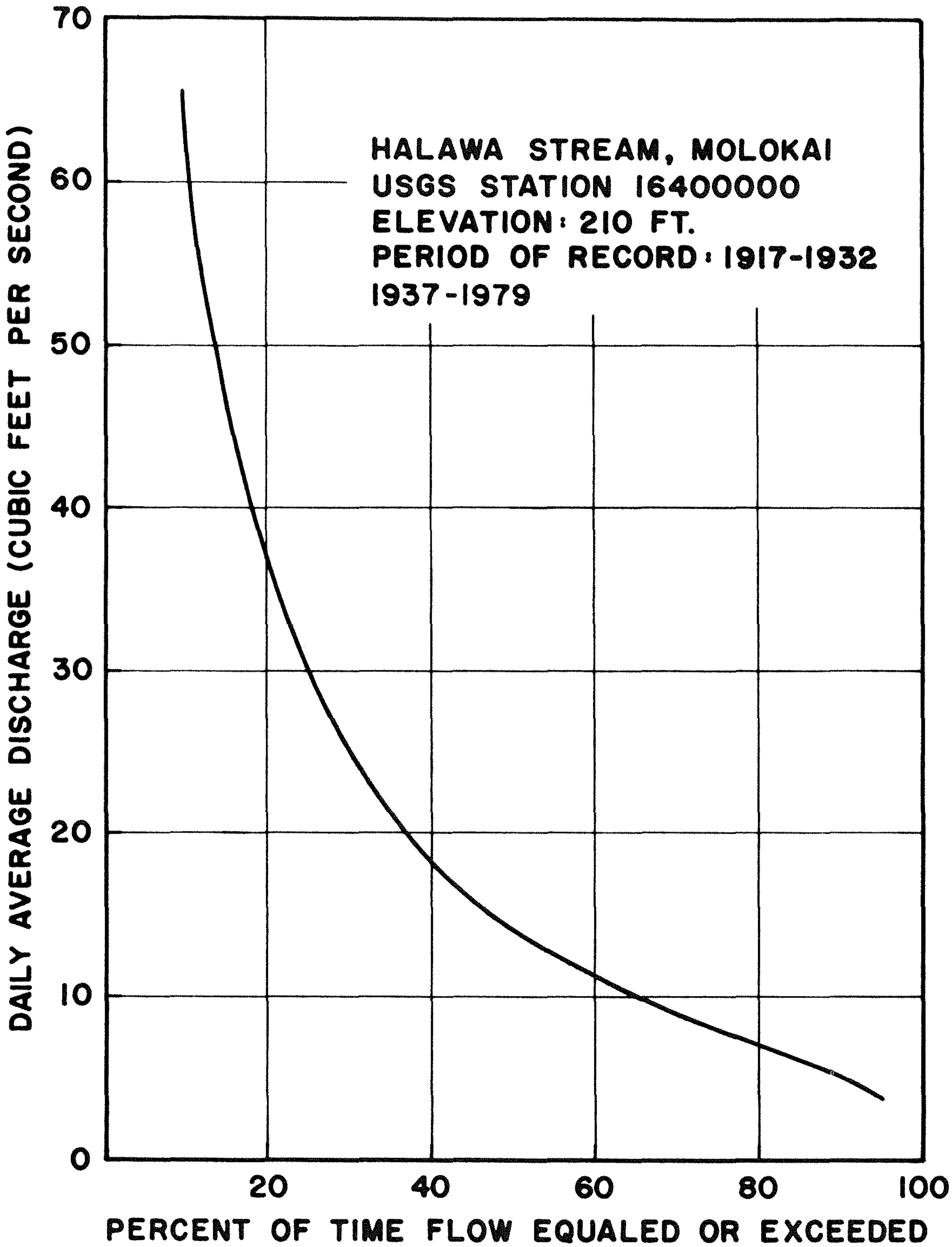



Figure D-20. Flow Duration Curve, Halawa Stream, Molokai.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-14. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Halawa Stream, Molokai

| | | |
|---|---|---|
| Turbine/Generators | 315,000 | |
| Station Electrical Equipment | 450,000 | |
| Penstock | 375,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 230,000 | |
| Access Road | 600,000 | |
| Transmission Line | 225,000 | |
| Miscellaneous Equipment | 225,000 | |
| SUBTOTAL | | 2,450,000 |
| Contingencies[2] | 490,000 | |
| Indirect Costs[3] | 585,000 | |
| TOTAL | | 3,525,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

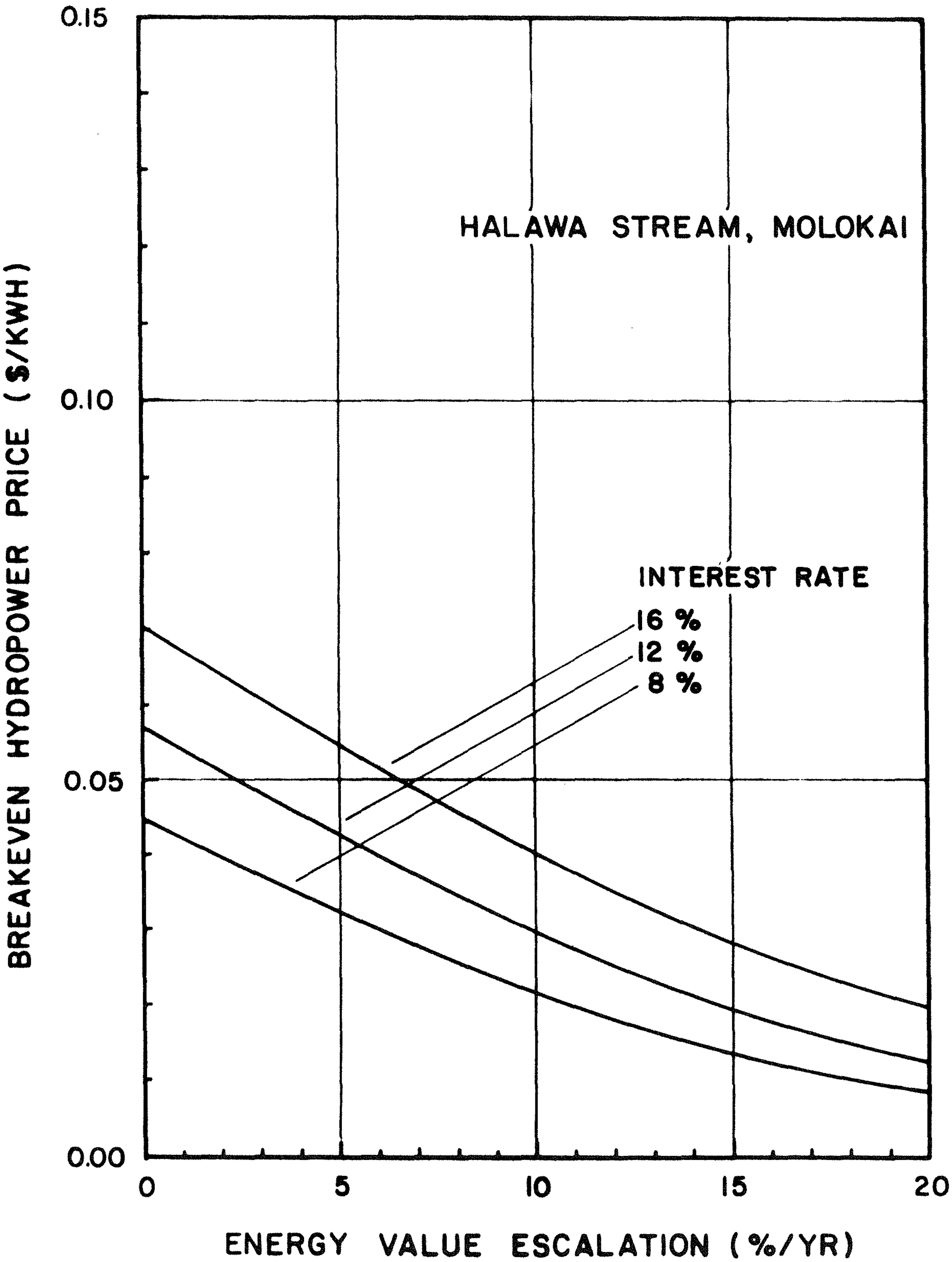



Figure D-21. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Halawa Stream, Molokai.

Table D-15. TECHNICAL DATA SUMMARY

PROJECT SITE Pelekunu Stream, Molokai

| | | | |
|---|---|---|---|
| Plant Capacity | | 860 | kw |
| Static Head | | 550 | ft |
| Penstock Length | | 8000 | ft |
| Average Gradient | | 0.069 | ft/ft |
| Stream Gage of Record | | USGS # 16404000 | |
| Streamflow Parameters | Average Flow | 16.4 | cfs |
| | $Q_{15}$ | 24.3 | cfs[1] |
| | $Q_{50}$ | 9.3 | cfs[1] |
| | $Q_{95}$ | 4 | cfs[1] |
| Turbine/Generator Capacities | 1. 380 kw | | |
| | 2. 480 kw | | |
| Average Annual Energy Production | | 3,798,000 | kwh |
| Overall Plant Factor | | 50% | % |

Miscellaneous:

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

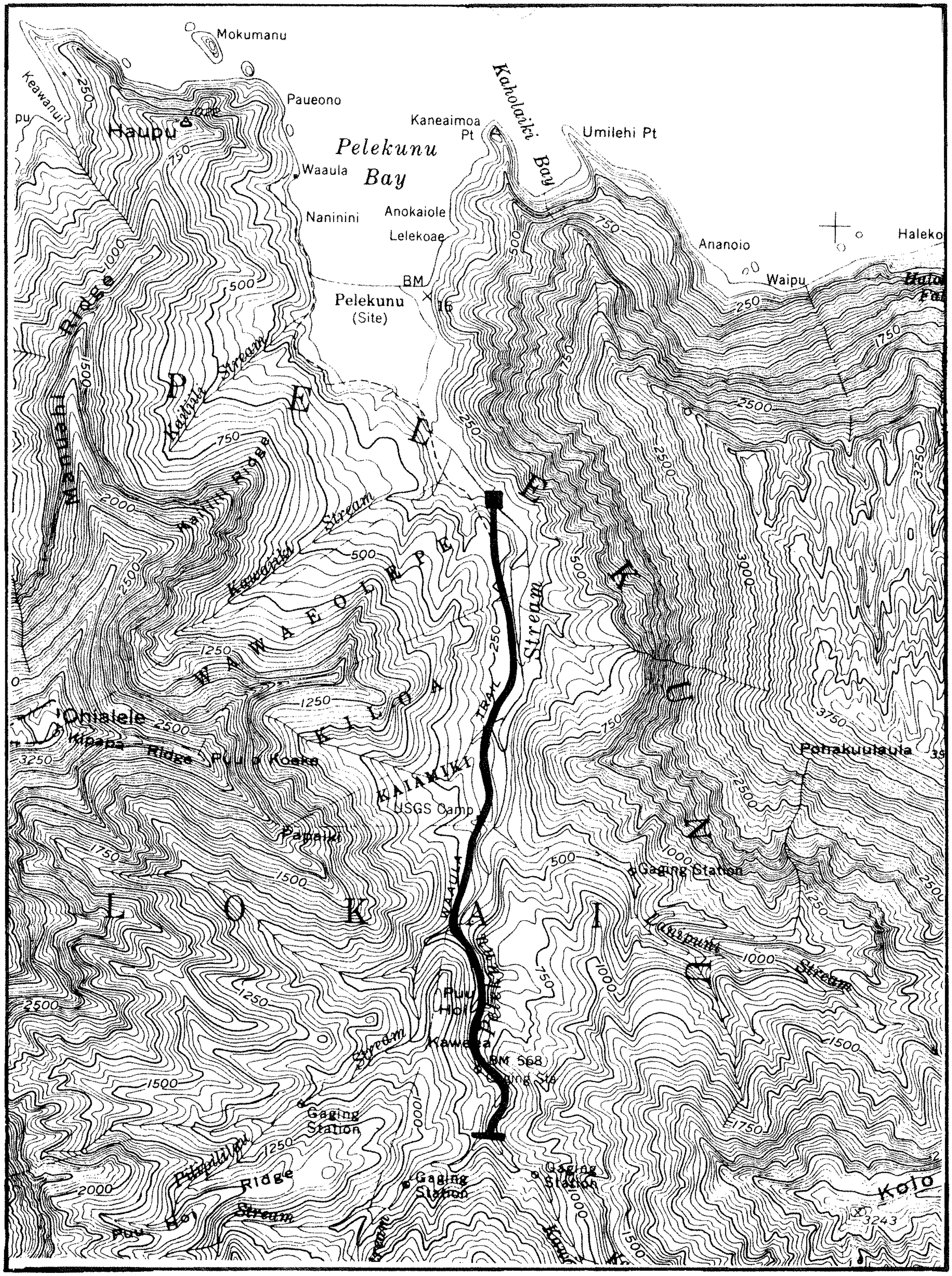



Figure D-22. Prospective Hydropower Site, Pelekunu Stream, Molokai.

Scale: 1 in. = 2000 ft.

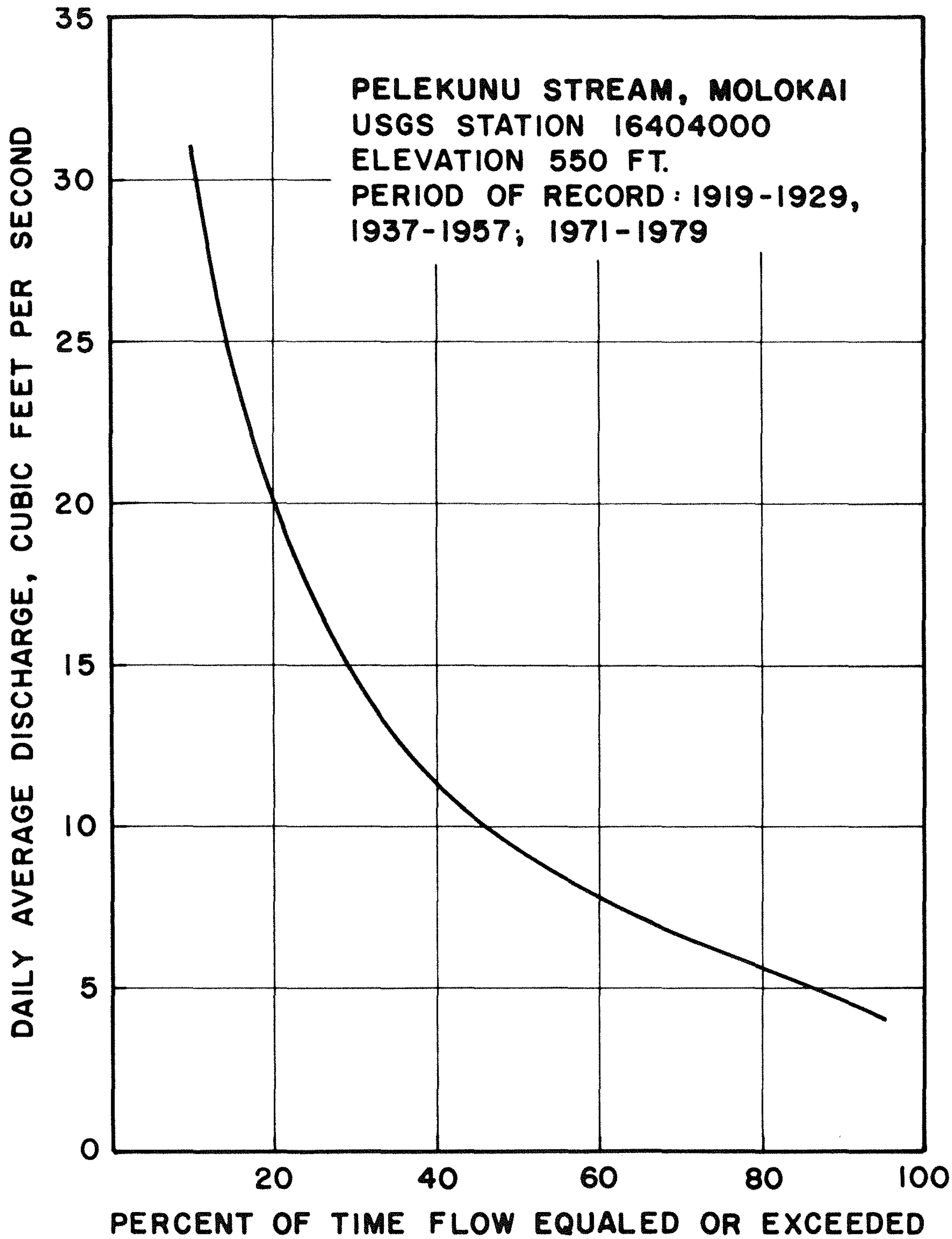



Figure D-23. Flow Duration Curve, Pelekunu Stream, Molokai.
(Based on U.S.G.S. Water Resources Division Stream Gage Data).

Table D-16. TECHNICAL DATA SUMMARY

PROJECT SITE Kualapuu Reservoir, Molokai

| | | | |
|---|---|---|---|
| Plant Capacity | | 70 | kw |
| Static Head | | 124 | ft |
| Penstock Length | | 21,000 | ft |
| Average Gradient | | 0.006 | ft/ft |
| Stream Gage of Record | | USGS # | 16405300 |
| Streamflow Parameters | Average Flow | 5.3 | cfs |
| | $Q_{15}$ | 7 | cfs[1] |
| | $Q_{50}$ | 4 | cfs[1] |
| | $Q_{95}$ | 2.4 | cfs[1] |
| Turbine/Generator Capacities | 70 kw | | |
| Average Annual Energy Production | | 293,000 | kwh |
| Overall Plant Factor | | 48 | % |

Miscellaneous:

Inflow to reservoir is via a 30" pipeline from the Molokai Tunnel West Portal (flow duration curve, next page). Powerplant is at the reservoir inlet. Hydro calculations took into account flow added to pipeline by Kalua Koi Corporation, and flow removed by Del Monte Corporation.

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

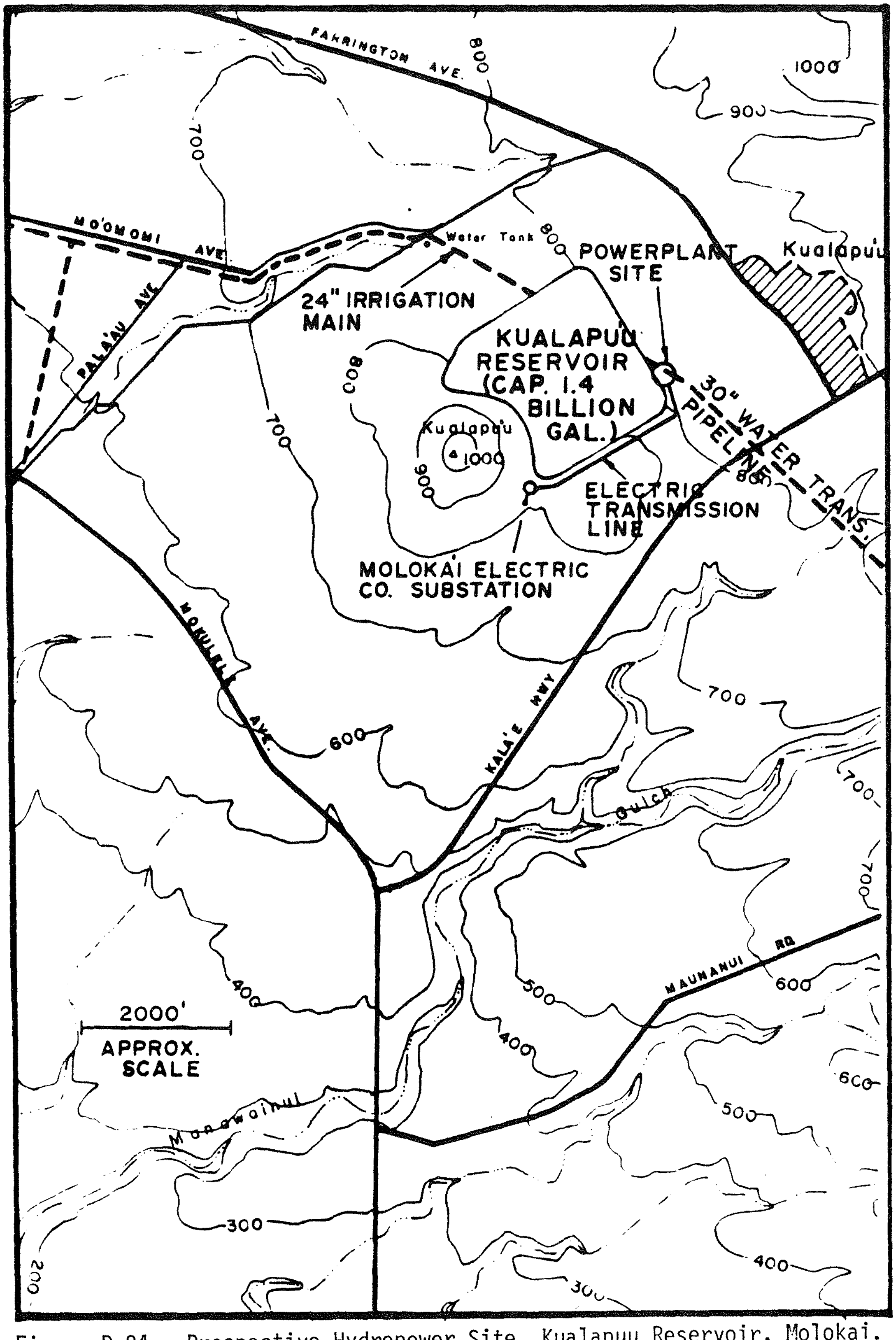



Figure D-24. Prospective Hydropower Site, Kualapuu Reservoir, Molokai.

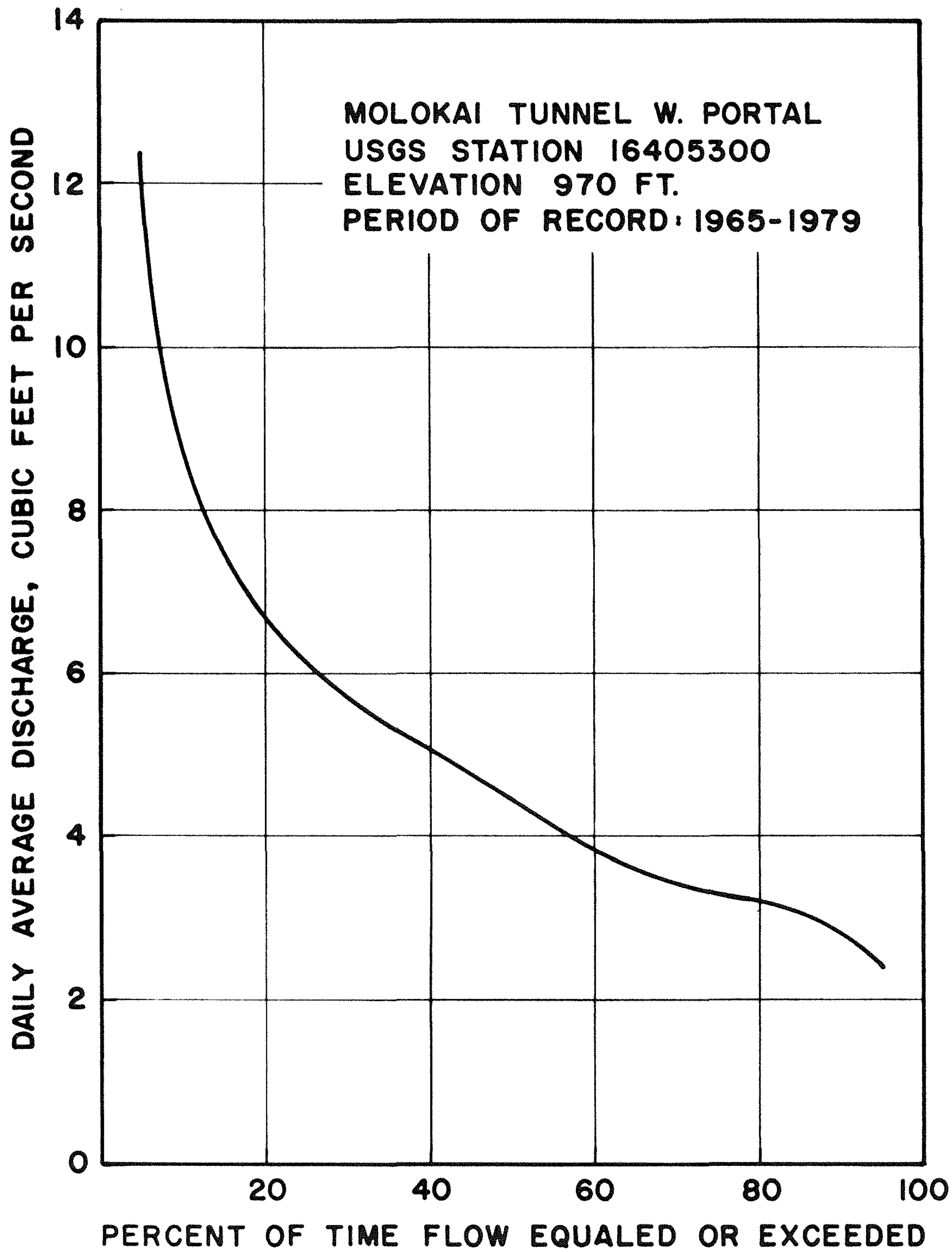



Figure D-25. Flow Duration Curve, Kualapuu Reservoir, Molokai. (Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-17. TECHNICAL DATA SUMMARY

PROJECT SITE East & West Wailuaiki Streams, Maui

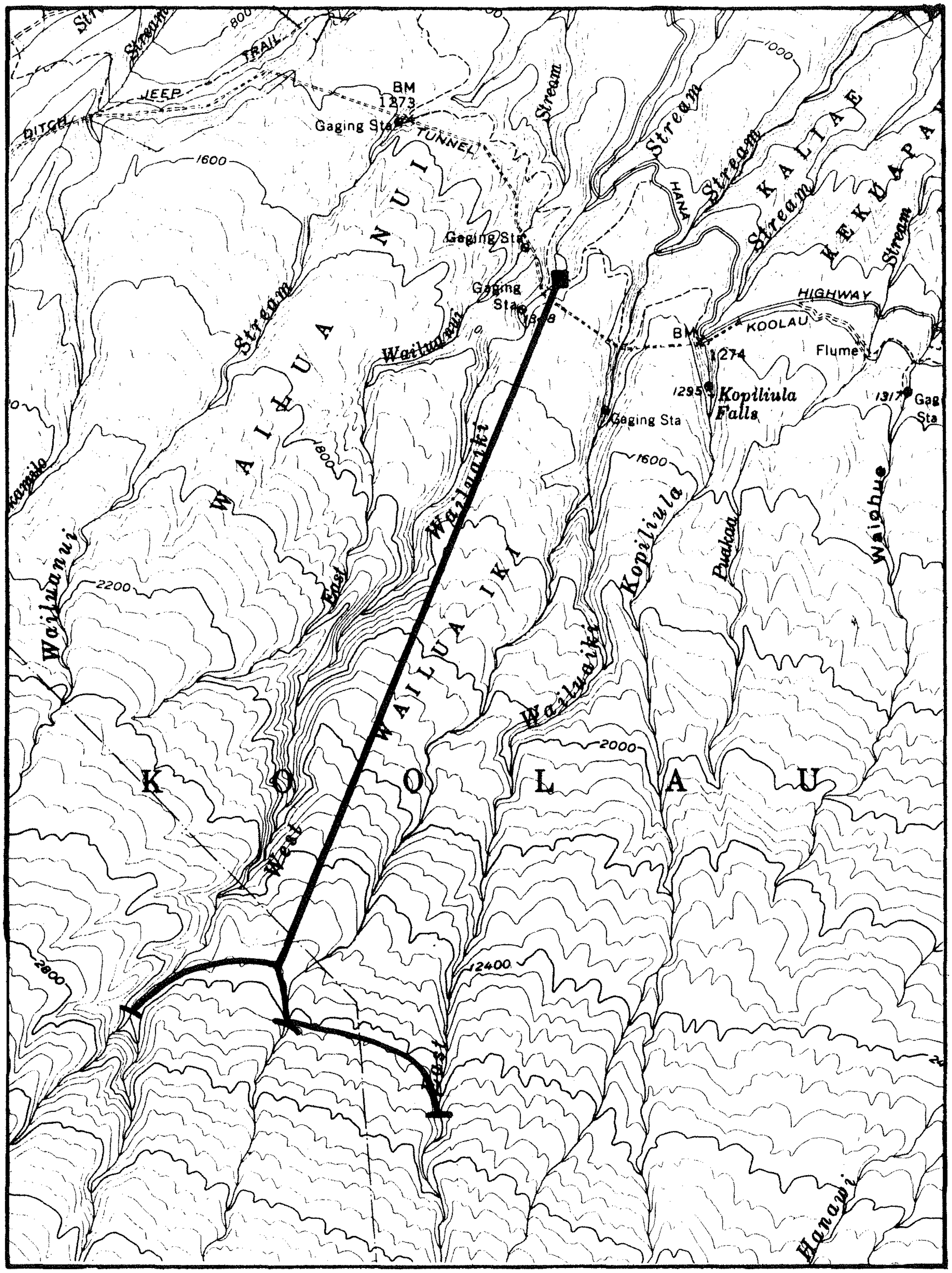
| | | | |
|---|---|---|---|
| Plant Capacity | | 2,750 | kw |
| Static Head | | 1,155 | ft |
| Penstock Length | | 9,500 | ft |
| Average Gradient | | 0.012 | ft/ft |
| Stream Gage of Record | | USGS # | 1651700 East Br.<br>1651800 West Br. |
| Streamflow Parameters | Average Flow | 69.8 | cfs |
| | $Q_{15}$ | 85 | cfs[1] |
| | $Q_{50}$ | 21 | cfs[1] |
| | $Q_{95}$ | 7.1 | cfs[1] |
| Turbine/Generator Capacities | 1. 1250 kw | | |
| | 2. 1500 kw | | |
| Average Annual Energy Production | | 15,080,000 | kwh |
| Overall Plant Factor | | 63 | % |

Miscellaneous:

Water diverted at high elevation from East and West Branches of stream into single powerhouse.

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-26. Prospective Hydropower Site, East & West Wailuaiki Streams, Maui.

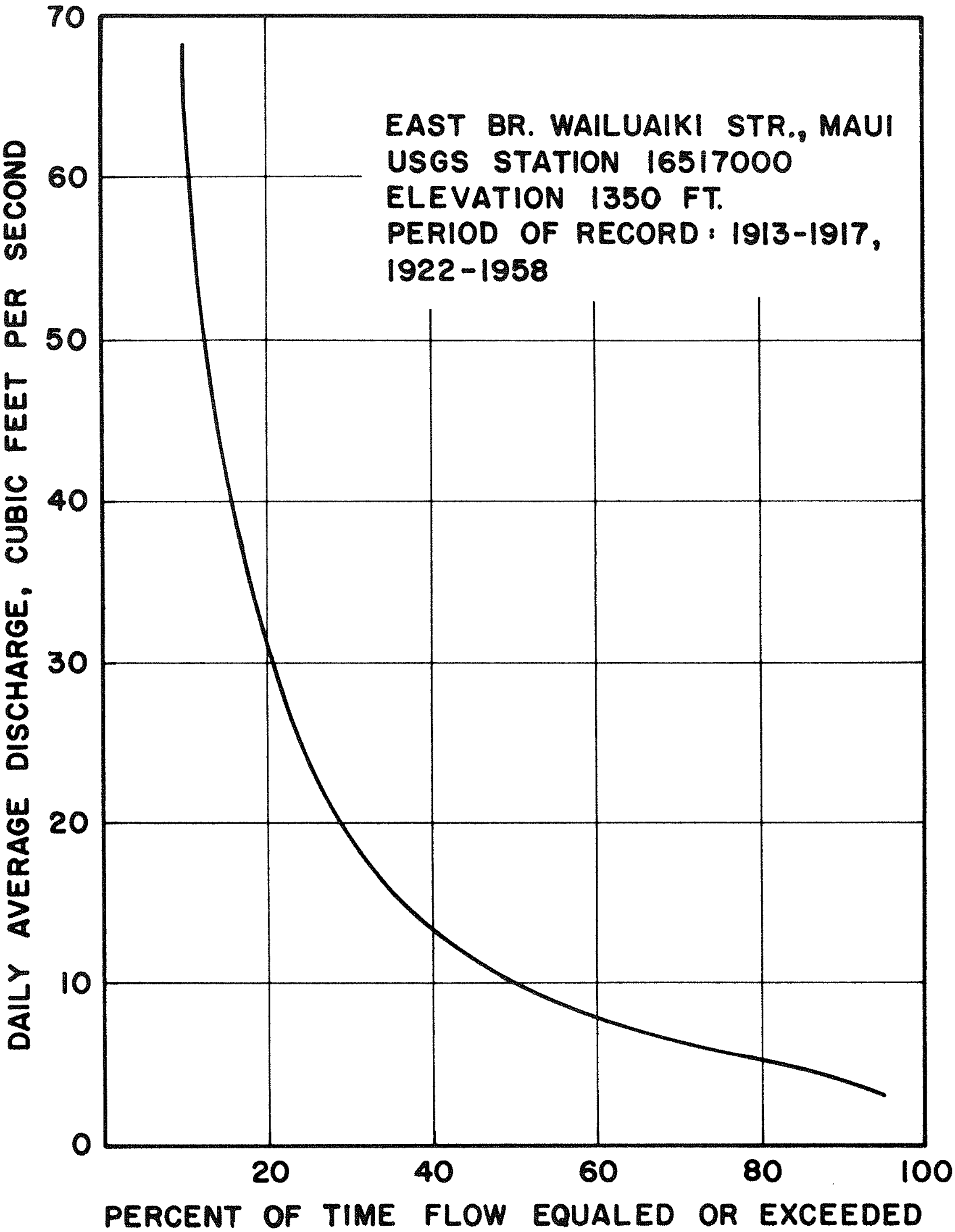



Figure D-27. Flow Duration Curve, East Branch, Wailuaiki Stream, Maui. (Based on U.S.G.S. Water Resources Division Stream Gage Data)

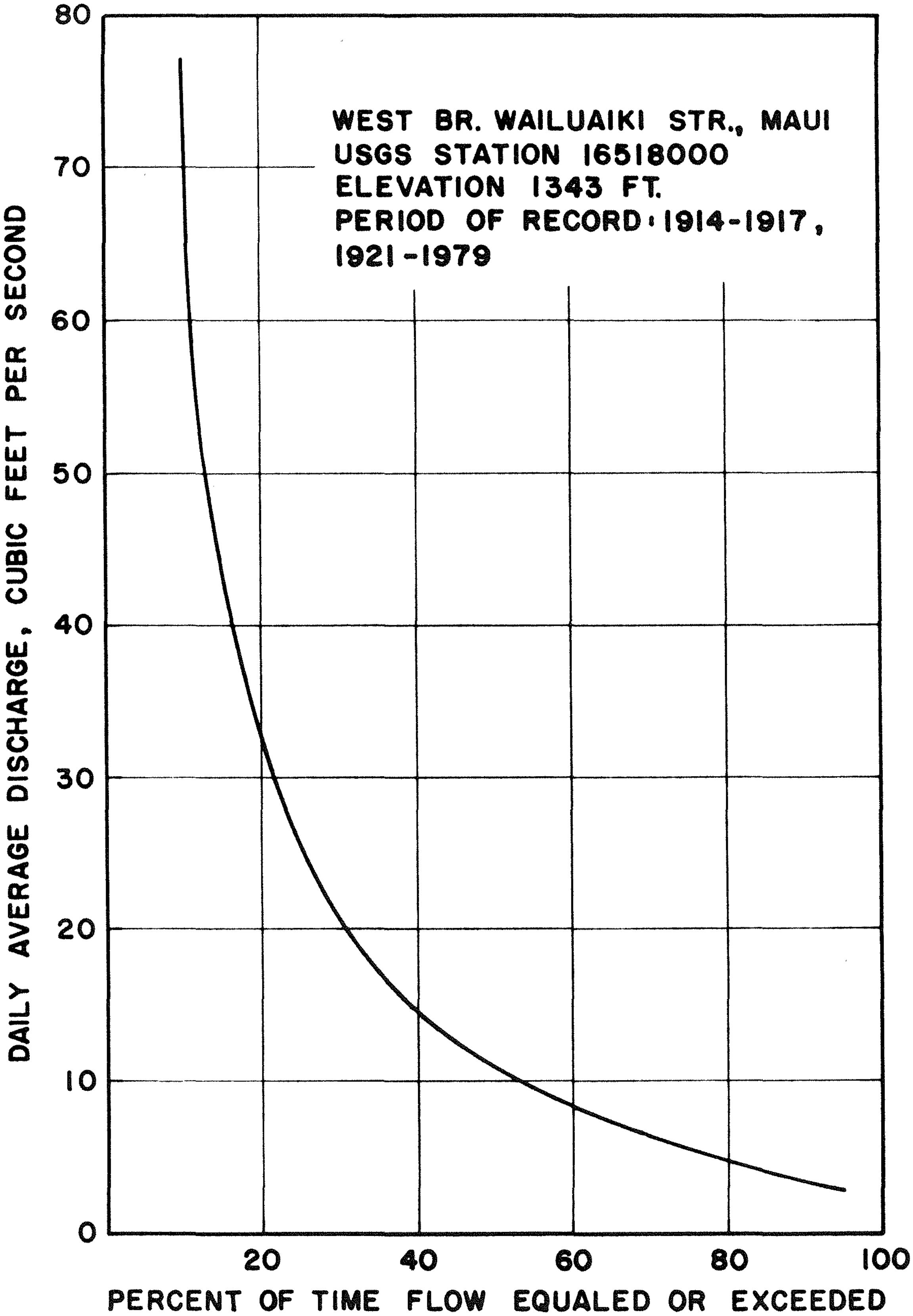



Figure D 28. Flow Duration Curve, West Branch, Wailuaiki Stream, Maui. (Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-18. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: East and West Wailuaiki Streams, Maui

| | | |
|---|---|---|
| Turbine/Generators | 380,000 | |
| Station Electrical Equipment | 495,000 | |
| Penstock | 950,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 225,000 | |
| Access Road | 450,000 | |
| Transmission Line | 210,000 | |
| Miscellaneous Equipment | 235,000 | |
| SUBTOTAL | | 2,975,000 |
| Contingencies[2] | 595,000 | |
| Indirect Costs[3] | 715,000 | |
| TOTAL | | 4,285,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

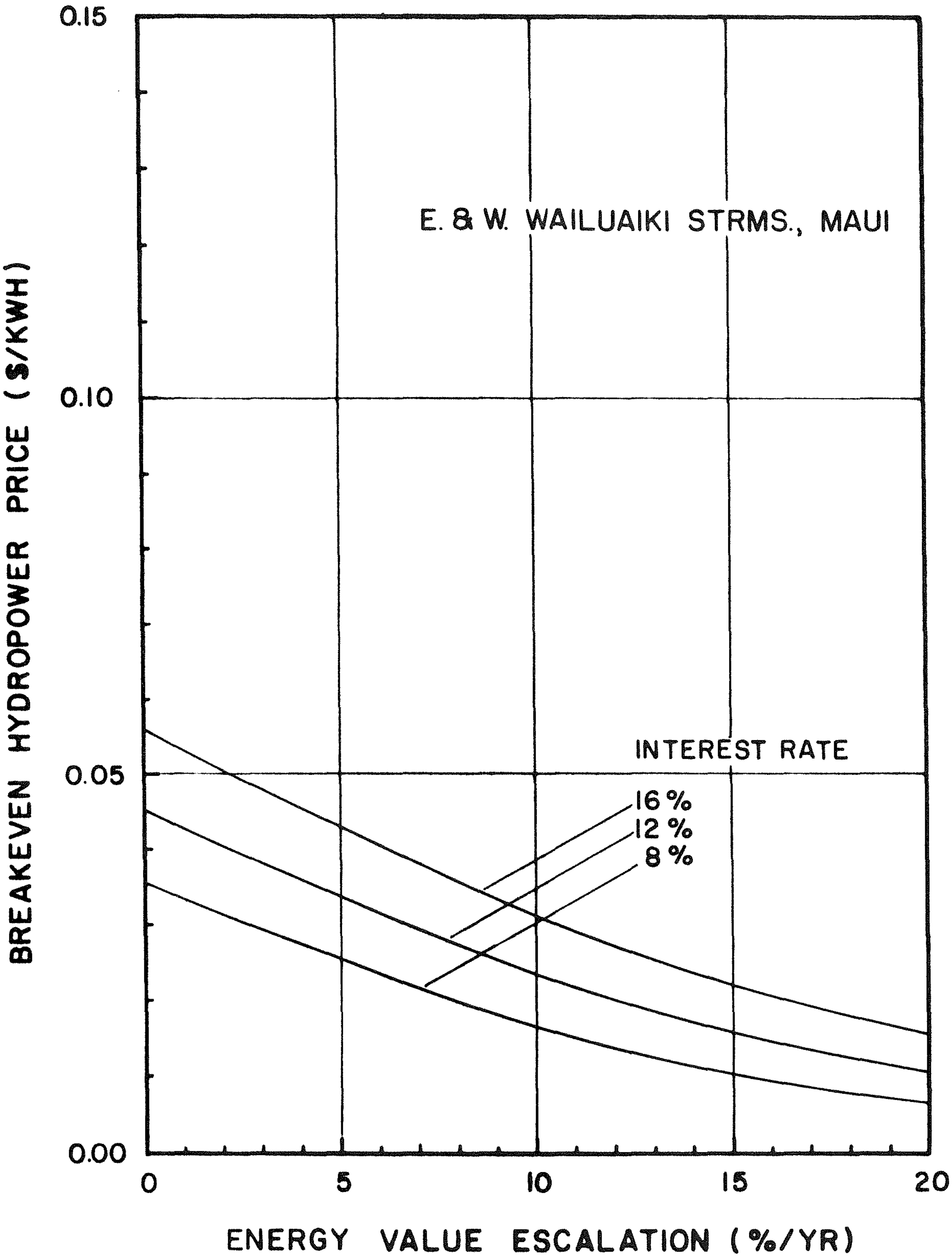



Figure D-29. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, East & West Wailuaiki Streams, Maui.

Table D-19. TECHNICAL DATA SUMMARY

PROJECT SITE Waihee Stream, Maui

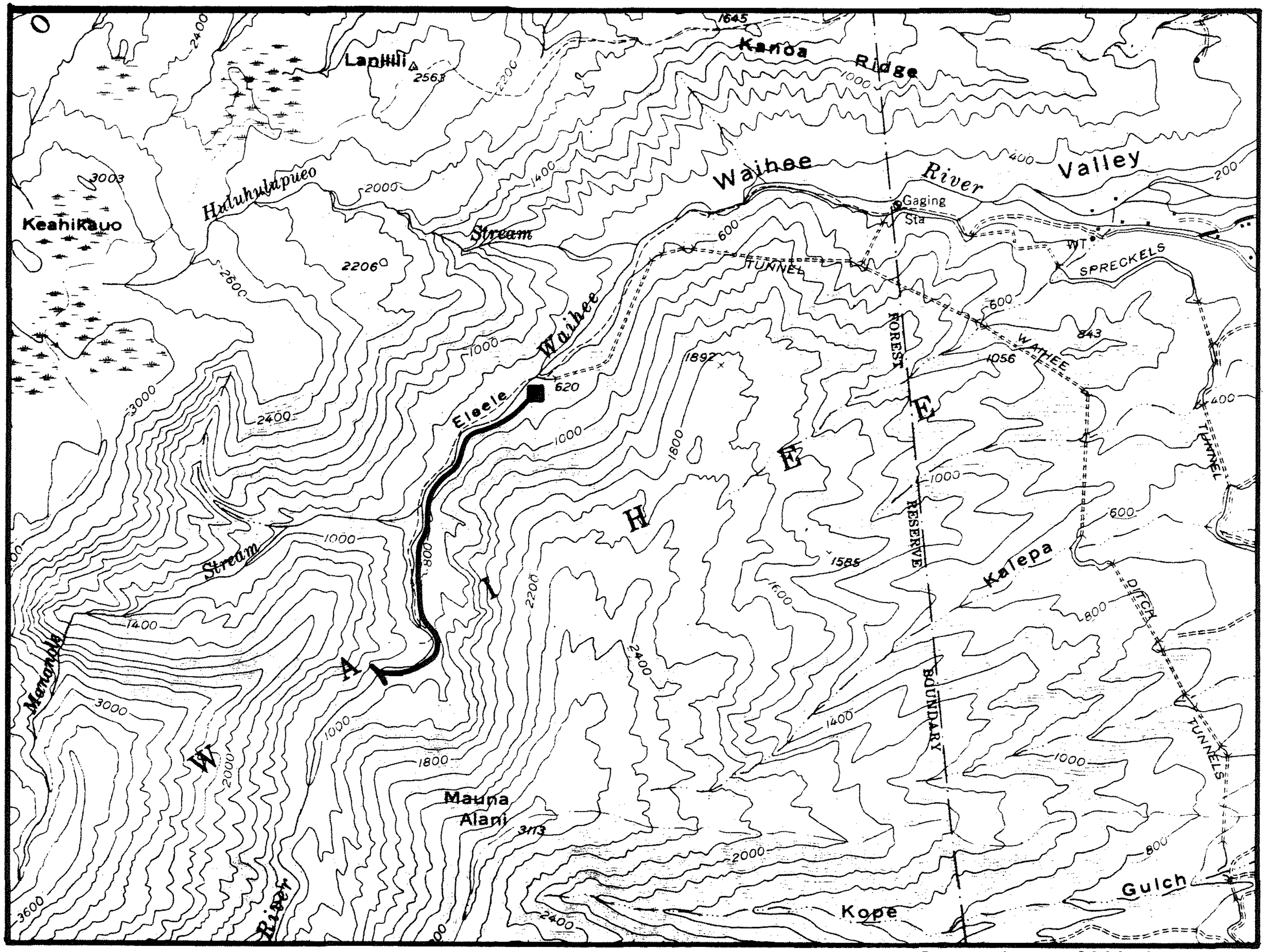
| | | | |
|---|---|---|---|
| Plant Capacity | | 1,860 | kw |
| Static Head | | 240 | ft |
| Penstock Length | | 4,400 | ft |
| Average Gradient | | 0.055 | ft/ft |
| Stream Gage of Record | | USGS # | 16612000 |
| Streamflow Parameters | Average Flow | 100 | cfs |
| | $Q_{15}$ | 150 | cfs[1] |
| | $Q_{50}$ | 74 | cfs[1] |
| | $Q_{95}$ | 42 | cfs[1] |
| Turbine/Generator Capacities | 1. 810 kw | | |
| | 2. 1050 kw | | |
| Average Annual Energy Production | | 8,486,000 | kwh |
| Overall Plant Factor | | 52 | % |

Miscellaneous:

Intake is assumed upstream of gaging station. Actual flows available are somewhat less than indicated above, because of the smaller watershed area at the intake.

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.



Scale: 1 in. = 2000 ft.

Figure D-30. Prospective Hydropower Site, Waihee Stream, Maui.

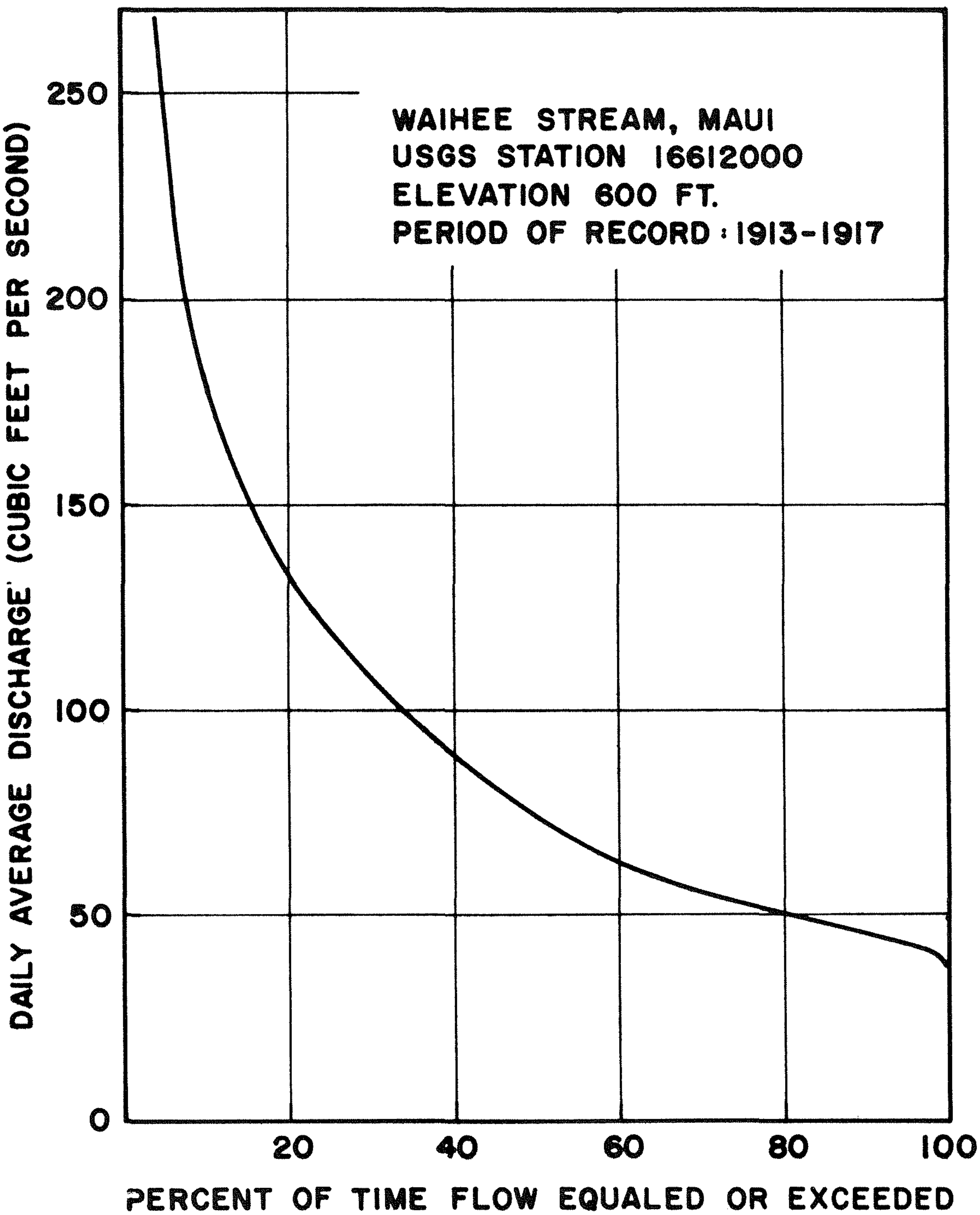



Figure D-31. Flow Duration Curve, Waihee Stream, Maui.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-20. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Waihee Stream, Maui

| | | |
|---|---|---|
| Turbine/Generators | 475,000 | |
| Station Electrical Equipment | 455,000 | |
| Penstock | 835,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 230,000 | |
| Access Road | 300,000 | |
| Transmission Line | 180,000 | |
| Miscellaneous Equipment | 225,000 | |
| SUBTOTAL | | 2,730,000 |
| Contingencies[2] | 545,000 | |
| Indirect Costs[3] | 655,000 | |
| TOTAL | | 3,930,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

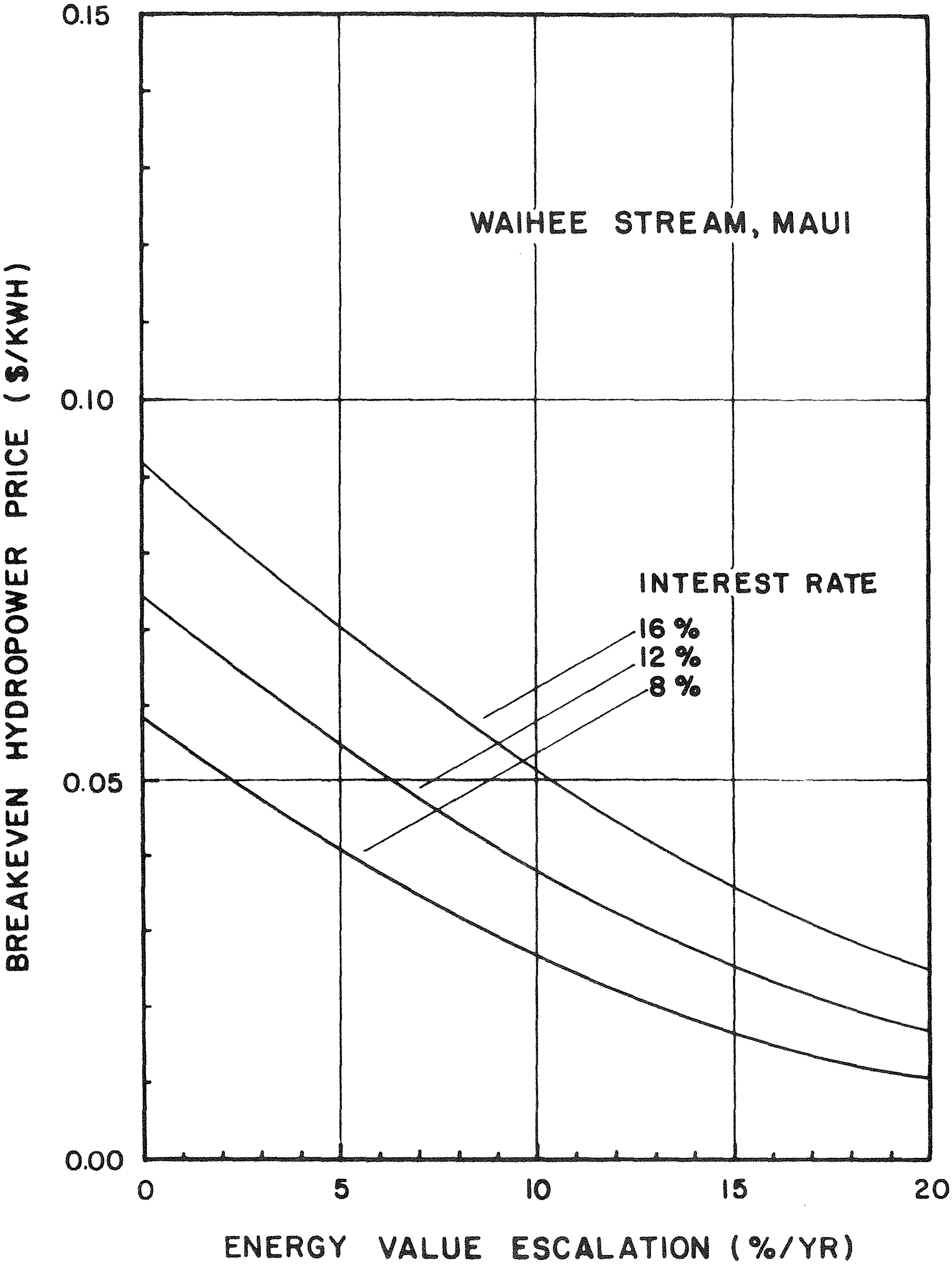



Figure D-32. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Waihee Stream, Maui.

Table D-21. TECHNICAL DATA SUMMARY

PROJECT SITE Hanawi Stream, Maui

| | | | |
|---|---|---|---|
| Plant Capacity | | 1000 | kw |
| Static Head | | 990 | ft |
| Penstock Length | | 7,000 | ft |
| Average Gradient | | 0.141 | ft/ft |
| Stream Gage of Record | | USGS # 16508000 | |
| Streamflow Parameters | Average Flow | 22.5 | cfs |
| | $Q_{15}$ | 29.6 | cfs[1] |
| | $Q_{50}$ | 7.2 | cfs[1] |
| | $Q_{95}$ | 2.5 | cfs[1] |
| Turbine/Generator Capacities | 1. 420 kw | | |
| | 2. 580 kw | | |
| Average Annual Energy Production | | 5,026,000 | kwh |
| Overall Plant Factor | | 57% | % |

Miscellaneous:

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[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

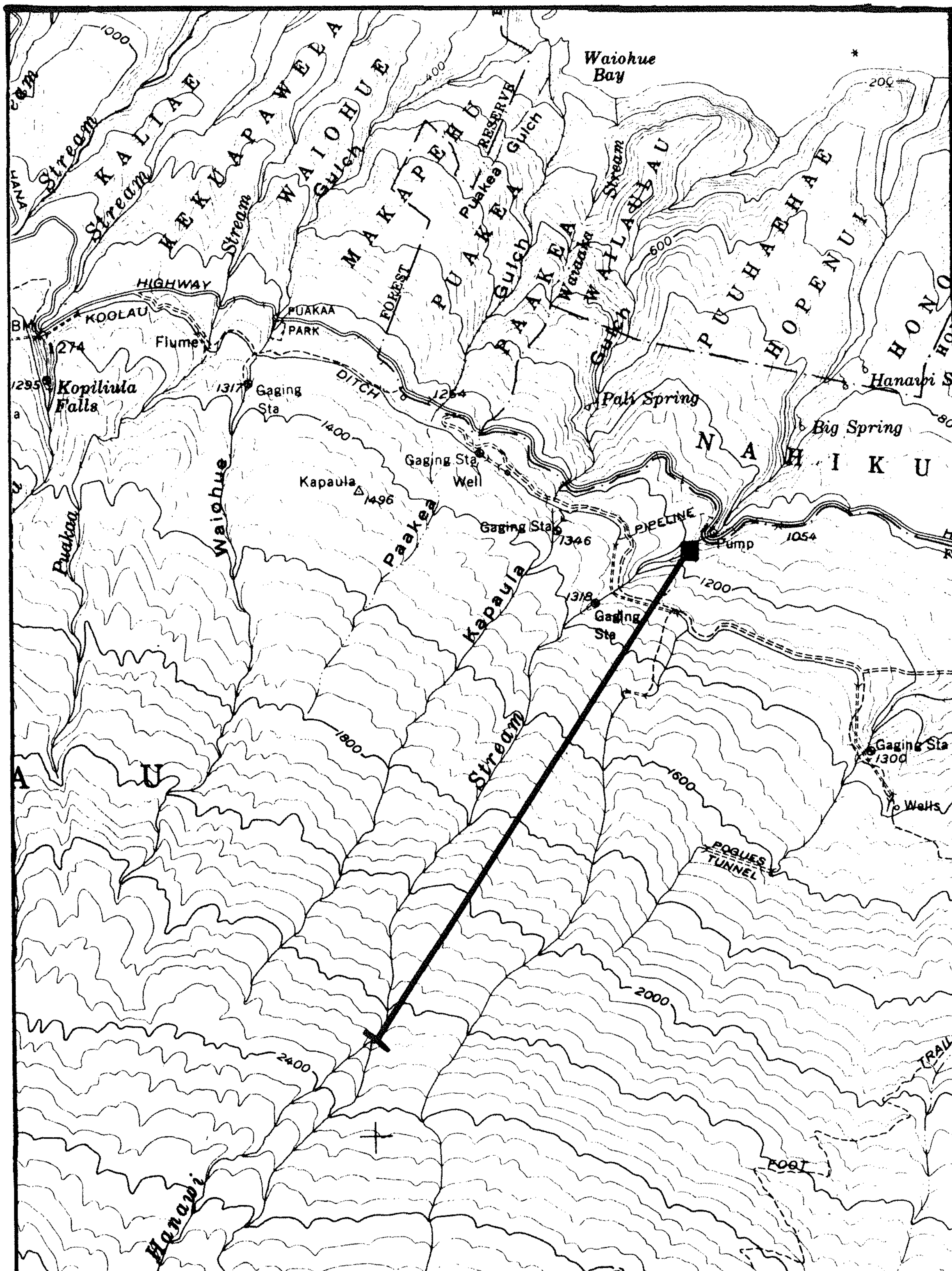



Figure D-33. Prospective Hydropower Site, Hanawi Stream, Maui.

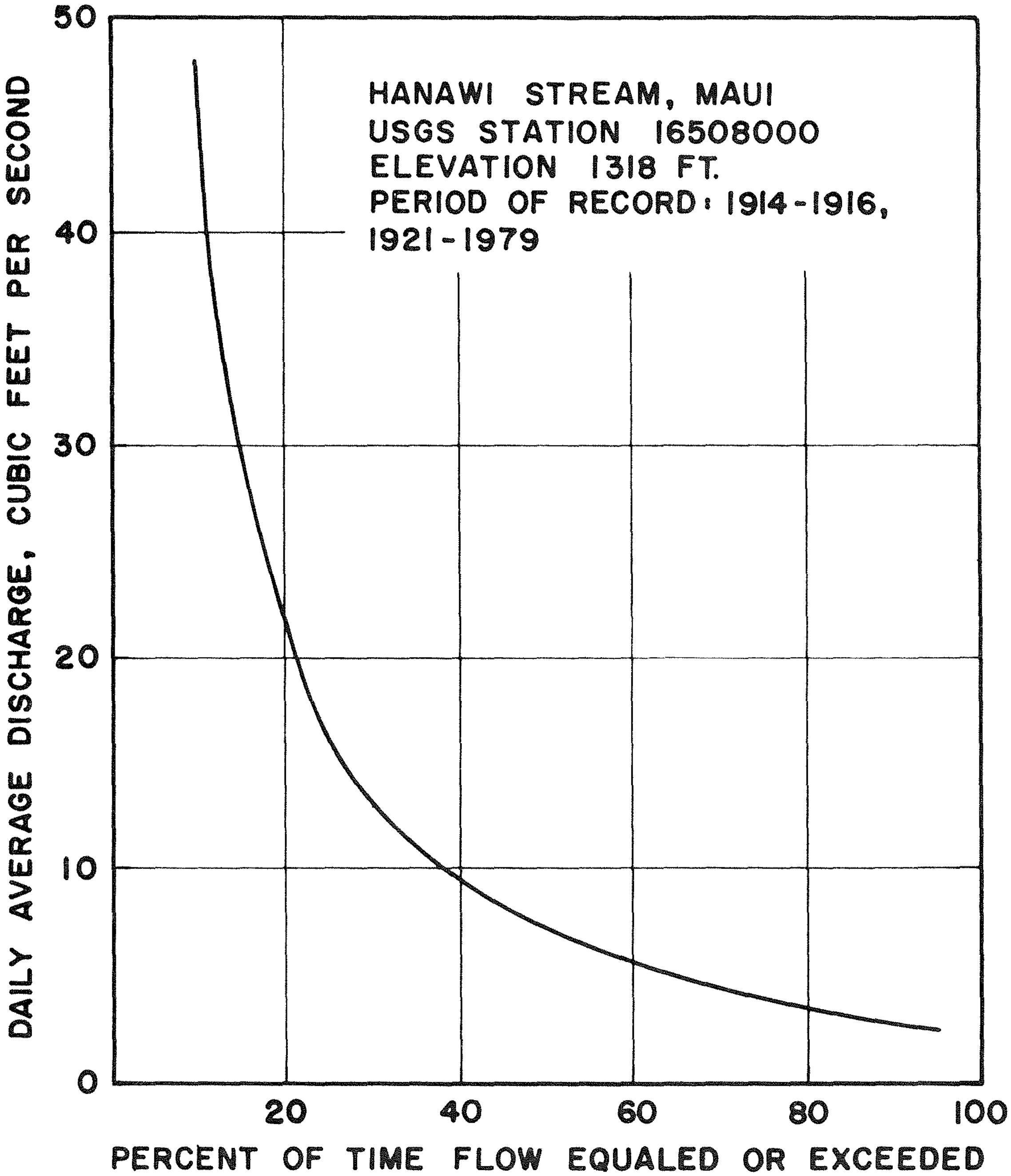



Figure D-34. Flow Duration Curve, Hanawi Stream, Maui.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-22. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Hanawi Stream, Maui

| | | |
|---|---|---|
| Turbine/Generators | 220,000 | |
| Station Electrical Equipment | 285,000 | |
| Penstock | 525,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 170,000 | |
| Access Road | 210,000 | |
| Transmission Line | 30,000 | |
| Miscellaneous Equipment | 210,000 | |
| SUBTOTAL | | 1,680,000 |
| Contingencies[2] | 335,000 | |
| Indirect Costs[3] | 400,000 | |
| TOTAL | | 2,415,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

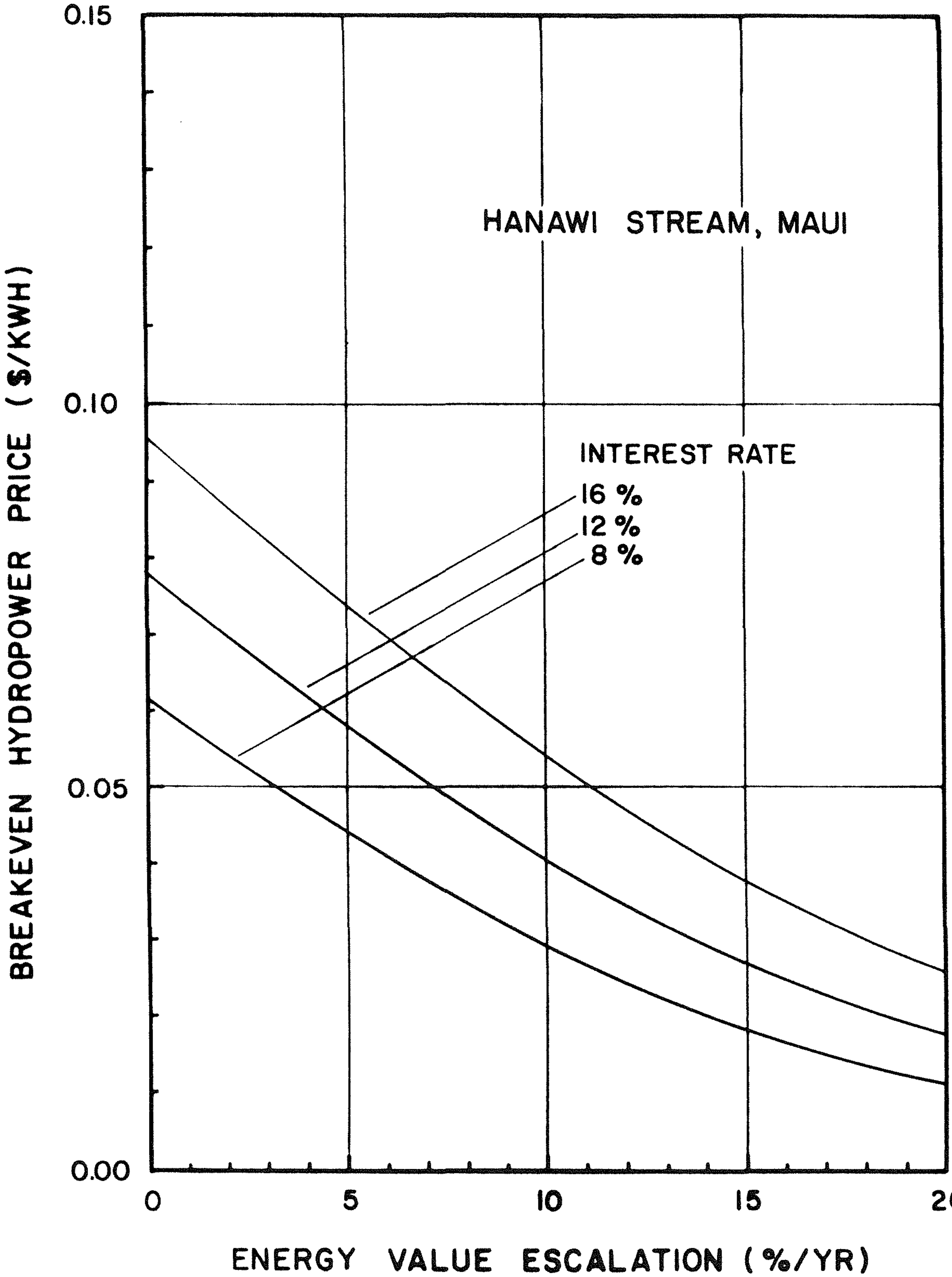



Figure D-35. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Hanawi Stream, Maui.

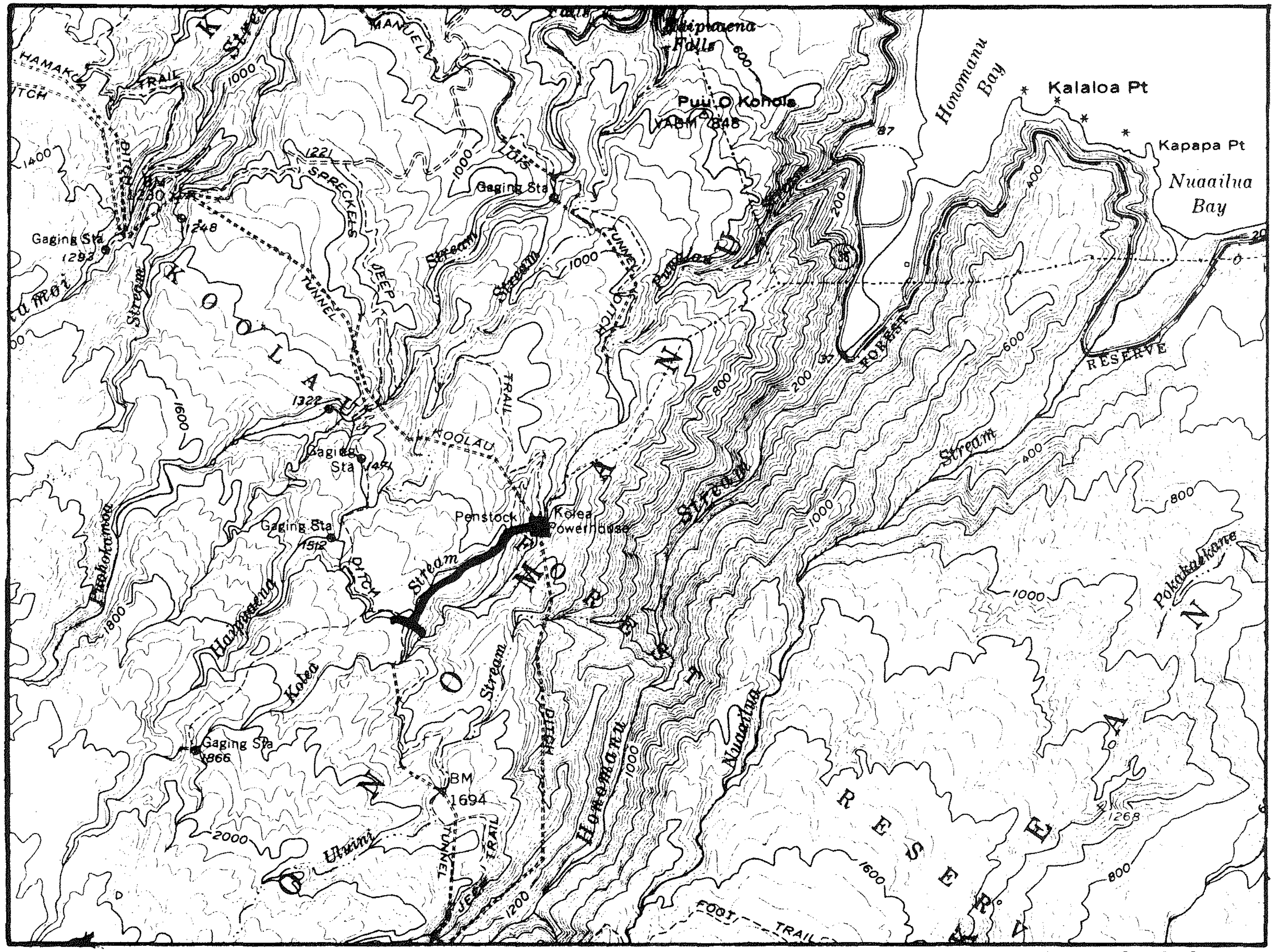
Table D-23. TECHNICAL DATA SUMMARY

PROJECT SITE Kolea, Maui

| | | | |
|---|---|---|---|
| Plant Capacity | | 1,100 | kw |
| Static Head | | 360 | ft |
| Penstock Length | | 2,500 | ft |
| Average Gradient | | 0.144 | ft/ft |
| Stream Gage of Record | | USGS # | 16538000 |
| Streamflow Parameters | Average Flow | 29.3 | cfs |
| | $Q_{15}$ | 46 | cfs[1] |
| | $Q_{50}$ | 16 | cfs[1] |
| | $Q_{95}$ | 1.1 | cfs[1] |
| Turbine/Generator Capacities | 1. 200 kw<br>2. 300 kw<br>3. 600 kw | | |
| Average Annual Energy Production | | 4,459,000 | kwh |
| Overall Plant Factor | | 46 | % |

Miscellaneous:

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-36. Prospective Hydropower Site, Kolea, Maui.

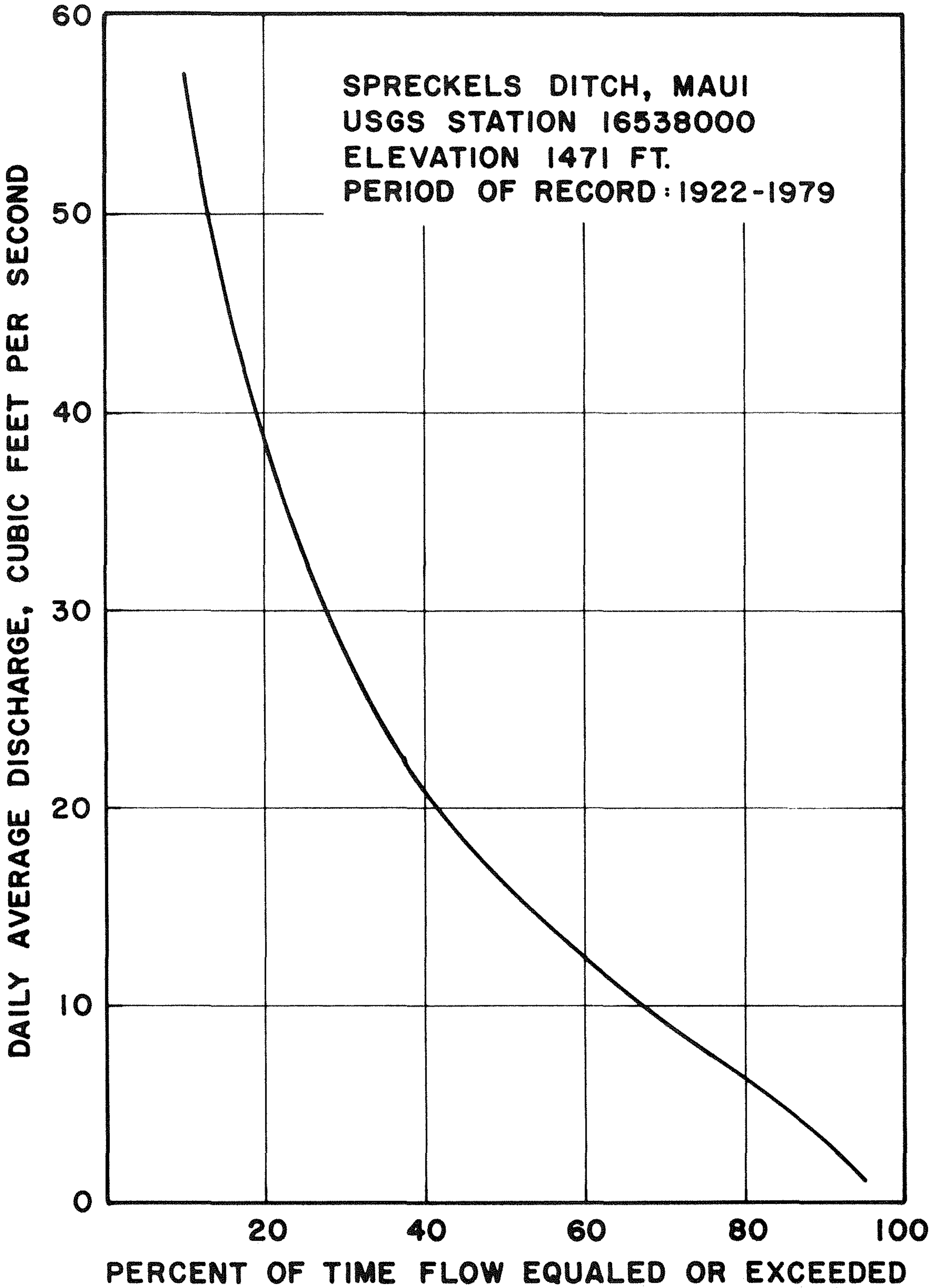



Figure D-37. Flow Duration Curve, Kolea, Maui (Spreckels Ditch).
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-24. TECHNICAL DATA SUMMARY

PROJECT SITE Hoopoi Chute, Maui

| | | | |
|---|---|---|---|
| Plant Capacity | | 2,000 | kw |
| Static Head | | 240 | ft |
| Penstock Length | | 5,500 | ft |
| Average Gradient | | 0.044 | ft/ft |
| Stream Gage of Record | | USGS # | N/A |
| Streamflow Parameters | Average Flow | N/A | cfs |
| | $Q_{15}$ | N/A | cfs[1] |
| | $Q_{50}$ | N/A | cfs[1] |
| | $Q_{95}$ | N/A | cfs[1] |
| Turbine/Generator Capacities | 1. 1000 kw | | |
| | 2. 1000 kw | | |
| Average Annual Energy Production | | 5,500,000 | kwh |
| Overall Plant Factor | | 31 | % |

Miscellaneous:

Most of the data and analysis were provided by Alexander and Baldwin, Inc. Flow duration data were not available. Just prior to publication, estimate was modified to 1,000 kw capacity, 3.0 million kwh per year. Financial analysis, however, is based on 2,000 kw, 5.5 million kwh per year.

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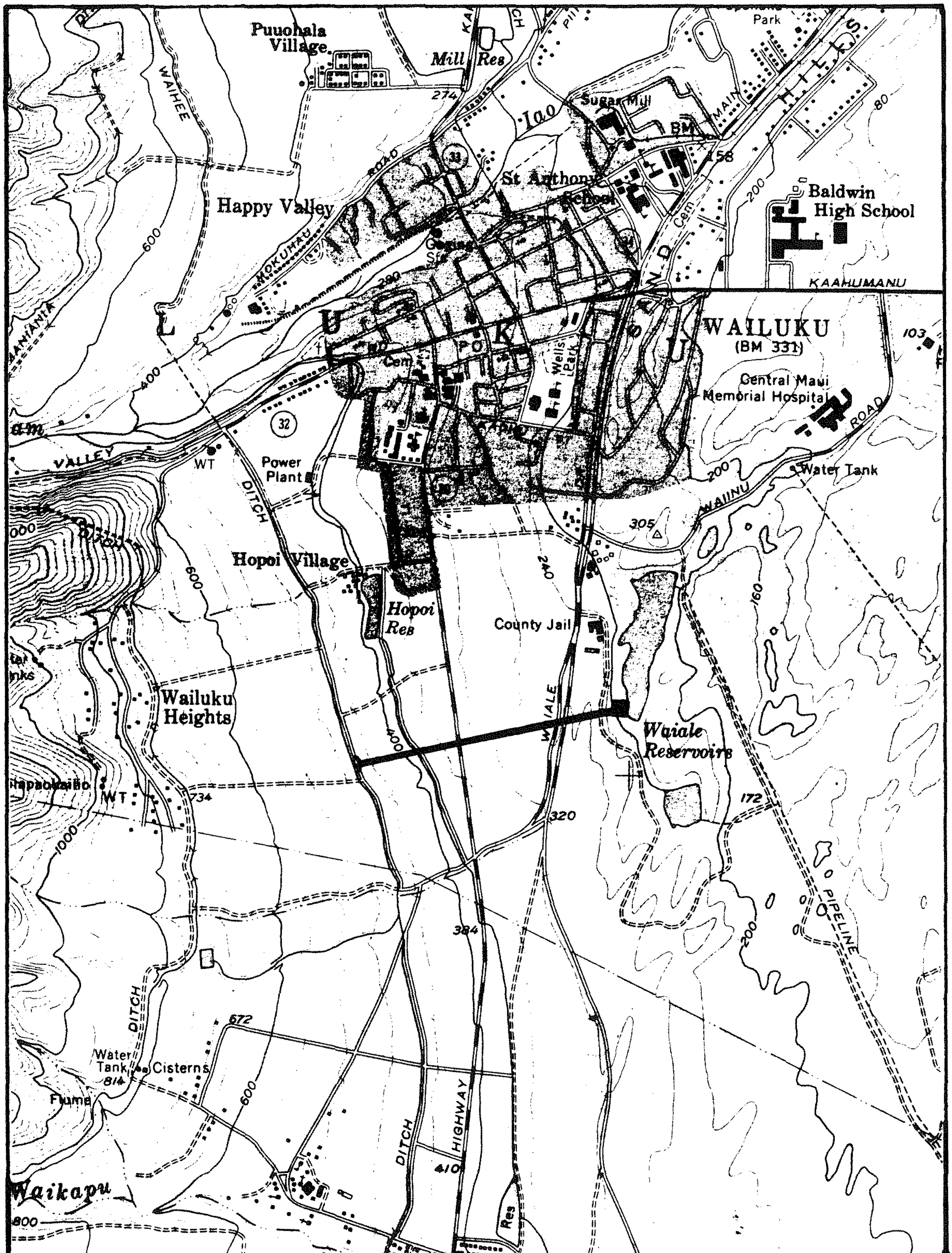
[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-38. Prospective Hydropower Site, Hoopoi Chute, Maui.

Table D-25. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Hoopoi Chute, Maui

| | | |
|---|---|---|
| Turbine/Generators | 470,000 | |
| Station Electrical Equipment | 445,000 | |
| Penstock | 1,100,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 170,000 | |
| Access Road | 0 | |
| Transmission Line | 30,000 | |
| Miscellaneous Equipment | 205,000 | |
| SUBTOTAL | | 2,450,000 |
| Contingencies[2] | 490,000 | |
| Indirect Costs[3] | 585,000 | |
| TOTAL | | 3,525,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

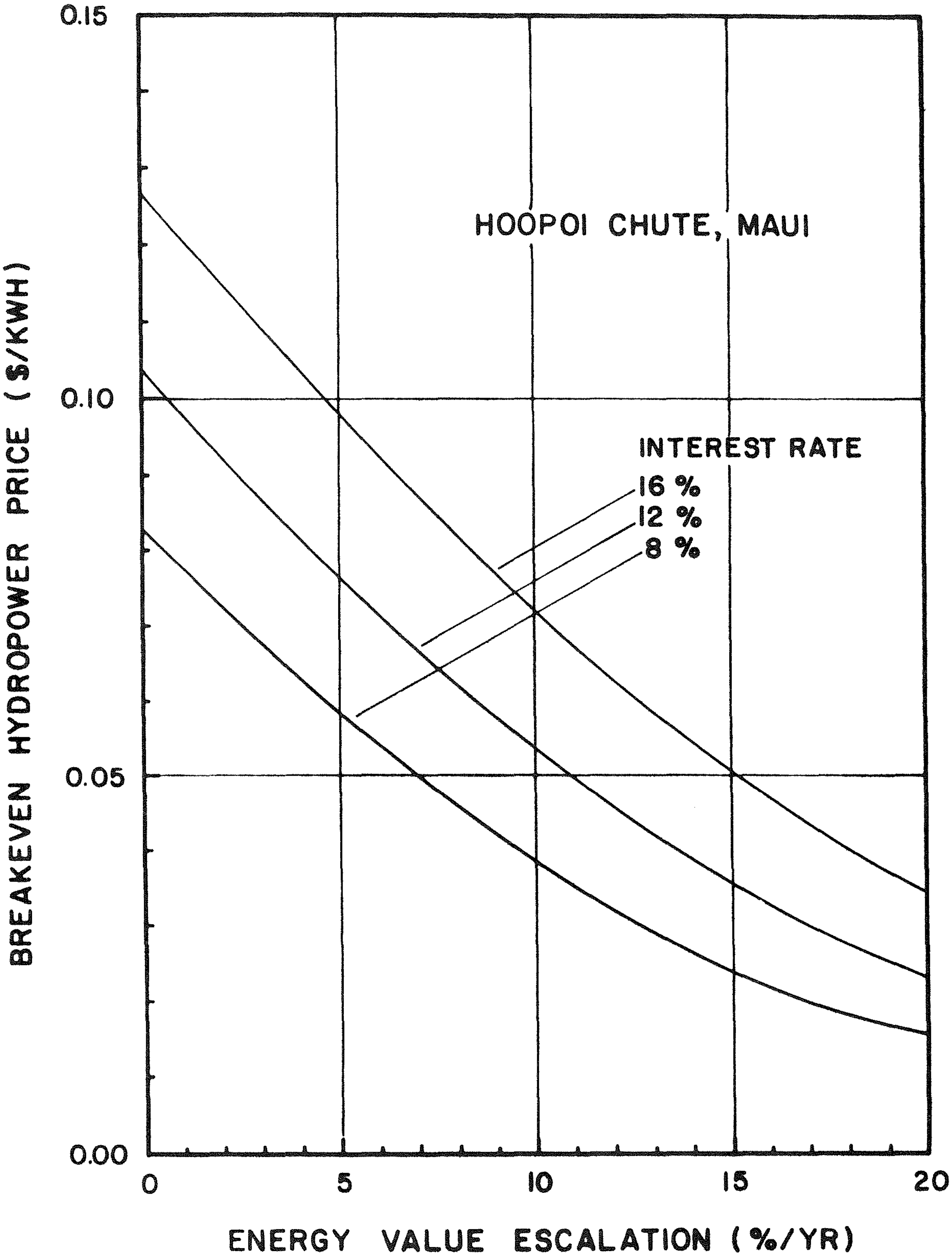



Figure D-39. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Hoopoi Chute, Maui.

Table D-26. TECHNICAL DATA SUMMARY

PROJECT SITE Nailiilihaele Stream, Maui

| | | | |
|---|---|---|---|
| Plant Capacity | | 470 | kw |
| Static Head | | 380 | ft |
| Penstock Length | | 2,300 | ft |
| Average Gradient | | 0.165 | ft/ft |
| Stream Gage of Record | | USGS # | 16570000 |
| Streamflow Parameters | Average Flow | 35.1 | cfs |
| | $Q_{15}$ | 50.5 | cfs[1] |
| | $Q_{50}$ | 16 | cfs[1] |
| | $Q_{95}$ | 4 | cfs[1] |
| Turbine/Generator Capacities | 1. 200 kw | | |
| | 2. 270 kw | | |
| Average Annual Energy Production | | 3,000,000 | kwh |
| Overall Plant Factor | | 73 | % |

Miscellaneous:

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[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

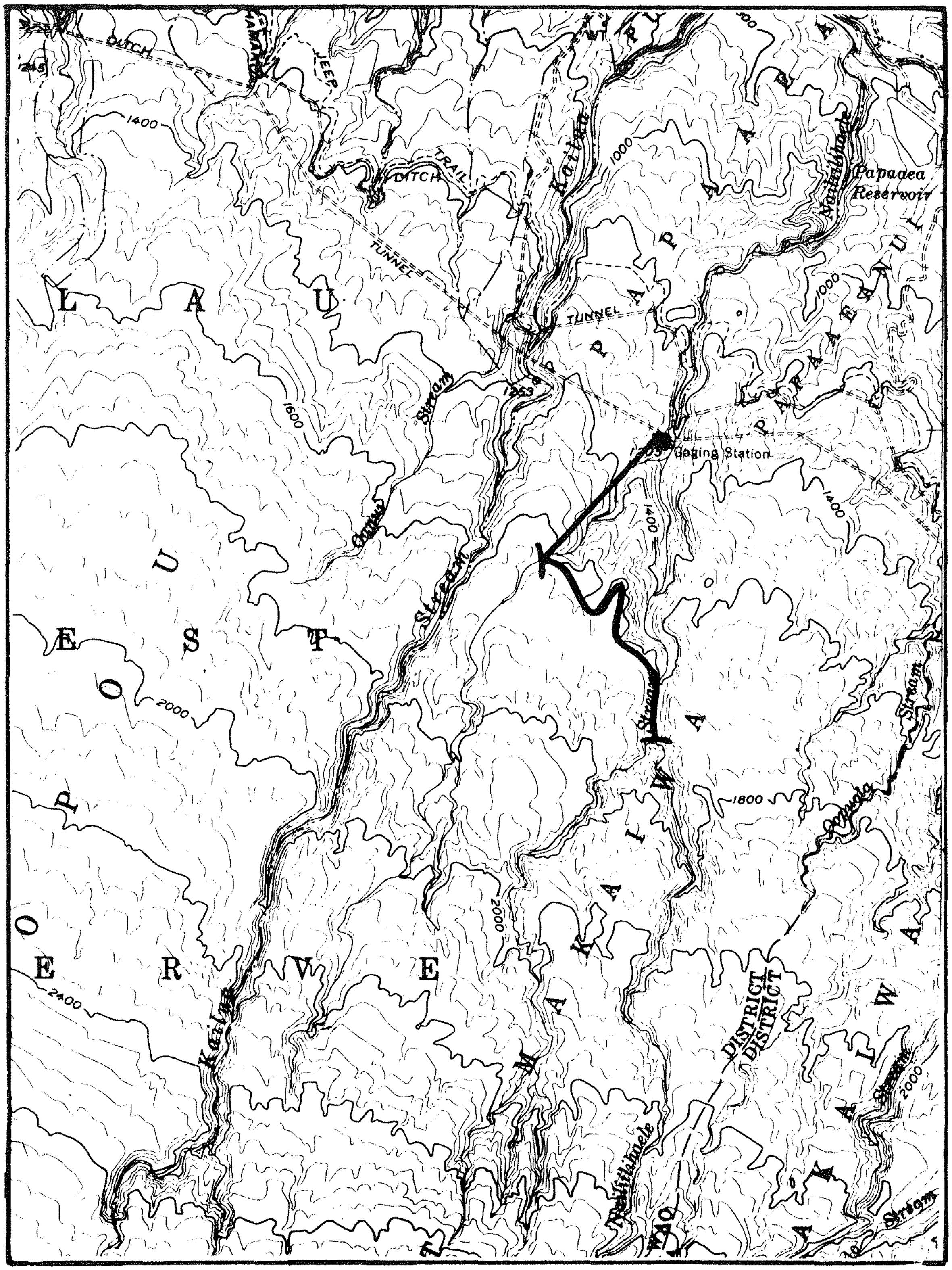



Figure D-40. Prospective Hydropower Site, Nailiilihaele Stream, Maui.

Scale: 1 in. = 2000 ft.

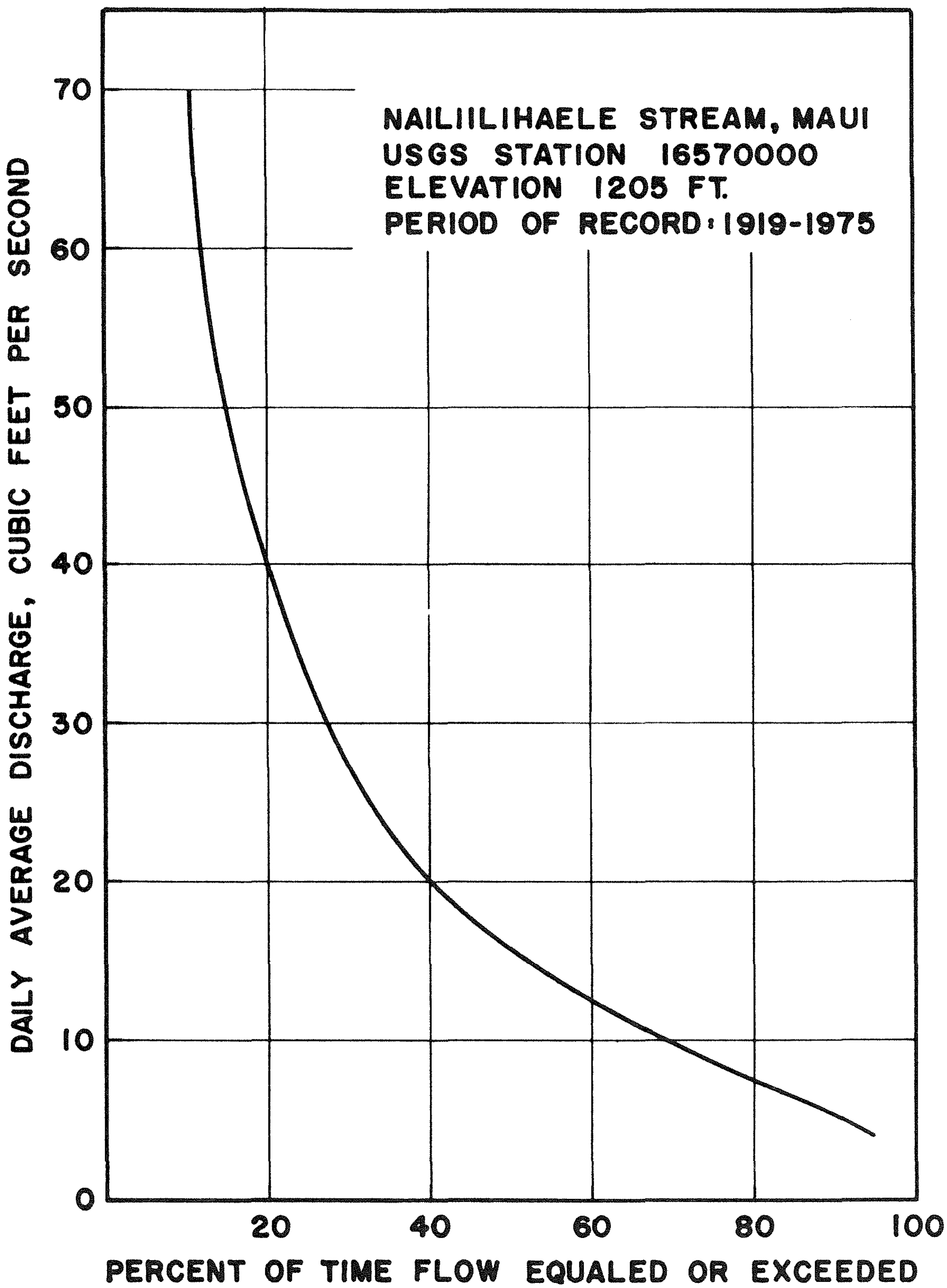



Figure D-41. Flow Duration Curve, Nailiilihaele Stream, Maui.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

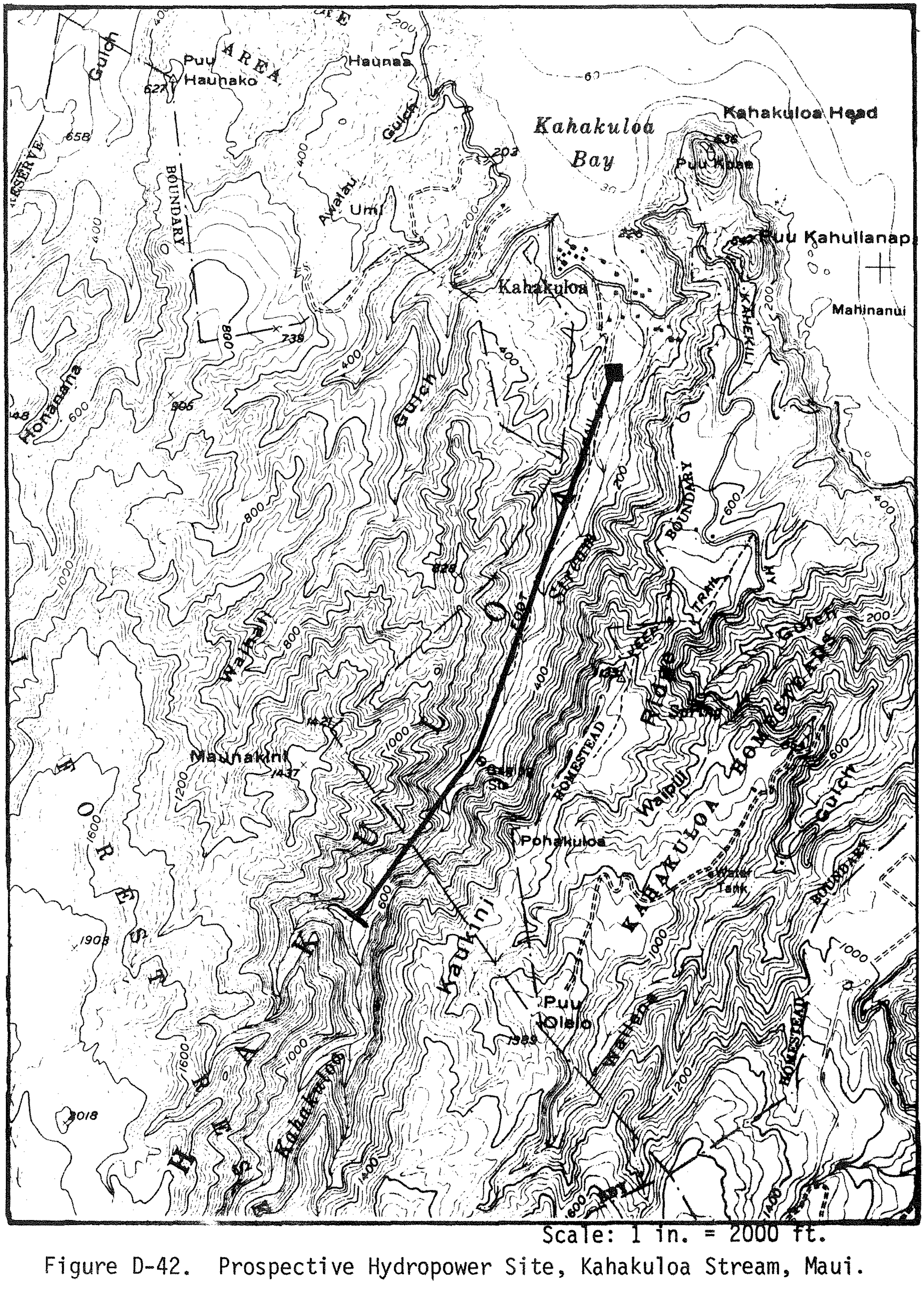
Table D-27. TECHNICAL DATA SUMMARY

PROJECT SITE Kahakuloa Stream, Maui

| | | | |
|---|---|---|---|
| Plant Capacity | | 233 | kw |
| Static Head | | 335 | ft |
| Penstock Length | | 7000 | ft |
| Average Gradient | | 0.048 | ft/ft |
| Stream Gage of Record | | USGS # 16618000 | |
| Streamflow Parameters | Average Flow | 16.8 | cfs |
| | $Q_{15}$ | 24.0 | cfs[1] |
| | $Q_{50}$ | 8.9 | cfs[1] |
| | $Q_{95}$ | 4.8 | cfs[1] |
| Turbine/Generator Capacities | 233 kw | | |
| Average Annual Energy Production | | 1,594,000 | kwh |
| Overall Plant Factor | | 78 | % |

Miscellaneous:

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.



Scale: 1 in. = 2000 ft.

Figure D-42. Prospective Hydropower Site, Kahakuloa Stream, Maui.

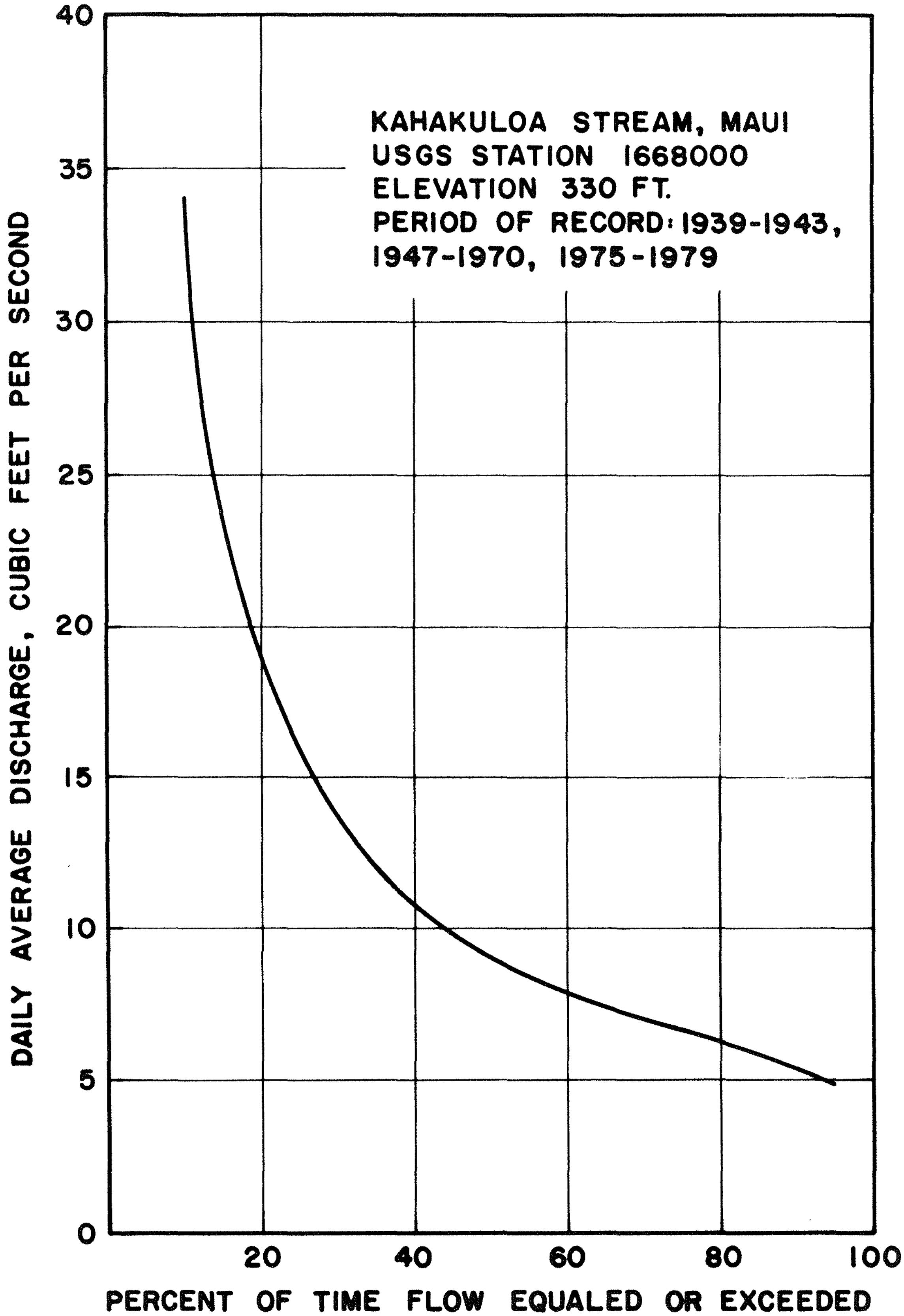



Figure D-43. Flow Duration Curve, Kahakuloa Stream, Maui.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-28. TECHNICAL DATA SUMMARY

PROJECT SITE Honokohau Ditch, Maui

| | | | |
|---|---|---|---|
| Plant Capacity | | 130 | kw |
| Static Head | | 46 | ft |
| Penstock Length | | 65 | ft |
| Average Gradient | | 0.078 | ft/ft |
| Stream Gage of Record | | USGS # | N/A |
| Streamflow Parameters | Average Flow | N/A | cfs |
| | $Q_{15}$ | 38 | cfs[1] |
| | $Q_{50}$ | 20 | cfs[1] |
| | $Q_{95}$ | 8 | cfs[1] |
| Turbine/Generator Capacities | 130 kw | | |
| Average Annual Energy Production | | 830,000 | kwh |
| Overall Plant Factor | | 73 | % |

Miscellaneous:

This site was previously developed, then abandoned. Powerhouse foundation and old turbine (not salvageable) remain. Site is at the intake to a siphon which transports Honokohau (or Honolua) Ditch water across gulch. There is a drop of 46 feet from the tunnel exit to the siphon intake. Flow data was supplied by Amfac, Inc.

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[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

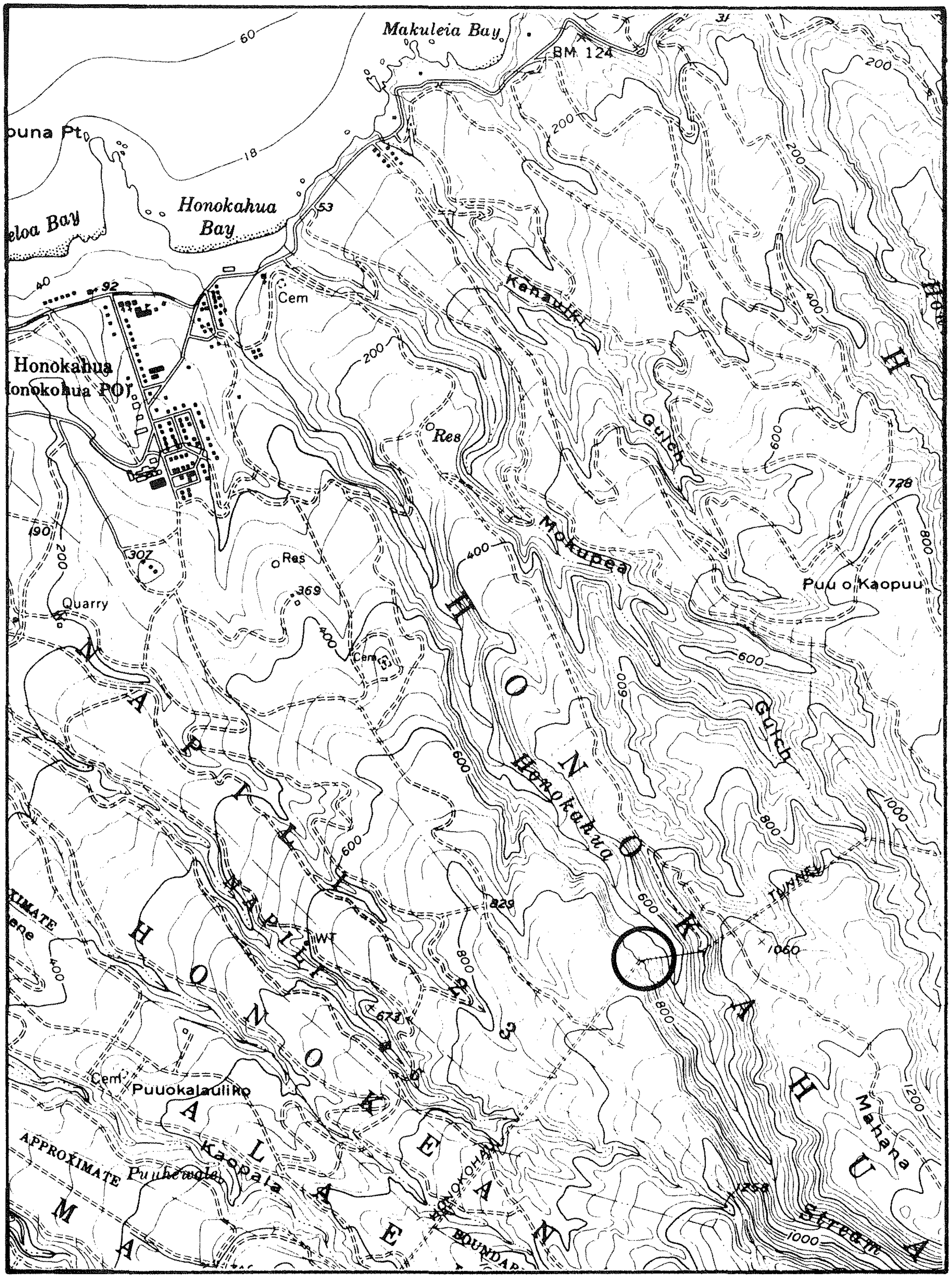



Figure D-44. Prospective Hydropower Site, Honokohau Ditch, Maui.

Scale: 1 in. = 2000 ft.

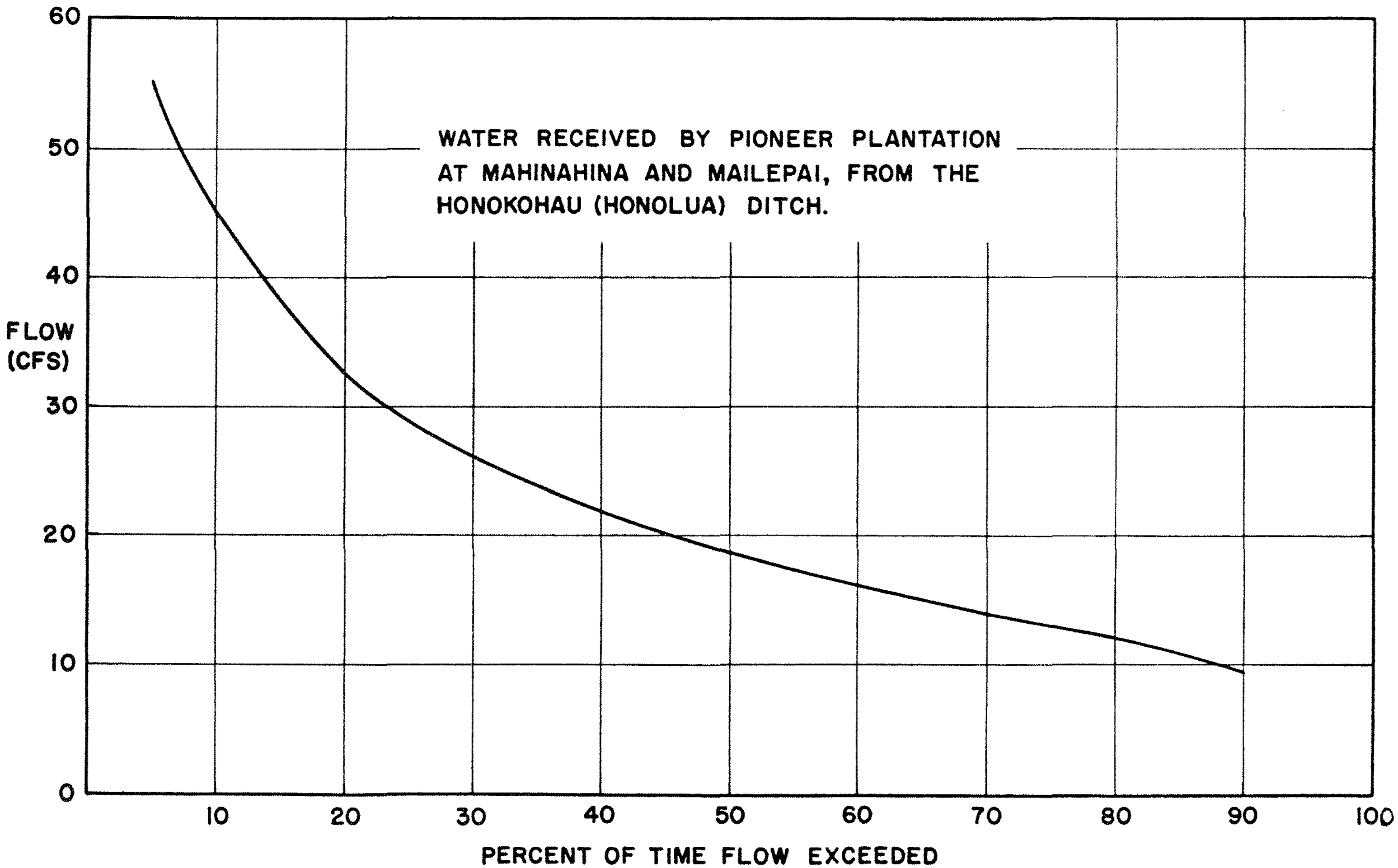



Figure D-45. Flow Duration Curve, Honokohau Ditch, Maui. (Based on data of Amfac, Inc.)

Table D-29. TECHNICAL DATA SUMMARY

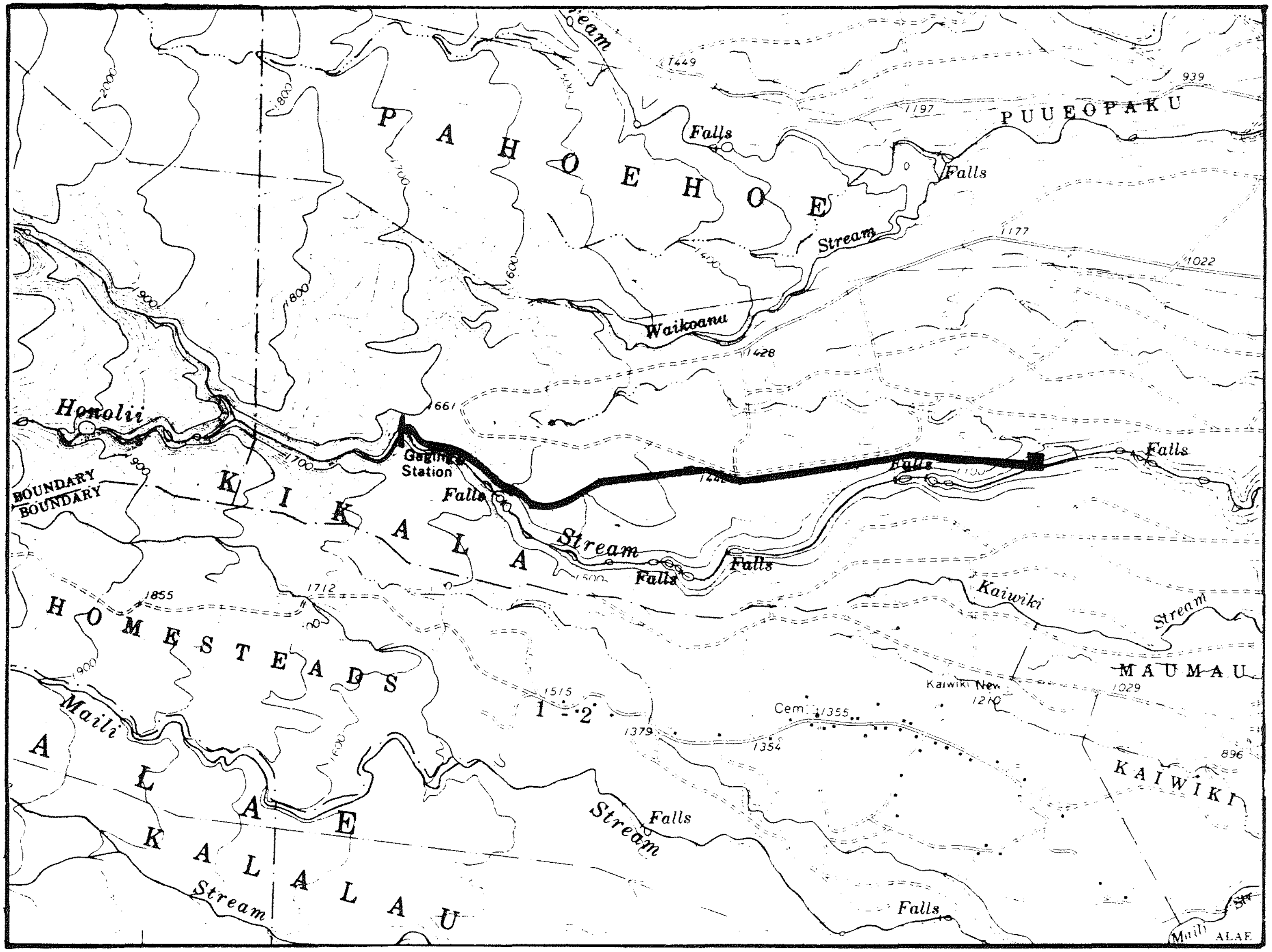
PROJECT SITE Honolii Stream, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 3900 | kw |
| Static Head | | 680 | ft |
| Penstock Length | | 8300 | ft |
| Average Gradient | | 0.082 | ft/ft |
| Stream Gage of Record | | USGS # 16717000 | |
| Streamflow Parameters | Average Flow | 125 | cfs |
| | $Q_{15}$ | 164 | cfs[1] |
| | $Q_{50}$ | 36 | cfs[1] |
| | $Q_{95}$ | 9 | cfs[1] |
| Turbine/Generator Capacities | 1. 2000 kw | | |
| | 2. 1900 kw | | |
| Average Annual Energy Production | | 17,572,000 | kwh |
| Overall Plant Factor | | 52 | % |

Miscellaneous:

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-46. Prospective Hydropower Site, Honolii Stream, Hawaii

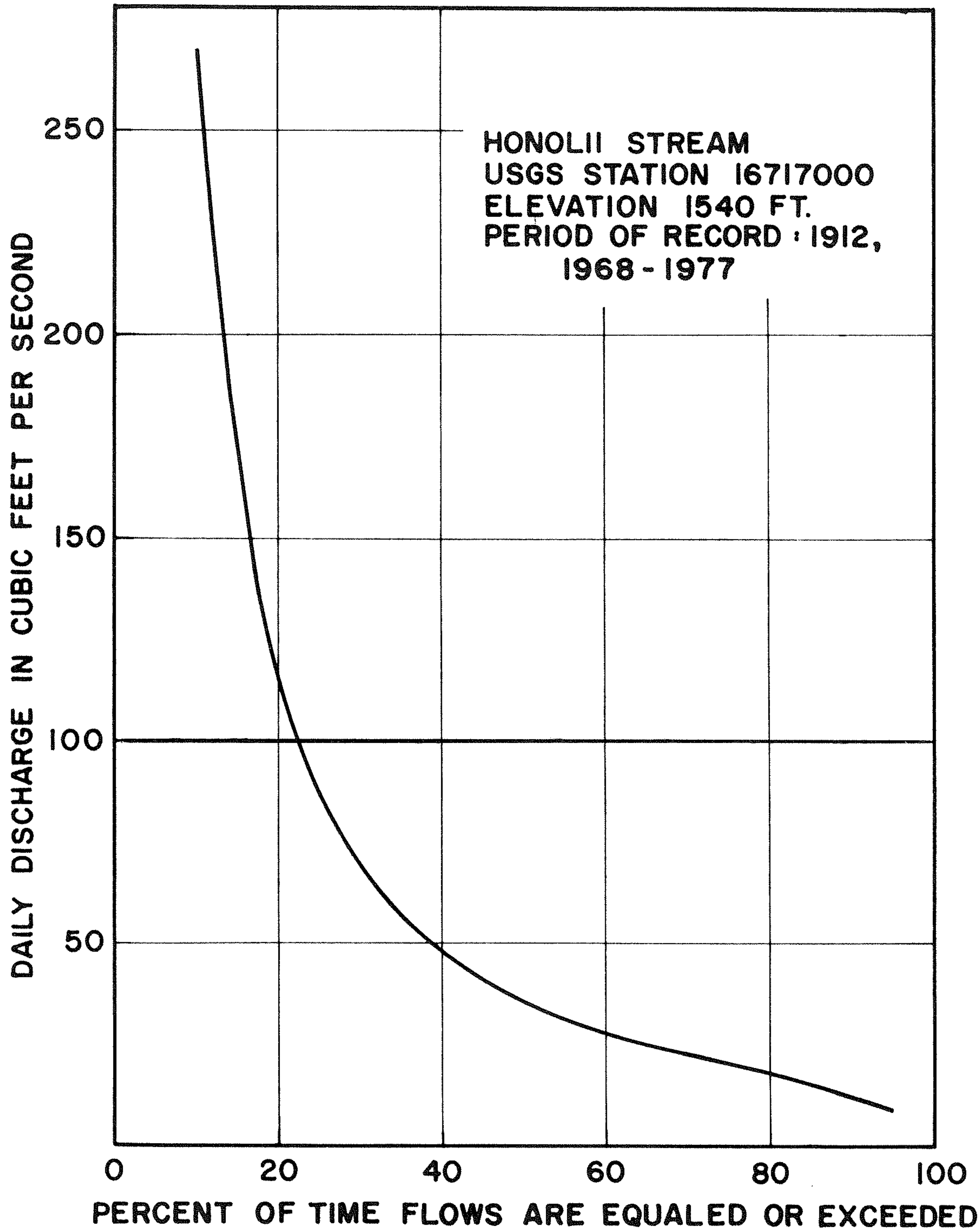



Figure D-47. Flow Duration Curve, Honolii Stream, Hawaii.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-30. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Honolii Stream, Hawaii

| | | |
|---|---|---|
| Turbine/Generators | 600,000 | |
| Station Electrical Equipment | 585,000 | |
| Penstock | 1,035,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 235,000 | |
| Access Road | 150,000 | |
| Transmission Line | 225,000 | |
| Miscellaneous Equipment | 245,000 | |
| SUBTOTAL | | 3,105,000 |
| Contingencies[2] | 620,000 | |
| Indirect Costs[3] | 745,000 | |
| TOTAL | | 4,470,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

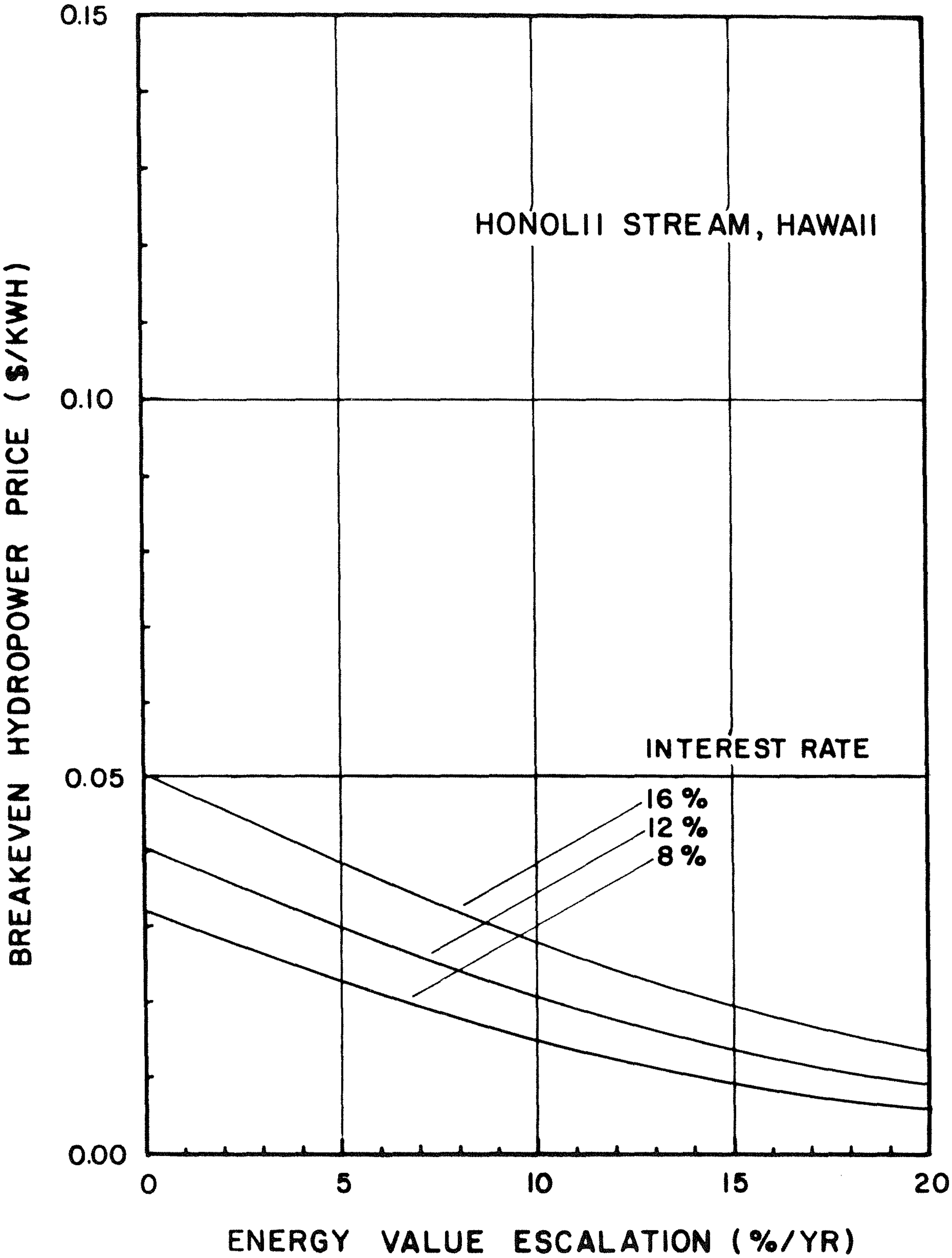



Figure D-48. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Honolii Stream, Hawaii.

Table D-31. TECHNICAL DATA SUMMARY

PROJECT SITE Wailuku River, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 2,000 | kw |
| Static Head | | 260 | ft |
| Penstock Length | | 3,000 | ft |
| Average Gradient | | 0.087 | ft/ft |
| Stream Gage of Record | | USGS # | 16704000 |
| Streamflow Parameters | Average Flow | 286 | cfs |
| | $Q_{15}$ | 380 | cfs[1] |
| | $Q_{50}$ | 82 | cfs[1] |
| | $Q_{95}$ | 14 | cfs[1] |
| Turbine/Generator Capacities | 1. 800 kw | | |
| | 2. 1,200 kw | | |
| Average Annual Energy Production | | 11,070,000 | kwh |
| Overall Plant Factor | | 64 | % |

Miscellaneous:

Site is upstream of the existing intake of the Waiau hydro plant. A ditch is required to divert water from a Wailuku River tributary to a forebay just upstream of Pukamaui Falls.

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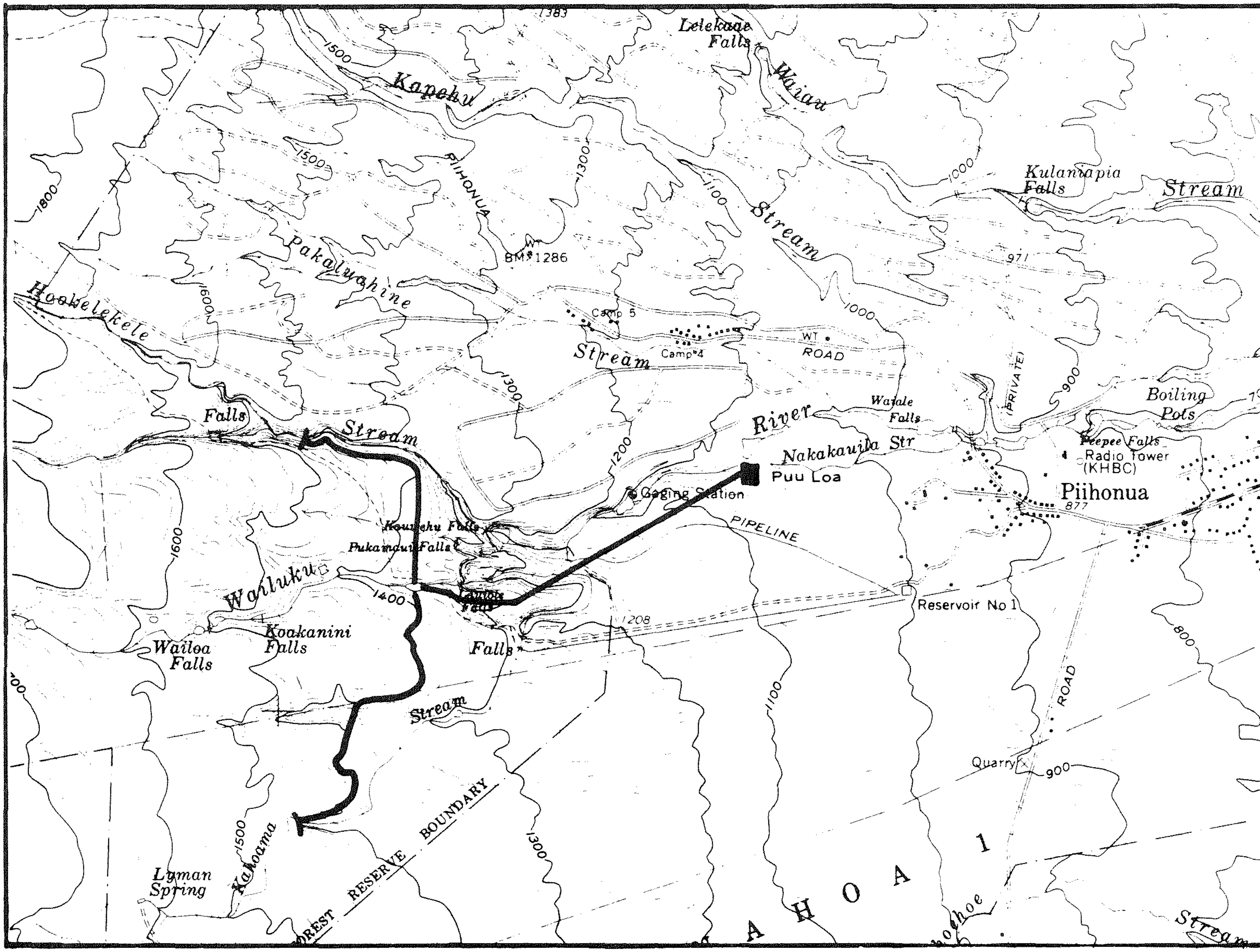
[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-49. Prospective Hydropower Site, Wailuku River, Hawaii.

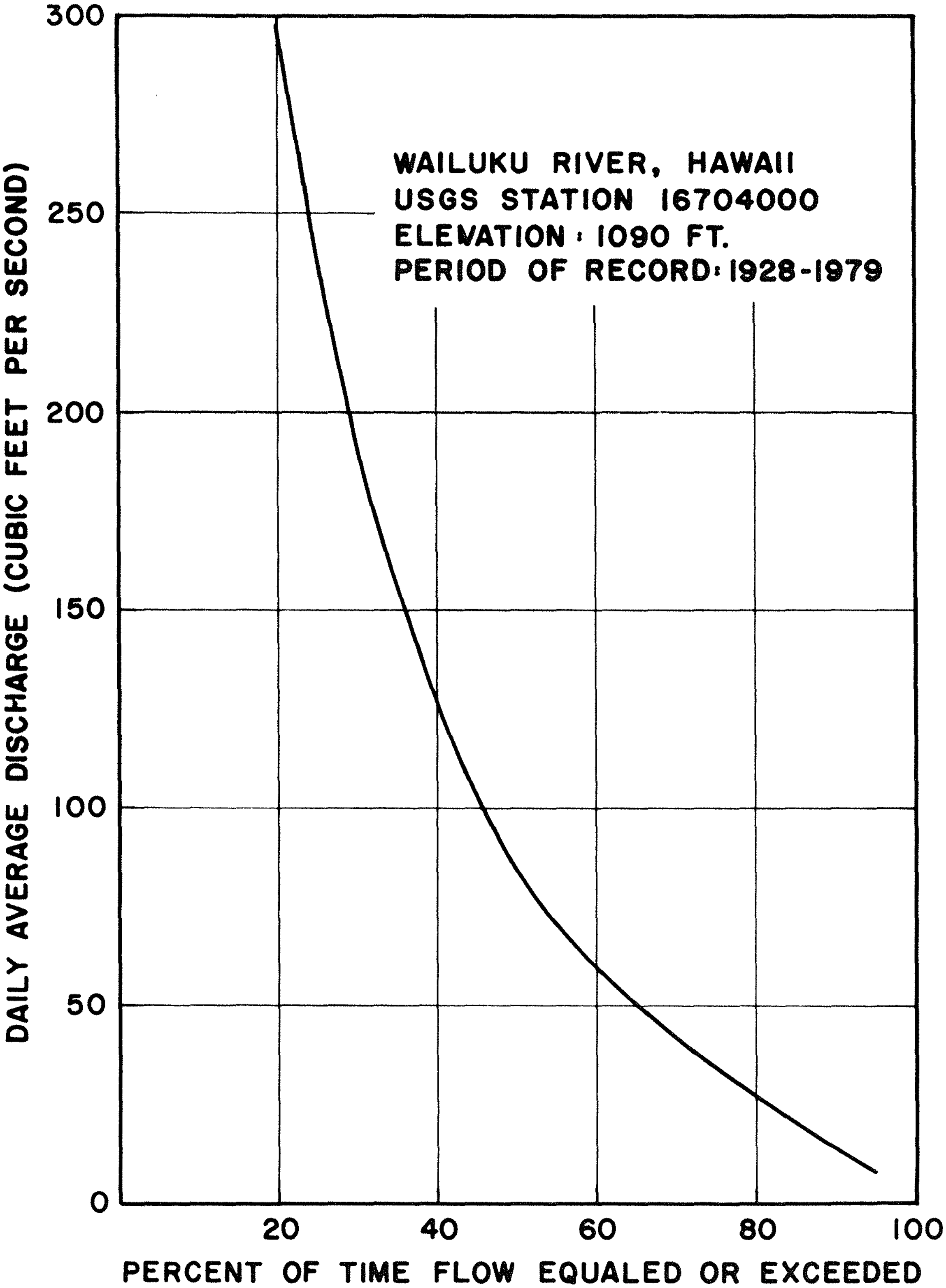



Figure D-50. Flow Duration Curve, Wailuku River, Hawaii.
(Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-32. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Wailuku River, Hawaii

| | | |
|---|---|---|
| Turbine/Generators | 510,000 | |
| Station Electrical Equipment | 470,000 | |
| Penstock | 480,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 200,000 | |
| Access Road | 480,000 | |
| Transmission Line | 75,000 | |
| Miscellaneous Equipment | 225,000 | |
| SUBTOTAL | | 2,470,000 |
| Contingencies[2] | 495,000 | |
| Indirect Costs[3] | 590,000 | |
| TOTAL | | 3,555,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

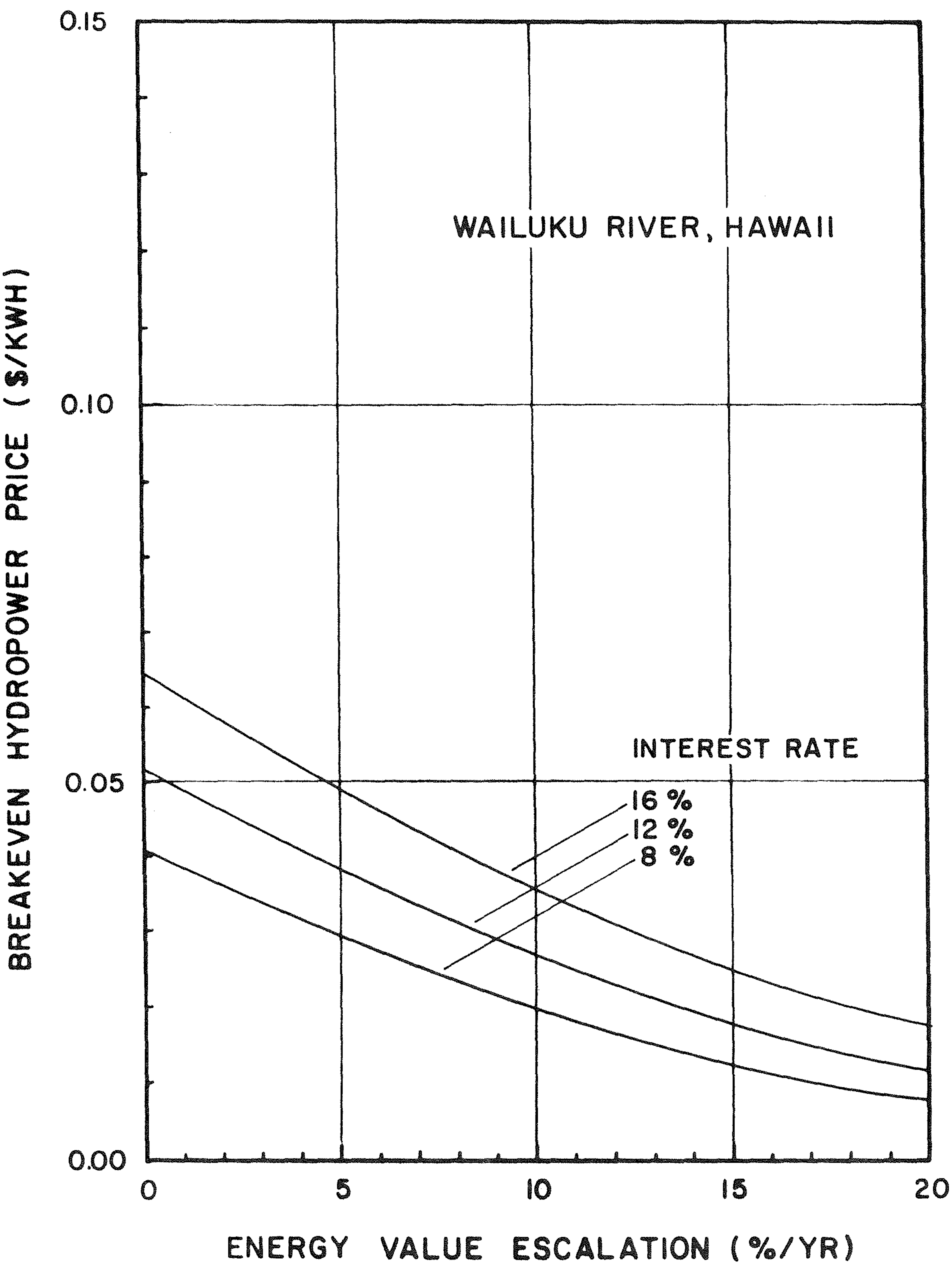



Figure D-51. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Wailuku River, Hawaii.

Table D-33. TECHNICAL DATA SUMMARY

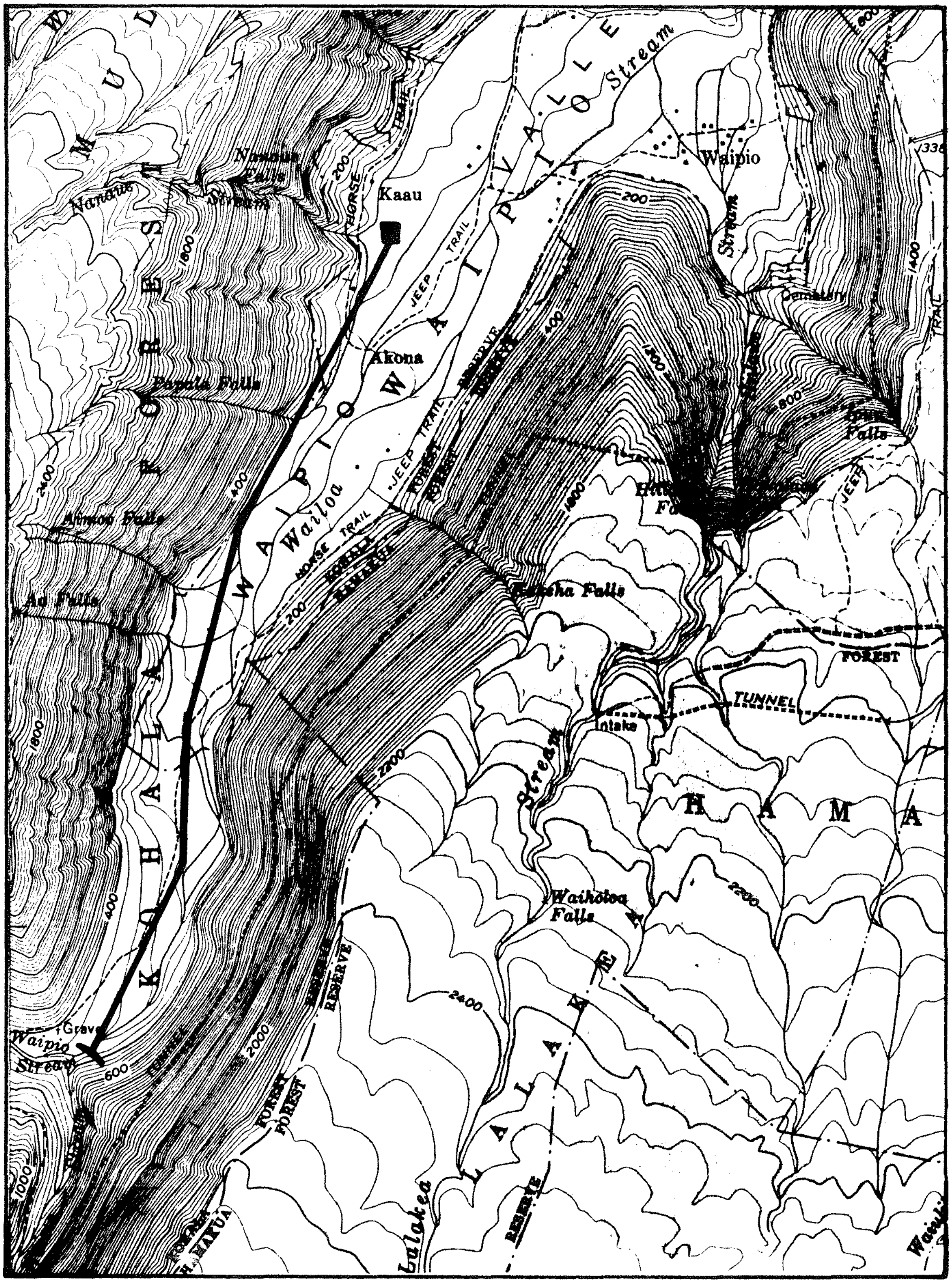
PROJECT SITE Wailoa River, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 1850 | kw |
| Static Head | | 300 | ft |
| Penstock Length | | 11,000 | ft |
| Average Gradient | | 0.027 | ft/ft |
| Stream Gage of Record | | USGS # 16732200 | |
| Streamflow Parameters | Average Flow | 73.5 | cfs |
| | $Q_{15}$ | 100 | cfs[1] |
| | $Q_{50}$ | 51 | cfs[1] |
| | $Q_{95}$ | 40 | cfs[1] |
| Turbine/Generator Capacities | 1850 kw | | |
| Average Annual Energy Production | | 10,292,000 | kwh |
| Overall Plant Factor | | 64 | % |

Miscellaneous:

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-52. Prospective Hydropower Site, Wailoa River, Hawaii.

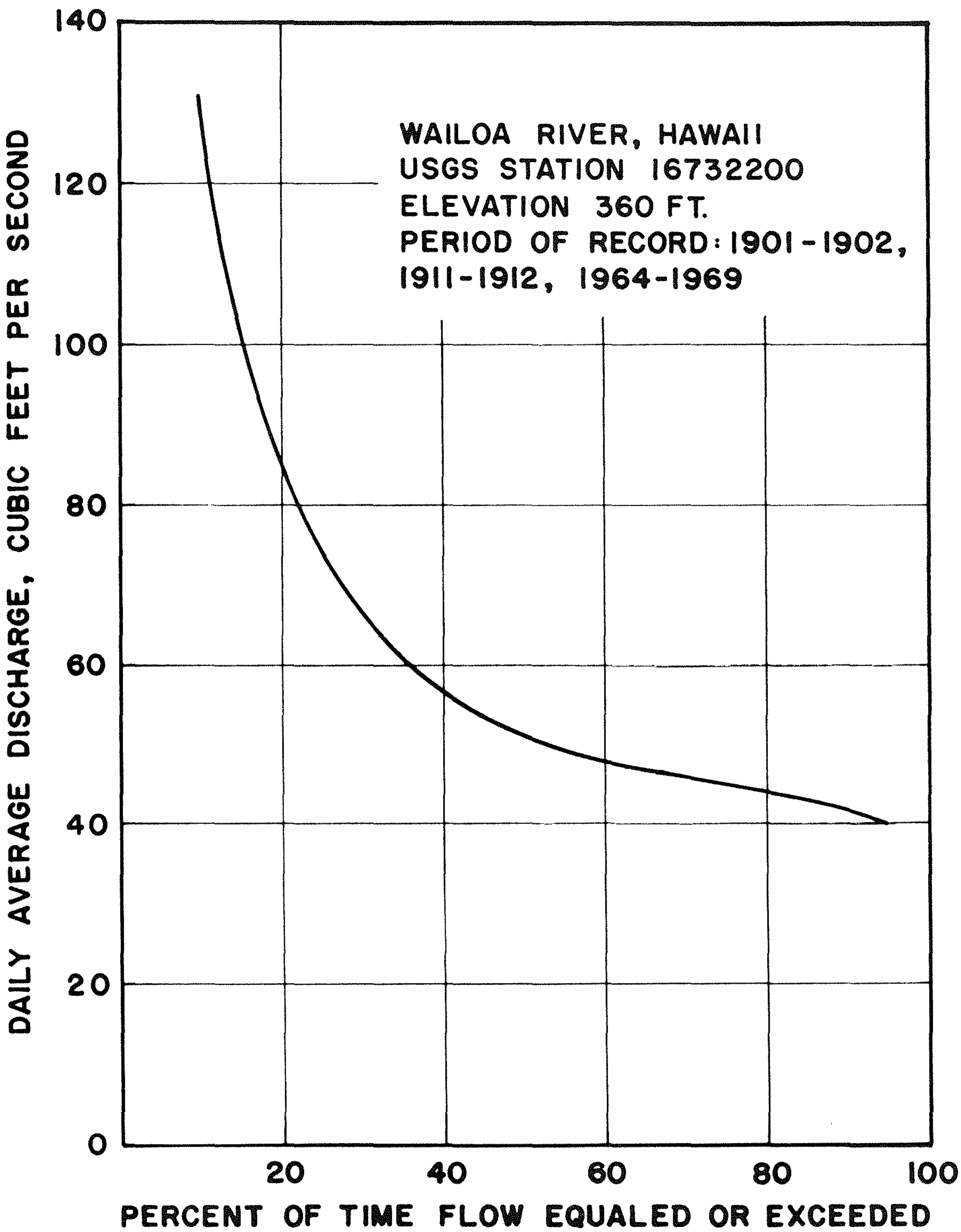



Figure D-53. Flow Duration Curve, Wailoa River, Hawaii. (Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-34. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Wailoa River, Hawaii

| | | |
|---|---|---|
| Turbine/Generators | 380,000 | |
| Station Electrical Equipment | 360,000 | |
| Penstock | 2,200,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 195,000 | |
| Access Road | 330,000 | |
| Transmission Line | 270,000 | |
| Miscellaneous Equipment | 225,000 | |
| SUBTOTAL | | 3,990,000 |
| Contingencies[2] | 800,000 | |
| Indirect Costs[3] | 955,000 | |
| TOTAL | | 5,745,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

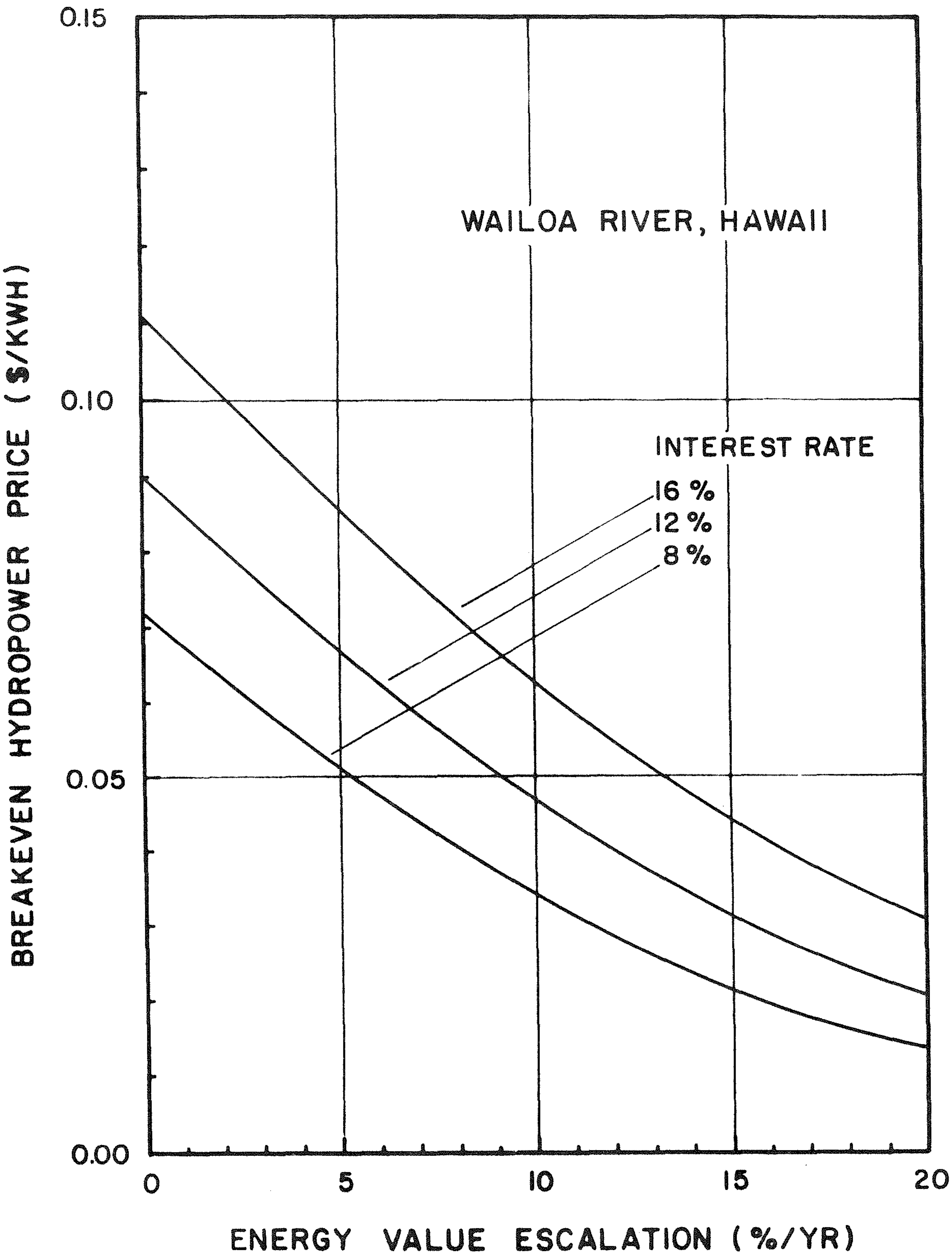



Figure D-54. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Wailoa River, Hawaii.

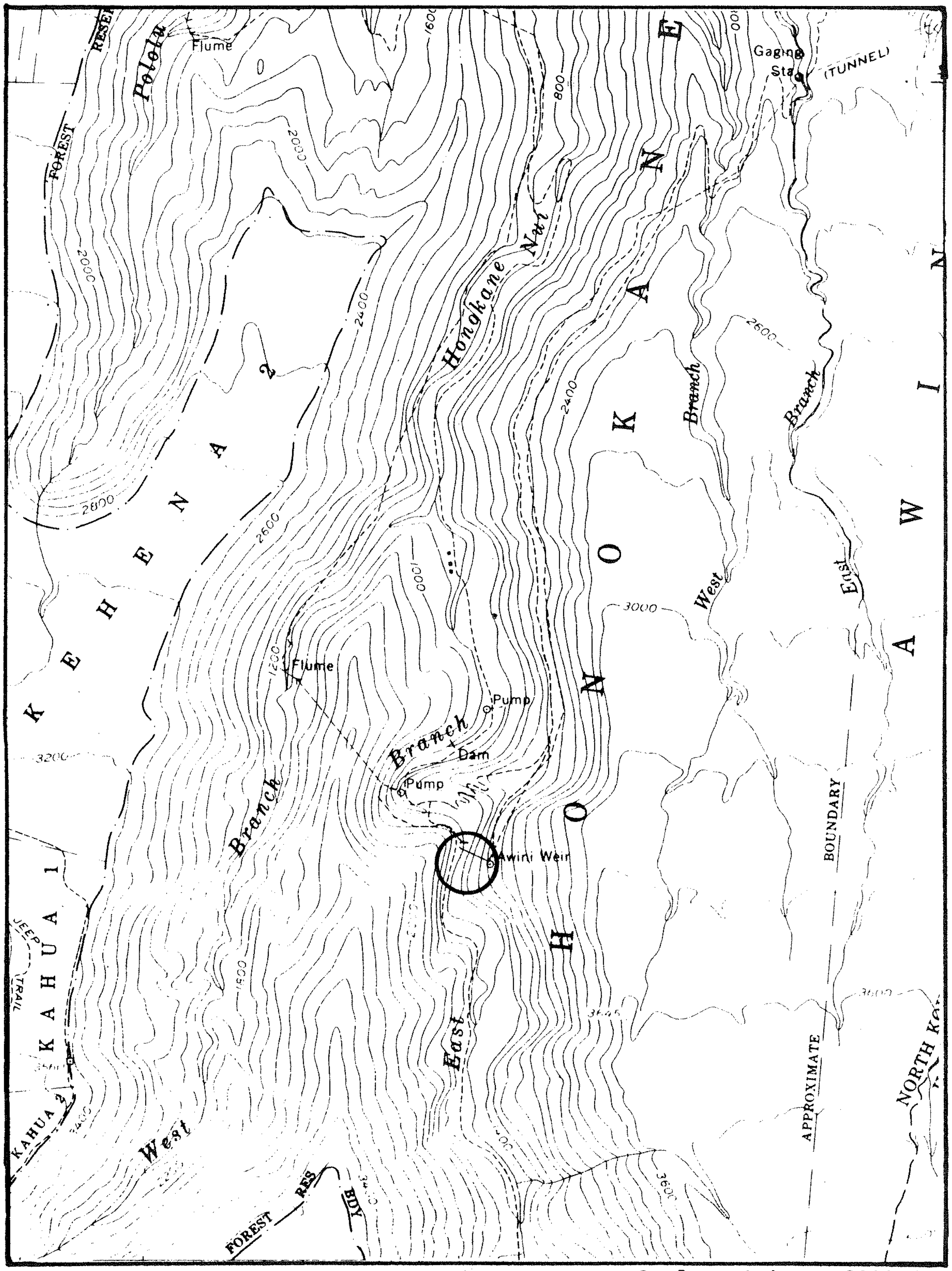
Table D-35. TECHNICAL DATA SUMMARY

PROJECT SITE Awini Falls, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 1500 | kw |
| Static Head | | 720 | ft |
| Penstock Length | | 900 | ft |
| Average Gradient | | 0.80 | ft/ft |
| Stream Gage of Record | | USGS # 16745500 | |
| Streamflow Parameters | Average Flow | 16.6 | cfs |
| | $Q_{15}$ | 31.3 | cfs[1] |
| | $Q_{50}$ | 18.3 | cfs[1] |
| | $Q_{95}$ | 2 | cfs[1] |
| Turbine/Generator Capacities | 1. 250 kw<br>2. 560 kw<br>3. 690 kw | | |
| Average Annual Energy Production | | 7,675,000 | kwh |
| Overall Plant Factor | | 58 | % |

Miscellaneous:

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.



Scale: 1 in. = 2000 ft.

Figure D-55. Prospective Hydropower Site, Awini Falls, Hawaii.

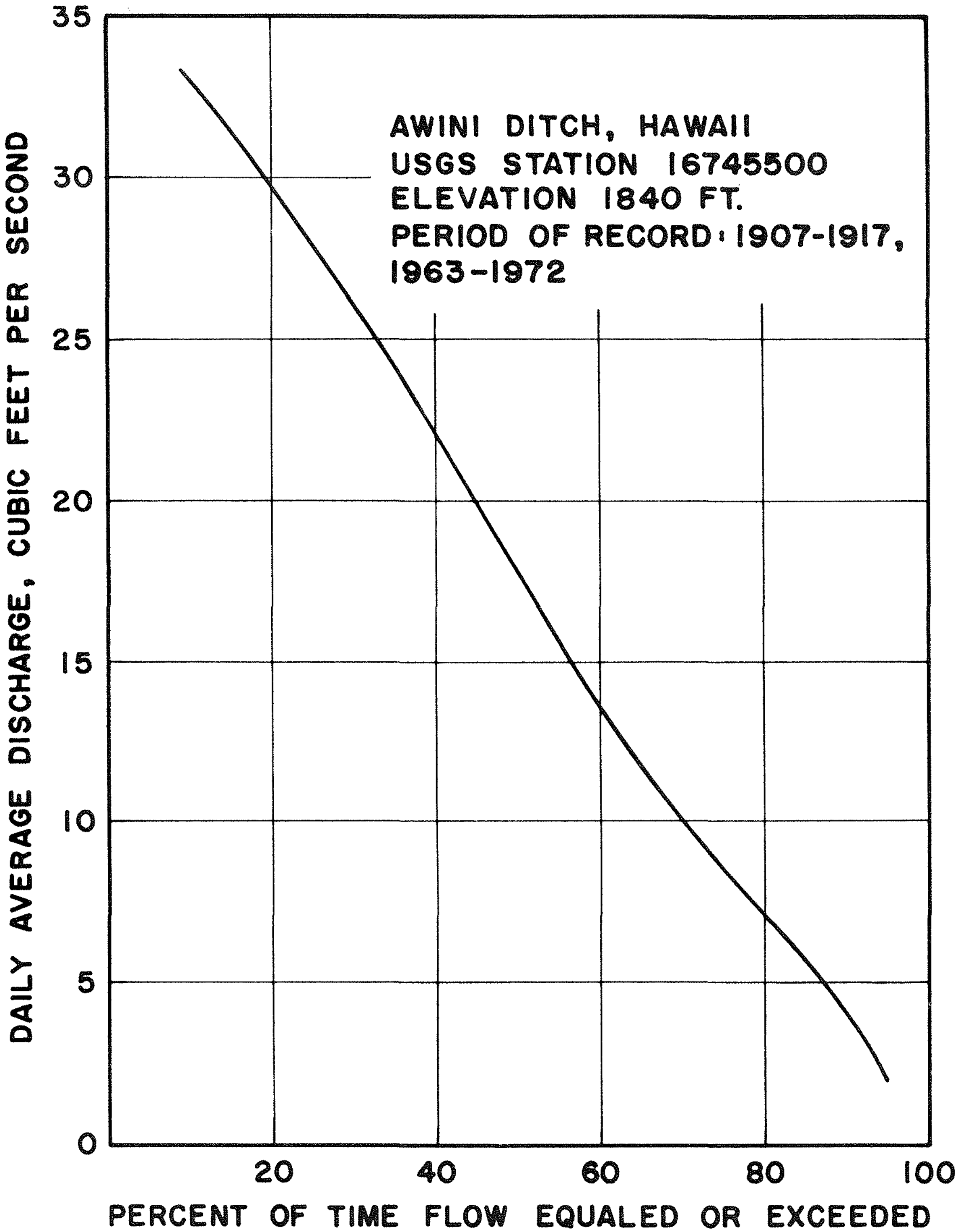



Figure D-56. Flow Duration Curve, Awini Falls, Hawaii (Awini Ditch). (Based on U.S.G.S. Water Resource Division Stream Gage Data)

Table D-36. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Awini Falls, Hawaii

| | | |
|---|---|---|
| Turbine/Generators | 340,000 | |
| Station Electrical Equipment | 480,000 | |
| Penstock | 180,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 220,000 | |
| Access Road | 900,000 | |
| Transmission Line | 440,000 | |
| Miscellaneous Equipment | 220,000 | |
| SUBTOTAL | | 2,810,000 |
| Contingencies[2] | 560,000 | |
| Indirect Costs[3] | 675,000 | |
| TOTAL | | 4,045,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

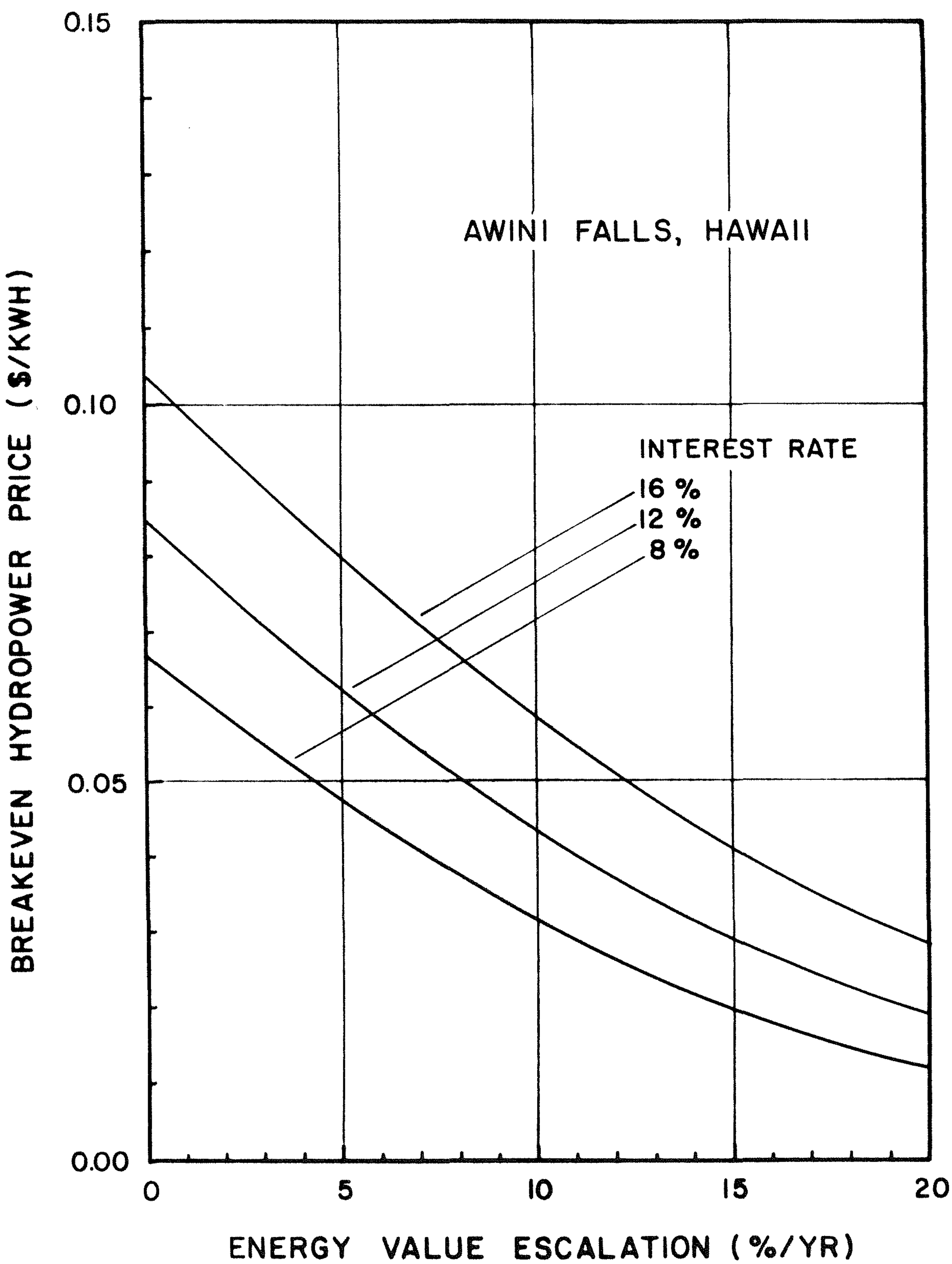



Figure D-57. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Awini Falls, Hawaii.

Table D-37. TECHNICAL DATA SUMMARY

PROJECT SITE East Br. Honokane Nui Stream, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 1,100 | kw |
| Static Head | | 435 | ft |
| Penstock Length | | 7,500 | ft |
| Average Gradient | | 0.058 | ft/ft |
| Stream Gage of Record | | USGS # | 16747500 |
| Streamflow Parameters | Average Flow | 25.7 | cfs |
| | $Q_{15}$ | 40.8 | cfs[1] |
| | $Q_{50}$ | 21 | cfs[1] |
| | $Q_{95}$ | 16 | cfs[1] |
| Turbine/Generator Capacities | 1100 kw | | |
| Average Annual Energy Production | | 6,194,000 | kwh |
| Overall Plant Factor | | 64 | % |

Miscellaneous:

Plant site is same as Awini Falls, but has a different intake and penstock arrangement. Co-development of both sites would allow sharing of facilities (powerhouse, switchyard, transmission line, access road) and would result in significant cost reductions.

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.

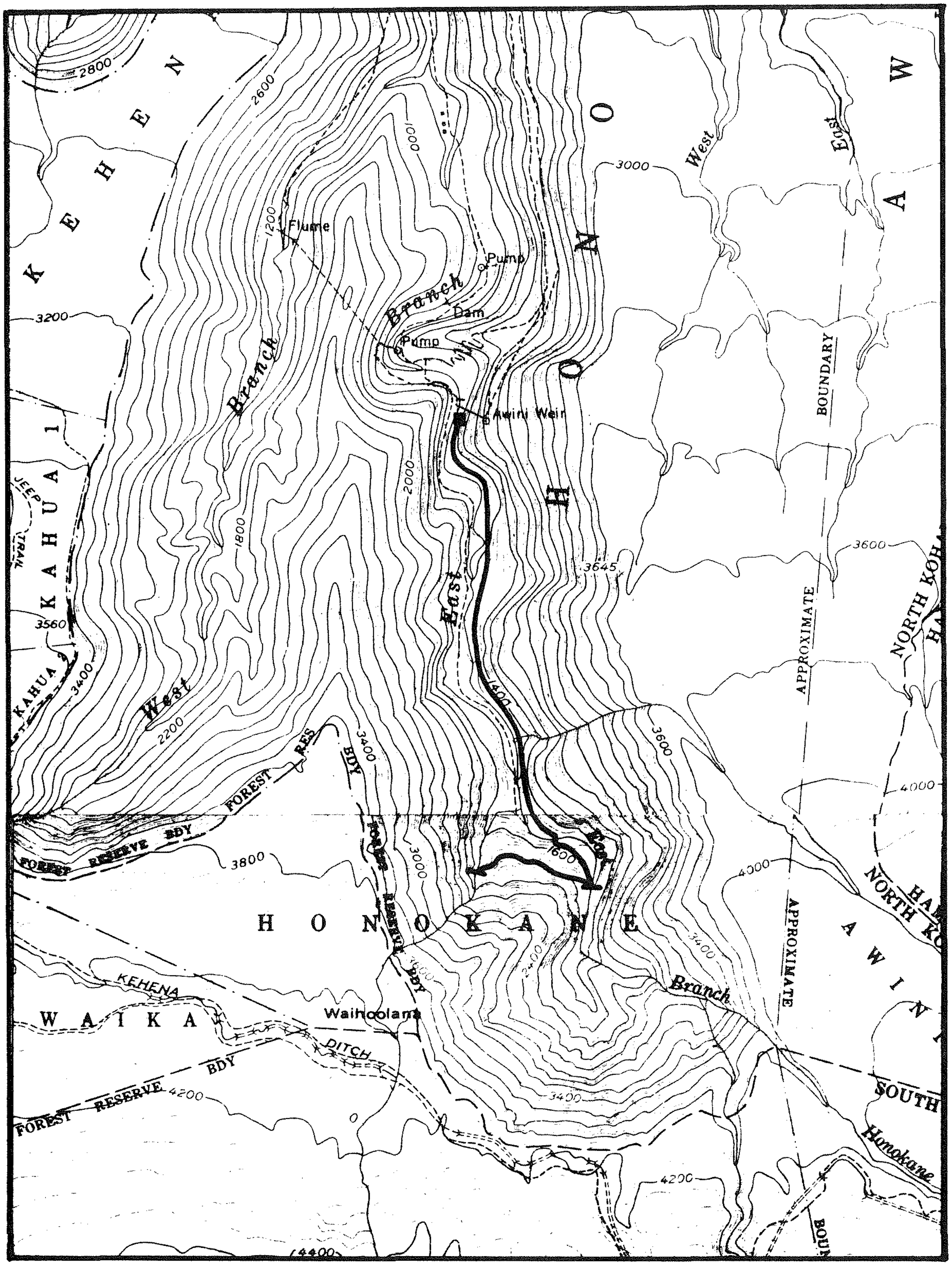



Figure D-58. Prospective Hydropower Site, East Branch Honokane Nui Stream, Hawaii.

Scale: 1 in. = 2000 ft.

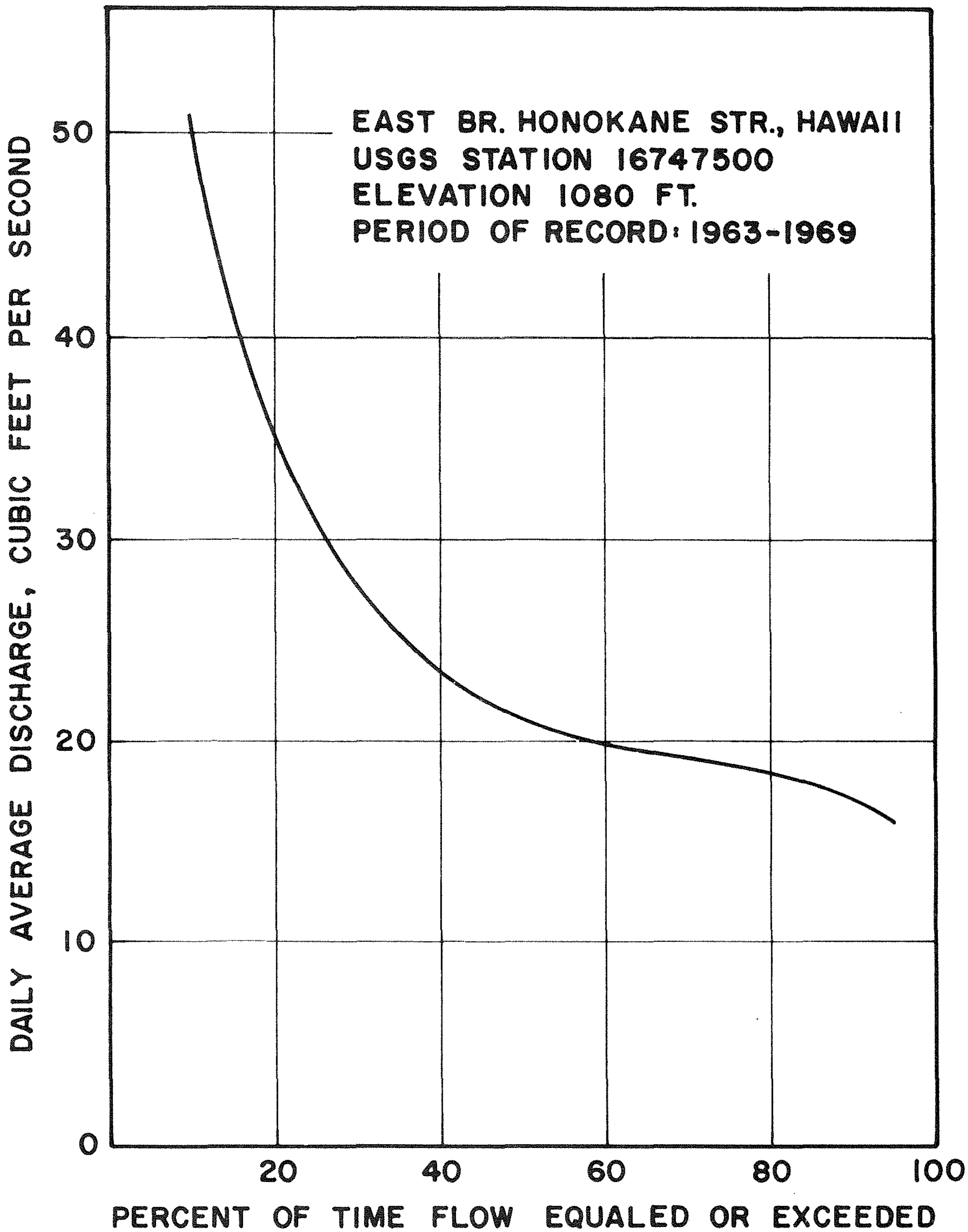



Figure D-59. Flow Duration Curve, E. Br. Honokane Nui Stream, Hawaii. (Based on U.S.G.S. Water Resources Division Stream Gage Data)

Table D-38. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: East Branch Honokane Nui Stream, Hawaii

| | | |
|---|---|---|
| Turbine/Generators | 220,000 | |
| Station Electrical Equipment | 340,000 | |
| Penstock | 750,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 170,000 | |
| Access Road | 900,000 | |
| Transmission Line | 440,000 | |
| Miscellaneous Equipment | 210,000 | |
| SUBTOTAL | | 3,060,000 |
| Contingencies[2] | 610,000 | |
| Indirect Costs[3] | 735,000 | |
| TOTAL | | 4,405,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

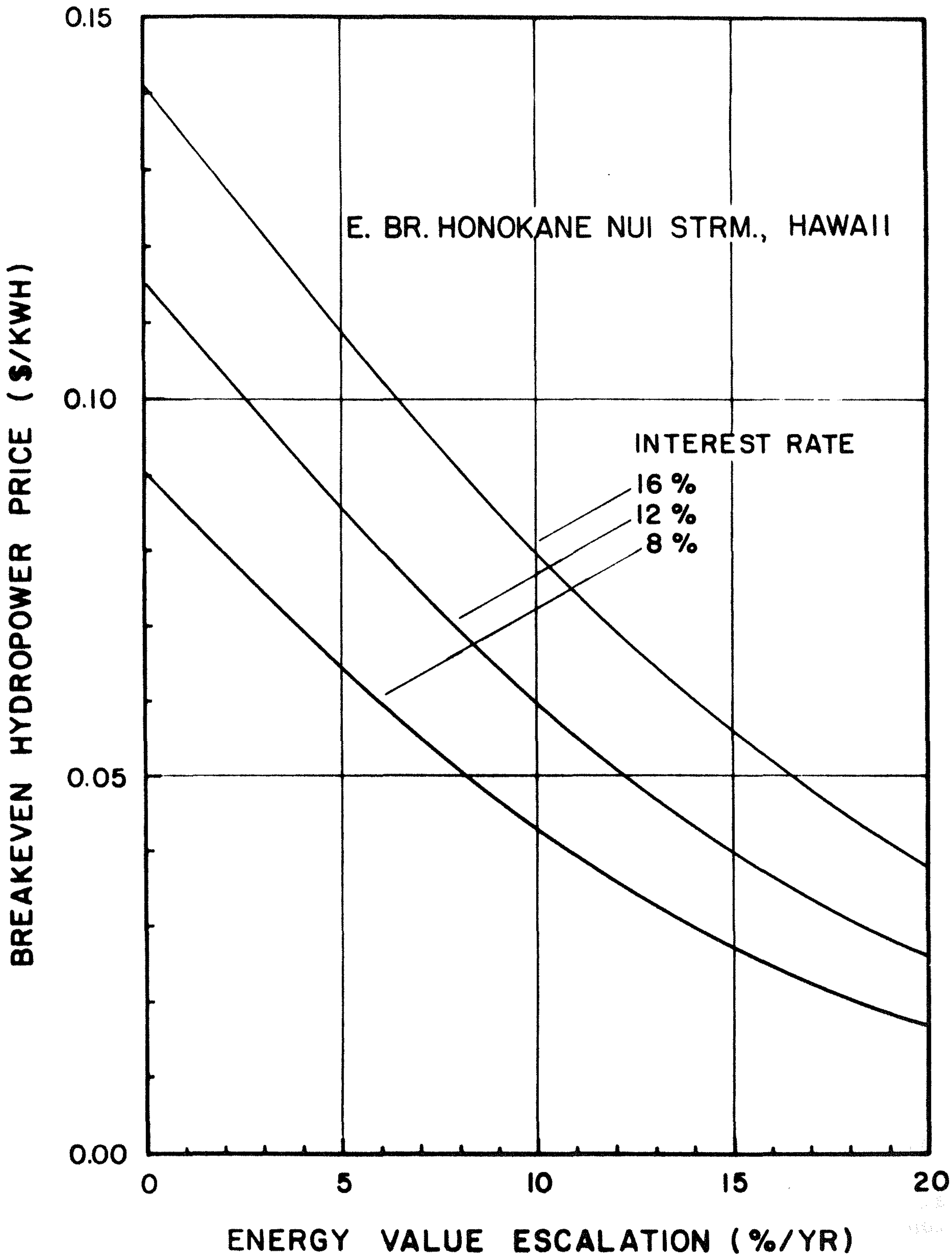



Figure D-60. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, E. Br. Honokane Nui Stream, Hawaii.

Table D-39. HYDROPOWER PROJECT COST SUMMARY[1]

PROJECT: Combination of Awini Falls-Honokane Nui Stream, Hawaii

| | | |
|---|---|---|
| Turbine/Generators | 560,000 | |
| Station Electrical Equipment | 615,000 | |
| Penstock | 930,000 | |
| Sitework | 30,000 | |
| Powerhouse Civil | 230,000 | |
| Access Road | 900,000 | |
| Transmission Line | 440,000 | |
| Miscellaneous Equipment | 230,000 | |
| SUBTOTAL | | 3,935,000 |
| Contingencies[2] | 785,000 | |
| Indirect Costs[3] | 945,000 | |
| TOTAL | | 5,665,000 |

[1]cost data as of October 1980.

[2]at 20% of construction costs; includes allowance of 10% for interest during construction(1 year).

[3]at 20% of construction costs + contingencies; includes costs of feasibility study, license and permit applications, engineering and design, construction management, and administration.

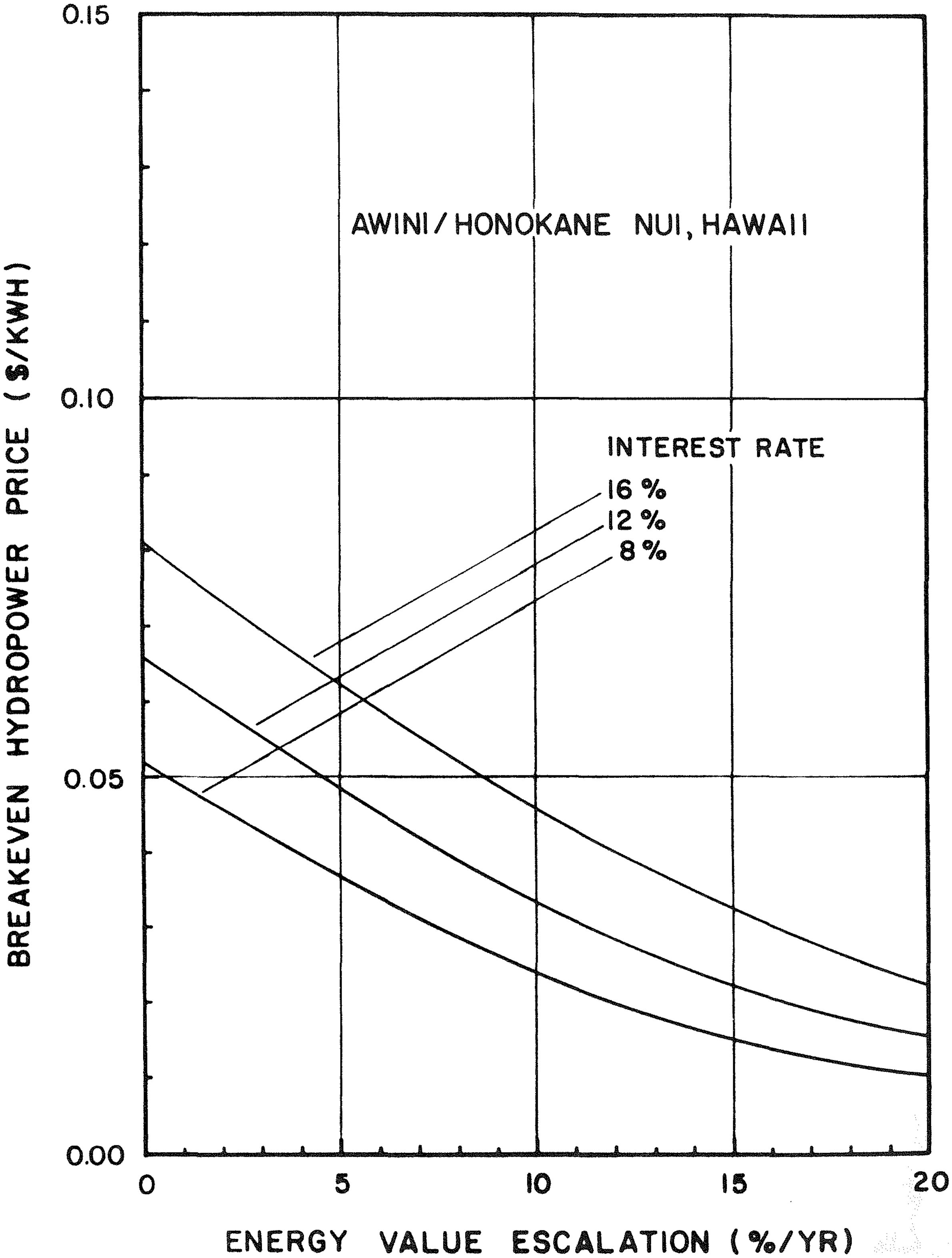



Figure D-61. Breakeven Hydropower Price as a Function of Interest Rate and Energy Value Escalation Rate, Combined Awini Falls - Honokane Nui Stream, Hawaii.

Table D-40. TECHNICAL DATA SUMMARY

PROJECT SITE Union Mill, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 500 | kw |
| Static Head | | 580 | ft |
| Penstock Length | | 8,700 | ft |
| Average Gradient | | 0.067 | ft/ft |
| Stream Gage of Record | | USGS # | 16751000 |
| Streamflow Parameters | Average Flow | 40.8 | cfs |
| | $Q_{15}$ | 60 | cfs[1] |
| | $Q_{50}$ | 37 | cfs[1] |
| | $Q_{95}$ | 20 | cfs[1] |

Turbine/Generator Capacities: 500 kw

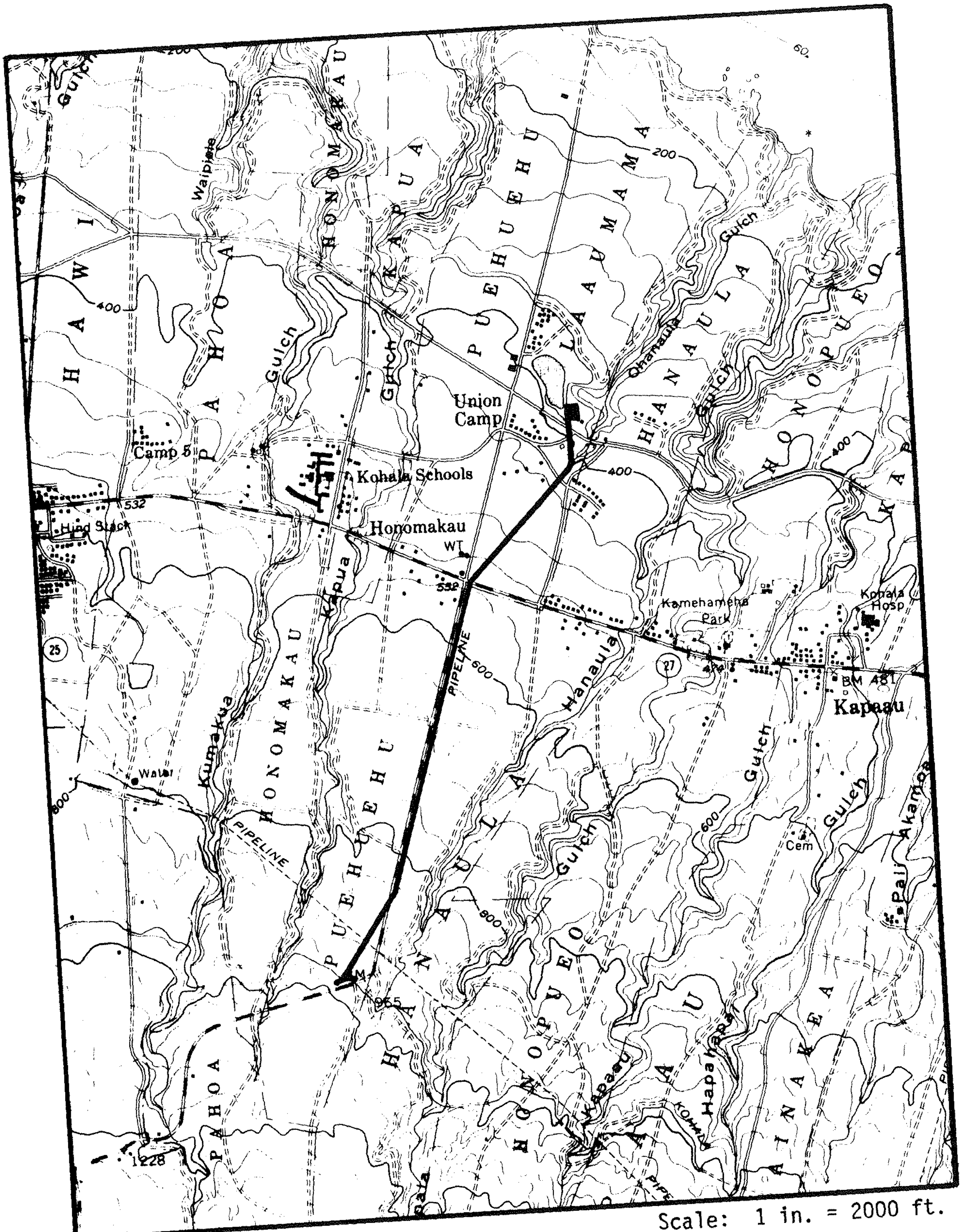
| | | |
|---|---|---|
| Average Annual Energy Production | 4,600,000 | kwh |
| Overall Plant Factor | 94 | % |

Miscellaneous:

Analysis performed by U.S. Army Corps of Engineers.

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.



Scale: 1 in. = 2000 ft.

Figure D-62. Prospective Hydropower Site, Union Mill, Hawaii.

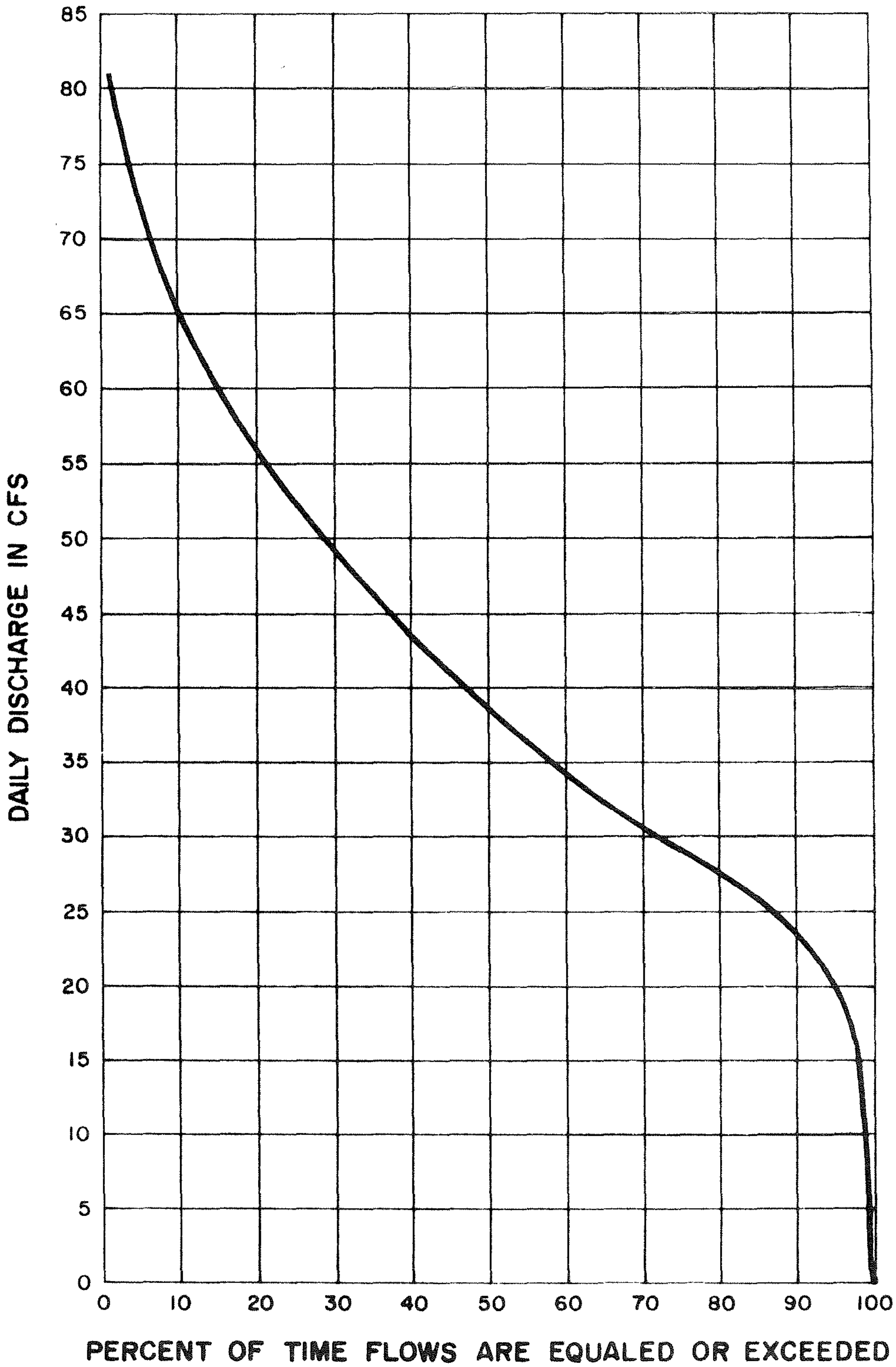



Figure D-63.

USGS STATION 16751000
KOHALA DITCH AT POLOLU NEAR NIULII
PERIOD OF RECORD: **44 YEARS**

Source: U.S. Army Corps of Engineers Reconnaissance Report for Small Hydropower, Union Mill, Hawi, Hawaii, October 1979.

R.E.I. REPORT UNION MILL, HAWAII

**FLOW DURATION CURVE**
**(KOHALA DITCH)**

U.S. ARMY ENGINEER DISTRICT, HONOLULU
FIGURE C 1

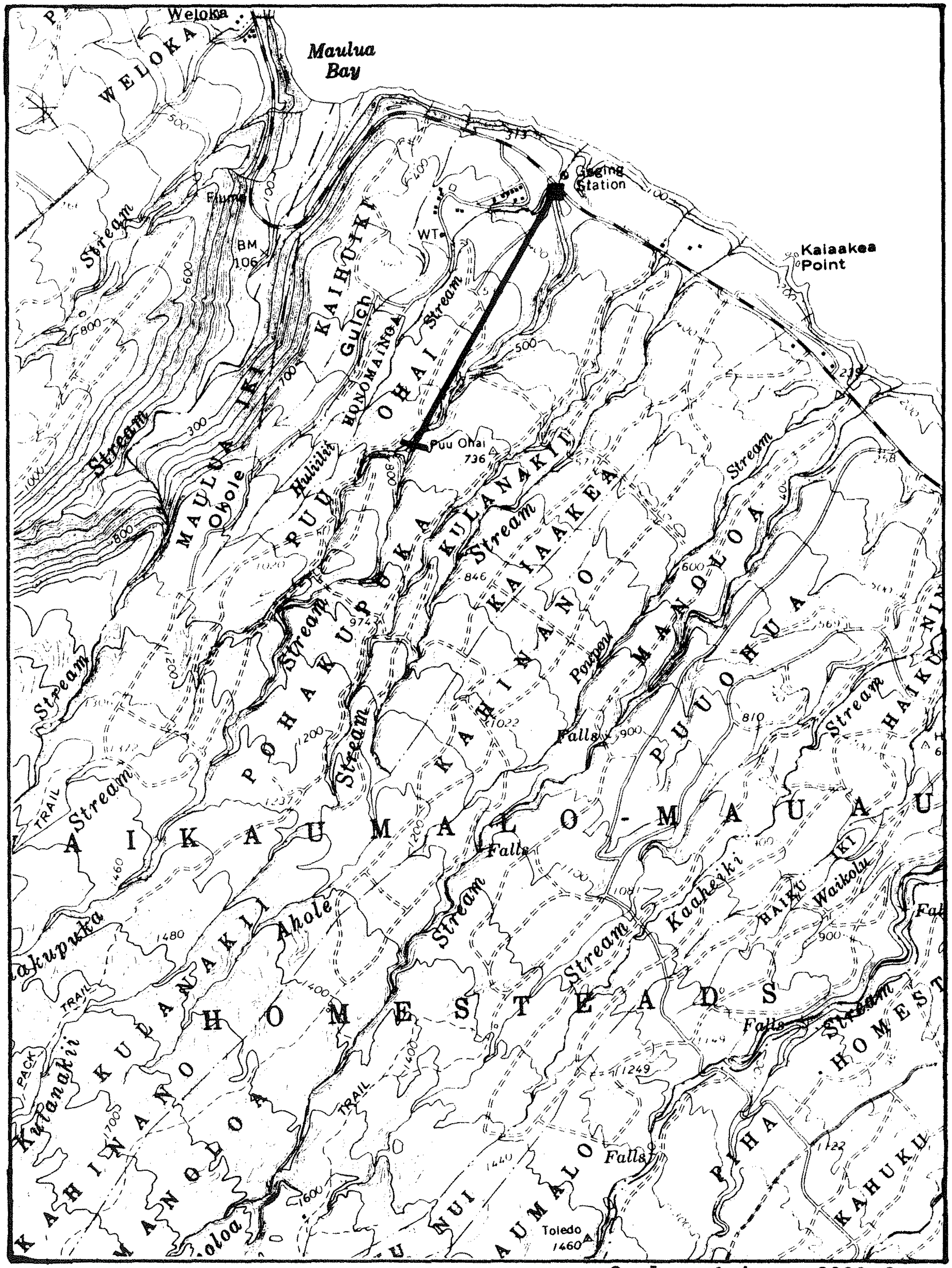
Table D-41. TECHNICAL DATA SUMMARY

PROJECT SITE Pohakupuka Stream, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 600 | kw |
| Static Head | | 370 | ft |
| Penstock Length | | 4000 | ft |
| Average Gradient | | 0.093 | ft/ft |
| Stream Gage of Record | | USGS # 16717800 | |
| Streamflow Parameters | Average Flow | 27.1 | cfs |
| | $Q_{15}$ | 37.5 | cfs[1] |
| | $Q_{50}$ | 7.7 | cfs[1] |
| | $Q_{95}$ | 1.3 | cfs[1] |
| Turbine/Generator Capacities | 1. 250 kw | | |
| | 2. 350 kw | | |
| Average Annual Energy Production | | 2,303,000 | kwh |
| Overall Plant Factor | | 44 | % |

Miscellaneous:

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.



Scale: 1 in. = 2000 ft.

Figure D-64. Prospective Hydropower Site, Pohakupuka Stream, Hawaii.

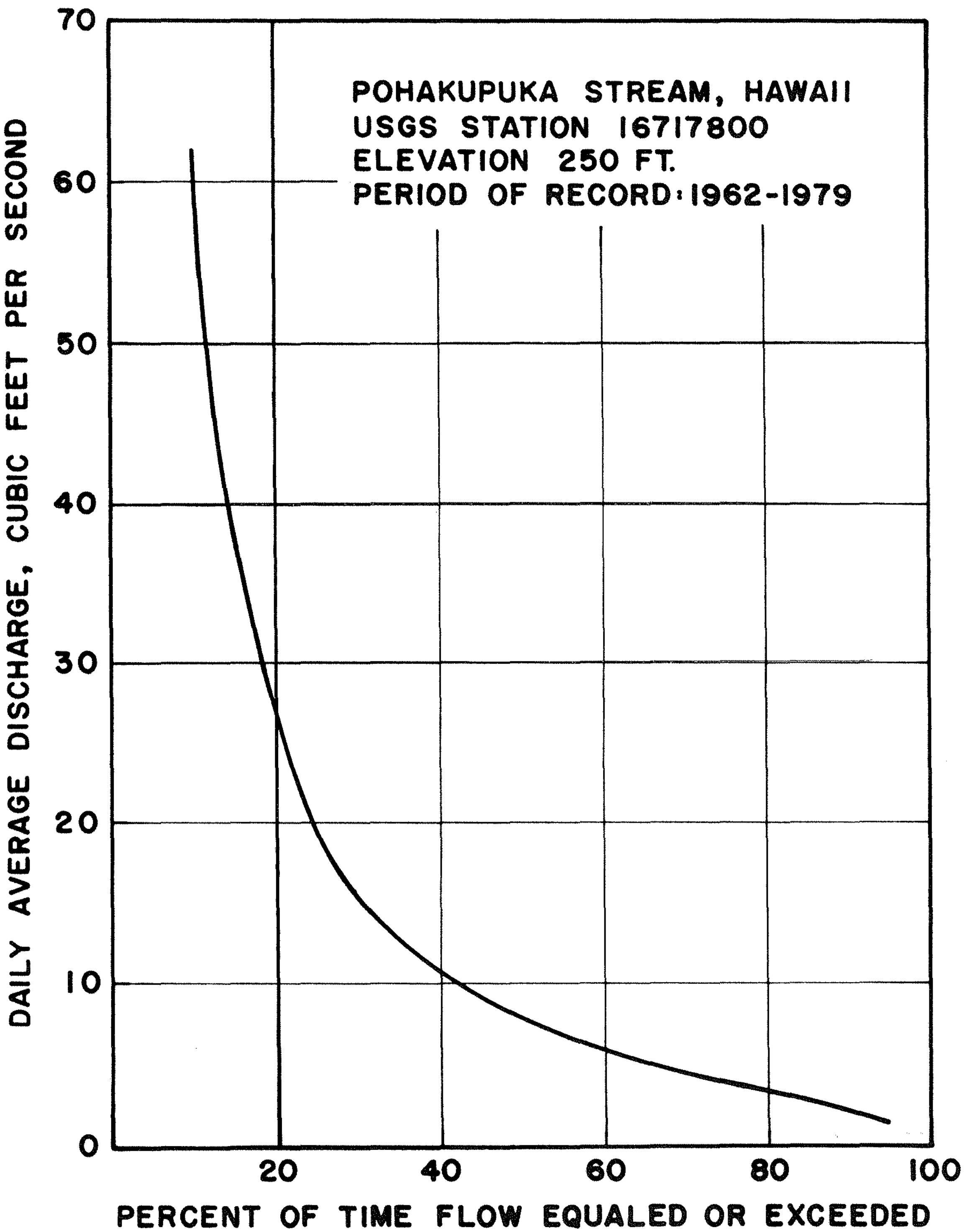



Figure D-65. Flow Duration Curve, Pohakupuka Stream, Hawaii.
(Based on U.S.G.S. Water Resource Division Stream Gage Data)

Table D-42. TECHNICAL DATA SUMMARY

PROJECT SITE Keaiwa-Meyer Reservoirs, Ka'u Sugar Company, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 280 | kw |
| Static Head | | 1,300, 570 | ft |
| Penstock Length | | 8,600, 7400 | ft |
| Average Gradient | | 0.151, 0.077 | ft/ft |
| Stream Gage of Record | | USGS # | N/A |
| Streamflow Parameters | Average Flow | N/A | cfs |
| | $Q_{15}$ | 2.3 | cfs[1] |
| | $Q_{50}$ | 1.8 | cfs[1] |
| | $Q_{95}$ | .7 | cfs[1] |
| Turbine/Generator Capacities | 1. 200 kw | | |
| | 2. 80 kw | | |
| Average Annual Energy Production | | 1,650,000 | kwh |
| Overall Plant Factor | | 67 | % |

Miscellaneous:

Water is developed from tunnels and transported via a ditch to Keaiwa Reservoir. Turbine #1 would be located at Meyer Reservoir, downstream of Keiawa (1,300 ft. head.). Turbine #2 would be located at the factory, utilizing the 570-foot drop from Meyer Reservoir. Flow data provided by Ka'u Sugar Company.

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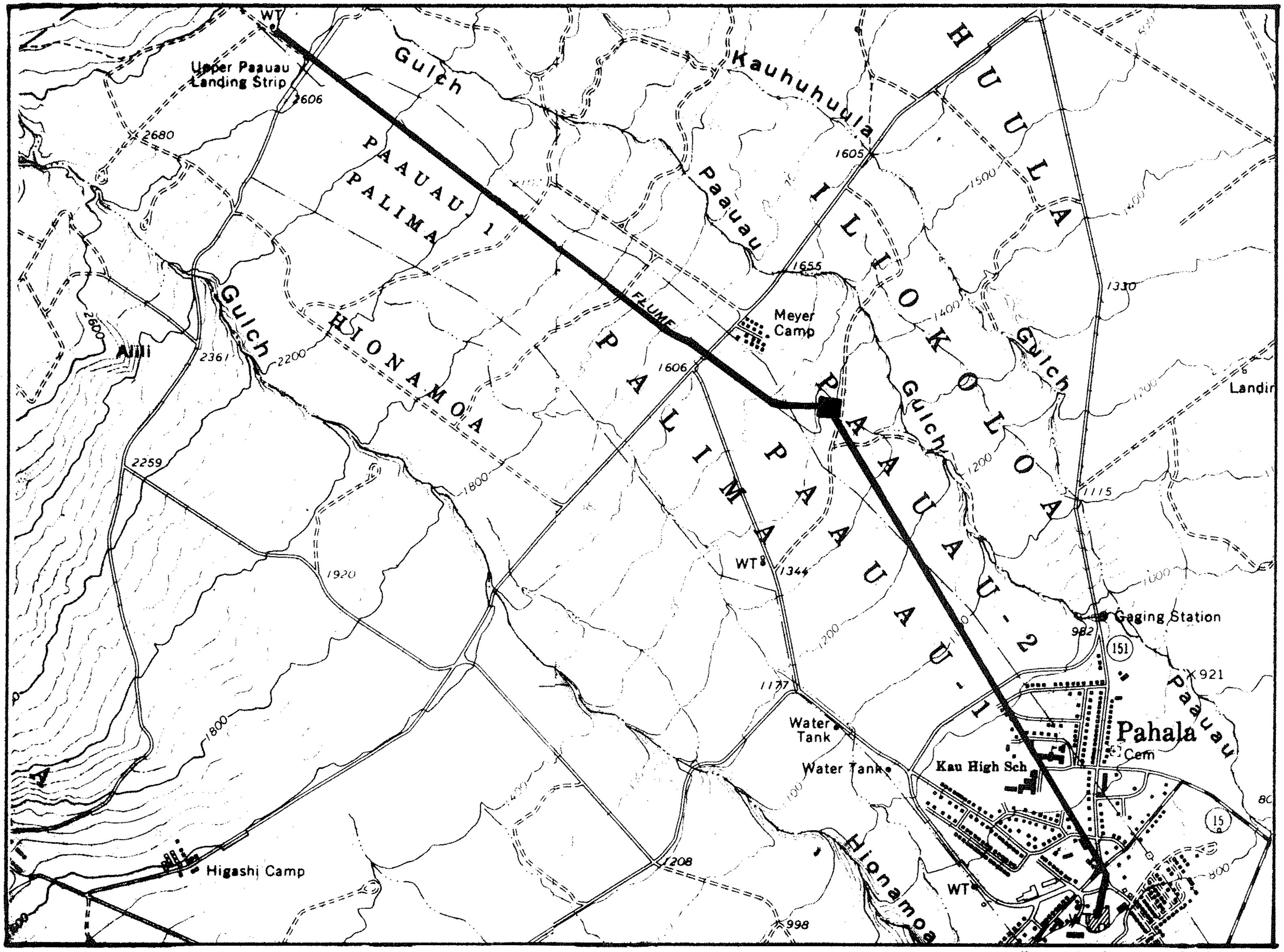
[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-66. Prospective Hydropower Site, Keaiwa-Meyer Reservoirs, Ka'u Sugar Company, Hawaii.

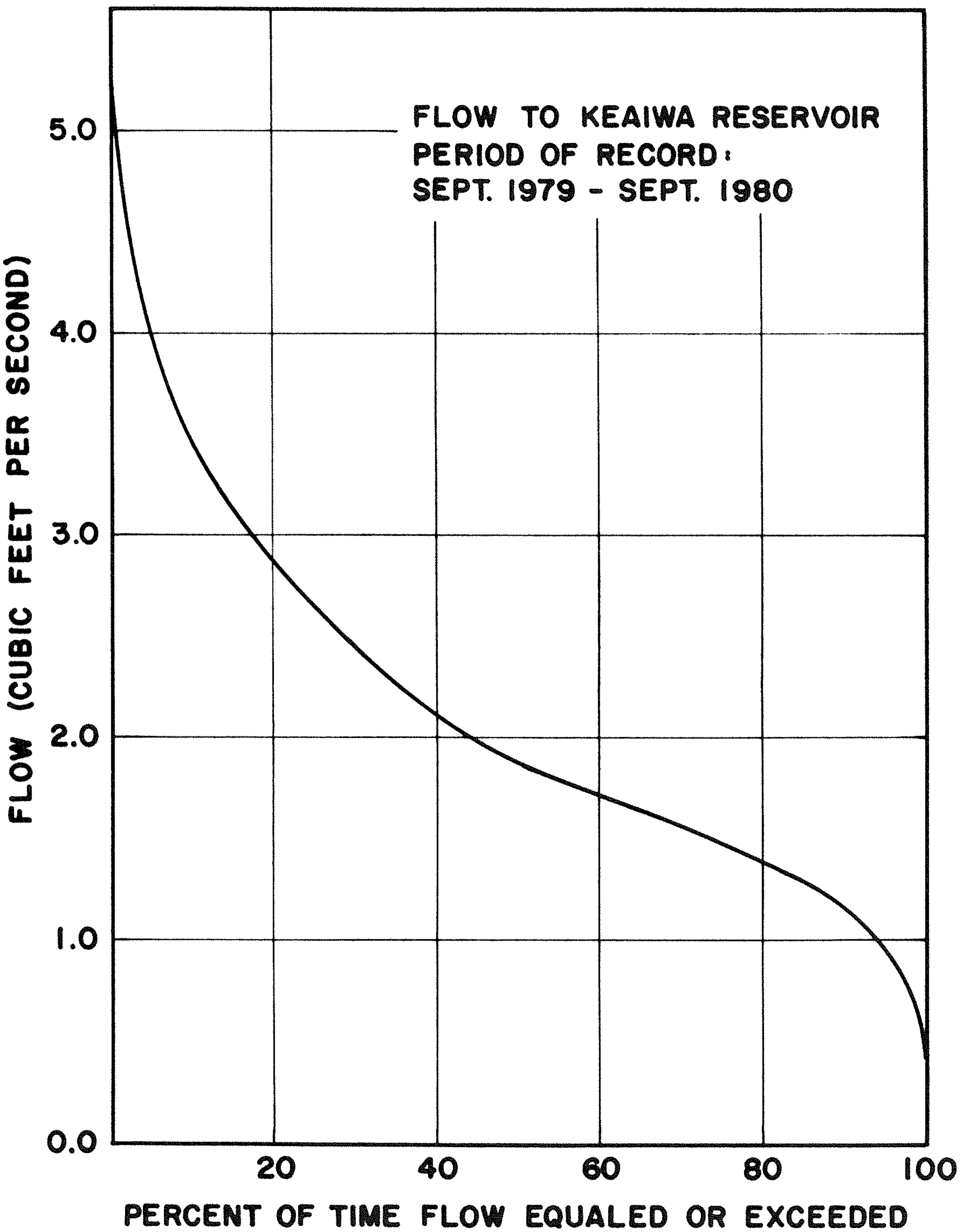



Figure D-67. Flow Duration Curve, Keaiwa Reservoir. (Based on Ka'u Sugar Company Data).

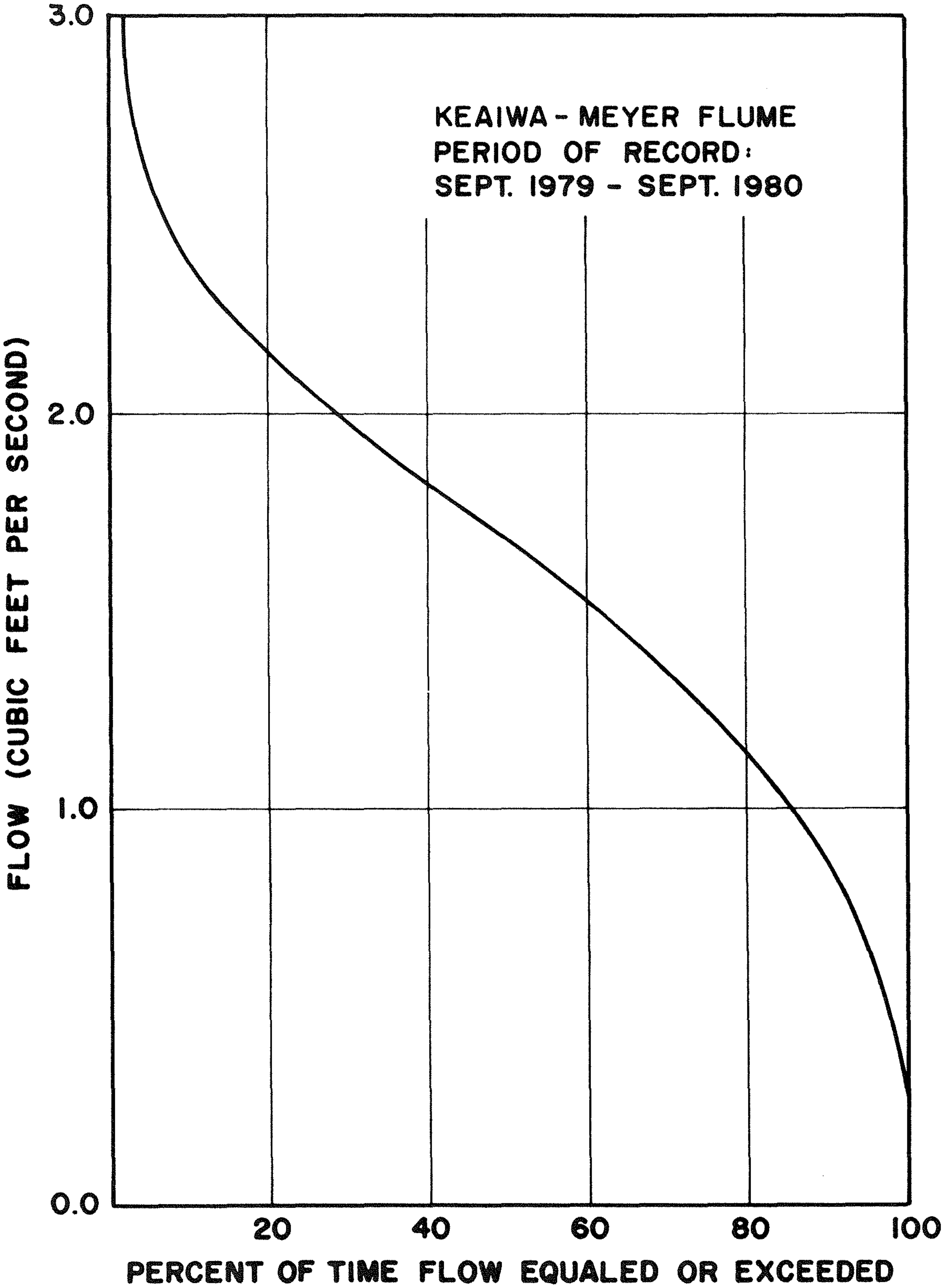



Figure D-68. Flow Duration Curve, Meyer Reservoir. (Based on Ka'u Sugar Company Data).

Table D-43. TECHNICAL DATA SUMMARY

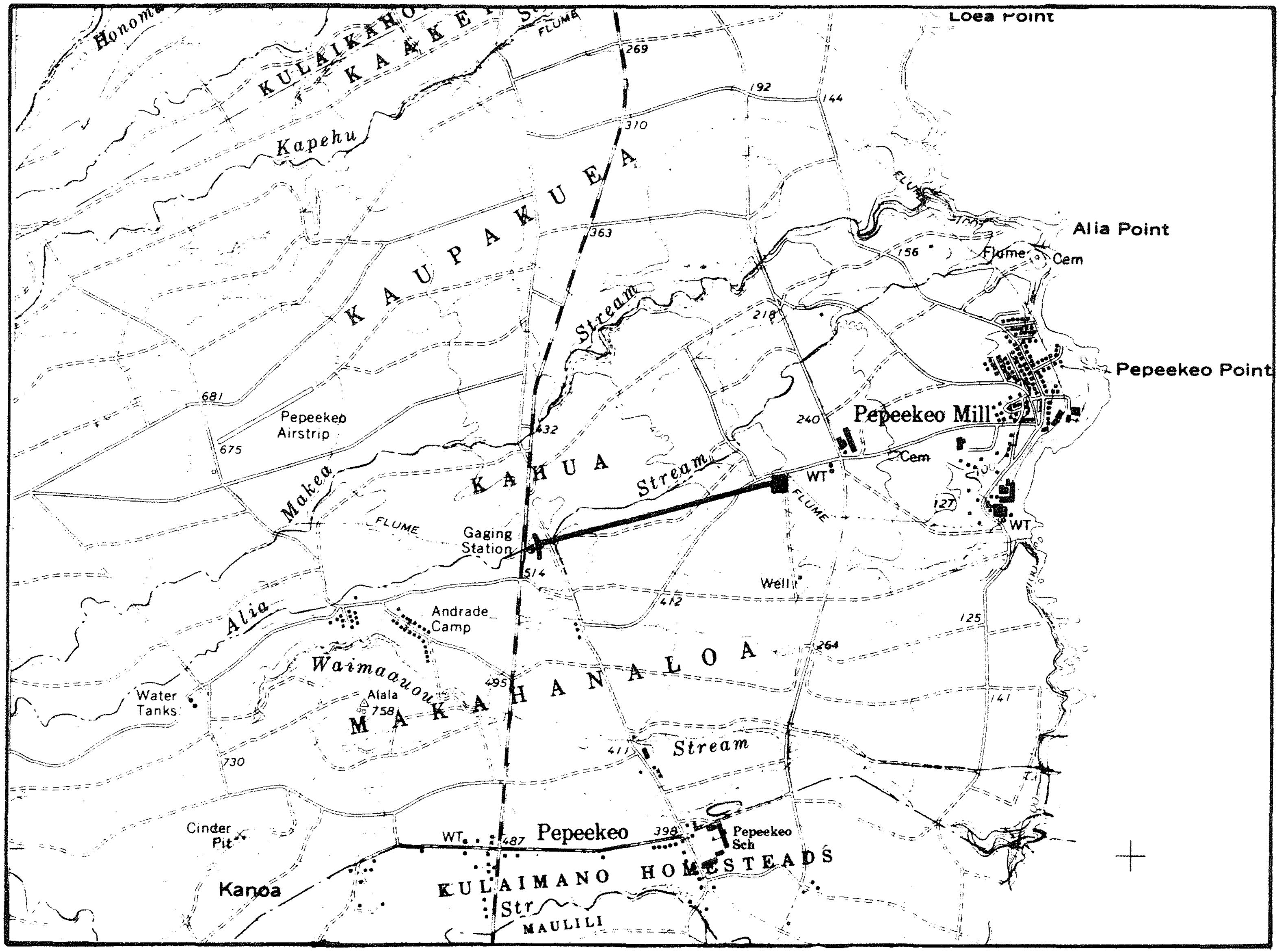
PROJECT SITE Alia Stream at Pepeekeo, Hawaii

| | | | |
|---|---|---|---|
| Plant Capacity | | 330 | kw |
| Static Head | | 210 | ft |
| Penstock Length | | 3,000 | ft |
| Average Gradient | | 0.07 | ft/ft |
| Stream Gage of Record | | USGS # | 167176 |
| Streamflow Parameters | Average Flow | 12.9 | cfs |
| | $Q_{15}$ | 18.9 | cfs[1] |
| | $Q_{50}$ | 12 | cfs[1] |
| | $Q_{95}$ | 4.0 | cfs[1] |
| Turbine/Generator Capacities | 1. 180 kw | | |
| | 2. 150 kw | | |
| Average Annual Energy Production | | 1,542,000 | kwh |
| Overall Plant Factor | | 53 | % |

Miscellaneous:

---

[1] $Q_N$ is the stream flow which is equaled or exceeded N percent of the time.




Scale: 1 in. = 2000 ft.

Figure D-69. Prospective Hydropower Site, Alia Stream, Hawaii.

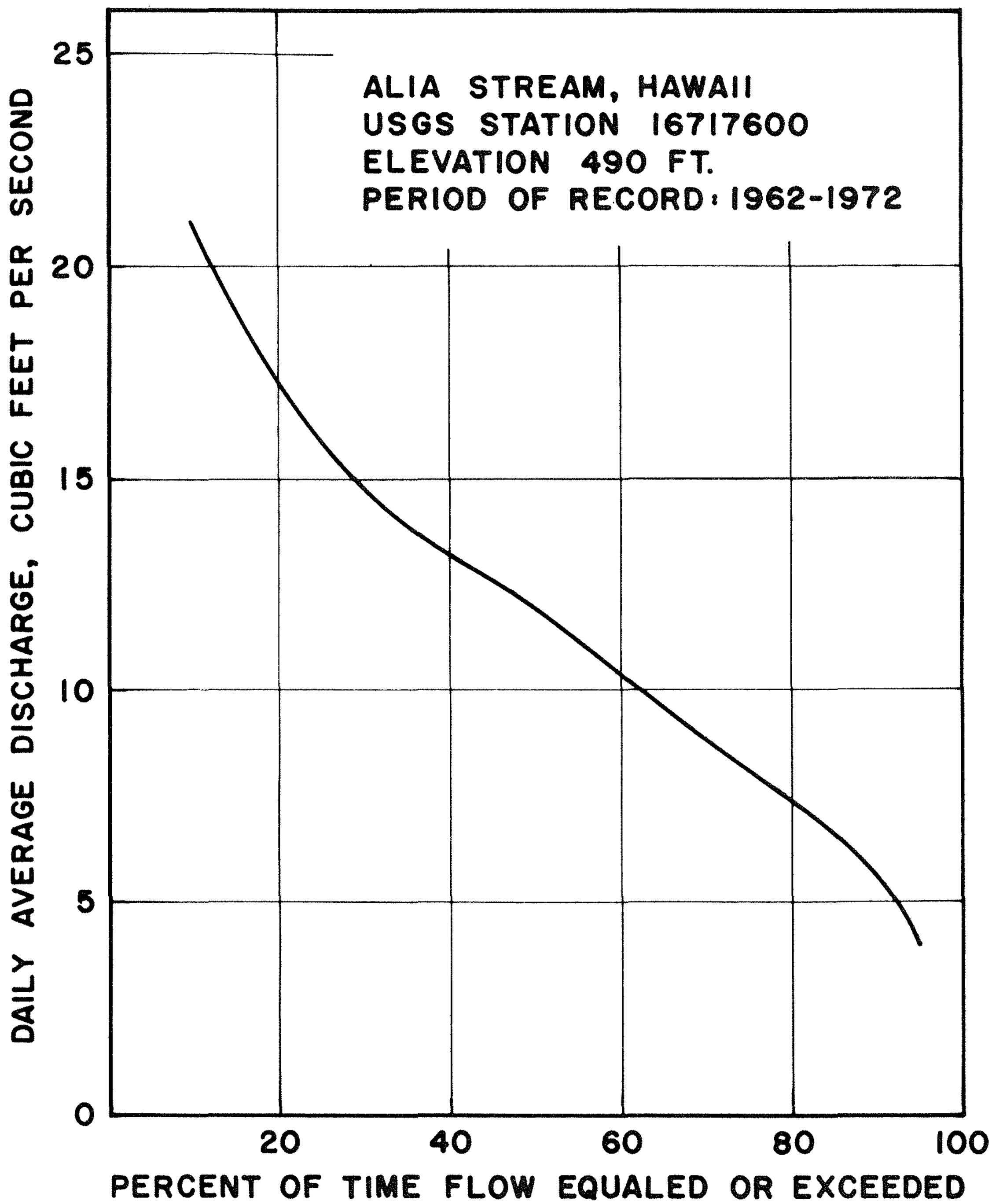



Figure D-70. Flow Duration Curve, Alia Stream, Hawaii. (Based on U.S.G.S. Water Resources Division Stream Gage Data).

PUMPED STORAGE IN HAWAII:
A STATEWIDE SITE SURVEY

DRAFT FINAL REPORT

by
W.A. Hirai and Associates, Inc.
Consulting Engineers
Hilo, Hawaii

30 September, 1980

prepared for the

Hawaii Integrated Energy Assessment

Department of Planning and Economic Development

State of Hawaii

ABSTRACT

A brief survey of prospective pumped storage hydroelectric sites in the State of Hawaii has been performed. Pumped storage is a method of providing energy storage for utility load-leveling. It utilizes the potential energy difference of water reservoirs at different elevations. Besides load-leveling, pumped storage is also useful for smoothing out the energy output fluctuations of variable-energy sources, such as wind turbines or photovoltaic arrays. Twelve sites throughout the State were identified in this survey as prospective pumped storage sites. The sites were chosen according to a number of general criteria, including high static head, short penstock length, use of existing reservoirs, favorable location near electric load centers, and good site accessibility. Included in the list of twelve were four sites on Oahu, three on Molokai, two each on Maui and the Big Island, and one site on Kauai.

Five sites were chosen from the list of twelve for a rough-cut economic analysis. Construction cost estimates were made for these five sites. The construction cost was amortized over the life of the project. The annual amortization costs and operation and maintenance costs were summed to obtain an overall annual cost of the pumped storage project. Then, using the expected hydroelectric energy output of the facility, a per-kilowatt-hour cost of pumped storage energy was computed. This cost was compared with the current cost of peak electric energy using oil-fired units.

The results show that pumped storage power is currently much more expensive than power from oil-fired units, and costs $0.16-0.23 per kilowatt-hour. However, pumped storage could become economical by the 1990's if the price of oil continues to escalate as it has during the 1970's, and the development of alternate energy systems results in unit energy prices that are significantly less than those from oil-fired units.

PUMPED STORAGE IN HAWAII: A STATEWIDE SITE SURVEY

PRELIMINARY REPORT

by

W.A. Hirai and Associates, Inc.
Consulting Engineers
Hilo, Hawaii

30 September, 1980

## 1.0 Purpose and Scope of This Study

The purpose of this study is to perform a brief survey of prospective sites for pumped storage hydroelectric plants in the State of Hawaii. A list of sites, their power potential, and other technical parameters was prepared. Identification of prospective sites was carried out by: 1) reviewing previous studies; 2) seeking expert opinions from the engineering community; and 3) a broad map reconnaissance using a set of site selection criteria. For each site which appears particularly promising from a technical standpoint, a rough-cut economic analysis was performed to determine whether the economics of the site are sufficiently encouraging to warrant further detailed engineering studies. It is not intended that this survey be exhaustive. It is a first attempt to identify promising sites statewide. The sites identified in this survey undoubtedly are not the only possible sites, and in fact they may not even be the best sites. The interested reader of this report may wish to add other promising sites to the list, and is encouraged to do so.

## 2.0 Introduction to Pumped Storage Concepts

Plants generating electricity work more efficiently when producing power at a constant level rather than trying to meet fluctuating demands. The normal usage pattern for electricity shows peaks of high demand at certain hours of the day and troughs of much less demand at others.

If a generating plant were to provide constant power at the peak load demand there would be excess energy production during the times of lower demand. On the other hand, a constant production of anything less than the peak demand would result in a deficit during peak load hours.

To allow a utility to base-load its most efficient generating units, while meeting the fluctuating demands throughout the day, an energy storage system can be employed. A storage system would help level the load faced by the generating plant. When production of power exceeds demand, the excess energy would be stored within the system to be discharged when demand exceeded production.

A pumped hydroelectric storage system is a viable method of providing energy storage for utility load leveling. A well developed, mature technology, the pumped hydro storage concept has been applied in many instal-ltions world-wide.

A pumped hydro storage system involves two bodies of water at different elevations connected by a penstock (see Figure 1). When energy production exceeds demand, the excess energy is used to pump water from the lower reservoir to the higher one. During times of peak demands, water is released from the upper reservoir to flow through turbines, producing hydroelectric power, into the lower reservoir. The hydroelectric power would help the production plant meet the demand load.

The amount of energy that could be generated would depend upon the elevation difference between the two reservoirs, and the length and diameter of the penstock.

The level and duration of hydroelectric power produced can be regulated by the amount of water released from the higher reservoir. Several configurations could be designed to meet the specific needs of the utility.

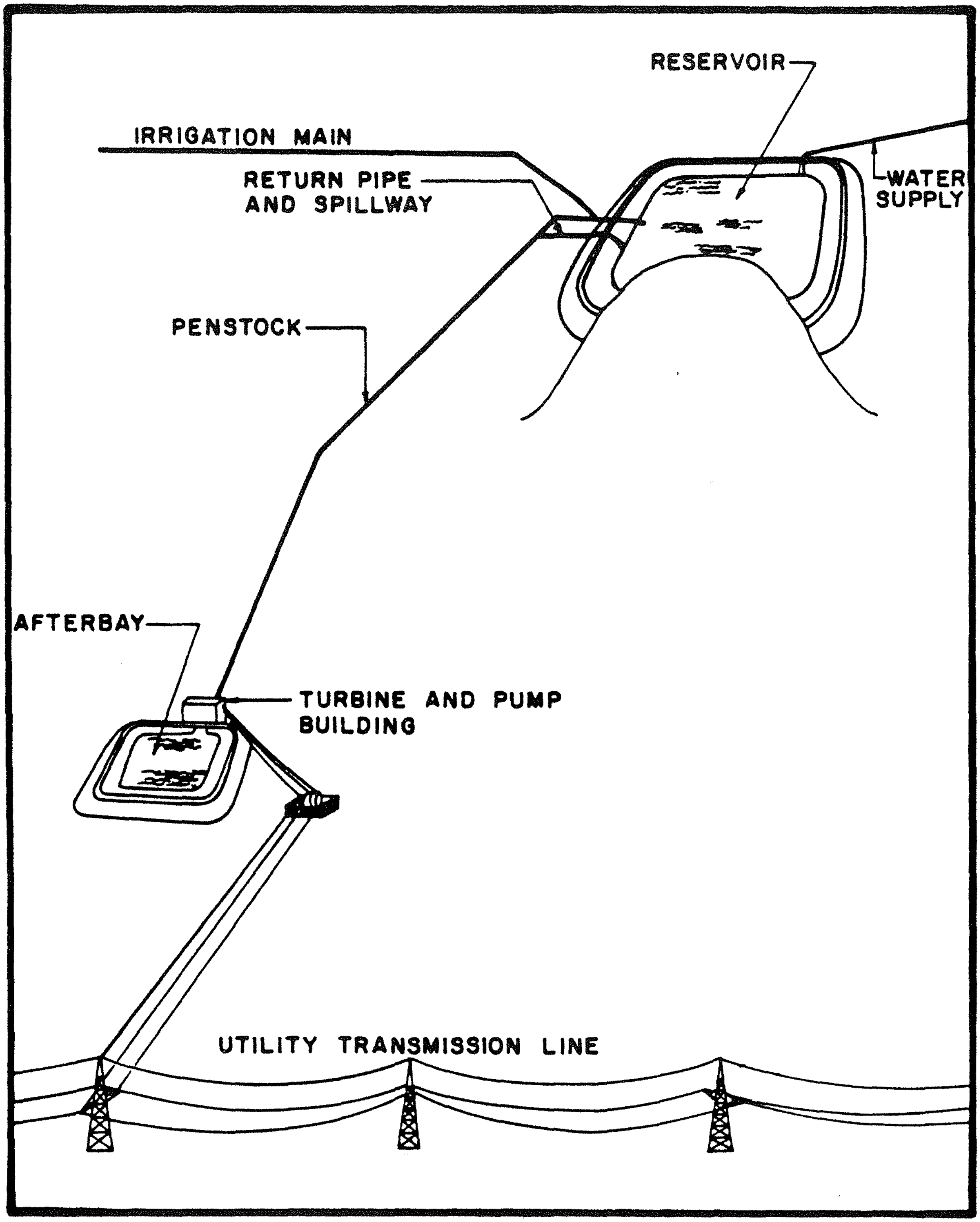



Figure 1. Pumped Storage Schematic

For example the power level could be steady or variable; the duration of power generation could be a fixed number of hours per day or only when the demand exceeded a pre-determined level.

Some energy is lost in the storage process which must be weighed against the benefits of the base load generating plant.

Utilization of pumped hydro storage systems is not limited to base loaded generating plants but may serve to help level the loads of alternate energy producing devices such as wind turbines or solar devices. These alternate energy devices have a fluctuating pattern of production which may not coincide with the energy demand pattern. A pumped hydro energy storage system can help to match the production to the demand much in the same manner as with a base loaded plant.

The power potential pumped storage system is taken to be the capacity of the hydroelectric facility, and not including the capacity of the pumping energy source. The capacity of the hydroelectric plant is determined by the equation:

(1) $$P = 0.085\ Q\ H\ e$$

where $P$ = power in kilowatts (kw)

$Q$ = flow in cubic feet per second (cfs)

$H$ = net head in feet (ft)

$e$ = efficiency of turbine/generator plant

In this formula, the net head is determined by:

$$H = H_s - h_f$$

where $H_s$ = static head, equal to the difference in elevation between the upper and lower reservoirs, in feet (ft)

$h_f$ = friction losses in the penstock, and intake, in feet (ft)

It is assumed that $h_f = 0.15\ H_s$, so therefore:

$$H = 0.85\ H_s$$

Assuming that the efficiency, e = 0.85, then equation (1) becomes:

(2) $$P = 0.061\ Q\ H_s \quad \text{(hydroelectric plant)}$$

An equation similar to equation (2) can be developed for the pumping power required. However, for the pump:

(3) $$P = \frac{0.085\ Q\ H}{e} \times C$$

where

$$C = \frac{\text{hours per day of hydroelectric operation}}{\text{hours per day of pumping}}$$

and $H = H_s + h_f$

For purposes of this report, it is assumed that the hydroelectric plant will operate in a peaking operation for just six hours per day, and pumping will occur the remaining 18 hours per day, so that C = 6/18 = 1/3. Furthermore in pumping, since C is less than 1.0, the flow rate through the penstock will be slightly less than in the hydroelectric mode, therefore friction losses will be somewhat less. It is therefore assumed that $h_f = 0.03\ H_s$, so the net head is:

$$H = 1.03\ H_s$$

Assuming a pump efficiency of e = 0.80, equation (3) becomes:

(4) $$P = 0.036\ Q\ H_s \quad \text{(pumping plant)}$$

Equations (2) and (4) are approximate formulas for rough-cut estimates of power potential. If the penstock diameter, length, and construction are known, the friction loss $h_f$ can be computed more exactly.

## 3.0 Utilities' Needs For Peaking Power

In sizing pumped storage facilities, the needs of the utility system must be considered. Each utility in the State has its own unique daily system load profile, into which the output of the pumped storage hydroelectric unit must be integrated. Typical system load profiles for each of the major utilities in Hawaii are included in Appendix B. In each case, the system load is smallest in the early morning hours and greatest in the early evening hours each day. Typically, the load rises rapidly to a "shoulder" level by mid-morning, where it remains relatively constant until mid-afternoon. The load then again increases rapidly toward a narrow peak, usually between six o'clock and eight o'clock in the evening, then declines to the nighttime low. Some utilities, notably Kauai and Molokai, experience load peaks on some days which are unpronounced, that is, they rise only slightly above the shoulder.

To obtain an idea of the "window" for pumped storge peaking power, one can examine the difference between the utility system's shoulder and peak power loads. Thus, for each island, the maximum practical size of a pumped storage peaking unit is estimated to be:

Oahu -- 150 megawatts

Hawaii -- 15 megawatts

Maui -- 15 megawatts

Kauai -- 5 megawatts

Molokai -- 1.5 megawatts

## 4.0 Method of Study

Three basic methods were used in the site reconnaissance. The first method was to review the previous studies of pumped storage in Hawaii. If the conclusions were found to be still valid, the power potential and cost estimate were modified according to the assumptions used in this study. The second method involved seeking expert opinions from persons in Hawaii who have expertise in hydroelectric systems, water resources, or other areas pertaining to pumped storage technology. A list of persons who have been contacted in this regard is included in Appendix C. The third method was a map reconnaissance using topographic maps of the U.S. Geological Survey, with supplementary data from State water resources reports and reports of the Army Corps of Engineers.

In performing the map reconnaissance for prospective sites, the following general selection criteria were used:

(1) Sites were sought at which two existing reservoirs were situated in the same vicinity, generally within about 3.0 miles of each other, but preferably closer. The elevation difference between the two reservoirs should be appreciable, at least 200 feet but preferably in the range of 500-2000 feet. The low-head sites are acceptable if the reservoirs have sufficiently large capacity. At high-head sites, reservoirs as small as 5 to 10 million gallons were considered, but at low-head sites the capacities should be at least 300 million gallons. There are twelve reservoirs in the State which are of about 300 million gallons or more capacity. These are listed in Table 1.

(2) Sites that have just one reservoir in place were acceptable if the reservoir had a large storage capacity, or the available head was extremely favorable, etc.

(3) Sites that have no existing reservoirs were acceptable if the available head was exceptional, i.e., at least 500 feet but sometimes up to 2000 feet. Also, the ratio of static head to penstock length should be large, preferably greater than about 0.10.

Table 1. Existing Large Reservoirs in the State of Hawaii

| Reservoir | Capacity (million gallons) |
|---|---|
| **Oahu:** | |
| Kaneohe-Kailua | 800 |
| Ku Tree | 320 |
| Nuuanu | 1400 |
| Wahiawa | 3000 |
| **Kauai:** | |
| Alexander | 850 |
| Kapaia | 520 |
| Koloko | 450 |
| Puu Lua | 290 |
| Wailua | 300 |
| Waita | 2600 |
| **Hawaii:** | |
| Puukapu | 315 |
| **Molokai:** | |
| Kualapuu | 1400 |

(4) Miscellaneous favorable site criteria included: good site accessibility, low degree of construction difficulty, availability of make-up water, proximity to existing utility transmission lines and load centers, and location in sparsely-populated areas.

Sites that were considered favorable according to the above general criteria were further evaluated by determining the pumped storage potential of the site. The power potential of a given site depends on many factors, including:

(1) The available head

(2) The available water supply

(3) The amount of available reservoir space

(4) The length of penstock required

(5) The source of the pumping power

(6) The need for peaking power in the area

The nature of the energy source for the supply of power for pumping the water to the upper reservoir affects the potential capacity of a given site, because it determines how efficiently the reservoir storage space can be utilized: Generally, energy sources may be divided into the following categories:

(1) Base-load, or dependable, energy sources, which supply a relatively constant amount of power with high reliability. These sources include thermal power plants fueled by fossil, nuclear, or biomass fuels, geothermal power plants, or OTEC plants.

(2) Variable energy sources, such as wind and solar energy, in which the amount of power supplied is unpredictable over short time periods, but whose long-term average may be fairly well established.

For variable energy sources, additional storage space must be included in the reservoirs to cover short-term shortages of pumping power due to, for example, calm-wind periods or sky overcast. Or, looking at this another way, for a given reservoir size, the hydroelectric capacity of a pumped storage site must be downgraded somewhat to take into account power shortages, if the system is to maintain a satisfactory degree of reliability. The degree to which the capacity must be downgraded depends on site-specific factors, such as the historical windspeed or overcast behavior trends.

For example, suppose that for a hypothetical site, it is known that the available head is 500 feet. It is desired to design a pumped storage system to provide 3,000 kilowatts of hydroelectric power for six hours each day. Using Equation (2), it is found that a flow of 100 cubic feet per second (cfs) will suffice. The capacity of the reservoirs required to contain 100 cfs for six hours is thus about 16 million gallons. This represents the capacity required if a reliable base-loaded energy source is available for pumping. Now, suppose that wind turbines are to be used to pump the water to the upper reservoir, and that occasional wind lulls of up to four days' duration are expected in the area. It is then necessary that both reservoirs have sufficient capacity so that the hydroelectric generator can continue to function through a four-day period without any pumping. Thus, they must be sized at 64 million gallons capacity. Alternatively, if the size of the reservoirs is fixed at 16 million gallons, the capacity of the hydroelectric generator must be four times smaller, or 750 kilowatts, if wind turbines are used. Or, if the system is fixed at 16 million gallons, 3,000 kilowatts, then the hydroelectric generator can only operate for 1½ hours per day during a four-day wind lull.

It is important to keep these considerations in mind when reviewing the sites included in this reconnaissance survey. It is assumed for these sites that a reliable, base-load pumping energy source is used. No adjustment is made for the possible use of variable-energy sources, such as wind turbines or photovoltaic generators, because these require further detailed study at specific sites to determine their availability factors.

The evaluation of power potential for each site was accomplished using formulas similar to Equations (2) and (4), but with friction loss $h_f$ computed by the well-known Hazen-Williams formula, one form of which is:

(5)

$$h_f = \left[ \frac{L}{d^{4.86}} \right] \times \left[ \frac{2.313Q}{C} \right]^{1.85}$$

where $h_f$ = friction head loss, in feet

$L$ = length of penstock, in feet

$d$ = diameter of penstock, in feet

$Q$ = average flow, in cubic feet per second

$C$ = a constant which depends on the roughness of the pipe (assume $C = 120$ in this analysis)

The penstock of diameter, d, was adjusted until a value of $h_f$ approximating 15% of the total static head was obtained. The average flow, Q, was constrained by either of two factors:

1) For small agricultural reservoirs, the maximum allowable pumped storage allocation was 25% of the reservoir's total capacity.

2) For most other cases, the flow was limited to keep the penstock diameter down to a reasonable size so that the penstock cost would not be excessive.

## 5.0 Utilization of Existing Agricultural Reservoirs for Pumped Storage

Because of the existing potential storage capacity of agricultural reservoirs, these are logical prospects for pumped storage. Indeed, some of larger agricultural reservoirs in Hawaii are good prospects for this concept. However, it must be recognized that the primary use of these reservoirs, for irrigation, conflicts with their use for energy storage, so that any consideration of these reservoirs for pumped storage must take into account irrigation patterns below the reservoir, and the supply of irrigation water. Most agricultural reservoirs are owned and used by sugar companies.

Hawaii's agricultural reservoirs could be classified into categories of "large" and "small," although the distinction between these two is fuzzy at best. Large reservoirs as defined here are those which are intended to store water on a seasonal or long-term cycle, as opposed to small reservoirs, which may be filled and drained in cycles of a day or a week duration only. Neglecting complicating factors, we can arbitrarily classify a reservoir as large if it has a capacity in excess of about 900 acre-feet, or about 300 million gallons. The large agricultural reservoirs of Hawaii are included in the list of the largest reservoirs in the State, Table 1.

Generally, a large reservoir can better tolerate concurrent irrigation and pumped storage operations than a small reservoir. The pumped storage system only "borrows" a small portion of the water contained in the reservoir and returns it to the reservoir each day. Normally, the large reservoir has sufficient reserve to be able to spare a small quantity of water each day without impacting irrigation needs. In time of severe drought, however, such as those which occur with a frequency of about once per decade, water levels in the reservoir may fall so low that a conflict could arise as to the use of the last few million gallons remaining. It could either be released to the fields below in a last-ditch effort to save the crop (in which case there may be peak power shortages), or the pumped storage system could continue to operate in the hope that normal rains will soon return. In either case, the financial losses could be substantial, and this question must be addressed on a site-specific basis. A solution could be that the installation of a pumped storage system at an existing reservoir should include provisions for an emergency supply of water in time of shortage, equal to the amount to be utilized by the system for power generation.

Smaller reservoirs are a more difficult problem when incorporating pumped storage. Many of these are filled and drained completely over a 24-hour cycle, and in water-short areas their capacity is not considered adequate just for irrigation purposes, let alone for pumped storage. Irrigation operations might have to cease completely for some reservoirs during the hydroelectric phase, which would probably be four to six hours per day in the late afternoon and early evening hours. These problems are not necessarily insurmountable, however the sugar companies will be extremely reluctant to allow use of their small reservoirs for pumped storage unless these concerns are completely satisfied. The capacity of an existing reservoir could be increased to accommodate pumped storage, and separate intake and outlet facilities for irrigation and energy production utilized. The reservoir, if leaky, could be lined to cut leakage of irrigation water. These modifications, of course, will increase the cost of the pumped storage system, and decrease the advantage of using an existing reservoir over developing a new site.

In this study, wherever the use of a small agricultural reservoir is proposed, it is arbitrarily assumed that only 25% of the reservoir capacity is to be utilized for pumped storage.

## 6.0 Descriptions of Candidate Sites

Table 2 is a list of the prospective pumped storage sites considered in this survey. There are a total of twelve sites in the list. Descriptions and location maps of these sites are given in the following sections. Information is given concerning the available head, conceptual penstock arrangement and size parameters, power potential, and storage requirements. Also included are information on site access, proximity to electric load centers, special construction requirements, and any significant environmental or safety concerns. The sites are not in any particular order of preference, but are arranged island by island, starting with Kauai and working eastward through Oahu, Molokai, Maui, and the Big Island. However, the two sites involving pumped storage of seawater are presented at the end, after a brief discussion of this concept.

From the list of twelve sites, five were selected for an economic analysis, which will be described in a later section.

Because of the limited scope and broad assumptions used, this survey can only be considered as highly preliminary. The sites which have been identified are not necessarily the best sites in the State, but rather represent the most obvious prospective sites for further study of pumped storage development. Other sites undoubtedly await identification in future surveys.

Table 2. Summary of Prospective Pumped Storage Sites Identified in This Survey

| Site | Static Head (ft) | Penstock Length (ft) | Ratio Head/Length | Hydropower Output (kw) | Reservoirs |
|---|---|---|---|---|---|
| Alexander Reservoir/ Elua Reservoir | 900 | 9,700 | 0.093 | 8,100 | (2) Existing |
| Nuuanu Reservoir/ Kaneohe-Kailua Reservoir | 800 | 15,000 | 0.053 | 9,600 | (2) Existing |
| Ku Tree Reservoir/ Wahiawa Reservoir | 260 | 15,300 | 0.017 | 15,600 | (2) Existing |
| Kaau Crater/Maunawili Valley | 1,400 | 9,000 | 0.156 | 16,800 | (2) Required |
| Puu Nana Reservoir/ Mahana | 905 | 9,400 | 0.096 | 430 | (1) Required |
| Kualapuu Reservoir/ Puu Anoano | 370 | 11,000 | 0.034 | 2,200 | (1) Required |
| Kahoma Reservoir/ Crater Reservoir | 1,440 | 8,500 | 0.169 | 4,300 | (2) Existing |
| Puu Moe/ Maalaea | 2,000 | 8,500 | 0.235 | 12,000 | (2) Required |
| Waipio Valley Rim/ Wailoa Stream | 2,300 | 4,000 | 0.550 | 5,000 | (1) Required |
| Kauku Cone/ Alala Cone | 1,100 | 17,000 | 0.064 | 13,200 | (2) Required |
| Diamond Head Crater/ Pacific Ocean | 200 | 1,000 | 0.200 | 12,000 | (1) Required |
| Kapale/Mimino Gulches | 630 | 1,200 | 0.525 | 1,150 | (1) Required |

## 7.0 Pumped Storage Using Seawater

There are two major advantages to using seawater in a pumped storage application:

(1) One avoids the need to construct a lower reservoir;

(2) The supply of makeup water (as well as the water required initially to "charge" the system) is, for all practical purposes, infinitely large. However, there are major disadvantages as well:

(1) Seawater is more corrosive to turbomachinery materials than fresh water.

(2) Leakage or catastrophic escape of seawater from the upper reservoir can cause environmental harm, particularly to fresh groundwater supplies.

There are ways to avoid or alleviate these disadvantages. More corrosion-resistant materials or coatings can be used in the equipment, although this will increase the overall cost of the system. Leakage can be eliminated by a suitable lining of the reservoir, as well as by careful site selection for suitable soil conditions. Similarly, catastrophic effects can be avoided by careful siting of the reservoir away from populated areas and significant potable water sources. Careful design can result in the safe, environmentally sound use of seawater for pumped storage, but the increased costs must be weighed against the advantages listed above.

Two sites were identified as prospective candidates for seawater pumped storage sites, one on Oahu and one on Molokai. These are described in more detail in the following sections.

## 8.0 Economic Analysis

From the list of prospective pumped storage sites, five sites were selected for further analysis of costs. The five selected were the ones which appear to be the most promising, and, except for the site on Molokai, they involve the use of existing reservoirs. Thus, the construction costs and environmental impacts are better defined at this stage than the sites for which new development is required. The remaining sites, therefore, are not being rejected outright, but additional study of these sites is needed before even a rough-cut cost estimate is made.

Construction costs were divided into the following categories:

- Powerplant
- Penstock
- Reservoirs
- Embankments
- Intakes and Outlets

These cost components were estimated using standard cost curves of the Army Corps of Engineers, and from date developed independently by the Consultant.

The costs of access roads and transmission lines were included in a contingency amount, assumed to be 20% of the equipment costs. Engineering and overhead were estimated using 15% of the project cost. Interest during construction was estimated using a two-year construction time and 7% interest. The construction cost was assumed to be amortized over 50 years at 7% interest, which corresponds to the current Federal discount rate. Annual operating and maintenance costs were assumed to be \$0.003 per kilowatt-hour of hydroelectric energy produced.

The source of the pumping energy is not explicitly defined, but it is assumed that a reliable source is available at a cost of $0.05/kwh. This is based on the energy cost of diesel fueled generators at current petroleum prices. The cost, availability, and reliability of the pumping energy source is a critical factor in pumped storage viability. In its role as an oil-saver, pumped storage must necessarily draw on alternate energy sources, for which cost information is inadequate at this time. It is apparent, however, that the cost of alternate energy sources must eventually become substantially less expensive than oil if the economics of pumped storage are to be realized.

The annual amortization, O & M, and pumping costs were summed to obtain a total annual project cost, and then a per-kilowatt-hour cost of hydroelectric energy was computed using the annual hydroelectric production.

Not included in this rough-cut analysis are the following factors:

o Other economic benefits obtained from multiple uses of the reservoirs, such as irrigation, flood control, or recreation. This is not a factor for sites where both reservoirs are existing, but could be a significant factor where a new reservoir is constructed.

o Additional hydroelectric power that may be obtainable at sites where the upper reservoir collects surface water from ditches or streams, which can be released to the lower reservoir for subsequent irrigation use.

o Additional energy produced by a variable pumping energy source such as a wind turbine, which is continuously fed into the utility grid even during the hydroelectric phase of the pumped storage cycle.

o Strategic value of petroleum saved by the use of alternate energy sources for peaking power.

o Higher interest costs if the project is privately financed, but also investment and energy tax credits available to private developers.

In any site-specific study of pumped storage, these factors would have to be taken into account in determining the economic feasibility of the pumped storage system.

The results for the six sites are shown in Table 3. It was found that pumped storage hydroelectric costs varied considerably among sites, ranging from about \$0.16 per kilowatt-hour to about \$0.23. Since the pumped storage system is intended to provide a firm source of peaking power, these costs may be compared to the current worth of peaking power based on the avoided costs of diesel units. These cost are approximately:

o \$0.05-0.06 per kilowatt-hour fuel costs, based on \$30 per barrel petroleum prices.

o \$0.02-0.03 per kilowatt-hour for operating and maintenance, distribution, and overhead costs.

Thus, peaking power is worth \$0.07-0.09 per kilowatt-hour at the present time, about half of what a pumped storage system would cost. Projecting the price of oil to \$50/barrel in 1985 and \$90/barrel in 1990 would give the following fuel costs:

1985: \$0.08-0.10 /kilowatt-hour

1990: \$0.15-0.18 /kilowatt-hour

Thus, pumped storage systems could begin to be economical in the 1990's, but <u>only if the costs of alternate energy sources for pumping do not rise rapidly with the price of oil,</u> but rather approach the 1980 price level for oil. The prospects for this depend on the following factors:

o Success of industry research and development efforts to lower the capital costs associated with, for example, photovoltaic materials and wind

Table 3. Summary of Results of Economic Analysis For Five Sites

| Site | Project Cost ($1,000,000) | Annual Energy Output (mwh) | Annual Energy Input (mwh) | Costs Per Kilowatt-Hour ($) | | |
|---|---|---|---|---|---|---|
| | | | | Hydro | Pumping | Total |
| Alexander Res./ Elua Res. | 17.00 | 17,600 | 32,000 | 0.073 | 0.091 | 0.164 |
| Nuuanu Res./ Kaneohe-Kailua Res. | 23.28 | 21,400 | 37,800 | 0.082 | 0.088 | 0.170 |
| Wahiawa Res./ Ku Tree Res. | 46.94 | 34,700 | 61,300 | 0.101 | 0.088 | 0.189 |
| Puu Nana Res./ Mahana | 1.99 | 1,000 | 1,700 | 0.147 | 0.085 | 0.232 |
| Kahoma Res./ Crater Res. | 9.32 | 9,900 | 16,900 | 0.071 | 0.086 | 0.157 |

turbines, through better production methods and development of a mass market.

o Regulation or legislation to discourage the linking of alternate energy prices to petroleum prices.

In summary, then, it could be said that while pumped storage is not economic today, it cannot be ruled out at this time as a future possibility, pending near-term developments in the oil-price situation and the alternate energy fields.

## List of Persons Consulted In This Study

Persons contacted in this study, regarding hydroelectric power and pumped storage sites:

Mr. E. W. Broadbent, Amfac, Inc.

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